IRRIGATION SCHEDULING AND FERTILIZER MANAGEMENT FOR PEACH PRODUCTION IN GEORGIA

by

SRIJANA THAPA MAGAR

(Under the Direction of Dario Chavez)

ABSTRACT

Irrigation and fertilizer management practices for peach production in Georgia need revision. The major goal of this study was to develop a proper irrigation scheduling tool and determine the optimal fertilizer rate to meet peach tree requirements specific to Georgia and Southeastern US. It aimed to evaluate the overall effects of different irrigation and fertilization practices on plant growth, physiology, yield, fruit quality, and nutritional profile in a young and mature peach orchard. The first study tested peach trees of the 'Julyprince' cultivar grafted onto 'Guardian' rootstock for nutritional aspects in different irrigation levels, irrigation systems, and fertilizer rates. Results indicated that an increase in fertilizer rates did not necessarily increase nutrient levels in soil, leaves, and fruit. Although nutrients were abundant in the soil, they were not necessarily available to young peach trees. In the second study, a SmartIrrigation Peach App was developed, which schedules weekly irrigation based on crop evapotranspiration. It was evaluated against sensor-based irrigation and no supplemental irrigation in a young orchard of 'Julyprince' grafted on 'Guardian' and 'MP-29' rootstocks. Results indicated that the app-based method used less water than the sensor-based method while producing comparable plant size and yield. The third study compared the performance of the Peach App to a sensor-based method in a mature peach orchard, along with two irrigation systems and two fertilizer rates. Results showed that water use by the app-based method was 85% of the sensor-based method, but the plant size, photosynthesis, yield, and fruit parameters were comparable between these methods. The fourth study compared the nutritional status of young and mature peach trees between irrigation methods, rootstocks, and fertilizer rates. Results suggested that the 'MP-29' rootstock was more efficient in nutrient uptake and distribution than 'Guardian'. Nutrient distribution within irrigation methods and fertilizer rates were comparable. Overall, this study provides valuable insights into the nutritional status of young and mature peach trees, the development of sustainable irrigation management, the potential of the SmartIrrigation Peach App as an efficient irrigation scheduling tool, and an optimal fertilizer rate that could be used for peach orchards in Georgia and Southeastern US.

INDEX WORDS: *Prunus persica*, drip system, micro-sprinkler system, drought, SmartIrrigation peach app, southeast, physiology, rootstocks, UGA smart sensor array, plant size, fruit, fruit quality, nutrient, nutrient uptake, nutrient distribution, macronutrients, micronutrients.

IRRIGATION SCHEDULING AND FERTILIZER MANAGEMENT FOR PEACH PRODUCTION IN GEORGIA

by

SRIJANA THAPA MAGAR

B.S., Tribhuvan University, Nepal, 2013

M.S., Kentucky State University, 2017

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2023

# IRRIGATION SCHEDULING AND FERTILIZER MANAGEMENT FOR PEACH PRODUCTION IN GEORGIA

by

SRIJANA THAPA MAGAR

Major Professor: Dario Chavez
Committee: George Vellidis
Wesley Porter
Vasileios Liakos
Timothy Coolong

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
May 2023

DEDICATION

I would like to dedicate this work to all the peach growers, in the hopes that my work will contribute to helping them increase their peach production. A special shout out to my parents (Gangaram Bahadur Magar/ Nirmala Devi Balampaki), who are living their dreams through my accomplishments, my brothers (Subas Thapa Magar/Samrat Thapa Magar) for being the two strongest pillars of my family, my sister-in-law (Radha Sherpunja) for the immense love and support, my beloved husband (Dipesh Shrestha) for always being there in good and bad times, my in-laws (Rajkumar Shrestha/ Maya Devi Shrestha/ Sumitra Shrestha/ Rupesh Shrestha/ Pratima Shrestha/ Ayush Shrestha/ Ayushma Shrestha) for their love, support, encouragement, and advice throughout this journey.

ACKNOWLEDGEMENTS

A lot of love and huge respect for my husband, Dipesh Shrestha, who sacrificed his dreams, tenure job, and comfort space, to be together and support me live my dreams. You have not only been a great partner but a huge inspiration for me to stay strong and happy at all times. I would also like to thank my entire family, relatives, and friends for their love, support, and kindness that boosted my confidence to finally achieve my goals.

Thank you, Dr. Dario Chavez, for believing in me and allowing me to work with you. I am grateful for all your advice, ideas, time, funding, and honest opinions throughout my Ph.D. journey. I look forward to many more collaborations in the future.

I would like to thank my committee members, Dr. George Vellidis, Dr. Wesley Porter, Dr. Vasileios Liakos, and Dr. Timothy Coolong for their valuable advice, guidance, moral support, and feedback on my research. I am truly feely blessed to have such cool advisory committee members. Special mention to Jose Andreis for his support throughout the SmartIrrigation Peach app-building process and beyond. I would also like to mention Dr. Andre Luiz Biscaia Ribeiro da Silva for always being ready to support my research.

I would like to acknowledge all my lab mates and fellow graduate students, Robert Beck (Robby), John Whitehurst, Leynar Leyton, Jordan Knapp Wilson, Deanna Bigio, Jamal Mohammed, and Hannah Cowart, for their support in collecting data, processing fruit and juice samples, and our friendship above all and wonderful times we have had together. I will cherish them forever. I would also like to thank all our interns for all your hard work and help during data collection.

A huge shout-out to my Griffin Campus family. Y'all have made my stay as wonderful as each of you is. My stress relievers: Dr. Carol Robacker, Dr. Rachel Itle, Dr. Dorn, Lynn, Donna, Jordan, Sherrod, Misty, Melissa Todd, Cherry, Lee, Avery, Darius, Sarah, Madeline, Ms. Chatman, Dr. Fortuna, Melissa Slaughter, UGA Griffin Ambassador team, SAC team, my Nepali Griffin family……………………. the list goes on and on.

Lastly, I would like to acknowledge the University of Georgia Department of Horticulture, Dr. Leonardo Lombardini, all the faculty, staff, and fellow students from the Athens, Griffin, and Tifton campus for your support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

# CHAPTER 1

# INTRODUCTION AND LITERATURE REVIEW

Peach (*Prunus persica* (L.) Batsch) is a widely cultivated deciduous fruit tree from the Rosaceae family. The United States is one of the leading producers of peaches, with a total acreage of 74,400 acres and a production of 688,770 tons in 2021 (USDA NASS, 2022). Peach production in Georgia accounts for 8,200 acres (bearing acreage), producing 35,300 tons valued at about $36 million (USDA NASS, 2022). However, managing irrigation and fertilization in peach orchards is challenging in the Southeastern United States due to the region's unique soil and humid climate. Additionally, there is a lack of information about the impact of various irrigation and fertilization strategies on peach tree growth and productivity in this region. Unlike other regions in the United States, such as California, there are no specific irrigation and fertilization management recommendations for peach production in Georgia.

Fertilization and irrigation are both critical management practices for tree growth and production. Improper use of either can negatively impact tree health and productivity. However, the guidelines for fertilization and irrigation management in Georgia and the Southeast are outdated and not optimized in the region. Excessive fertilizer application is common in commercial orchards (Carranca et al., 2018), but this does not necessarily increase productivity. It can instead result in increased production costs, soil nutrient loss, and pollution (Zhou and Melgar, 2020; Casamali et al., 2021b). It is important to understand the nutritional needs of peach trees for efficient orchard management.

Currently, peach growers in Georgia use the fertilizer recommendations found in The Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide (Blaauw et. al, 2018), but this information needs to be updated. Previous research by Zhou and Melgar (2020) and Casamali et al. (2021a) have investigated the nutrient status of peach trees, through the annual removal of nutrients through leaves, fruitlets, fruits, and wood, which can be used to determine the optimal nutrient requirements for the trees.

Water scarcity is a growing concern globally, with agriculture consuming 70-80% of total freshwater resources in arid and semi-arid regions (Mirás-Avalos et al., 2017). Therefore, optimizing irrigation management for agricultural crops is crucial to promote efficient water use. Conversely, water shortage can have a significant impact on crop yields. For example, drought in California resulted in a statewide loss of $3.8 billion to agriculture between 2014 and 2016, with 5% of irrigated land going out of production (Lund et al., 2018). Although the Southeastern U.S. has a humid climate, droughts can still be common in this region. For a decade, a large portion of Georgia has experienced moderate to extreme droughts (Figure 1.1). According to a study conducted at the University of Georgia, drought conditions had a significant impact on non-irrigated young peach trees compared to irrigated trees (Casamali et al., 2021b). The non-irrigated trees were considerably smaller and produced a significantly lower fruit yield. Even after a year of receiving supplemental irrigation, the reduced yield persisted in those trees. Therefore, it is crucial to develop a sustainable irrigation management tool specific to Georgia's unique environmental conditions to enhance peach tree growth and productivity.

The SmartIrrigation Peach App aims to provide peach growers with a proper irrigation scheduling tool that will offer information on when and how much to irrigate.

This tool will not only increase the profitability of peach production but also promote optimal water use in agriculture. Proper irrigation and fertilizer management are essential for growers to optimize tree growth and productivity, especially in light of water scarcity concerns. Thus, the development of the SmartIrrigation Peach App and determining the optimal fertilizer rate are crucial for sustainable peach production in Georgia.

**Peach: Origin, Botany, and Economic Importance**

Peach [*Prunus persica* (L.) Batsch] is a stone fruit of immense economic importance that belongs to the Rosaceae family. Originating in China, peaches have been cultivated for over 3000 years and hold significant cultural significance in Chinese culture, where they are regarded as symbols of immortality and unity, and the peach tree is referred to as the tree of life (Layne and Bassi, 2008). China is the largest producer of fresh peaches worldwide, accounting for a total production of 8.8 million tons (FAO-STAT, 2022).

Peach trees require approximately 500 chill hours and thrive in temperate climates, although low-chill varieties can also be found in subtropical and tropical regions. Ideal growth conditions include well-drained soil with a pH range of 6-6.5, along with ample sunlight. Typically, peach trees grow up to 7 meters in height, but in orchards, they are maintained at 3-4 meters through regular pruning. The root system of peach trees is shallow, with a majority of roots within 80 cm from the soil surface and extending horizontally up to 250 cm from the tree trunk (Havis, 1938).

Peach leaves are glossy green, lanceolate, long pointed, and widest in the center, while the flowers are pink, white, or red. Flowering typically begins in early spring, before the leaves break. During summer, pubescent fruits are produced, which are fleshy inside and contain a stony endocarp with a pit (Layne and Bassi, 2008). The fruit comes in varying shapes, sizes, skin colors, and flesh types, and is highly nutritious, providing vitamins A, B, and C. As climacteric fruit, peaches require proper harvest and post-harvest management. Each fruit contains a single large seed covered by a hard-wood shell externally. Although seed propagation is the major mode of propagation, vegetative propagation through cuttings, grafting, and budding is also common (Souza et al., 2011).

With a small genome size of 265 Mb and diploid nature (2n=16), the peach boasts a wide genetic diversity within the Rosaceae family, making it an ideal model species for genetic studies (Zhou et al., 2023). The broad genetic diversity enables peach trees to adapt to various environmental conditions, including growth habits, tree size, flower and fruit color, flavor, disease resistance, chilling hours, production, and root system, which increases their survival rate. However, pest and disease management pose a challenge in peach production, with various pests and diseases such as plum curculio, Peachtree borer, scale insects, mites, brown rot, scab, bacterial spot, and leaf curl posing a threat to fruit quality and yield. As a result, there have been considerable efforts to develop insect and disease-resistant cultivars through peach breeding programs (Chavez et al., 2019).

With the availability of different peach cultivars, peach is grown worldwide from temperate to tropical climates. In 2021, the total peach and nectarine together accounted for 1.5 million hectares of land with a total production of 24.9 million tons in the world (FAO-STAT, 2022). Production-wise, Asia ranks first followed by Europe and America. The top five countries producing peach and nectarine in the world are China (57%), Italy (9%), Spain (8%), the U.S. (7%), and Greece (5%) (FAO-STAT, 2022).

## History and Current Status of Peach Production in Georgia

Spanish and Portuguese explorers brought peach to the United States in the 1500s and since then the United States is one of the major peach-producing countries in the world (Hancock, 2008). Production-wise, the U.S. ranks third after China and European Union in the world (FAO-STAT, 2022). In 2021, U.S. peach acreage accounted for 74,400 acres with a total production of 688,770 tons worth $624 million (USDA NASS, 2022). Although peach-bearing acreage in the U.S. dropped by 2% compared to 2020, the total production and value of utilized production increased by 5.5 and 7.6% respectively in 2021 with better orchard management practices. Currently, 20 states in the U.S. contribute to peach production.

Georgia ranks third after California and South Carolina in terms of peach production in the U.S. It accounted for 8,200 peach-bearing acreages and produced 35,300 tons worth $35.6 million in 2021. It is also referred to as 'Peach State' for its history of developing the first commercial peach cultivar in the U.S., called 'Elberta'. This peach cultivar, with its yellow flesh and crimson blush skin, was created by Samuel H. Rumph in Macon, Georgia, and was famous for its high fruit and shipping quality. It was later extensively used for breeding programs to obtain high-quality peaches, well adapted to the U.S. climate (Chavez et al., 2014). Now, there are hundreds of peach cultivars of various flavors, colors, and uses easily available at various nurseries.

## Challenges of Peach Production in Georgia

Over the years, the peach industry in Georgia has faced significant drops in production, with an 80% reduction in 2017 compared to the previous year. Several challenges such as low chilling hours, late freeze injury, and disease pressure contributed to this drop. While the industry has seen some recovery in recent years, challenges such as weather conditions, disease pressure, and poor management practices continue to pose a threat.

Drought is another common and recurring challenge in the Southeast, observed over a decade now. Droughts are responsible for the third-highest economic loss resulting from natural hazards in the Southeast in the last 50 years (FEMA, 2018). The National Drought Mitigation Center in the U.S. indicated moderate to extreme drought conditions in most of this region. It is worth noting that there are currently no irrigation and fertilization management guidelines specific to the Southeast region. Irrigation systems are often not installed until the peach trees start bearing fruit, due to high initial cost. This often poses a high risk to the young peach trees. Moreover, the declining global water resources pose a significant threat to agriculture, which already uses 70-80% of freshwater sources (Mirás-Avalos et al., 2017). Excess fertilizer application on the other hand is resulting in higher costs, nutrient leaching, and environmental pollution (Carranca et al., 2018; Zhou and Melgar., 2020). Efficient irrigation and fertilizer management are thus crucial for sustainable peach production in this region.

**Peach Fertilization Management and Its Impacts**

Fertilizer application provides nutrients to the trees and ensures their growth and productivity. When it comes to fertilizing peach trees, timing, application, and fertilizer type are critical. In general, peach trees require fertilizer applications in early spring before new growth begins and again in summer after fruit harvest (Blaauw et al., 2018; Casamali et al., 2021a). Peach trees require balanced fertilization including macronutrients and micronutrients. Macronutrients such as nitrogen promote tree growth and leaf production, phosphorus promotes flowering and fruit development, and potassium helps with overall tree health and fruit quality (Havlin et al., 2016). Micronutrients such as boron, manganese, copper, and iron are equally important for metabolic processes such as photosynthesis, respiration, and protein synthesis (Tripathi et al., 2015). Casamali et al. (2021b) studied the effects of four different fertilizer rates (25, 50, 100, and 200%), with 100% indicating the current rate recommended by Blaauw et al. (2018), on a young peach orchard. He determined no consistent significant differences in plant or fruit parameters for any fertilizer rates used. This aligns with the statement by Carranca et al. (2018) about excess fertilizer application in peach orchards in Georgia. Excess fertilization not only increases the input cost and leads to nutrient leaching, but it can also lead to excessive vegetative growth, reducing fruit production and quality, increasing susceptibility to diseases and pests, and also nutrient imbalances in a crop (Zhou and Melgar, 2020). On the other hand, deficit fertilization can result in nutrient deficiencies that directly affect the crop. Nitrogen deficiency results in reduced vegetative growth, smaller fruits, and low yields in peach trees (Johnson, 2008). Iron deficiency causes interveinal chlorosis and results in reduced plant size, fruit production, fruit size, and quality in many crops such as tomato, citrus, pineapple, and deciduous fruit tree crops such as peach, plum, and cherry. (Rombolà and Tagliavini, 2006; Àlvarez-Fernàndez et al., 2006).

It is thus important to understand a crop's nutrient requirement and fertilize it optimally. Several studies have investigated the nutrient status of peach trees, by analyzing nutrients removed annually through leaves, fruits, fruits, and wood, which can be used to determine the optimal nutrient requirements for the trees (Zhou and Melgar, 2020; Casamali et al., 2021a).

## Peach Irrigation Management Practices and Its Impacts

Irrigation is important for crop growth and development. Irrigation scheduling involves determining the right amount of water to meet a crop's requirement at different growth stages. In general, the commonly used scheduling methods are weekly irrigation for furrow irrigation and daily (or as needed to be determined by soil moisture sensors) for surface and subsurface drip. Different kinds of sensors are used to determine the volumetric water content or water tension of the soil, and based on these probes, irrigation is scheduled. Other methods include determining the peach water requirement at various developmental stages through weather parameters.

Furrow irrigation was a commonly used practice in peach orchards (Bryla et al., 2003). It was simple and inexpensive to install and a potential option in a flat topography with good soil drainage. It is still prevalent in such areas. However, it involved a high labor input and uneven distribution of water resulting in lower efficiency. Growers became more inclined to modern irrigation techniques, such as micro-sprinkler, microjet, surface drip, and subsurface drip irrigation, which involved low water volumes, uniform distribution, enhanced plant growth and yield, and improved cultural practices. Replacing surface systems by micro-sprinkler or drip on average reduced water consumption by 54% and 76%, respectively, while maintaining the same level of crop yield (Jägermeyr et al., 2015).

Considering the limited water supply for agricultural purposes, new approaches to optimize agricultural water use without affecting the crop have emerged, such as deficit irrigation (DI) and alternate partial root-zone irrigation (APRI). Deficit irrigation refers to supplying optimal water at certain critical growth stages to maintain a certain level of water stress without affecting crop yield (Kirda, 2002). Different deficit irrigation strategies, such as sustained deficit irrigation (SDI) and cyclic deficit irrigation (CDI), have been implemented. While SDI refers to continuous water restriction throughout the growing season, CDI refers to irrigating whenever the soil volumetric water content falls below 50% of its field capacity (Guizani et al., 2019). A study showed that moderate water stress in peaches helps to increase the Abscisic acid (ABA) stimulated sugar levels in fruits compared to no stress, thus increasing the fruit quality (Kobashi et al., 2000). However, under severe stress, other physiological changes counteracted the effect of ABA. Under CDI, *Vitis vinifera* plants developed the ability to adapt to water stress conditions (Gómez-del-Campo et al., 2015). The water stress induced a decrease in the leaves and stem growth compared to the root growth in *Laurus nobilis* trees. These trees were more prone to SDI compared to CDI in terms of growth inhibition (Maatallah et al., 2010). According to Berman and DeJong (1996), peaches have high water requirements and are sensitive to water stress during certain growth stages. Despite this, peach growers in the Southeastern region typically follow irrigation recommendations designed for peach production in Mediterranean regions. However, these recommendations likely overestimate water requirements in this region due to differences in climate, soil, timing of plant growth stages, and cultivars. Furthermore, peaches cannot tolerate waterlogging conditions (Iacona et al., 2013), which highlights the need to develop appropriate irrigation recommendations for the Southeastern region's hot, humid, and subtropical climate.

Alcobendas et al. (2013) investigated the effect of two irrigation treatments (full irrigation and regulated deficit irrigation) on the mid-late maturing peach cultivar 'Catherine' and found that RDI resulted in comparatively smaller tree size and yield. However, water stress resulted in higher soluble solids, glucose, sorbitol, and malic, citric, and tartaric acids, likely due to low crop load. Mirás-Avalos et al. (2017) compared three irrigation treatments based on peach tree phenological stages: control with daily irrigation above crop evapotranspiration, precision treatment, and regulated deficit irrigation (RDI) with full irrigation during critical periods. They found that RDI treatment increased water productivity while maintaining fruit yield and quality. Williamson and Coston (1990) compared two irrigation treatments (irrigation replacement based on 12.5% or 100% of the daily evapotranspiration) during all fruit development stages in 'Redhaven' peach trees in South Carolina and found no significant differences in plant size and fruit yield. These studies suggest that plant-based water requirements are more precise in determining actual water needs, and irrigation scheduling based on this parameter is recommended.

Peach growers in Georgia traditionally start irrigation practices in an orchard in the third or fourth year after planting when the first commercial yield is expected. In Georgia, irrigating young peach trees since orchard establishment has been found to enhance plant growth, development, and yield (Casamali et al., 2021b). Irrigation during the fruit development phase is equally essential as it largely correlates with the fruit size and crop yield (Crisosto et al., 1994). Research indicates that irrigation deficit at an early phase of plant growth resulted in limited shoot extension and limb diameter, although the fruit size increased (Li et al., 1989b, Williamson and Coston, 1990). Peach trees required 233, 441, and 743 mm of water during their first three growing seasons, and vegetative growth was enhanced compared to no irrigation, regardless of any irrigation method used (Bryla et al., 2003; Bryla et al., 2005).

### Crop coefficient (Kc)

The crop coefficient of a plant is a property used to predict crop evapotranspiration. It differs as a function of the region, environmental parameters, and physiological factors (Ayars et al., 2003). In peaches, there have been multiple studies to determine the crop coefficient. These studies are summarized in Table 1.1. The Penman-Monteith FAO-56 equation is used to predict crop evapotranspiration Kc=ETc/ETo. Crop evapotranspiration (ETc) refers to the crop's daily water use and is used to estimate the accurate irrigation needs of a crop (Jensen, 1968). Reference evapotranspiration (ETo) is the cumulative amount of water that is transpired by the reference crop at its most active growth stage along with the water evaporated from soil under ideal conditions. This method of irrigation scheduling is widely used these days for various crops such as avocado, cotton, citrus, soybean, turf and vegetables (Migliaccio et al., 2015). In peach, it has been found that the replacement of 100% of daily evapotranspiration (ET) during all fruit development stages compared to 12.5% ET during the first two stages plus 100% at the third stage resulted in no significant difference for fruit yield, fruit size, and other vegetative growth parameters (Williamson and Coston, 1990).

### SmartIrrigation App for Irrigation Scheduling

SmartIrrigation App is a smart phone-based application that helps the user to schedule irrigation based on the soil and plant characteristics along with real-time weather data. It uses the crop coefficient curve as a parameter in the irrigation scheduling process. A grower will receive his crop's irrigation scheduling via a smartphone with this app. It provides notifications on any irrigation requirements, thus it will not be necessary for the growers to check the app daily (Vellidis et al., 2016). Currently, growers have been using these apps in cotton, peanuts, corn, and citrus, and have experienced ease in irrigation management in large areas (Migliaccio et al., 2015). These apps have shown improvement in crop yield as well as the crop's water use efficiency (Vellidis et al., 2016, Mbabazi et al., 2017). This success has been translated into increasing demand for these apps by growers in various crops (Bartlett et al., 2015; Vellidis et al., 2016).

**Research Objectives**

The overall objective of this research is to develop a proper irrigation scheduling tool that would meet the crop water requirements for peach production in Georgia. The specific objectives of each chapter are as follows:

Chapter 2) To evaluate the nutritional distribution of young peach trees in soil, leaf, and fruits under different irrigation and fertilization practices in Georgia.

Chapter 3) To develop a proper irrigation scheduling tool, SmartIrrigation Peach App, based on crop evapotranspiration and evaluate its performance in young peach orchards.

Chapter 4) To compare the performance of SmartIrrigation Peach App with the sensor-based irrigation system (UGA Smart Sensor Array) in a mature peach orchard.

Chapter 5) To understand the effects of newly developed irrigation scheduling tools and fertilizer rates on nutrient profiling of young and mature peach trees in Georgia.

## Literature Cited

Abrisqueta, I., Abrisqueta, J. M., Tapia, L. M., Munguía, J. P., Conejero, W., Vera, J., & Ruiz-Sánchez, M. C. (2013). Basal crop coefficients for early-season peach trees. *Agricultural Water Management*, *121*, 158-163.

Alcobendas, R., Miras-Avalos, J. M., Alarcón, J. J., & Nicolas, E. (2013). Effects of irrigation and fruit position on size, colour, firmness and sugar contents of fruits in a mid-late maturing peach cultivar. *Scientia Horticulturae*, *164*, 340-347.

Allen, R. G., Smith, M., Pereira, L. S., & Pruitt, W. O. (1996, September). Proposed revision to the FAO procedure for estimating crop water requirements. In *II International Symposium on Irrigation of Horticultural Crops 449* (pp. 17-34).

Àlvarez-Fernàndez, A., Abadía, J., & Abadía, A. (2006). Iron deficiency, fruit yield and fruit quality. *Iron nutrition in plants and rhizospheric microorganisms*, 85-101.

Ayars, J. E., Johnson, R. S., Phene, C. J., Trout, T. J., Clark, D. A., & Mead, R. M. (2003). Water use by drip-irrigated late-season peaches. *Irrigation Science*, *22*, 187-194.

Ayars, J., Trout, T., Mead, R., Phene, C., & Johnson, R. S. (1999, June). Crop coefficients for mature peach trees are well correlated with midday canopy light interception. In *III International Symposium on Irrigation of Horticultural Crops 537* (pp. 455-460).

Bartlett, A. C., Andales, A. A., Arabi, M., & Bauder, T. A. (2015). A smartphone app to extend use of a cloud-based irrigation scheduling tool. *Computers and Electronics in Agriculture*, *111*, 127-130.

Berman, M. E., & DeJong, T. M. (1996). Water stress and crop load effects on fruit fresh and dry weights in peach (Prunus persica). *Tree physiology*, *16*(10), 859-864.

Blaauw, B., Brannen, P., Bellinger, B., Lockwood, D. and Ritchie, D. (2018). Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide. University of Georgia Cooperative Extension, Athens, GA.

Bryla, D. R., Dickson, E., Shenk, R., Johnson, R. S., Crisosto, C. H., & Trout, T. J. (2005). Influence of irrigation method and scheduling on patterns of soil and tree water status and its relation to yield and fruit quality in peach. *HortScience*, *40*(7), 2118-2124.

Bryla, D. R., Trout, T. J., Ayars, J. E., & Johnson, R. S. (2003). Growth and production of young peach trees irrigated by furrow, microjet, surface drip, or subsurface drip systems. *HortScience*, *38*(6), 1112-1116.

Carranca, C., Brunetto, G., & Tagliavini, M. (2018). Nitrogen nutrition of fruit trees to reconcile productivity and environmental concerns. *Plants*, *7*(1), 4.

Casamali, B., van Iersel, M. W., & Chavez, D. J. (2021 a). Nitrogen Partitioning in Young "Julyprince" Peach Trees Grown with Different Irrigation and Fertilization Practices in the Southeastern United States. *Agronomy*, *11*(2), 350.

Casamali, B., van Iersel, M. W., & Chavez, D. J. (2021 b). Plant growth and physiological responses to improved irrigation and fertilization management for young peach trees in the southeastern United States. *HortScience*, *56*(3), 336-346.

Chavez, D. J., Beckman, T. G., Werner, D. J., & Chaparro, J. X. (2014). Genetic diversity in peach [Prunus persica (L.) Batsch] at the University of Florida: past, present and future. *Tree genetics & genomes*, *10*, 1399-1417.

Chavez, D. J., Florkowska, M., Chen, C., & Cook, J. (2019). Home Garden Plums. *UGA Extension Circular,* University of Georgia, Extension, Athens, Georgia.

Crisosto, C. H., Johnson, R. S., Luza, J. G., & Crisosto, G. M. (1994). Irrigation regimes affect fruit soluble solids concentration and rate of water loss of O'Henry'peaches. *HortScience*, *29*(10), 1169-1171.

FAO-STAT. (2022). Food and Agriculture Organization of the United Nations (FAO-STAT). [WWW document]. Food Agric. Organ. United Ntions. URL http://www.fao.org/faostat/en/#data/QC (accessed 3.7.22).

Federal Emergency Management Agency. (2018). 2017 Hurricane Season FEMA After-Action Report.

Girona, J., Mata, M., Arbonès, A., Alegre, S., Rufat, J., & Marsal, J. (2003). Peach tree response to single and combined regulated deficit irrigation regimes under shallow soils. *Journal of the American Society for Horticultural Science*, *128*(3), 432-440.

Gómez-del-Campo, M., Baeza, P., Ruiz, C., & Lissarrague, J. R. (2015). Water-stress induced physiological changes in leaves of four container-grown grapevine cultivars (Vitis vinifera L.). *VITIS-Journal of Grapevine Research*, *43*(3), 99.

Guizani, M., Dabbou, S., Maatallah, S., Montevecchi, G., Hajlaoui, H., Rezig, M., ... & Kilani-Jaziri, S. (2019). Physiological responses and fruit quality of four peach cultivars under sustained and cyclic deficit irrigation in center-west of Tunisia. *Agricultural Water Management*, *217*, 81-97.

Hancock, J. F. (Ed.). (2008). *Temperate fruit crop breeding: germplasm to genomics*. Springer Science & Business Media.

Havis, L. (1938). Peach tree root distribution. *Ecology*, *19*(3), 454-462.

Havlin, J. L., Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (2016). *Soil fertility and fertilizers*. Pearson Education India.

Iacona, C., Cirilli, M., Zega, A., Frioni, E., Silvestri, C., & Muleo, R. (2013). A somaclonal myrobalan rootstock increases waterlogging tolerance to peach cultivar in controlled conditions. *Scientia Horticulturae, 156*, 1-8.

Jägermeyr, J., Gerten, D., Heinke, J., Schaphoff, S., Kummu, M., & Lucht, W. (2015). Water savings potentials of irrigation systems: dynamic global simulation. *Hydrology & Earth System Sciences Discussions*, *12*(3).

Jensen, M. E. (1968). Water consumption by agricultural plants (Chapter 1).

Kirda, C. (2002). Deficit irrigation scheduling based on plant growth stages showing water stress tolerance. *Food and Agricultural Organization of the United Nations, Deficit Irrigation Practices, Water Reports*, *22*(102).

Kobashi, K., Gemma, H., & Iwahori, S. (2000). Abscisic acid content and sugar metabolism of peaches grown under water stress. *Journal of the American Society for Horticultural Science*, *125*(4), 425-428.

Layne, D., & Bassi, D. (Eds.). (2008). *The peach: botany, production and uses*. Cabi.

Li, S. H., Huguet, J. G., & Bussi, C. (1989 a). Irrigation scheduling in a mature peach orchard using tensiometers and dendrometers. *Irrigation and Drainage Systems, 3*, 1-12.

Li, S. H., Huguet, J. G., Schoch, P. G., & Orlando, P. (1989 b). Response of peach tree growth and cropping to soil water deficit at various phenological stages of fruit development. *Journal of Horticultural Science, 64*(5), 541-552.

Lund, J., Medellin-Azuara, J., Durand, J., & Stone, K. (2018). Lessons from California's 2012–2016 drought. *Journal of Water Resources Planning and Management*, *144*(10), 04018067.

Maatallah, S., Ghanem, M. E., Albouchi, A., Bizid, E., & Lutts, S. (2010). A greenhouse investigation of responses to different water stress regimes of Laurus nobilis trees from two climatic regions. *Journal of arid environments*, *74*(3), 327-337.

Marsal, J., & Girona, J. (1997). Relationship between leaf water potential and gas exchange activity at different phenological stages and fruit loads in peach trees. *Journal of the American Society for Horticultural Science*, *122*(3), 415-421.

Mbabazi, D., Migliaccio, K. W., Crane, J. H., Fraisse, C., Zotarelli, L., Morgan, K. T., & Kiggundu, N. (2017). An irrigation schedule testing model for optimization of the Smartirrigation avocado app. *Agricultural Water Management*, *179*, 390-400.

Migliaccio, K. W., Morgan, K. T., Vellidis, G., Zotarelli, L., Fraisse, C., Rowland, D. L., ... & Zurweller, B. A. (2015). Smartphone apps for irrigation scheduling. In *2015 ASABE/IA Irrigation Symposium: Emerging Technologies for Sustainable Irrigation-A Tribute to the Career of Terry Howell, Sr. Conference Proceedings* (pp. 1-16). American Society of Agricultural and Biological Engineers.

Mirás-Avalos, J. M., Pérez-Sarmiento, F., Alcobendas, R., Alarcón, J. J., Mounzer, O., & Nicolás, E. (2017). Maximum daily trunk shrinkage for estimating water needs and scheduling regulated deficit irrigation in peach trees. *Irrigation science*, *35*, 69-82.

Paço, T. A., Ferreira, M. I., Rosa, R. D., Paredes, P., Rodrigues, G. C., Conceição, N., ... & Pereira, L. S. (2012). The dual crop coefficient approach using a density factor to simulate the evapotranspiration of a peach orchard: SIMDualKc model versus eddy covariance measurements. *Irrigation Science*, *30*, 115-126.

Rombolà, A. D., & Tagliavini, M. (2006). Iron nutrition of fruit tree crops. *Iron nutrition in plants and rhizospheric microorganisms*, 61-83.

Souza, A. D. G., Chalfun, N. N. J., Faquin, V., & Souza, A. A. D. (2011). Production of peach grafts under hydroponic conditions. *Ciência e Agrotecnologia*, *35*, 322-326.

Tripathi, D. K., Singh, S., Singh, S., Mishra, S., Chauhan, D. K., & Dubey, N. K. (2015). Micronutrients and their diverse role in agricultural crops: advances and future prospective. *Acta Physiologiae Plantarum*, *37*, 1-14.

U.S. Department of Agriculture, National Agricultural Statistics Service. 2022. Noncitrus Fruits and Nuts 2021 Summary. U.S. Department of Agriculture. Washington, D.C.

Vellidis, G., Liakos, V., Andreis, J. H., Perry, C. D., Porter, W. M., Barnes, E. M., ... & Migliaccio, K. W. (2016). Development and assessment of a smartphone application for irrigation scheduling in cotton. *Computers and Electronics in Agriculture*, *127*, 249-259.

Williamson, J. G., & Coston, D. C. (1990). Planting method and irrigation rate influence vegetative and reproductive growth of peach planted at high density. *Journal of the American Society for Horticultural Science*, *115*(2), 207-212.

Zhou, H., Sheng, Y., Qiu, K., Ren, F., Shi, P., Xie, Q., ... & Zhang, J. (2023). Improved Annotation of the Peach (Prunus persica) Genome and Identification of Tissue-or Development Stage-Specific Alternative Splicing through the Integration of Iso-Seq and RNA-Seq Data. *Horticulturae*, *9*(2), 175.

Zhou, Q., & Melgar, J. C. (2020). Tree Age Influences Nutrient Partitioning among Annually Removed Aboveground Organs of Peach. *HortScience*, *55*(4), 560-564.

Table 1.1 Kc values for peach production around the world

| **Year** | **Source** | **Kc values** | **Reference** |
|---|---|---|---|
| 1990 | South Carolina, USA. | Kc average: 0.7 | (Williamson and Coston, 1990) |
| 1997 | FAO | With active ground cover - Kc initial: 0.8 / Kc mid: 1.15 / Kc end: 0.85 | (Allen et al., 1996) |
| 1997 | FAO | No active ground cover – Kc initial: 0.55 / Kc mid: 0.90 / Kc end: 0.65 | (Allen et al., 1996) |
| 1997 | Spain | Kc initial: 0.25 / Kc mid: 1.0 (or 1.05 during rapid fruit growth) / Kc end: 0.55 | (Marsal and Girona, 1997) |
| 1999 | California | Kc average: 0.86 | (Ayars et al., 1999) |
| 2003 | Spain | Kc initial: 0.25 / Kc mid: 1.0 (or 1.05 during rapid fruit growth) / Kc end: 0.55 | (Girona et al., 2003) |
| 2003 | California | Kc bloom: 0.25 / Kc mid: 0.7 / Kc harvest: 1 / Kc late: 0.6 | (Ayars et al., 2003) |
| 2012 | Portugal | Evaluated only at end of season kc: 0.5 | (Paço et al., 2012) |
| 2013 | Spain | Kcb initial: 0.15 to 0.45 / Kcb mid: 1.0 / Kcb end: 0.15 to 0.45 | (Abrisqueta et al., 2013) |

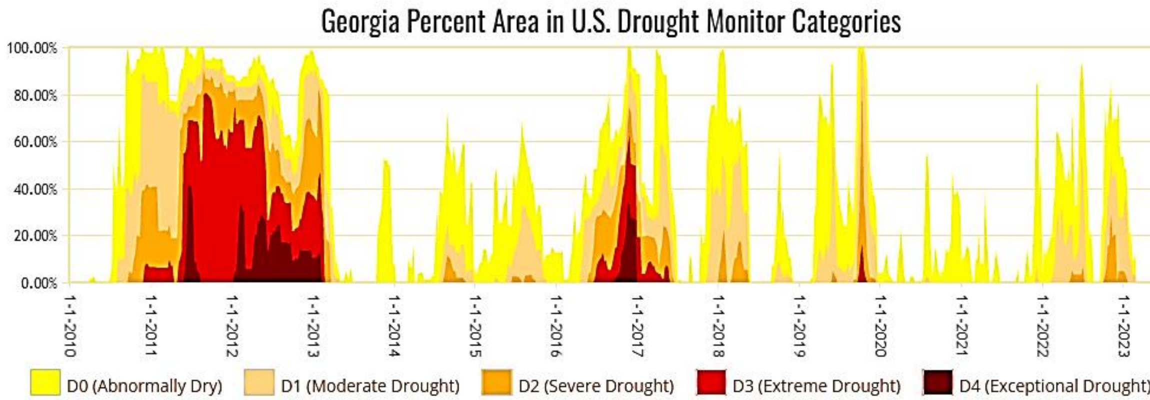



Figure 1.1 Drought monitor indicating moderate to severe drought incidence in Georgia from 2010-2023 (Source: U.S.Drought Monitor, 2023; https://droughtmonitor.unl.edu/ )

# CHAPTER 2

# IRRIGATION AND FERTILIZATION EFFECTS ON NUTRIENT DISTRIBUTION IN YOUNG PEACH ORCHARDS IN GEORGIA

[1]Thapa Magar, S, B. Casamali, D.J. Chavez. To be submitted to ***Agronomy.***

**Abstract**

Irrigation establishment in peach orchards in Georgia and the Southeastern U.S. starts typically three to four years after orchard establishment. Fertilizer recommendations also need to be updated. This study aimed to evaluate the effects of different irrigation and fertilization practices on nutrient distribution in a young orchard. Peach trees cv. ‘Julyprince’ grafted onto ‘Guardian’ rootstock was established in 2015 at the Peach Research and Extension Orchard in Griffin, GA. Two irrigation levels (irrigated and non-irrigated), two irrigation systems (drip and micro-sprinkler), and four fertilizer rates (25%, 50%, 100%, and 200% of the yearly recommended rate) were tested. Soil samples were collected and analyzed for macro- and micro-nutrients, pH, and CEC at two depths (8” and 16”) in March. Leaf and fruit samples were collected and analyzed in late June and July, respectively. Soil nutrient analysis results revealed that higher fertilizer rates resulted in higher concentrations of N, P, K, and Mn, but a lower pH and Mg. Irrigation resulted in increased soil pH and Mg concentration. Similarly, drip irrigation yielded higher levels of N, Zn, Mn, and Fe at lower soil pH compared to micro-sprinkler irrigation. Soil pH was lower at 0-20 cm depth where CEC and all soil nutrients were higher compared to 20-40 cm. Leaf nutrient analyses showed that higher concentrations of K, Mn, and Ca were associated with higher fertilizer levels. Irrigation yielded higher Ca and B concentrations in leaves but did not affect other nutrient concentrations. Irrigation and fertilizer rates did not affect fruit nutritional status; however, fruits were deficient in Ca, Zn, Mn, and Fe. Overall, results indicated that although macro- and micro-nutrients were abundant in the soil, they were not necessarily available to young peach trees. Irrigating young peach trees enhanced vegetative growth and yield, however, it only contributed to higher nutrient

uptake of a few nutrients. An increase in the fertilizer rates in peach production in Georgia did not necessarily translate to an increased nutrient level in the soil, leaves, and fruit. Our results provided insight into the nutritional status of young peach trees and nutrient deficiencies that will need further studies.

**Additional index words**: *Prunus persica*; macronutrients, micronutrients; young peach trees, nutrient balance, fertilizer rates, water

**Introduction**

Both irrigation and fertilization, are vital management practices for tree growth and production. Lack or excess application of one or both can severely affect tree health and productivity. Fertilization and irrigation management guidelines in Georgia and most of the Southeast are outdated and need to be improved. These fertilizer guidelines are variable (Ferree and Krewer, 1996; Taylor, 2012). They are believed to have been taken and modified from peach production in California and the Mediterranean regions of the world. However, the variable soil and weather conditions don't make these recommendations optimal for the Southeast regions. Furthermore, excessive fertilizer application in commercial orchards is common (Carranca et al., 2018). High rates of fertilizer do not necessarily result in increased productivity. It instead increases the cost of production, resulting in soil nutrient losses, and pollution (Zhou and Melgar, 2020). It is important to understand the peach tree's nutritional status for efficient orchard management. Optimal fertilizer application is thus of growing interest (Casamali et al., 2021a). Currently, peach growers in Georgia use the fertilizer recommendations found in The Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide (Blaauw et. al, 2018). Georgia and the Southeastern U.S. fertilizer recommendations need to be updated based on the tree's requirements for our region. Previous research has investigated the peach tree's nutritional status and how many nutrients are removed annually through leaves, fruitlets, fruits, and wood (Zhou and Melgar, 2020; Casamali et al., 2021a). This estimate can be used to determine the tree's optimal nutrient requirement.

On the other hand, irrigation management in Georgia and most of the Southeastern U.S. is not commonly done until trees reach fruit-bearing age (3-4 years after planting). Prior research has shown that irrigation since initial tree establishment resulted in plants with higher vigor and overall production (Casamali et al., 2021b). The irrigated trees produced significantly larger trunk cross-sectional area and canopy volume compared to non-irrigated trees. This difference in plant size was pronounced during the drought in 2016. One of the major reasons for this difference is soil moisture level. Irrigation ensures water availability in the plant root zone which facilitates nutrient movement and its uptake by plants. Plants absorb most of the macronutrients from the soil through mass flow from soil solution in response to transpiration. Thus, a lack of water in the soil can limit nutrient uptake despite nutrient abundance in the soil (Duman, 2012). Casamali et al. (2021a) support this statement as a greater amount of N was removed from the irrigated trees in comparison to non-irrigated trees considering nutrient removal from the leaves and summer pruning.

The majority of the studies in peach focus on macronutrient levels in soil and leaves. However, micronutrients are not generally emphasized. Micronutrients, although required in small amounts, are key components to plant growth and productivity. Micronutrients such as Fe, Zn, Cu, Mn, and B play a crucial role in various plant metabolic processes such as photosynthesis, respiration, and protein synthesis (Tripathi et al., 2015).

They also help improve plants' tolerance to biotic and abiotic stresses. These macro and micro-nutrients play an important role in plant growth, fruit production, and fruit quality. For example, a Nitrogen deficiency results in smaller fruits, shorter shoots, and low yields in peach trees (Johnson, 2008), and calcium deficiency in apples results in the bitter pit, a physiological disorder that causes large postharvest losses (Gomez and Kalcsits, 2020). Iron deficiency causes interveinal chlorosis and results in reduced plant size, fruit production, fruit size, and quality in many crops such as tomato, citrus, pineapple, and deciduous fruit tree crops such as peach, plum, and cherry. (Rombolà and Tagliavini, 2006; Àlvarez-Fernàndez et al., 2006). In peaches, iron deficiency results in a reduced number of fruits per tree, and smaller fruit size thus resulting in lower fruit yields (Àlvarez-Fernàndez et al., 2006). This is mainly due to a reduction in leaf chlorophyll content where severely chlorotic trees led to a >80% reduction in the number of fruits per tree compared to Fe-sufficient peach trees. The same study also confirmed the reduction in fruit size by 30% in severely Fe-deficient trees leading to a potential yield reduction of almost 50%. In *Citrus spp*., Fe deficiency results in higher citric acid concentrations in juice at maturity which tend to drop as the fruit matures (Pestana et al., 2002). Fe deficiency is also seen to delay ripening in tomatoes (Lyon et al., 1943) and peach (Sanz et al., 1997). Boron deficiency affects fruit set, fruit growth and development in grapes (Christensen et al., 2006), and hollow heart in peanuts (Rerkasem et al., 1993).

Nutrient distribution in tree fruit depends on various factors such as irrigation, fertilizer application, tree age, and environmental conditions. Casamali et al. (2021a) reported that supplemental irrigation of peach trees since establishment resulted in higher vegetative growth and yield. As a result, cumulative N removal was higher for irrigated trees mainly in vegetative removal events (stems and leaves). Policarpo et al. (2002) also studied N partitioning in early and late-season peach cultivars and determined that leaves were the main sinks of N during the entire growing season. Similarly, it was found that different fertilizer levels did not affect the plant's N partitioning (stems, fruitlets, leaves, and fruit). Zhou and Melgar, (2020) reported that tree age determines nutrient distribution in various aboveground organs in peaches. They compared 6-year-old (mature) and 20-year-old (old) 'Cresthaven' peach trees and found that mature peach trees allocated more nutrients (N, P, K, and Ca) to pruned wood and fruit than leaves compared to old trees. N fertilization in mature pear trees made a small contribution to leaf growth compared to its contribution in young pear trees (Sanchez et al., 1992; Quartieri et al., 2002). Carranca et al. (2018) reported that young nonfruiting trees differed in their nutrient uptake pattern and requirements from mature trees. Mature trees have a larger storage pool thus the nutrient resorption, storage, and remobilization are higher than the young trees (Netzer et a., 2017; Weinbaum et al., 2001). In another study, abundant soil nutrients did not always translate to optimal nutrient translocation, which can often result in nutrient deficiency in plants (Samiullah et al., 2013). Overall, multiple factors could create a nutrient imbalance, leading to nutrient deficiency. It is thus important to study and compare the nutritional status of soil, leaves, and fruit over years to determine any nutrient deficiency and rationalize fertilizer application accordingly.

The objective of this study was to understand the nutritional status of a peach orchard at the soil, leaf, and fruit level under various irrigation and fertilization practices in Georgia. Our first hypothesis was that irrigated young peach trees would have better nutrient status. Our second hypothesis was that the application of higher fertilizer rates would result in higher nutrient distribution in young peach trees. Understanding the effects of irrigation and fertilizer applications on the nutritional status of young peach plants can help researchers and growers in optimizing water and nutrient requirements for peach production in Georgia and the Southeastern U.S.

## Materials and Methods

### *Plant Material and Field Conditions*

This study was conducted in a young peach orchard established in 2015 at the University of Georgia Peach Research and Extension Orchard in Griffin, Georgia, USA (33°14’55” N, 84°17’57” W). A commercial cultivar ‘Julyprince’ grafted onto ‘Guardian’ rootstock was planted in a Cecil sandy loam soil at the planting density of 4.5 m x 6 m (358 trees per ha). A soil amendment with phosphorus, potassium, and lime was applied before the orchard establishment following the guidelines from Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide (Blaauw et al., 2018).

### *Experimental Design*

The experimental design was a split-plot randomized complete block design with irrigation systems as main plots as previously described by Casamali et al. (2021a, b). There were four blocks with three treatments in each block. Each treatment combination had one replication per block. The treatments were (1) irrigation levels (irrigated vs. non-irrigated); (2) irrigation systems (drip vs. micro-sprinkler); and (3) fertilization rates (25, 50, 100, and 200%). Irrigation was maintained from May to September following three different threshold levels considering the volumetric water content (VWC) of the soil: (1) 25% from early May to Early August; (2) 20% from early August to mid-September; and (3) 15% from mid-September to late September. The drip irrigation system consisted of four emitters (SB-20 Bowsmith: Exeter, CA) placed around a tree with a total irrigation rate of 30.4 $L \cdot h^{-1}$. Micro-sprinkler irrigated system consisted of a Micro-Quick™ spray (QN-08) with the same irrigation rate. The micro-sprinklers were set in pattern E (down spray pattern) with a diameter of ~0.9 m during the first two years of establishment. The micro-sprinklers were set in a pattern A (360° Star Bird™ pattern) with a diameter of ~4.3 m considering the growth in plant size. The fertilizer levels were based on the current recommended rates for peach production. The current recommended rate is 65, 95, and 98 $kg \cdot ha^{-1}$ N for one, two, and three-year-old peach trees respectively (Blaauw et. al, 2018). For the first two years, the first fertilizer application was 10.0N-4.4P-8.3K (Farmers Favorite Fertilizer, Agri-AFC, Evergreen, AL, USA) was applied in March followed by two applications of 15.5N-0P-0K (Yara Live Tropicote, Yara, Tampa, FL, USA) in May and July. From the third year onward, there were only two applications, March (10.0N-4.4P-8.3K) and August (15.5N-0P-0K). 15.5N-0P-0K was a high-quality Calcium Nitrate product and included 19% Ca.

*Nutrient Analysis*

Soil samples were collected in April each year using a soil probe. The baseline soil sampling was done in April 2016 at a 0-40 cm depth. In 2017 and 2018, soil sampling was done for each data tree (64 in total). Samples were collected around the tree from within the tree canopy diameter (4 cores per tree per soil depth) at two soil depths (0-20 and 20-40 cm) in 2017 and 2018 and only at 0-20 cm in 2019. The four cores were then mixed and transferred to a paper bag. Each soil depth was kept separated. Then samples were dried at

65$^{o}$C for two days prior to being sent to Waters Agricultural Laboratories, Camilla, Georgia, USA for nutrient analysis.

Leaf samples were collected in July after harvest. Approximately 100 leaf samples from each data tree were collected. Leaves were collected from the canopy mid-section and mid-way within a stem from the current season fruiting wood. These samples were then placed in a paper bag and dried at 65°C for two days. Once dried, they were then sent to Waters Agricultural Laboratories, Camila, Georgia, USA for nutrient analysis using the Kjeldahl method.

Fruit samples from each data tree were collected during harvest. Individual tree samples were kept in grocery bags in a cooler with ice. Samples were transported to a laboratory for further size measurements. A total of ten fruit samples were used for these measurements and out of these, five fruit were quartered per data tree. Portions of each fruit's flesh were then collected and mixed. These samples were then dried in a 100mL Erlenmeyer flask at 65°C for two days. Dried samples were transferred to a paper bag and sent out for nutrient analyses.

*Data Analysis*

Nutrient data included macro- and micro-nutrients in soil (N measured as $NO_3$ and $NH_4$), leaf, and fruit. Macronutrients included Nitrogen (N), Phosphorus (P), Potassium (K), Magnesium (Mg), and Calcium (Ca) and micronutrients included Boron (B), Zinc (Zn), Manganese (Mn), Iron (Fe), and Copper (Cu). For soil, soil pH and cation exchange capacity (CEC) were also measured. Soil pH indicates if the soil is acidic or alkaline and it greatly affects the availability of different nutrients in the soil (Figure 1). CEC indicates the measure of total negative charges within the soil that adsorb plant nutrient cations. The

CEC of the soil varies with soil pH. The higher the CEC, the greater the plant nutrient availability in the soil for plant uptake. All the nutrient data were analyzed using SAS 9.4 (SAS Institute Inc., Cary, NC). Treatment means were separated using Tukey's Honest Significant Difference method with a significance level of $P \leq 0.05$. All data were compared across the years to determine if there was any significance across the years. Upon any significant differences, the data were then analyzed within each year to determine how each treatment evaluated affected the nutrient concentration in soil, leaf, and fruit in young peach trees.

**Results and Discussion**

Results for plant growth characteristics, fruit yield, and N partitioning in this research can be found in Casamali et al. (2021a, b). It was determined that irrigating young peach trees since tree establishment significantly increased the plant size (canopy volume and trunk cross-sectional area) and yield (Casamali et al., 2021b). The difference in plant size was notably higher during the drought conditions in 2016 between irrigated and non-irrigated trees. This difference in plant size in particular was carried over to 2017 and 2018. Regarding the different fertilizer rate applications and irrigation systems (drip and micro-sprinkler) used, no significant differences were observed in terms of plant size or yield. However, the drip irrigation system used 35% less water compared to the micro-sprinkler system. Casamali et al. (2021a) presented the results of N partitioning in peach trees, where irrigated trees accumulated more N with increased vegetative growth thus resulting in larger canopy growth and yield. Different fertilizer rates did not translate to a difference in N partitioning in young peach trees. The above results suggested irrigating peach trees at an early stage and reducing the current recommended fertilizer rates for optimal growth, yield, and potential economic savings. The nutritional aspect (including all macro- and micro-nutrients) of this experiment however is presented in this study below.

*Soil Nutrient Profile*

The soil nutrient analysis baseline performed in April 2016 indicated that the soil pH was on average 5.95 and all nutrient levels were at medium to an adequate level (Table 2.1) (Casamali et al., 2021a). The soil nutrients analyzed across years (2017, 2018, and 2019) were found to have significant differences thus analysis within each year was done to determine nutritional status within each year (Table 2.2). Soil pH increased slightly over years, but the change was not significant. However, soil pH did change with respect to the soil depth in which the soil sample at 20 cm depth was significantly lower than that collected at 40 cm depth. CEC in this experiment site was within the range of 5-10 meq per 100g for the sandy loam soil (Table 2.3) (Sonon et al., 2022). CEC increased significantly over years in this experiment indicating higher nutrient availability for plant uptake (Sonon et al., 2022). CEC was also higher at a depth of 20 cm (Table 2.3). Usually, the CEC is higher at the soil surface as most of the nutrients are available in this region. It is supported by our results since the nutrient concentration of soil samples at 20 cm of depth was consistently higher across years than samples at 40 cm of depth for P, K, Ca, B, Zn, Fe (2017), and Cu (2017). Other nutrients did not show differences across soil sampling depths (Tables 2.4- 2.7).

For all the nutrients compared across years, few nutrients had a higher concentration in the soil while the rest had lower concentration compared to 2016 (Tables 2.4-2.7). Nutrients like $NH_4$, Ca, B, Zn, and Mn were comparatively higher over years along with soil pH and CEC. Contrarily, NO3, P, K, Mg, Fe, and Cu were comparatively lower over years. In 2018, the soil samples were collected right after the fertilizer application thus the concentrations of nutrients in the soil were higher than that in 2017. The overall results suggest that the young peach trees were absorbing some of the nutrients quite efficiently for their growth and development compared to the rest. The higher concentration of nutrients like Ca and $NH_4$ in soil probably is the result of the use of fertilizer (YaraLiva Tropicote) that supplies Ca and N in a higher percentage. Also, a drought occurred in 2016 which is a possible reason for the lower Ca concentration in the soil. B, Zn, and Mn are categorized as immobile plants and are also found to bind with organic compounds, limiting their uptake by plants (Havlin et al., 2016).

*i. Irrigation effects on soil nutrient profile*

Overall, irrigating young peach trees since the orchard establishment had positive impacts on nutrient distribution, uptake, and overall vegetative growth compared to non-irrigated trees. Treatments with irrigation had significantly higher soil pH but CEC was not affected by the presence or absence of irrigation (Table 2.3). Irrigation resulted in a lower concentration of various nutrients ($NH_4$, $NO_3$, P, K, Mn, and Fe) in the soil (Tables 2.4-2.7), indicating the fact that these nutrients were either absorbed by the plants or lost through leaching. Irrigation did increase the Mg concentration in soil but decreased P and K concentrations (Table 2.4 and 2.5). Ca concentration was not affected across treatments. However, Ca and Mg concentrations are known to have an inverse relationship with N and K concentrations where a higher concentration of one reduces the plant uptake of the other (Havlin et al., 2016). Micronutrients such as Mn, Fe, and Cu were significantly higher in non-irrigated treatments (Table 2.6 and 2.7).

In terms of the irrigation systems, soil pH was significantly higher in the micro-sprinkler irrigated plants but some of the nutrients ($NH_4$, $NO_3$, Zn, Mn, Fe, and Cu) were abundant in drip irrigation system (Table 2.4- 2.7).

ii. *Fertilizer rates effects on soil nutrient profile*

The application of four different fertilizer rates had significant differences in terms of soil nutrient distribution (Tables 2.4- 2.7). Higher fertilizer rate application resulted in a significant decrease in soil pH within each season. The CEC was the lowest at 50% fertilizer rate application in 2017, (Table 2.3) but there was no significant difference in the following years. Concentrations of a few nutrients such as $NH_4$, P, and K increased consistently with increased fertilizer rates within each season, opposite to Mg which significantly decreased. Low soil pH at higher fertilizer rates as well as the inverse relationship with N and K concentration are the possible reasons for lower Mg concentrations. Ca, B, Zn (2017) and Cu did not change with an increased rate of fertilizer (Table 2.5- 2.7).

*Leaf Nutrient Profile*

All leaf nutrient levels for our research plot were within the sufficiency range in 2016 (Johnson, 2008; Tables 2.9-2.12). Over the study years, the concentration of all the nutrients in the leaf changed (Table 2.8). While some of the nutrients increased significantly, others decreased. The relative concentration of most nutrients such as N, P, K, S, B, and Cu in the leaf increased significantly when comparing data from multiple years suggesting that uptake of these nutrients increased as the trees matured (independently of the treatment effect evaluated) (Table 2.8). The concentration of Ca, Mg, Fe, Zn, and Mn in the leaf started to drop as the tree started bearing fruit (Tables 2.10 and 2.11). This suggests that the tree is allocating nutrients more toward wood and fruit as suggested by Carranca et al. (2018) and Zhou and Melgar, (2020). It is also likely that the bicarbonates present in the irrigation water resulted in forming carbonates with Ca and Mg thus restricting their uptake by the plants. Upon testing the irrigation water in this experiment, the bicarbonate levels were high. While Mg was still within the sufficiency range, others dropped below this level. It is thus recommended to apply nutrients, especially micronutrients to meet the crop's requirement at different crop growth stages.

*i. Irrigation effects on leaf nutrient profile:*

Irrigation did not affect the leaf nutrient distribution except for P, K, and Ca (Tables 2.9 and 2.10). P and K concentrations in leaves under irrigated treatments were significantly higher in 2016 but not in the other years. P and K are the nutrients that are transported through mass flow and irrigation plays a significant role in this process (Havlin et al., 2016). Since the drought occurred in 2016, the irrigation factor significantly affected the P and K uptake. Ca uptake is driven by transpiration (Havlin et al., 2016) and its concentration was higher in irrigated trees compared to non-irrigated trees across all seasons. The irrigation system overall did not affect leaf nutrient concentration. In 2018, Ca and Mg concentrations were significantly higher in the micro-sprinkler system compared to the drip system (Table 2.10). Considering the higher vegetative growth in the drip irrigation system, it is likely that nutrients were allocated to support more vegetative growth in the drip system (Casamali et al., 2021b). Zn was significantly higher in the drip system throughout the growing stages (Table 2.11). No differences were reported for Fe and Cu when comparing micro-sprinkler versus drip irrigation across all seasons (Table 2.12).

*ii. Fertilizer rates effects on leaf nutrient profile:*

Different fertilizer levels did not have a significant effect in terms of nutrient concentration except Mg (Tables 2.9-2.12). Mg was significantly higher at the lowest fertilizer level compared to the current recommended rate in mature trees. It is similar to Mg concentration in terms of soil and justified by the difference in soil pH as the fertilizer rates are increased. Mn concentration in the leaf was higher at the highest fertilizer rates while Fe concentration was significantly higher at the lowest level compared to the current recommended rate in 2016 only. The results whatsoever were not consistent. Moreover, higher fertilizer rates didn’t necessarily result in a higher concentration of nutrients in leaves.

*Fruit Nutrient Profile*

The 2017 season was the first year of harvest followed by a second harvest in 2018. The fruit concentration of all the nutrients except B and Cu was significantly lower in 2018 compared to 2017 (Tables 2.13). The trees in 2017 were comparatively smaller and produced a lower yield than in 2018 (Casamali et al., 2021b). This indicates nutrient distribution allocated more toward plant growth and production in 2018 rather than accumulation. All the macronutrients in fruit were within the optimum nutrient range except for Ca (Table 2.14-2.15) (Johnson and Uriu, 1989). Calcium transport is driven by transpiration and is very immobile in the phloem (Havlin et al., 2016). This limits Ca transportation to fruit, storage organs, and young roots, which results in Ca deficiency in fruit. Also, the high amount of bicarbonates could have resulted in lower uptake of Ca similar to that in the leaf. In addition, high vegetative vigor leads to transpiration imbalances that could affect the Ca allocation to developing fruit (Wunsche and Ferguson, 2010). This statement aligns with our results which indicate comparatively lower Ca levels in fruits from irrigated trees, which had significantly larger vegetative growth than non-irrigated trees in 2017 and 2018. For micronutrients, B and Cu concentrations were within the optimum range, while Zn, Mn, and Fe concentrations were lower in 2018 (Table 2.15).

*i. Irrigation effects on fruit nutrient profile:*

Irrigation treatments did not affect nutrient concentration in fruit in either of these years (Tables 2.14 and 2.15). One of the possible reasons could be rainfall in 2017 (952 mm) and 2018 (940 mm) respectively which was comparable to the historic normal (947 mm) at the Dempsey farm in Griffin Georgia. Only N was significantly higher in fruit under non-irrigated treatments in 2018 (Table 2.14 and 2.15). All the nutrients were comparatively higher in the drip irrigation system than micro-sprinkler system (Table 2.14 and 2.15). Macronutrients like N, K, and Mg and micronutrients like Zn, Mn, Fe, and Cu in 2017 were significantly higher in the drip system compared to the micro-sprinkler system. However, these results were not significant in 2018. A possible explanation for this could be an advective freeze that occurred in 2018 and mainly affected the drip-irrigated side, the outcome of which is a significant drop in fruit yield in the drip-irrigated trees (Casamali et al., 2021b). Also, the trees irrigated with a micro-sprinkler system had smaller plant sizes indicating a different growth rate than the drip system. It is possible that the micro-sprinkler irrigated trees were allocating their nutrients to leaves, woods, and other permanent organs than fruits. The leaf nutrient analysis results indicated higher Ca and Mg concentrations in leaves in micro-sprinkler supporting this statement (Table 2.14). Overall, a drip irrigation system is known for its efficiency in terms of water use and nutrient uptake by plants.

*ii. Fertilizer rate effects on fruit nutrient profile:*

Higher fertilizer rate application does not always translate to higher nutrient concentration in the crop. Various factors such as environment, soil moisture, crop, nutrient uptake mechanism, and mobility within a crop can affect the nutrient distribution in the crop. In this experiment, for different fertilizer rates applied (25, 50, 100, and 200%), higher fertilizer rates did not ensure higher nutrient distribution in fruit (Tables 2.14 and 2.15). N and K concentrations were significantly lower at the 50% fertilizer rate compared to the 100% fertilizer rate, but 25% produced comparable N and K concentrations in fruit as the 100% and 200% fertilizer rates. There were no significant differences in the fruit micronutrient concentration across the different fertilizer rates applied, except for B. The B concentration in fruit at a 100% fertilizer rate was significantly higher than 50% and 200% but comparable to the 25% fertilizer rate in 2018.

Our overall results indicated that most of the nutrients were optimally distributed throughout young peach plants. The soil analysis results indicated abundant nutrients available to the plant, however, uptake and allocation to leaf and fruits were not adequate for certain nutrients. Upon comparing the leaf and fruit nutrient distribution, most of the nutrients in the leaf increased over the years whereas the nutrient concentration in the fruit decreased. This aligns with increasing vegetative vigor for the first three years. The commercial production in peach trees starts from its fourth year onward, it is thus likely that a larger number of fruits and higher production in a tree creates competition for available nutrients and may result in nutrient deficiency. It is therefore important to assess the needs of the tree and fertilize it appropriately.

**Conclusion**

The soil was abundant in terms of both macro and micronutrient concentrations. However, some of the management practices did not deliver optimal nutrient allocation to peach trees over the years. The young peach trees in general had sufficient macro- and micronutrients based on leaf analysis. Increased leaf nutrients over years supported higher vegetative growth. Macronutrients like Ca and Mg, despite being abundant in soil, were decreasing in leaves over the years. The immobile nature, binding property to the organic compounds in soil, and their inverse relationship to N and K uptake and translocation explain this trend. In fruits, nutrients like Ca, Zn, Mn, and Fe concentrations were lower than the optimum range for the first two years of harvest. These nutrients play an important role in metabolic activities, energy storage, and structural integrity. Their deficiency could adversely affect fruit set, production, and postharvest quality. It is thus important to understand why plants are having issues with nutrient uptake and their allocation to various parts. Some of the possible reasons we identified during this experiment are the drought that occurred during the growing season, soil moisture availability near the root zone, irrigation water nutrient content, plant growth, fruit yield, nutrient availability in the soil, soil pH, nutrient mobility within soil and plant, nutrient uptake mechanisms and nutrient allocation by the tree itself under nutrient deficient or sufficient conditions.

We identified that irrigating young peach trees with a drip irrigation system helped increase nutrient uptake of most of the nutrients and resulted in higher vegetative vigor of trees with higher fruit yield. The nutrient deficiency in fruits, regardless of any irrigation or fertilizer treatment we applied in this experiment, might be addressed through foliar applications. Further studies should be done to better understand the efficiency of nutrients by foliar applications in peach trees. It is also important to identify the irrigation source and run the nutrient test for possible bicarbonates in the water. These bicarbonates bind with Ca and Mg present in the soil and form their carbonates restricting the availability of Ca and Mg ions to plants. In terms of fertilizer rates, higher fertilizer rate application to young peach trees did not translate to higher nutrient distribution. It suggests that the current fertilizer recommendation should be reduced. Cutting the current recommended rate by 75% was sufficient to supply a similar amount of nutrients to the young peach trees. Thus, we recommend reducing fertilizer use for young peach trees. It not only ensures tree health at reduced production cost but also is environmentally friendly.

**Literature cited**

Àlvarez-Fernàndez, A., Abadía, J., & Abadía, A. (2006). Iron deficiency, fruit yield and fruit quality. *In Iron nutrition in plants and rhizospheric microorganisms* (pp. 85-101). Springer, Dordrecht.

Blaauw, B., Brannen, P., Bellinger, B., Lockwood, D. and Ritchie, D. (2018). Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide. University of Georgia Cooperative Extension, Athens, GA.

Casamali, B., van Iersel, M. W., & Chavez, D. J. (2021a). Nitrogen Partitioning in Young "Julyprince" Peach Trees Grown with Different Irrigation and Fertilization Practices in the Southeastern United States. *Agronomy*, *11(2),* 350.

Casamali, B., van Iersel, M. W., & Chavez, D. J. (2021b). Plant Growth and Physiological Responses to Improved Irrigation and Fertilization Management for Young Peach Trees in the Southeastern United States. *HortScience*, *56(3),* 336-346.

Carranca, C., Brunetto, G., & Tagliavini, M. (2018). Nitrogen nutrition of fruit trees to reconcile productivity and environmental concerns. *Plants, 7(1),* 4.

Christensen, L., Beede, R., & Peacock, W. (2006). Fall foliar sprays prevent boron-deficiency symptoms in grapes. *California Agriculture*, *60*(2), 100-103.

Duman, F. (2012). Uptake of mineral elements during abiotic stress. *In Abiotic Stress Responses in Plants* (pp. 267-281). Springer, New York, NY.

Ferree, M. E. & Krewer, G. W. (1996). Peaches and Nectarines. *UGA Extension Circular*, University of Georgia, Extension, Athens, Georgia.

Gomez, R., & Kalcsits, L. (2020). Physiological factors affecting nutrient uptake and distribution and fruit quality in ‘Honeycrisp’and ‘WA 38’apple (Malus× domestica Borkh.). *HortScience, 55(8),* 1327-1336.

Havlin, J. L., Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (2016). *Soil fertility and fertilizers*. Pearson Education India.

Johnson, R. S. (2008). Nutrient and water requirements of peach trees. *In The peach: botany, production and uses* (pp. 303-331). Wallingford UK: CABI.

Johnson, R. S., & Uriu, K. (1989). Mineral nutrition. *Growing and handling for fresh market: Division of Agriculture Resource; Larue J, Johnson RS (eds.). pp*, 68-81.

Lyon, C. B., Beeson, K. C., & Ellis, G. H. (1943). Effects of micro-nutrient deficiencies on growth and vitamin content of the tomato. *Botanical Gazette*, *104*(4), 495-514.

Netzer, F., Schmid, C., Herschbach, C., & Rennenberg, H. (2017). Phosphorus-nutrition of European beech (Fagus sylvatica L.) during annual growth depends on tree age and P-availability in the soil. *Environmental and Experimental Botany, 137*, 194-207.

Pestana, M., Correia, P. J., Miguel, M. G., Varennes, A., Abadía, J. and Faria, E. A. (2002) Foliar treatments as a strategy to control iron chlorosis in orange trees, *Acta Horticulturae. 596,* 223-228.

Policarpo, M., Di Marco, L., Caruso, T., Gioacchini, P., & Tagliavini, M. (2002). Dynamics of nitrogen uptake and partitioning in early and late fruit ripening peach (Prunus persica) tree genotypes under a Mediterranean climate. *Plant and soil, 239*, 207-214.

Quartieri, M., Millard, P., & Tagliavini, M. (2002). Storage and remobilisation of nitrogen by pear (Pyrus communis L.) trees as affected by timing of N supply. *European Journal of Agronomy*, *17*(2), 105-110.

Rerkasem, B., Bell, R. W., Lodkaew, S., & Loneragan, J. F. (1993). Boron deficiency in soybean [Glycine max (L.) Merr.] peanut (Arachis hypogaea L.) and black gram [Vigna mungo (L.) Hepper]: Symptoms in seeds and differences among soybean cultivars in susceptibility to boron deficiency. *Plant and Soil*, *150*, 289-294.

Rombolà, A. D., & Tagliavini, M. (2006). Iron nutrition of fruit tree crops. *Iron nutrition in plants and rhizospheric microorganisms*, 61-83.

Samiullah, Z. S., Tariq, M., Shah, T., Latif, A., & Shah, A. (2013). Micronutrients status of peach orchards in Swat valley. *Sarhad J. Agric*, 29(4), 485-493.

Sanchez, E. E., Righett, T. L., Sugar, D., & Lombard, P. B. (1992). Effects of timing of nitrogen application on nitrogen partitioning between vegetative, reproductive, and structural components of mature 'Comice'pears. *Journal of Horticultural science*, *67*(1), 51-58.

Sanz, M., Pascual, J., & Machín, J. (1997). Prognosis and correction of iron chlorosis in peach trees: Influence on fruit quality. *Journal of Plant Nutrition*, *20*(11), 1567-1572.

Sonon, L. S., Kissel, D. E., & Saha, U., (2022). Cation Exchange Capacity and Base Saturation. University of Georgia, Extension, Athens, Georgia

Taylor, K. C. (2012). Peach orchard establishment and young tree care. *UGA Extension Circular*, University of Georgia, Extension, Athens, Georgia.

Tripathi, D. K., Singh, S., Singh, S., Mishra, S., Chauhan, D. K., & Dubey, N. K. (2015). Micronutrients and their diverse role in agricultural crops: advances and future prospective. *Acta Physiologiae Plantarum*, *37*, 1-14.

Weinbaum, S. A., Brown, P. H., & Johnson, R. S. (2001, September). Application of selected macronutrients (N, K) in deciduous orchards: physiological and agrotechnical perspectives. In *International Symposium on Foliar Nutrition of Perennial Fruit Plants 594* (pp. 59-64).

Wünsche, J. N., Ferguson, I. B., & Janick, J. (2010). Crop load interactions in apple. *Horticultural reviews, 31*, 231-290.

Zhou, Q., & Melgar, J. C. (2020). Tree Age Influences Nutrient Partitioning among Annually Removed Aboveground Organs of Peach. *HortScience*, *55*(4), 560-564.

Table 2.1 Soil analysis from the experimental plot (0-40 cm depth) in 2016 at Dempsey Farm, University of Georgia.

| **pH** | **P** | **K** | **Mg** | **Ca** | **B** | **Zn** | **Mn** | **Fe** | **Cu** | **$NO_3$** | **$NH_4$** | **CEC**[1] | **OM**[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | kg·ha$^{-1}$ | | | | | | | | | | | cmol·kg$^{-1}$ | % |
| 5.95 | 58.9 | 188.4 | 184.8 | 866.4 | 0.5 | 3.3 | 22.4 | 66.2 | 1.4 | 17.0 | 5.4 | 4.84 | 1.51 |

Table 2.2 ANOVA table with p-values indicating significance of nutrients in soil against different treatments in young peach orchard.

| **Factors** | **Soil pH** | **P** | **K** | **Mg** | **Ca** | **B** | **Zn** | **Mn** | **Fe** | **Cu** | **CEC** | **$NH_4$** | **$NO_3$** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **<.0001** | **0.0003** | **<.0001** | **0.0088** | **<.0001** | **0.0005** | 0.6224 | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** |
| **Irrigation** | **0.0043** | **0.0454** | **0.0017** | **0.0417** | 0.2003 | 0.1108 | 0.7607 | 0.762 | 0.0267 | **0.002** | 0.513 | 0.5481 | 0.1726 |
| **Year*Irrigation** | 0.1048 | 0.7838 | 0.4583 | 0.7097 | 0.866 | 0.9627 | 0.7608 | 0.0541 | 0.9214 | 0.9717 | 0.9753 | 0.0702 | 0.6383 |
| **Fertilizer** | **<.0001** | **<.0001** | **0.0034** | **<.0001** | **0.0195** | 0.9363 | **0.036** | 0.5497 | **<.0001** | 0.6281 | 0.3315 | **<.0001** | **0.0002** |
| **Year*Fertilizer** | 0.1628 | 0.7905 | **0.0003** | 0.2178 | **0.0217** | 0.7789 | 0.9921 | 0.1348 | 0.8206 | 0.9875 | 0.5847 | **0.0001** | **0.0153** |
| **Irrigatio*Fertilizer** | 0.2286 | 0.8033 | 0.5234 | 0.6143 | 0.1111 | 0.0859 | **0.0272** | 0.659 | 0.0025 | **0.0083** | 0.2072 | 0.8315 | 0.9951 |
| **Year*Irrigat*Fertili** | 0.8787 | 0.9619 | 0.8929 | 0.9714 | 0.9032 | 0.7882 | 0.9996 | 0.9768 | 0.9879 | 0.9766 | 0.9928 | 0.4369 | 0.0724 |
| **System** | <.0001 | 0.0018 | 0.0884 | 0.0466 | 0.5274 | **0.0475** | <.0001 | <.0001 | 0.0004 | 0.4509 | 0.001 | 0.0015 | 0.0003 |
| **Year*System** | 0.0316 | 0.3771 | 0.7977 | 0.5082 | 0.8016 | 0.4887 | 0.719 | 0.5792 | 0.404 | 0.6896 | 0.9356 | 0.7148 | 0.0412 |
| **System*Fertilizer** | 0.0075 | 0.0011 | 0.6593 | 0.6175 | 0.1633 | **0.7668** | 0.0002 | 0.0007 | 0.0002 | 0.006 | 0.0681 | 0.4964 | 0.4253 |
| **Year*Fertilizer** | 0.3948 | 0.9364 | 0.0944 | 0.7914 | 0.5324 | 0.6837 | 0.9632 | 0.1358 | 0.8443 | 0.9981 | 0.8227 | 0.0003 | 0.2536 |
| **Year*System*Fertiliz** | 0.1292 | 0.6884 | 0.4675 | 0.7436 | 0.7595 | **0.724** | 0.9561 | 0.8197 | 0.8681 | 0.9132 | 0.9017 | 0.1934 | 0.7572 |

$P \leq 0.05$ indicates significance. Significant values are in bold letters.

[1] CEC: Cation Exchange Capacity
[2] OM: Organic Matter

Table 2.3 Soil pH and CEC in soil under different treatments for 3 years (2017, 2018 and 2019) in young peach orchard.

| **Treatments** | **pH** | | | **CEC (meq/100g)** | | |
|---|---|---|---|---|---|---|
| | **2017** | **2018** | **2019** | **2017** | **2018** | **2019** |
| **Irrigation** | | | | | | |
| Yes | 6.09 a[z] | 6.07 a | 6.12 | 5.41 | 6.23 | 6.51 |
| No | 5.80 b | 5.96 b | 6.18 | 5.27 | 6.04 | 6.63 |
| **System** | | | | | | |
| Drip | 5.86 b | 5.88 b | 6.15 | 5.78 a | 6.48 | 7.03 |
| Micro-Sprinkler | 6.33 a | 6.25 a | 6.22 | 5.04 b | 5.99 | 6.23 |
| **Fertilizer** | | | | | | |
| 25% | 6.19 a | 6.19 a | 6.32 a | 5.69 a | 6.15 | 6.58 |
| 50% | 6.13 a | 6.15 ab | 6.47 a | 5.00 b | 5.98 | 6.59 |
| 100% | 5.83 b | 5.98 b | 6.18 a | 5.27 ab | 6.23 | 7.00 |
| 200% | 5.65 c | 5.73 c | 5.65 b | 5.41 ab | 6.18 | 6.11 |
| **Depth** | | | | | | |
| 8" | 5.836 b | 5.925 b | | 5.790 a | 6.619 a | |
| 16" | 6.061 a | 6.102 a | | 4.887 b | 5.650 b | |

[z]Means followed by a different lowercase letter in a treatment effect within a year are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 2.4. Relative concentrations of $NH_4$, $NO_3$, P, and K in soil under different treatments in 2017, 2018 and 2019 in young peach orchard.

| Treatments | $NH_4$ (kg/ha) | | | $NO_3$ (kg/ha) | | | P (kg/ha) | | | K (kg/ha) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2017 | 2018 | 2019 | 2017 | 2018 | 2019 | 2017 | 2018 | 2019 | 2017 | 2018 | 2019 |
| **Irrigation** | | | | | | | | | | | | |
| Yes | 3.32 | 48.11 | 6.42 b[z] | 21.52 b | 46.77 | 4.00 | 72.59 b | 99.82 | 135.73 | 139.00 | 225.40 b | 160.03 |
| No | 5.13 | 66.64 | 8.67 a | 37.84 a | 50.22 | 4.00 | 81.38 a | 123.08 | 127.61 | 159.39 | 262.12 a | 150.61 |
| **System** | | | | | | | | | | | | |
| Drip | 4.36 a | 58.59 a | 9.78 | 26.45 a | 35.44 b | 5.68 a | 66.85 | 93.77 | 99.75 b | 150.08 a | 241.08 | 156.31 |
| Micro-Sprinkler | 2.28 b | 37.63 b | 7.57 | 16.59 b | 58.11 a | 2.31 b | 78.33 | 105.88 | 155.47 a | 127.93 b | 209.72 | 144.90 |
| **Fertilizer** | | | | | | | | | | | | |
| 25% | 2.28 | 15.47 c | 7.29 | 17.16 b | 37.26 b | 4.39 | 57.68 b | 69.62 c | 89.88 b | 155.01 | 183.19 c | 146.58 |
| 50% | 2.39 | 43.49 b | 6.67 | 22.35 b | 45.56 ab | 2.86 | 59.96 b | 87.43 bc | 104.72 b | 143.99 | 224.46 b | 150.99 |
| 100% | 4.69 | 47.65 b | 7.88 | 30.92 ab | 47.64 a | 6.67 | 84.95 a | 123.10 ab | 138.10 b | 141.51 | 245.04 ab | 162.89 |
| 200% | 7.55 | 122.88 a | 8.35 | 48.27 a | 63.53 a | 2.08 | 105.35 a | 165.66 a | 193.90 a | 156.27 | 322.35 a | 160.79 |
| **Depth** | | | | | | | | | | | | |
| 8" | 4.76 | 86.05 a | | 31.37 | 44.93 | | 107.78 a | 155.19 a | | 160.98 a | 289.17 a | |
| 16" | 3.69 | 28.70 b | | 27.99 | 52.07 | | 46.18 b | 67.71 b | | 137.41 b | 198.35 b | |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 2.5. Relative concentrations of Mg and Ca in soil under different treatments in 2017, 2018 and 2019 in young peach orchard.

| **Treatments** | **Mg (kg/ha)** | | | **Ca (kg/ha)** | | |
|---|---|---|---|---|---|---|
| | **2017** | **2018** | **2019** | **2017** | **2018** | **2019** |
| **Irrigation** | | | | | | |
| Yes | 149.71 a[z] | 170.84 a | 145.70 | 1207.86 | 1546.07 | 1574.69 |
| No | 130.29 b | 154.18 b | 151.13 | 1126.14 | 1457.96 | 1623.87 |
| **System** | | | | | | |
| Drip | 152.29 | 175.21 | 173.95 | 1191.12 | 1498.94 | 1670.63 |
| Micro-Sprinkler | 147.14 | 166.46 | 128.31 | 1224.62 | 1593.20 | 1577.11 |
| **Fertilizer** | | | | | | |
| 25% | 187.15 a | 200.24 a | 197.96 a | 1199.98 | 1454.60 | 1593.97 ab |
| 50% | 149.94 b | 172.38 ab | 166.95 a | 1132.14 | 1432.73 | 1780.39 a |
| 100% | 116.20 c | 162.58 b | 147.49 a | 1172.39 | 1624.00 | 1766.52 ab |
| 200% | 106.72 c | 114.84 c | 81.27 b | 1163.50 | 1496.75 | 1253.23 b |
| **Depth** | | | | | | |
| 8" | 147.12 | 171.43 | | 1293.78 a | 1648.82 a | |
| 16" | 132.88 | 153.58 | | 1040.23 b | 1355.22 b | |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 2.6 Relative concentrations of B, Zn, and Mn in soil under different treatments in 2017, 2018 and 2019 in young peach orchard.

| **Treatments** | **B (kg/ha)** | | | **Zn (kg/ha)** | | | **Mn (kg/ha)** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **2017** | **2018** | **2019** | **2017** | **2018** | **2019** | **2017** | **2018** | **2019** |
| **Irrigation** | | | | | | | | | |
| Yes | 0.43 | 0.47 | 0.61 | 6.34 | 5.80 | 5.66 | 24.12 b[z] | 34.13 | 25.13 |
| No | 0.43 | 0.44 | 0.56 | 5.12 | 5.56 | 7.69 | 27.62 a | 34.28 | 26.88 |
| **System** | | | | | | | | | |
| Drip | 0.41 | 0.42 b | 0.59 | 9.88 a | 8.38 a | 11.74 a | 26.88 a | 38.89 a | 28.63 a |
| Micro-Sprinkler | 0.45 | 0.52 a | 0.62 | 2.79 b | 3.21 b | 3.64 b | 21.35 b | 29.37 b | 25.13 b |
| **Fertilizer** | | | | | | | | | |
| 25% | 0.44 | 0.44 | 0.58 | 8.30 | 6.35 a | 7.19 | 23.14 b | 31.40 ab | 25.62 |
| 50% | 0.42 | 0.46 | 0.58 | 4.05 | 4.52 b | 5.04 | 23.31 ab | 30.42 b | 27.37 |
| 100% | 0.41 | 0.44 | 0.63 | 5.39 | 6.21 ab | 6.53 | 27.37 ab | 34.58 ab | 25.90 |
| 200% | 0.44 | 0.47 | 0.53 | 5.18 | 5.636 ab | 7.93 | 29.65 a | 40.43 a | 25.13 |
| **Depth** | | | | | | | | | |
| 8" | 0.48 a | 0.48 a | | 6.42 a | 6.46 a | | 26.30 | 33.37 | |
| 16" | 0.38 b | 0.43 b | | 5.04 b | 4.89 b | | 25.43 | 35.04 | |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 2.7 Relative concentrations of Fe and Cu in soil under different treatments in 2017, 2018 and 2019 in young peach orchard.

| Treatments | Fe (kg/ha) | | | Cu (kg/ha) | | |
|---|---|---|---|---|---|---|
| | 2017 | 2018 | 2019 | 2017 | 2018 | 2019 |
| **Irrigation** | | | | | | |
| Yes | 59.81 | 48.74 b | 57.83 | 1.44 b | 1.33 | 1.27 |
| No | 64.63 | 54.92 a | 53.35 | 1.60 a | 1.35 | 1.12 |
| **System** | | | | | | |
| Drip | 68.92 a | 52.40 a | 57.55 | 1.532 a | 1.52 | 1.13 a |
| Micro-Sprinkler | 50.72 b | 45.08 b | 49.15 | 1.344 b | 1.14 | 1.10 b |
| **Fertilizer** | | | | | | |
| 25% | 59.57 ab | 50.37 ab | 50.82 ab | 1.53 | 1.41 | 1.17 |
| 50% | 56.53 b | 45.68 b | 45.92 b | 1.55 | 1.26 | 1.23 |
| 100% | 68.01 a | 57.54 a | 58.10 ab | 1.52 | 1.22 | 1.15 |
| 200% | 64.79 a | 53.73 ab | 67.48 a | 1.47 | 1.46 | 1.20 |
| **Depth** | | | | | | |
| 8" | 69.14 a | 54.43 | | 1.66 a | 1.22 b | |
| 16" | 55.30 b | 49.23 | | 1.38 b | 1.45 a | |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 2.8 ANOVA table with p-values indicating significance of nutrients in leaf against different treatments in young peach orchard.

| Factors | N | P | K | Mg | Ca | S | B | Zn | Mn | Fe | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** |
| **System** | 0.3263 | 0.9571 | 0.1188 | **0.0042** | 0.2013 | 0.8256 | 0.0743 | **<.0001** | **0.0027** | 0.7985 | **0.0006** |
| **Year*System** | 0.6679 | 0.8822 | 0.7056 | 0.2363 | 0.0473 | 0.5092 | 0.7536 | **0.0124** | **0.0469** | 0.4535 | **0.0015** |
| **Irrigation** | 0.1767 | **0.0033** | **0.0018** | 0.3624 | **<.0001** | 0.4251 | **0.0004** | 0.1097 | **0.0131** | 0.3084 | **0.0084** |
| **Year*Irrigation** | 0.4268 | **0.0071** | 0.0802 | 0.6758 | **0.0065** | 0.8603 | **0.0046** | 0.0687 | **0.0486** | 0.734 | **0.0062** |
| **Fertilizer** | 0.2565 | 0.8368 | 0.2742 | **0.0214** | 0.1524 | 0.1287 | 0.1132 | 0.5613 | **<.0001** | **0.0313** | 0.5704 |
| **Year*Fertilizer** | 0.6744 | 0.1635 | 0.3457 | 0.9377 | 0.1981 | 0.5107 | 0.4085 | 0.2942 | 0.7326 | 0.0967 | 0.2197 |
| **System*Fertilizer** | 0.4421 | 0.8815 | 0.7343 | 0.7657 | 0.1844 | 0.2943 | 0.0819 | 0.9062 | 0.1219 | 0.4365 | 0.0929 |
| **Year*System*Fertiliz** | 0.7277 | 0.5051 | 0.5219 | 0.9985 | 0.8332 | 0.2064 | 0.4423 | 0.8567 | 0.3218 | 0.49 | 0.6844 |
| **Irrigatio*Fertilizer** | 0.5281 | **0.0044** | 0.5113 | 0.1373 | 0.9321 | 0.1638 | **0.0496** | 0.1186 | 0.4311 | 0.4782 | 0.8768 |
| **Year*Irrigat*Fertili** | **0.0312** | 0.1706 | 0.5993 | **0.0389** | 0.4896 | 0.064 | 0.6015 | 0.6999 | 0.8128 | 0.3269 | 0.4855 |
| **Year*Syst*Irri*Ferti** | 0.8491 | 0.2778 | 0.5549 | 0.9599 | 0.4815 | 0.8223 | 0.2889 | 0.4468 | 0.8216 | 0.4407 | 0.1206 |

$P \leq 0.05$ indicates significance. Significant values are in bold letters.

Table 2.9 Relative concentrations of macronutrients N, P, and K in leaves under different treatments in 2016, 2017 and 2018 in young peach trees.

| Treatments | N (%) | | | P (%) | | | K (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2016 | 2017 | 2018 | 2016 | 2017 | 2018 |
| **Irrigation** | | | | | | | | | |
| Yes | 3.454 | 3.935 | 3.879 | 0.193 a[z] | 0.253 | 0.256 | 2.628 a | 3.034 | 3.315 |
| No | 3.430 | 4.005 | 3.994 | 0.172 b | 0.249 | 0.252 | 2.360 b | 2.977 | 3.194 |
| **System** | | | | | | | | | |
| Drip | 3.527 | 3.928 | 3.924 | 0.193 | 0.254 | 0.255 | 2.647 | 3.066 | 3.361 |
| Micro-Sprinkler | 3.381 | 3.942 | 3.834 | 0.194 | 0.251 | 0.257 | 2.608 | 3.001 | 3.269 |
| **Fertilizer** | | | | | | | | | |
| 25% | 3.289 | 3.972 | 3.947 | 0.181 | 0.257 | 0.254 | 2.499 | 3.065 | 3.241 |
| 50% | 3.456 | 3.979 | 3.894 | 0.179 | 0.253 | 0.261 | 2.387 | 2.936 | 3.240 |
| 100% | 3.431 | 3.928 | 3.965 | 0.183 | 0.249 | 0.253 | 2.526 | 3.092 | 3.302 |
| 200% | 3.592 | 4.001 | 3.940 | 0.187 | 0.244 | 0.248 | 2.564 | 2.929 | 3.236 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 2.10 Relative concentrations of macronutrients Mg, Ca, and S in leaves under different treatments in 2016, 2017 and 2018 in young peach trees.

| Treatments | Mg (%) | | | Ca (%) | | | S (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2016 | 2017 | 2018 | 2016 | 2017 | 2018 |
| **Irrigation** | | | | | | | | | |
| Yes | 0.448 | 0.371 | 0.328 | 1.664 a[z] | 1.537 | 1.312 a | 0.178 | 0.188 | 0.181 |
| No | 0.453 | 0.381 | 0.323 | 1.358 b | 1.489 | 1.168 b | 0.179 | 0.196 | 0.185 |
| **System** | | | | | | | | | |
| Drip | 0.448 | 0.367 | 0.308 b | 1.691 | 1.520 | 1.197 b | 0.178 | 0.192 | 0.184 |
| Micro-Sprinkler | 0.448 | 0.374 | 0.349 a | 1.637 | 1.554 | 1.427 a | 0.177 | 0.184 | 0.178 |
| **Fertilizer** | | | | | | | | | |
| 25% | 0.468 | 0.381 | 0.343 a | 1.480 | 1.583 | 1.286 | 0.178 | 0.188 | 0.184 |
| 50% | 0.448 | 0.381 | 0.334 ab | 1.434 | 1.448 | 1.233 | 0.180 | 0.197 | 0.184 |
| 100% | 0.438 | 0.370 | 0.312 b | 1.543 | 1.562 | 1.231 | 0.173 | 0.188 | 0.181 |
| 200% | 0.449 | 0.371 | 0.314 ab | 1.588 | 1.459 | 1.209 | 0.182 | 0.194 | 0.183 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 2.11 Relative concentrations of micronutrients B, Zn, and Mn in leaves under different treatments in 2016, 2017 and 2018 in young peach trees.

| Treatments | B (ppm) | | | Zn (ppm) | | | Mn (ppm) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2016 | 2017 | 2018 | 2016 | 2017 | 2018 |
| **Irrigation** | | | | | | | | | |
| Yes | 32.01 a[z] | 33.07 a | 35.18 | 22.37 b | 20.96 | 17.72 | 67.15 b | 50.68 | 37.87 |
| No | 28.13 b | 32.82b | 33.72 | 26.07 a | 21.13 | 17.73 | 73.20 a | 49.84 | 36.64 |
| **System** | | | | | | | | | |
| Drip | 32.89 | 33.36 | 35.69 | 23.51 a | 23.20 a | 18.27 a | 66.04 | 60.05 a | 39.98 |
| Micro-Sprinkler | 31.13 | 32.79 | 34.67 | 21.22 b | 18.72 b | 17.17 b | 68.27 | 41.31 b | 35.76 |
| **Fertilizer** | | | | | | | | | |
| 25% | 30.13 | 34.10 | 35.04 | 22.20 | 21.35 | 17.81 | 56.76 b | 41.39 b | 30.64 c |
| 50% | 30.49 | 32.76 | 34.68 | 30.72 | 20.77 | 17.53 | 86.07 a | 49.85 ab | 33.42 bc |
| 100% | 29.40 | 33.48 | 35.33 | 21.11 | 21.09 | 17.63 | 69.37 ab | 47.73 ab | 38.81 ab |
| 200% | 30.27 | 31.44 | 32.76 | 22.83 | 20.96 | 17.93 | 68.52 ab | 62.07 a | 46.15 a |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 2.12 Relative concentrations of Fe and Cu in leaves under different treatments in 2016, 2017 and 2018 in young peach trees.

| Treatments | Fe (ppm) | | | Cu (ppm) | | |
|---|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2016 | 2017 | 2018 |
| **Irrigation** | | | | | | |
| Yes | 96.64 | 72.06 | 68.82 | 7.88 a | 7.97 | 9.11 |
| No | 91.63 | 72.21 | 68.92 | 6.70 b | 7.93 | 8.99 |
| **System** | | | | | | |
| Drip | 99.11 | 70.42 | 70.25 | 8.79 a | 8.06 | 9.24 |
| Micro-Sprinkler | 94.16 | 73.70 | 67.40 | 6.96 b | 7.88 | 8.98 |
| **Fertilizer** | | | | | | |
| 25% | 99.01 a[z] | 69.15 | 72.61 | 6.84 | 8.11 | 9.19 |
| 50% | 93.69 ab | 74.78 | 67.63 | 7.50 | 7.96 | 9.31 |
| 100% | 90.79 b | 69.04 | 66.21 | 7.39 | 7.87 | 8.87 |
| 200% | 93.04 ab | 75.57 | 69.03 | 7.43 | 7.86 | 8.83 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 2.13 ANOVA table with p-values indicating significance of nutrients in fruit against different treatments in young peach orchard.

| Factors | N | P | K | Mg | Ca | S | B | Zn | Mn | Fe | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **<.0001** | **0.0001** | **<.0001** | **<.0001** | **<.0001** | **0.0012** | 0.0685 | **<.0001** | **<.0001** | **<.0001** | 0.5029 |
| **System** | **0.044** | 0.0833 | **0.0235** | 0.0845 | 0.7575 | 0.6336 | 0.4596 | **0.003** | **0.0011** | 0.1618 | **0.0276** |
| **Year*System** | 0.2119 | 0.8446 | 0.1348 | 0.6213 | 0.3566 | 0.7399 | 0.8628 | 0.0139 | 0.1498 | 0.2592 | 0.9159 |
| **Irrigation** | 0.1664 | 0.2787 | 0.423 | 0.0911 | 0.6631 | 0.8291 | 0.6412 | 0.8426 | 0.4131 | **0.0388** | 0.5116 |
| **Year*Irrigation** | 0.2736 | 0.8405 | 0.8376 | 0.9732 | **0.0475** | 0.8529 | 0.9827 | 0.6129 | 0.8655 | 0.3415 | 0.8241 |
| **Fertilizer** | **0.0256** | **0.0213** | **0.0042** | **0.0298** | 0.3419 | **0.0066** | **0.0004** | 0.098 | 0.7585 | **0.0169** | 0.0923 |
| **Year*Fertilizer** | 0.3375 | 0.9782 | 0.5159 | 0.8879 | 0.1371 | 0.9432 | 0.4573 | 0.8119 | 0.8044 | 0.4667 | 0.9359 |
| **System*Fertilizer** | 0.7505 | 0.6852 | 0.5215 | 0.5818 | 0.5402 | 0.3599 | 0.6131 | 0.6662 | 0.4925 | 0.3819 | 0.8346 |
| **Year*System*Fertiliz** | 0.8016 | 0.1714 | 0.2822 | 0.2888 | 0.6269 | 0.2527 | 0.1847 | 0.2696 | 0.2004 | 0.8758 | 0.4444 |
| **Irrigatio*Fertilizer** | 0.6837 | 0.4442 | 0.153 | 0.1667 | 0.1355 | 0.103 | 0.2203 | 0.1314 | 0.0941 | 0.8653 | 0.3343 |
| **Year*Irrigat*Fertili** | 0.8802 | 0.9761 | 0.9934 | 0.8649 | 0.6408 | 0.9877 | 0.9237 | 0.8219 | 0.6744 | 0.8768 | 0.9098 |

$P \leq 0.05$ indicates significance. Significant values are in bold letters.

Table 2.14 Relative concentrations of macronutrients in fruit under different treatments in 2017 and 2018 in young peach trees.

| Treatments | N (%) | | P (%) | | K (%) | | Mg (%) | | Ca (%) | | S (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| **Irrigation** | | | | | | | | | | | | |
| Yes | 1.385 | 1.139 b$^{z}$ | 0.188 | 0.167 | 1.951 | 1.662 | 0.073 | 0.064 | 0.041 | 0.029 | 0.044 | 0.038 |
| No | 1.369 | 1.183 a | 0.196 | 0.175 | 2.045 | 1.745 | 0.077 | 0.068 | 0.044 | 0.032 | 0.046 | 0.039 |
| **System** | | | | | | | | | | | | |
| Drip | 1.449 a | 1.149 | 0.191 | 0.176 | 2.034 a | 1.746 | 0.075 a | 0.067 | 0.042 | 0.030 | 0.044 | 0.040 |
| Micro-Sprinkler | 1.32 b | 1.128 | 0.184 | 0.158 | 1.868 b | 1.577 | 0.0706 b | 0.061 | 0.041 | 0.029 | 0.043 | 0.036 |
| **Fertilizer** | | | | | | | | | | | | |
| 25% | 1.413 ab | 1.159 | 0.194 | 0.174 | 2.011 | 1.768 ab | 0.076 | 0.068 | 0.043 | 0.029 | 0.046 | 0.039 |
| 50% | 1.304 b | 1.144 | 0.181 | 0.159 | 1.929 | 1.583 b | 0.072 | 0.061 | 0.044 | 0.031 | 0.041 | 0.036 |

| Treatments | N (%) | | P (%) | | K (%) | | Mg (%) | | Ca (%) | | S (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| 100% | 1.438 a | 1.176 | 0.206 | 0.179 | 2.128 | 1.772 a | 0.080 | 0.069 | 0.043 | 0.031 | 0.050 | 0.041 |
| 200% | 1.353 ab | 1.163 | 0.185 | 0.172 | 1.924 | 1.693 ab | 0.072 | 0.066 | 0.041 | 0.032 | 0.043 | 0.039 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 2.15. Relative concentrations of micronutrients in fruit under different treatments in 2017 and 2018 in young peach trees.

| Treatments | B (ppm) | | Zn (ppm) | | Mn (ppm) | | Fe (ppm) | | Cu (ppm) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| **Irrigation** | | | | | | | | | | |
| Yes | 28.702 | 26.901 | 7.402 | 6.198 | 5.390 | 3.712 | 18.618 | 11.980 | 6.435 | 6.409 |
| No | 29.697 | 28.032 | 7.732 | 6.210 | 5.467 | 4.046 | 21.054 | 12.468 | 6.681 | 6.697 |
| **System** | | | | | | | | | | |
| Drip | 28.931 | 28.771 | 8.251 a[z] | 6.432 | 5.616 a | 3.949 a | 18.992 a | 12.069 | 6.714 a | 6.764 |
| Micro-Sprinkler | 28.473 | 25.032 | 6.552 b | 5.964 | 5.164 b | 3.474 b | 18.245 b | 11.891 | 6.156 b | 6.054 |
| **Fertilizer** | | | | | | | | | | |
| 25% | 29.739 | 28.831 ab | 7.793 | 6.316 | 5.171 | 3.793 | 20.093 | 12.868 | 6.718 | 6.978 |
| 50% | 27.915 | 25.176 b | 7.263 | 6.279 | 5.652 | 3.698 | 17.489 | 11.201 | 6.214 | 6.158 |
| 100% | 31.397 | 29.055 a | 8.009 | 6.301 | 5.469 | 3.783 | 21.294 | 12.794 | 6.889 | 6.725 |
| 200% | 27.746 | 26.868 b | 7.202 | 5.926 | 5.422 | 4.226 | 20.469 | 12.054 | 6.412 | 6.354 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

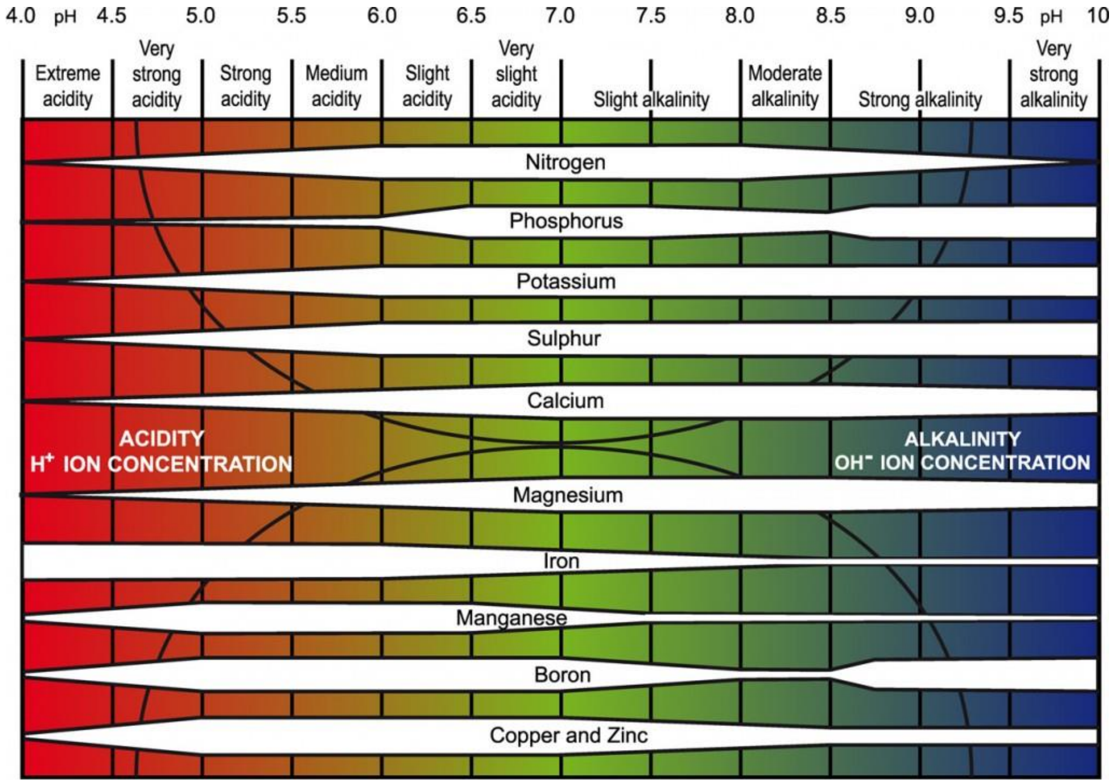



Figure 2.1 Impact of soil pH on nutrient availability (Havlin et al., 2016)

`

# CHAPTER 3

# SMARTIRRIGATION PEACH APP: A NOVEL IRRIGATION SCHEDULING TOOL FOR YOUNG PEACH TREES

[1]Thapa Magar, S, G. Vellidis, W. Porter, V. Liakos, J.H. Andreis, D.J. Chavez. To be submitted to ***Computers and Electronics in Agriculture.***

**Abstract**

Water availability plays a significant role in crop productivity. Irrigation scheduling for peaches in Georgia and the Southeastern U.S. is rudimentary and variable from farm to farm. It is imperative for the industry to move towards sustainable irrigation management. The goal of this study was to develop an easy-to-use irrigation scheduling app for peach production that generates an optimal irrigation program to meet the current crop's water requirements. A smartphone app, known as SmartIrrigation Peach App, was developed by the University of Georgia based on the interactive evapotranspiration-based soil water balance crop model. This app estimates weekly crop evapotranspiration based on local/national weather data, crop growth stages, and available soil water. The app schedules weekly irrigation based on orchard and irrigation system capabilities while acknowledging rainfall observed. The SmarIrrigation Peach app was evaluated against sensor-based irrigation and no supplemental irrigation in a young orchard of 'Julyprince' grafted on 'Guardian' and 'MP-29' rootstocks since establishment. Results from three years of the study indicated that the peach app was more water-use efficient than the sensor-based method. The water use between the two irrigation methods and rootstocks was comparable in the first year of planting. In the second and third years, the app-based irrigation method used less water (~27 to ~55% per tree per season, respectively) than the sensor-based irrigation method. Both irrigation scheduling methods produced comparable plant size and yield. Contrarily, non-irrigated trees were significantly smaller than irrigated trees with both irrigation scheduling methods. Trees grafted onto 'Guardian' rootstock used more water (~44% per tree per season) but produced 57% more canopy and 125% more TCSA than trees grafted onto 'MP-29' in 2022. Overall, our results indicated that the

SmartIrrigation Peach App can be used as an efficient irrigation scheduling tool for young peach orchards.

**Additional index words:** *Prunus persica*, Kc, crop coefficient, crop evapotranspiration, smartphone, plant size, plant physiology, fruit yield, drought

## Introduction

Peach (*Prunus persica*) is a high-value fruit crop in the U.S. Georgia ranks 3rd in the nation for production and annually produces about 35,000 tons with a farm gate value of $36 million (USDA-NASS, 2021). Peach ranks 3rd among Georgia's fruit and nuts farm gate value (University of Georgia Center for Agribusiness and Economic Development, 2022). Georgia possesses a unique environment in terms of variable soil, humid climate, and drought incidence thus challenging irrigation management in peach orchards. Furthermore, droughts have become more common in this region. A common practice in peach production is to not install irrigation during orchard establishment. Recent studies have also shown that irrigation from tree establishment enhances plant vigor and productivity (Casamali et al., 2021b). However, information on proper irrigation scheduling that meets a crop's water requirement at different growth stages is still lacking. Developing a proper irrigation management practice is crucial for Georgia and the Southeastern U.S. peach production as the existing practices are outdated and not specific to this region.

A crop's water requirement varies based on the crop itself, its growth stages, and the environment in which the crop is grown. A proper irrigation scheduling tool must consider these parameters to ensure higher water use efficiency. There are different methods available for irrigation scheduling with the most common being based on visible stress, feel of the soil, soil moisture sensors, weather report, and calendar schedules (USDA-NASS, 2019). Similarly, various web-based irrigation tools have been developed. These have easy access to meteorological data and some examples include The University of Florida's PeanutFARM, Washington State University's AgWeatherNet, and The University of Arkansas Irrigation Scheduler (Vellidis et al., 2016). A major drawback to these web-based tools is the requirement of regular user interaction and access via a desktop or laptop. Today, smartphones are easily available and have unlimited internet access, thus bringing smartphone-based tools to the limelight. These tools process complex irrigation models and deliver effortless irrigation schedule information to users. SmartIrrigation apps are the pool of several smartphone-based apps developed for scheduling optimal irrigation based on either crop evapotranspiration or the soil water balance. Some commonly used apps are for citrus, cotton, avocado, blueberry, strawberry, turf, and vegetables (SmartIrrigationApps.org, n.d.). These apps have proved to be water-use efficient, easy to use, and popular among users.

Peaches have high water requirements and are sensitive to water stress at certain growth stages (Berman and DeJong, 1996). Peach growers in the Southeastern region mainly follow the irrigation recommendations available for peach production in Mediterranean regions. However, these recommendations likely overestimate the actual requirement in this region, given the differences in climate, soil, timing of different plant growth stages, and cultivars. Peaches cannot tolerate waterlogging conditions (Iacona et al., 2013) thus, it creates the need to develop a proper irrigation recommendation for the Southeastern region with its hot, humid, and subtropical climate. Irrigating young peach trees since orchard establishment in Georgia has been found to enhance plant growth and development as well as increase yield (Casamali et al., 2021b). Alcobendas et al., 2013 subjected the mid-late maturing peach cultivar

'Catherine' to two irrigation treatments: full irrigation (FI) and regulated deficit irrigation (RDI) and found that RDI resulted in comparatively smaller tree size and yield. However, the water stress resulted in higher soluble solids, glucose, sorbitol, and malic, citric, and tartaric acids, probably because of the low crop load. Mirás-Avalos et al. (2013) compared three irrigation treatments based on peach tree phenological stages: control with daily irrigation above crop evapotranspiration; precision treatment and regulated deficit irrigation (RDI) with full irrigation during critical periods. They determined that RDI treatment increased water productivity while maintaining fruit yield and quality. Williamson and Coston (1990) also compared two irrigations (irrigation replacement based on 12.5% or 100% of the daily evapotranspiration) during all the fruit development stages in 'Redhaven' peach trees in South Carolina and found no significant differences in plant size and fruit yield. These studies indicate that plant-based water requirements are more precise to determine the actual water requirements thus irrigation scheduling based on this parameter is recommended.

The goal of this study was to develop a SmartIrrigation Peach App (referred to as Peach App) that generates an irrigation schedule to meet peach trees' water requirements based on an interactive crop evapotranspiration-based soil water balance model using real-time weather data. We hypothesized that the Peach App will be more efficient than other irrigation management methods used in Georgia.

## Materials and Methods

### *Kc curve calibration*

The basic principle behind the SmartIrrigation Peach App is estimating crop evapotranspiration at a specific crop growth stage and creating an irrigation schedule based on the need or absence of supplemental irrigation at a given time. An estimate of crop evapotranspiration (ETc) is calculated using the Penman-Monteith FAO-56 equation (Allen et al., 2005). The Penman-Monteith FAO-56 equation is:

$$ETc = ETo \times Kc$$

where reference evapotranspiration (ETo) and crop coefficient (Kc) are used to estimate crop evapotranspiration. ETo is the cumulative amount of water that is transpired by the reference crop at its most active growth stage along with water evaporated from soil under ideal conditions. Kc is a plant property that differs as a function of region, environmental parameters, and physiological factors (Ayars et al., 2003).

The app uses meteorological data gathered from the Florida Automated Weather Network (FAWN), the Automated Environmental Monitoring Network (AEMN), and Dark Sky to estimate the ETo. Kc value varies at different growth stages throughout the year. For perennial crops, it also varies with tree age. In peaches, the Kc value within a season is the lowest during the dormant period and increases as the tree reaches active growth during mid-season but then drops as the tree reaches leaf senescence and dormancy (Figure. 3.1) (Allen et al., 2005). In addition, the Kc value for a one-year-old peach tree is lower compared to two-year-old peach trees given their difference in canopy size. Table 3.1 includes a compilation of the Kc values for mature peach trees at different stages published around the world. These studies were conducted under different environmental conditions than in Georgia. Most weather effects on ETc are estimated by ETo thus Kc largely depends on the crop characteristics than the region itself. For this reason, standard Kc values are widely used at different locations and climates. For our study, we thus decided to extrapolate the Kc curve from the literature available on the monthly basis. However, we modified our Kc curve to develop four different Kc curves based on each tree age group (Figure. 3.2). This modification was based on the canopy coverage percentage respective to tree age for peach trained on an open-vase system (Table 3.2). These modified Kc curves were hence used in the peach app development further.

*Irrigation schedule (amount and duration) calculation*

The SmartIrrigation Peach app schedules irrigation based on the crop evapotranspiration data in the past seven days. These are estimated based on ETo and our modified Kc curve. The amount of water is the amount to be supplemented through irrigation. The peach app requires basic information about an orchard such as area (acres), soil type (sand, sandy loam, clay loam, and clay), planting spacing (between trees and rows), tree age (1-4 and above), irrigation system (single line/ double line drip system and micro-sprinkler system), irrigation rate (gallons/minute), and efficiency (%). All these parameters will be used to provide the user with a precise irrigation schedule. Figure 3.3 sketches the basic principle behind the Peach app.

The irrigation schedule differs per user based on the irrigation system a grower has installed in the orchard. The common irrigation systems in peach production in Georgia and the Southeastern U.S. are either drip or micro-sprinkler irrigation. Different approaches were considered to calculate the irrigated area value under both systems. Other SmartIrrigation apps available were used as a reference [Citrus app (for the micro-sprinkler system) and Blueberry app (for the drip system)]. Unlike blueberries, peaches are planted at a specific planting distance thus not all the area between peach trees is irrigated. It was therefore important to consider the area to be irrigated for precise irrigation calculation. Thus, we considered Eq. (1) for the drip and Eq. (2) for the micro-sprinkler calculations as follows.

$$Irrigated\ area\ (Drip) =$$

$$\frac{\pi \times (emitter\ radius\ in\ m)^2 \times (Number\ of\ emitters\ under\ a\ tree \times Number\ of\ trees)}{square\ m\ in\ a\ hectare} \ldots\ldots\ldots\ldots\ldots (1)$$

$Irrigated\ area\ (Micro - sprinkler) =$

$$\frac{\left(\frac{emitter pattern}{360}\right)\times\pi\times(emitter\ radius\ in\ m)^2\times(Number\ of\ trees)}{square\ meter\ in\ a\ hectare}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Once the irrigated area is calculated, the irrigation amount and duration to deliver that amount of water can be calculated by using Eq. (3 & 4) depending upon the number of irrigation events selected by the user per week. The higher the irrigation events per week, the lower will be the irrigation amount per event and vice-versa. However, having fewer irrigation events per week can result in longer irrigation duration, resulting in runoff. To avoid this situation, the peach app has an additional feature where it recommends the user for additional irrigation events whenever the crop evapotranspiration is greater than the soil available water as shown in Eq. (5). Soil available water is calculated with this Eq. (6). Root depth for peach trees and soil water holding capacity of each soil type were determined through the literature published. Root density (Number of roots per 100 $cm^3$ of soil volume) was calculated using an equation from Paltineanu et al. (2016).

$$Irrigation\ amount(gallons) = gallons\ in\ an\ acre \times irrigated\ area \times ETc(in)\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$Irrigation\ duration = \left(\frac{Irrigation\ amount}{Irrigation\ rate}\right) + minutes\ to\ pressurize\ irrigation\ system\ \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$Additional\ number\ of\ irrigation\ events = \left(\frac{Crop\ evapotranspiration}{soil\ available\ water}\right) - Number\ of\ irigation\ events\ set\ per\ week\ \ldots\ldots(5)$$

$$Soil\ available\ water = Root\ depth \times soil\ water\ holding\ capacity\ \times Root\ density\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

*Rainfall adjustment*

For any rainfall observed in the field for the past five days of the irrigation event (data obtained from weather stations or grid data), a rainfall-weighted average is calculated on the day of the irrigation event as shown in Eq. (7). This is done to consider the impact of rainfall on the current irrigation schedule and to provide the grower with a recommendation to adjust irrigation accordingly. The Peach App sends a notification with this information. The average rainfall is then converted to its equivalent irrigation amount and then duration (based on irrigation system parameters). This is also known as rainfall adjustment, following Eq. (3 & 4). The growers can also confirm the rainfall data by installing a rain gauge in the orchard for accuracy.

$$Average\ Rainfall = (70\%\ of\ yesterday) + (10\%\ of\ 2nd\ day) + (10\%\ of\ 3rd\ day) + (5\%\ of\ 4th\ day) + (5\%\ of\ 5th\ day) \quad \text{……………………}(7)$$

*SmartIrrigation Peach App Development*

A peach app demo was developed in 2019 to generate precise irrigation schedules for peach production in Georgia and the Southeastern U.S. Originally, it was only designed to operate on the Android platform using the official tools and programming language from Google® (Java and Android SDK). Later in 2022, the iOS version was also made available using Swift and iOS SDK from Apple®. The intercommunication between the server database and the peach app is allowed by specific web utilities and the response is received in JSON (JavaScript Object Notation) format. The app then parses the response provided and displays the results to the users. Any notifications regarding irrigation are sent via push notifications by the app.

*User interaction*

The peach app can be downloaded and installed from the 'Smartirrigationapps.org' website. First, the user is directed to create an account. Next, the user is asked to do a field registration, with the option of creating multiple fields in the same account. The first step to field registration is locating the field on a map. By default, the Peach app pins the exact location of the user's smartphone which can be repositioned by tapping and dragging it to the actual field location (Figure. 3.5). The user is required to enter a unique field name. Managing multiple fields is easy with unique field names. The user then selects the tree age. Since irrigation requirement differs based on tree age, there are four categories listed based on their age. Peach trees reach full size in an open-vase canopy training system at year four and are therefore maintained at the same plant size through yearly pruning. Thus, trees that are four years old and above are categorized in the same tree age group in the peach app (Figure. 3.5). Next, the user can select the peach cultivar grown. There is a pre-filled drop list of different peach cultivars along with their ripening period commonly found in Georgia and most of the Southeastern U.S. (Figure. 3.5). The user can directly select from the list or add/save a new cultivar name. The user then is directed to enter the acreage of the field. Based on the location of the field, the app displays the four closest weather stations along with their distance from the field and gives the user the option to select which station he/she would like to use (Figure. 3.6). The weather station closest to the field is recommended over others for precise weather data. The Peach app also includes the national weather data grid option, thus widening the geographical footprint of the Peach app. For users selecting the national weather data grid, the app uses the Forecasted Reference crop Evapotranspiration (FRET) estimate from the National Weather Service and if this data is missing then it uses the evapotranspiration estimate from Dark Sky. The user is then directed to select a soil type (sandy, sandy loam, clay loam, and clay), plant spacing (between trees and between rows), irrigation system type (single/double line drip system and micro-sprinkler system), and irrigation details (rate in gallons/min and efficiency in %) based on the system selected (Figure. 3.6). Generally, a single drip line is commonly used in peach irrigation in Georgia, but having two drip lines on both sides of the tree will be more efficient for irrigation. The app includes the option of double drip lines for future considerations. The grower has the option to choose the irrigation schedule as to which days in a week to irrigate. Furthermore, the app includes three water conservation modes: normal mode [100% replacement of estimated water loss, seasonal water savings mode (75% replacement of estimated water loss when rainfall exceeds water losses), and year-round water savings mode (75% replacement of estimated water loss throughout the year)].

Once finished, the main user interface screen shows the irrigation schedule of an individual field that includes the irrigation amount and the duration of irrigation (Figure. 3.6). It also displays the rainfall adjustment recommendations for any rainfall observed. The user can also access individual field information and edit any information if required. For each field, the rainfall details of the past five days are also included. The main user interface also includes further information such as weather forecasts, app notifications, and its development partners.

The app model runs once a day early in the morning once the past day's weather data are available. The app then sends the irrigation schedule notification to the user at 7 AM. The user can make any changes at any given time and the model will update itself thus displaying the updated irrigation schedules. The app also notifies of any rainfall recorded by the weather station.

*Field evaluations*

The peach app was evaluated against other irrigation scheduling methods in a young peach orchard in the University of Georgia's Peach Research and Extension Orchard in Griffin, Georgia (33°24'85" N, 84°30'06" W). A total of 80 'Julyprince' trees were planted on a Cecil sandy loam soil, with planting spacing of 4.5m × 6m. The study comprised of two main factors: 1) Irrigation scheduling methods [a) Peach app, b) Sensor-based method, and c) No irrigation]; and 2) Rootstocks [a) Guardian and b) MP-29) (Thapa Magar et al., 2022). For the sensor-based method, the University of Georgia Smart Sensor Array (UGA SSA) recommendations were followed. UGA SSA is a low-cost wireless soil moisture sensing system (Vellidis et al., 2013). It consists of smart sensor nodes that can include up to three Watermark® (Irrometer, Riverside, California, USA) sensors. For our purpose, we included three Watermark sensors at 20, 40, and 60 cm depth, considering the root distribution pattern of peach trees (Havis, 1938). These watermark sensors read the soil water potential values (KPa) at corresponding depths. Two different weighted averages of these sensor readings are considered for the irrigation recommendations for a young (AverageShallow) and a mature peach orchard (AverageDeep). For young trees (1-3-year-old trees), the root distribution mainly remains within the top 40 cm depth. Thus, in AverageShallow, we only consider the weighted average of sensor readings from the top two sensors at 20 cm (60%) and 40 cm (40%). For the mature trees (4 years and above), the AverageDeep includes the weighted average of all three sensor readings at 20 cm (50%), 40 cm (30%), and 60 cm (20%). For this experiment, the AverageShallow was considered for the young peach trees. The van Genuchten model was then used to convert the soil water potential data to irrigation recommendations in depth. The irrigation recommendation in depth was then converted to irrigation duration using Eq. (3 & 4) While irrigated treatments received water based on the recommendations from the peach app or the sensors, non-irrigated treatments relied on rainfall only. The UGA SSA system was however installed in the non-irrigated treatments to compare the soil moisture status across treatments. A single pipe system with individual valves and a flowmeter were used to deliver water separately to each irrigation treatment to avoid any confounding effect. Orchard management practices were based on the recommendations from the Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide (Blaauw et al., 2018).

*Data Collection and Analysis*

Plant parameters: trunk cross-sectional area (TCSA), canopy volume (CV), net photosynthetic assimilation ($A_n$), stem water potential (SWP), and yield were collected in 2020, 2021, and 2022. TCSA and CV were calculated using Eq (8 and 9). Mid-day $A_n$ and SWP were measured in a fully expanded mature leaf using the Li-COR 6400XT (Li-COR, Lincoln, NE) and pressure chamber (1505D-EXP; PMS Instrument Company, Albany, OR) on a sunny day, respectively. These parameters were collected monthly throughout the year. The amount of water applied to each irrigation method and rootstock treatment was recorded throughout the year. Data collected were analyzed using PROC MIXED in SAS 9.4 (SAS Institute Inc.; Cary, NC). Means were separated using Tukey's Honest Significant Difference test with a significance level of $P \leq 0.05$.

$$TCSA = л \times \left(\frac{average\ trunk\ diameter}{2}\right)^2 \text{……………………………………………..(8)}$$

$$CV = л \times \left(\frac{average\ canopy\ diameter}{2}\right)^2 \times \left(\frac{tree\ height}{3}\right) \text{………………………………..(9)}$$

**Results and Discussion**

The study was conducted in 2020, 2021, and 2022. These years were comparable in terms of maximum and minimum temperature but differed in terms of rainfall and drought occurrence as recorded in the University of Georgia's Dempsey Farm weather station (Figures 3.6 and 3.7). The 2020 season was a year with rain above average while 2021 and 2022 were comparatively drier.

*Irrigation Methods Effect*

The overall performance of peach trees under three different irrigation methods is briefly summarized in Figures 3.8- 3.10. For the three different irrigation methods tested, the control treatment only relied on precipitation while the rest had supplemental irrigation since establishment. The app and sensor-based method varied in terms of how was calculated the amount of water for irrigation (as previously described in Materials and Methods). Both methods were comparable in terms of water use in the first year of the orchard establishment. Plants irrigated using the app-based method received 27 and 55% less water than the sensor-based method in the 2021 and 2022 seasons, respectively. Vellidis et al. (2016) reported similar results in cotton where the Cotton app-based irrigation method used comparatively less water than the Checkbook and UGA SSA methods. Upon comparing the tree characteristics, the non-irrigated trees were comparable to the irrigated treatments for plant size and stem water potential in 2020 and 2021 (above-average rainfall). However, irrigated trees started to outcompete the non-irrigated trees in plant size in 2021. In 2022, the non-irrigated trees were significantly smaller than the irrigated trees throughout the year (Figure 3.8). Our results matched previous reports by Casamali et al. (2021a, b) and Layne et al. (2002), who reported that peach trees with supplemental irrigation since establishment resulted in higher plant growth/size. The net assimilation rate ranged within 10-20 $\mu molCO_2m^{-2}s^{-1}$ across years. The stem water potential values stayed above the water stress range ($\leq$-1.0 MPa) in 2020. However, the stem water potential values dropped below -1.0 MPa during mid-summer in 2021 and 2022, coinciding with drought incidence (Figures 3.7 and 3.9). The non-irrigated plants suffered higher water stress during these times. Although both these physiological parameters were not consistently different across irrigation methods over years, we saw a trend where the non-irrigated trees had comparatively lower net assimilation rates than the irrigated trees when their stem water potential was significantly lower. This indicated that trees that suffered water stress had lower photosynthetic assimilation. Similar results were observed by Casamali et al. (2021b), where non-irrigated trees had significantly lower SWP and net photosynthetic assimilation during drought conditions in 2016. 2022 was the first year of fruit production for these young trees. Fruits from this plot were harvested a week in advance of the traditional harvest window to reduce any possible losses due to constant rainfalls and brown rot pressure. Fruit yield per tree was small and comparable among all irrigation methods and the control (Figure 3.10) unlike Casamali et al. (2021b) where irrigated trees produced significantly higher yields than non-irrigated trees. This difference could have been the result of the difference in plant size between irrigated and non-irrigated trees in the first year of fruit production in both studies. Upon comparison of the plant size, the non-irrigated trees in this experiment were 65-70% of the irrigated trees but ~75-80% in the study by Casamali et al. (2021b). This size difference is attributed to the use of semi-dwarf rootstock, 'MP-29', along with 'Guardian' in this study whereas only 'Guardian' was used in Casamali et al. (2021b).

Water Use Efficiency is referred to as the total gain in TCSA per unit of water used by the crop. WUE was higher for the app-based method than the sensor-based method as it used less water to produce similar TCSA (Table 3.3). The WUE for the app-based method increased substantially in 2022 and was double that for the sensor-based method. For the sensor-based method, the sensor readings were very high during summer due to drought incidence (Figure 3.7), resulting in higher irrigation amounts and durations. Likely, plants were not losing much water during this period because of other environmental factors, or some other mechanisms (like stomatal closing) as supported by the evapotranspiration data from the app. The app recommendations were thus not as high as a sensor-based method, resulting in higher WUE.

*Rootstocks Effect*

There was a clear distinction between plants that budded onto 'Guardian' and 'MP-29' rootstocks in terms of water use as well as the plant characteristics throughout the experiment (Figure 3.11-3.13). Plants on 'Guardian' rootstocks used ~43% more water than plants on 'MP-29' rootstocks in 2021 and 2022. Plants grafted on 'Guardian' rootstocks had significantly larger TCSA and higher canopy volume when compared to 'MP-29' from 2020-2022. (Figure 3.11). Plants on 'MP-29' set the terminal growth a month before 'Guardian' budded plants (Chavez personal communication). Our research results are consistent with other reports (Beckman et al., 2012, Minas et al., 2022, Coneva, 2022, Reighard et al., 2022) supporting the dwarfing nature of the 'MP-29' rootstock. The yield for the first-year crop in this study was not significantly different between the two rootstocks (Figure 3.13). These results align with results from Beckman et al. (2012) where 'MP-29' was compared with 'Guardian' and 'Sharpe' under the same management practices in central Georgia. In this study, the annual and cumulative yield from 2000-2010 was compared, and results determined that 'MP-29' and 'Guardian' overall produced comparable yields over years. An ongoing study comparing 'Guardian' and 'MP-29' in two different scions (Bounty and Julyprince) in Alabama also suggests similar results in terms of plant size and yield (Coneva, 2022). The yield use efficiency (YUE), defined as the ratio of total yield by TCSA, of the 'Julyprince' cultivar grafted onto 'MP-29' was almost double the YUE of the 'Julyprince' cultivar grafted on 'Guardian' rootstock (Table 3.4). Minas et al. (2022) and Coneva, 2022 observed similar results with the highest yield efficiency for 'MP-29' among other rootstocks. Water use efficiency (WUE) however was higher for

'Guardian' rootstock as it produced significantly larger TCSA for the amount of water used per season (Table 3.4). In addition to higher yield use efficiency, reduced tree vigor of 'MP-29' facilitates higher-density planting. This suggests that it might be profitable to have an orchard with 'MP-29' as a rootstock at a higher-density planting setup than with 'Guardian'.

The net photosynthetic assimilation for both rootstocks ranged from 10-20 $\mu molCO_2m^{-2}s^{-1}$ and stem water potential on both rootstocks was higher than the water stress range (≤-1.0 MPa) indicating no water stress experienced in 2020 and 2021 (Figure 3.12). Trees on both rootstocks experienced water stress during the mid-summer (June and July) of 2022. Drought was experienced during this period in 2022 (Figure 3.7). Upon comparing $A_n$ and SWP data across years, $A_n$ of trees grafted onto 'Guardian' rootstock was higher when their SWP was higher than that of 'MP-29'. In the contrast, $A_n$ of trees grafted onto 'MP-29' was significantly higher than that of 'Guardian' under water stress conditions in 2022 (Figure 3.12).

**Conclusion**

This research highlighted that irrigating young peach trees despite the method was important for plant growth. The tree relying only on rainfall lagged over time and this effect was more severe during the drought conditions. The study also revealed that the water requirements of peach trees vary based on the growth stages and the environment in which they are grown. The app-based irrigation method allowed for precise water management and reduced the risk of under or over-irrigation, resulting in optimal plant growth and yield. The Peach app was more water-use efficient compared to a sensor-based method, given that it resulted in comparable plant size using less amount of irrigation water. Following the app recommendations throughout the season was very convenient as it only required checking the irrigation schedules on the smartphone. The sensor-based method on the other hand had to go through some complex calculations and ran through various maintenance issues often. Based on our results, the SmartIrrigation peach app could be used as a reliable tool for the irrigation management of young peach orchards. For the rootstocks, trees grafted onto 'MP-29' were almost half the size of trees on 'Guardian' and used less water compared to Guardian but resulted in higher yield use efficiency. This suggests that MP-29 is a semi-dwarf rootstock and when planted in a high-density setup can greatly increase productivity and profitability.

This research highlights the importance of developing region-specific irrigation management practices for high-value crops such as peaches, which are sensitive to water stress and require proper irrigation scheduling for optimal growth and yield. The SmartIrrigation Peach App provides a practical solution for peach growers in Georgia and other regions with similar environmental conditions.

**Literature cited**


Abrisqueta, I., Abrisqueta, J., Tapia, L., Munguía, J., Conejero, W., Vera, J., and Ruiz-Sánchez, M. (2013). Basal crop coefficients for early-season peach trees. *Agricultural Water Management 121*, 158-163.

Alcobendas, R., Miras-Avalos, J. M., Alarcón, J. J., & Nicolas, E. (2013). Effects of irrigation and fruit position on size, colour, firmness and sugar contents of fruits in a mid-late maturing peach cultivar. *Scientia Horticulturae, 164*, 340-347.

Allen, R., Smith, M., Pereira, L., and Pruitt, W. (1996). Proposed revision to the FAO procedure for estimating crop water requirements. Paper presented at: *II International Symposium on Irrigation of Horticultural Crops* (Chania, Crete, Greece).

Allen, R.G., Pereira, L.S., Smith, M., Raes, D. and Wright, J.L. (2005). FAO-56 dual crop coefficient method for estimating evaporation from soil and application extensions. *Journal of irrigation and drainage engineering 131*, 2-13.

Ayars, J., Johnson, R., Phene, C., Trout, T., Clark, D., and Mead, R. (2003). Water use by drip-irrigated late-season peaches. *Irrigation Science 22*, 187-194.

Blaauw, B., Brannen, P., Bellinger, B., Lockwood, D., and Ritchie, D. (2018). Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide. University of Georgia Cooperative Extension, Athens, GA.

Beckman, T.G., Chaparro, J.X., and Sherman, W.B. (2012). ‘MP-29’, a clonal interspecific hybrid rootstock for peach. *HortScience 47*, 128-131.

Berman, M. E., & DeJong, T. M. (1996). Water stress and crop load effects on fruit fresh and dry weights in peach (Prunus persica). *Tree physiology*, *16*(10), 859-864.

Casamali, B., van Iersel, M.W. and Chavez, D.J. (2021a). Nitrogen Partitioning in Young "Julyprince" Peach Trees Grown with Different Irrigation and Fertilization Practices in the Southeastern United States. *Agronomy, 11(2),* p.350.

Casamali, B., van Iersel, M.W., and Chavez, D.J. (2021b). Plant Growth and Physiological Responses to Improved Irrigation and Fertilization Management for Young Peach Trees in the Southeastern United States. *HortScience 56,* 336-346.

Coneva, E. (2022). Disease resistant, size-controlling 'MP-29' rootstock for Alabama peaches viewed. Fruit Growers News. Alabama A&M and Auburn Universities Extension.

Girona, J., Mata, M., Arbonès, A., Alegre, S., Rufat, J., and Marsal, J. (2003). Peach tree response to single and combined regulated deficit irrigation regimes under shallow soils. *Journal of the American Society for Horticultural Science 128*, 432-440.

Havis, L. (1938). Peach tree root distribution. Ecology 19, 454-462.

Iacona, C., Cirilli, M., Zega, A., Frioni, E., Silvestri, C., & Muleo, R. (2013). A somaclonal myrobalan rootstock increases waterlogging tolerance to peach cultivar in controlled conditions. *Scientia Horticulturae, 156,* 1-8.

Layne, D. R., Cox, D. B., & Hitzler, E. J. (2002). Peach systems trial: the influence of training system, tree density, rootstock, irrigation and fertility on growth and yield of young trees in South Carolina. *Acta Horticulturae,* 592.

Thapa Magar, S., Vellidis, G., Porter, W., Liakos, V., Andreis, J.H. and Chavez, D. (2022). Development and evaluation of a SmartIrrigation Peach App in a young peach orchard. *Acta Horticulturae, 1352*, 575-582.

Marsal, J., & Girona, J. (1997). Relationship between leaf water potential and gas exchange activity at different phenological stages and fruit loads in peach trees. *Journal of the American Society for Horticultural Science*, *122*(3), 415-421.

Minas, I. S., Reighard, G. L., Black, B., Cline, J. A., Chavez, D. J., Coneva, E., ... & Winzeler, H. E. (2022). Establishment performance of the 2017 NC-140 vigor-limiting peach rootstock trial across ten sites in North America. *Acta Horiculturae*, 1346.84.

Miras-Avalos, J. M., Alcobendas, R., Alarcón, J. J., Valsesia, P., Génard, M., & Nicolás, E. (2013). Assessment of the water stress effects on peach fruit quality and size using a fruit tree model, QualiTree. *Agricultural Water Management*, *128*, 1-12.

Paltineanu, C., Septar, L., Gavat, C., Chitu, E., Oprita, A., Moale, C., ... & Lamureanu, G. (2016). Characterising root density of peach trees in a semi-arid Chernozem to increase plant density. *International Agrophysics*, *30*(1).

Reighard, G. L., Ouellette, D., & Minas, I. S. (2022). Field performance of peach rootstock cultivars in South Carolina. *ActaHorticulturae*, 1352.8.

SmartIrrigationApps.org. (n.d.). Apps. [online] Available at:https://smartirrigationapps.org/apps/ [Accessed 12 August 2022].

University of Georgia Center for Agribusiness and Economic Development. (2022). Georgia Farm Gate Value Report 2021. Available at https://caed.uga.edu/publications/farm-gate-value.html [Accessed 10 March 2023].

U.S. Department of Agriculture, National Agricultural Statistics Service (2019). 2018 Irrigation and Water Management Survey.

U.S. Department of Agriculture, National Agricultural Statistics Service (2021). Noncitrus Fruits and Nuts 2020 Summary. U.S. Department of Agriculture, Washington, D.C.

Vellidis, G., Tucker, M., Perry, C., Reckford, D., Butts, C., Henry, H., Liakos, V., Hill, R., and Edwards, W. (2013). A soil moisture sensor-based variable rate irrigation scheduling system. *In Precision agriculture'13*, (Springer), pp. 713-720.

Vellidis, G., Liakos, V., Andreis, J., Perry, C., Porter, W., Barnes, E., Morgan, K., Fraisse, C., and Migliaccio, K.W. (2016). Development and assessment of a smartphone application for irrigation scheduling in cotton. *Computers and Electronics in Agriculture 127*, 249-259.

Williamson, J. G., & Coston, D. C. (1990). Planting method and irrigation rate influence vegetative and reproductive growth of peach planted at high density. *Journal of the American Society for Horticultural Science, 115(2)*, 207-212.

Table 3.1 Kc values for peach production around the world.

| Year | Source | Kc values | Tree age | Reference |
|---|---|---|---|---|
| 1990 | South Carolina, USA. | Kc average: 0.7 | 3 | (Williamson and Coston, 1990) |
| 1997 | FAO | With active ground cover - Kc initial: 0.8 / Kc mid: 1.15 / Kc end: 0.85 | | (Allen et al., 1996) |
| 1997 | FAO | No active ground cover – Kc initial: 0.55 / Kc mid: 0.90 / Kc end: 0.65 | | (Allen et al., 1996) |
| 1997 | Spain | Kc initial: 0.25 / Kc mid: 1.0 (or 1.05 during rapid fruit growth) / Kc end: 0.55 | 5 | (Marsal and Girona, 1997) |
| 1999 | California | Kc average: 0.86 | 4-7 | (Ayars et al., 1999) |
| 2003 | Spain | Kc initial: 0.25 / Kc mid: 1.0 (or 1.05 during rapid fruit growth) / Kc end: 0.55 | 5 | (Girona et al., 2003) |
| 2003 | California | Kc bloom: 0.25 / Kc mid: 0.7 / Kc harvest: 1 / Kc late: 0.6 | 4-7 | (Ayars et al., 2003) |
| 2012 | Portugal | Evaluated only at end of season kc: 0.5 | 3-4 | (Paço et al., 2012) |
| 2013 | Spain | Kcb initial: 0.15 to 0.45 / Kcb mid: 1.0 / Kcb end: 0.15 to 0.45 | 6-9 | (Abrisqueta et al., 2013) |

Table 3.2 Canopy coverage percentage correspondent to peach tree age.

| Peach Tree Age | Canopy Coverage (%) |
|---|---|
| 1-year-old | 40 |
| 2-year-old | 60 |
| 3-year-old | 80 |
| 4 years and above | 100 |

Table 3.3 Amount of water used, and the water use efficiency (WUE) for each irrigation methods in a young peach orchard.

| Year rain (mm)[1] | Irrigation Methods | TCSA ($mm^2$) | Yield ($kgtree^{-1}$) | Irrigation ($Ltree^{-1}$) | WUE [2] ($mm^2L^{-1}$) |
|---|---|---|---|---|---|
| **2020 (1894)** | **App** | 1066 | No fruit | 1650.71 | 0.646 |
| | **Control** | 963 | No fruit | 0 | |
| | **Sensor** | 939 | No fruit | 1581.6 | 0.594 |
| **2021 (1272)** | **App** | 2362 | No fruit | 3700.67 | 0.638 |
| | **Control** | 1979 | No fruit | 0 | |
| | **Sensor** | 2514 | No fruit | 5115.5 | 0.491 |
| **2022 (1195)** | **App** | 5525 [a] | 7.65 | 3494.35 | 1.581 |
| | **Control** | 3880 [b] | 9.36 | 0 | |
| | **Sensor** | 5877 [a] | 10.18 | 7677.23 | 0.766 |

Table 3.4 Amount of water used, water use efficiency (WUE), and yield use efficiency (YUE) for different rootstocks in a young peach orchard.

| Year rain (mm)[1] | Rootstock | TCSA ($mm^2$) | Yield ($kgtree^{-1}$) | YUE ($kgmm^{-2}$) | Irrigation ($Ltree^{-1}$) | WUE [2] ($mm^2L^{-1}$) |
|---|---|---|---|---|---|---|
| **2020 (1894)** | **Guardian** | 1129 [a] | No fruit | | 1648.56 | 0.685 |
| | **MP-29** | 850 [b] | No fruit | | 1583.76 | 0.537 |
| **2021 (1272)** | **Guardian** | 3129 [a] | No fruit | | 5186.24 | 0.603 |
| | **MP-29** | 1505 [b] | No fruit | | 3629.89 | 0.415 |
| **2022 (1195)** | **Guardian** | 7175 [a] | 9.83 | 0.0014 | 6582.76 | 1.090 |
| | **MP-29** | 3196 [b] | 8.33 | 0.0026 | 4588.86 | 0.696 |

[x]Means followed by different letters within a treatment indicate significant difference, $P \leq 0.05$.
[1] Precipitation in mm during the growing season
[2]YUE= Yield Use Efficiency= (Total yield/TCSA)
[3]WUE= Water Use Efficiency= (TCSA/Irrigation amount)

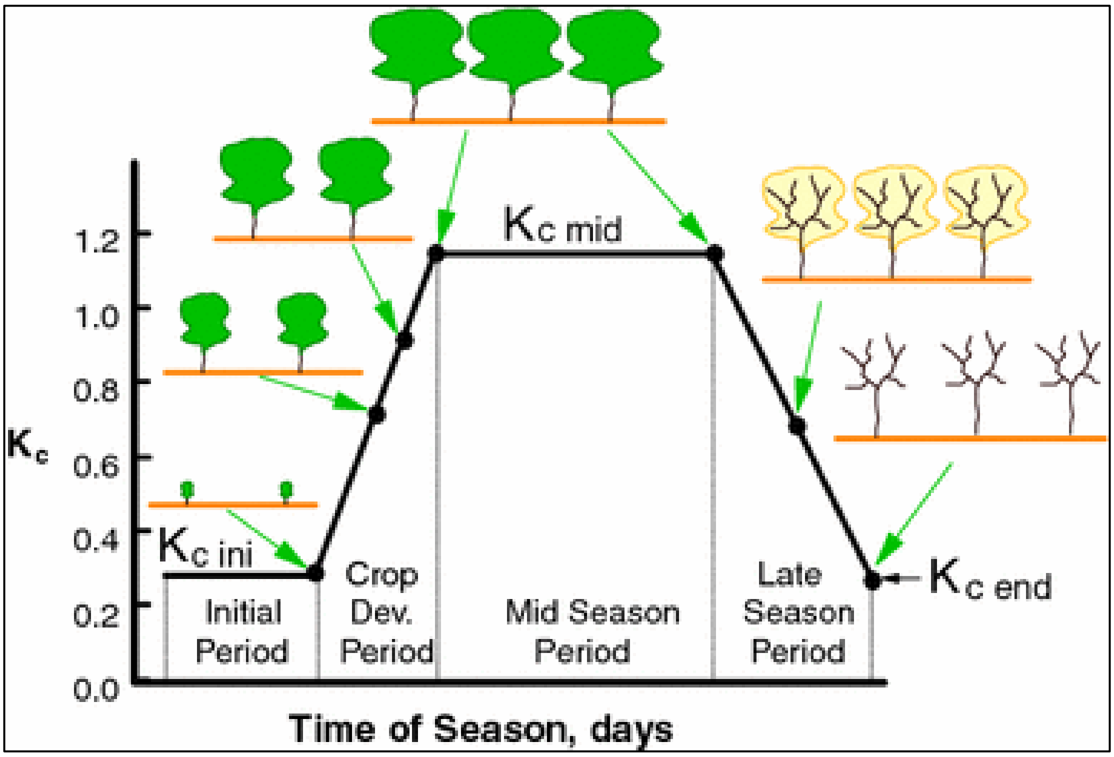



Figure 3.1 FAO Kc curve with three Kc values (Allen et al., 2005)

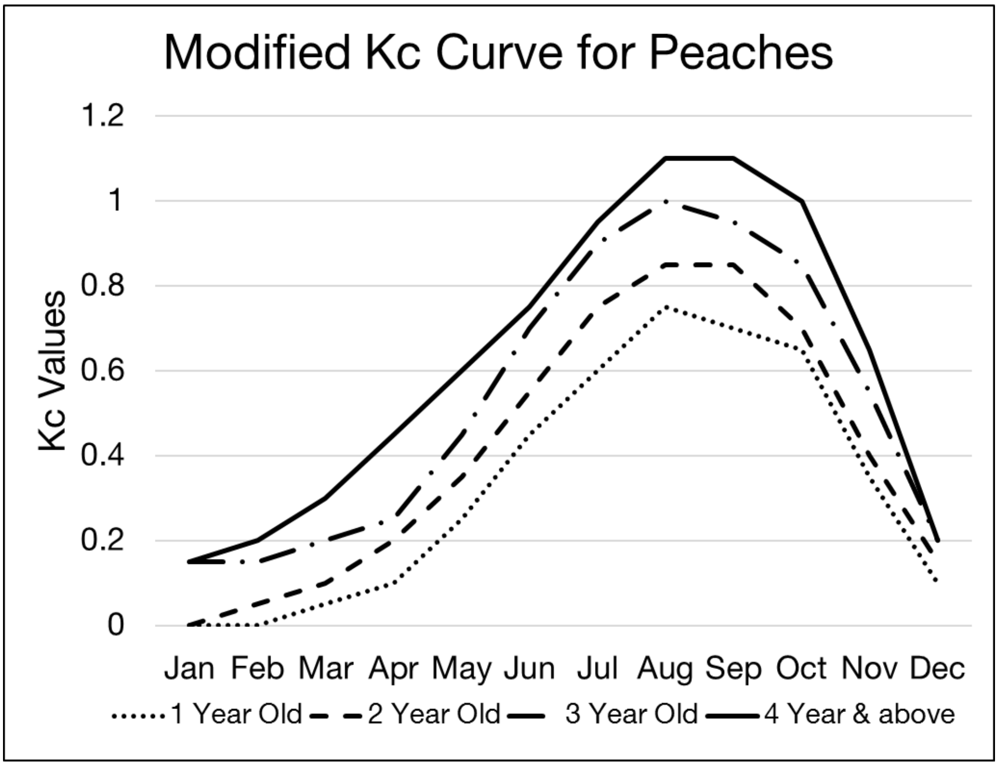



Figure 3.2 Modified Kc curve based on tree age (Reference: Abrisqueta et al., 2013)

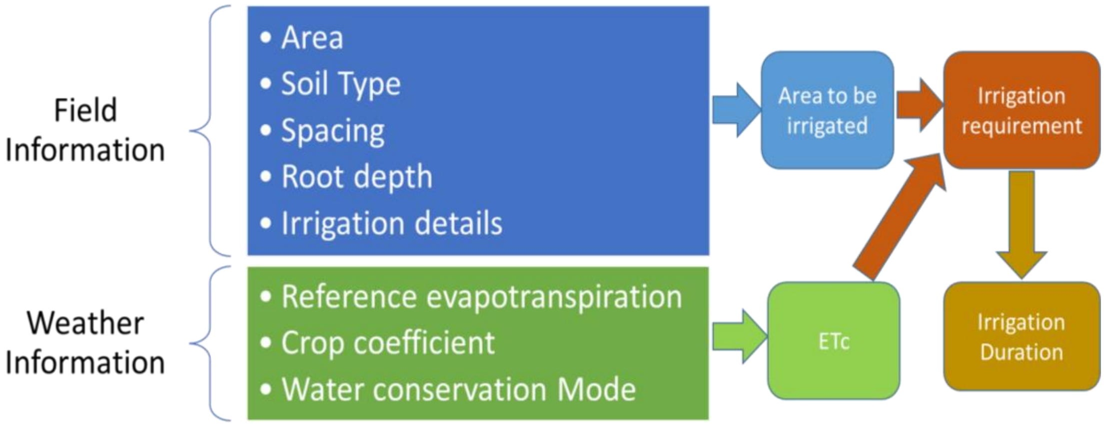



Figure 3.3 Basic Principle of SmartIrrigation Peach App Development. The model includes the field information entered by the user and weather information from the weather station to generate precise irrigation schedules for the field. (Reference: Vellidis et al., 2016)

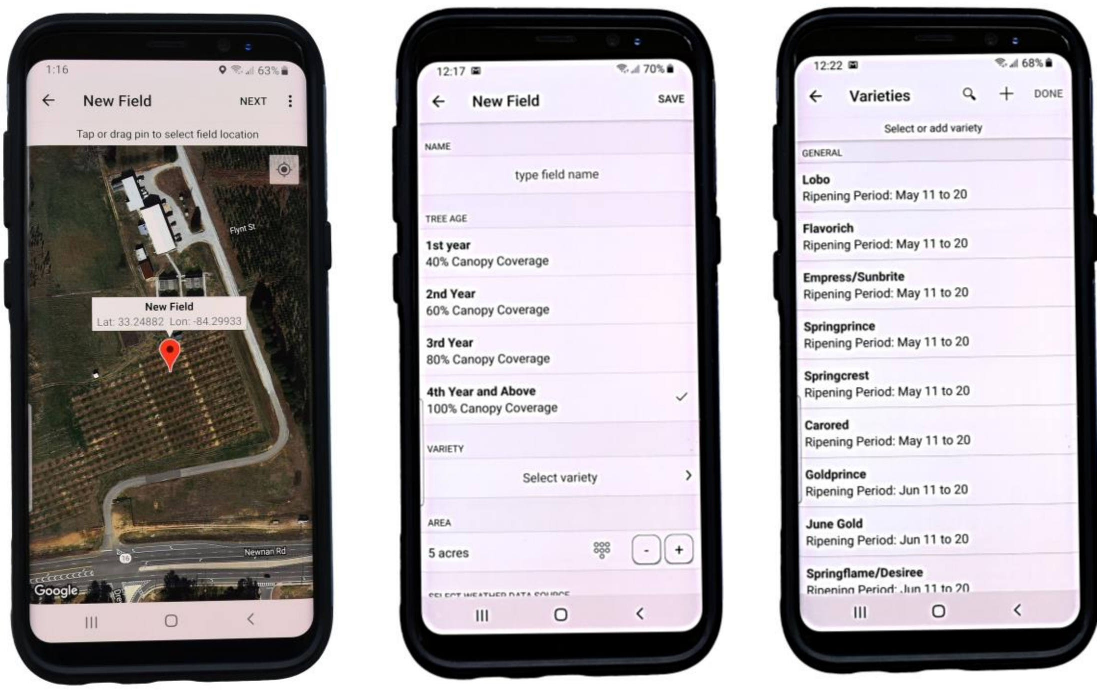



Figure 3.4 Screenshots of stepwise procedures of using Peach App[1]. The app pins the location of the field on the map (left). The user must type the unique field name and select a few crop and field parameters (middle). The user selects the peach variety (right).

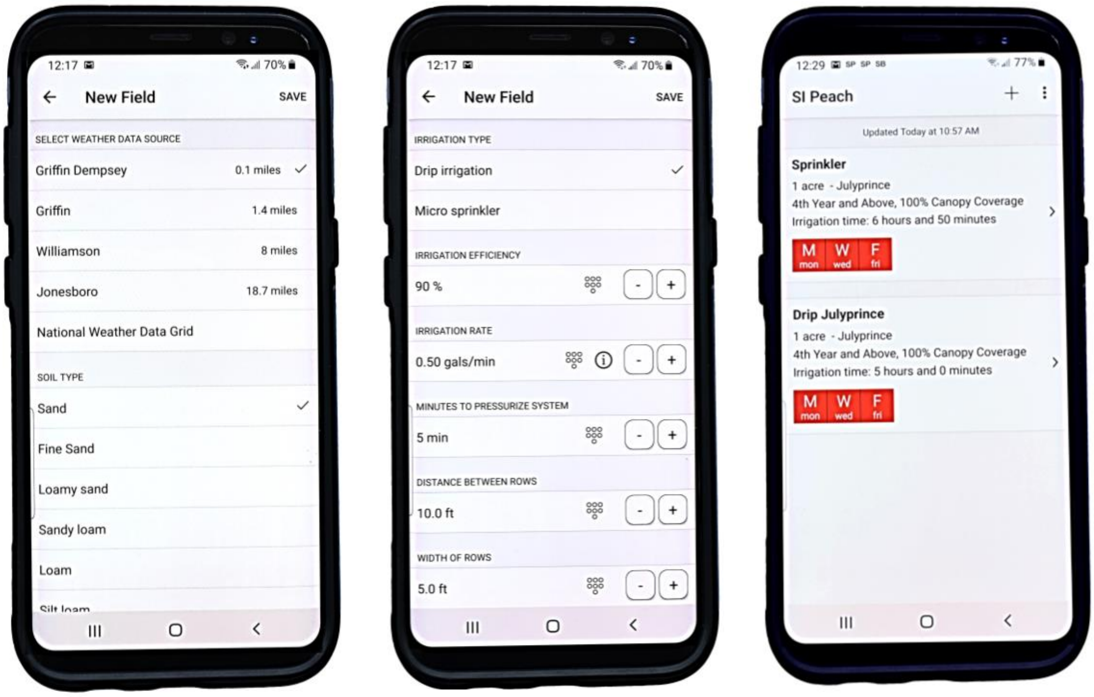



Figure 3.5 Screenshots of stepwise procedures of using Peach App[2]. The app displays four closest weather stations and the national weather data grid (left). The user then selects the soil type from the options listed (left). The user indicates the irrigation system with irrigation rate, efficiency and plant spacing (middle). The main user interface screen of the app displays the multiple fields registered along with the irrigation schedule information (right).

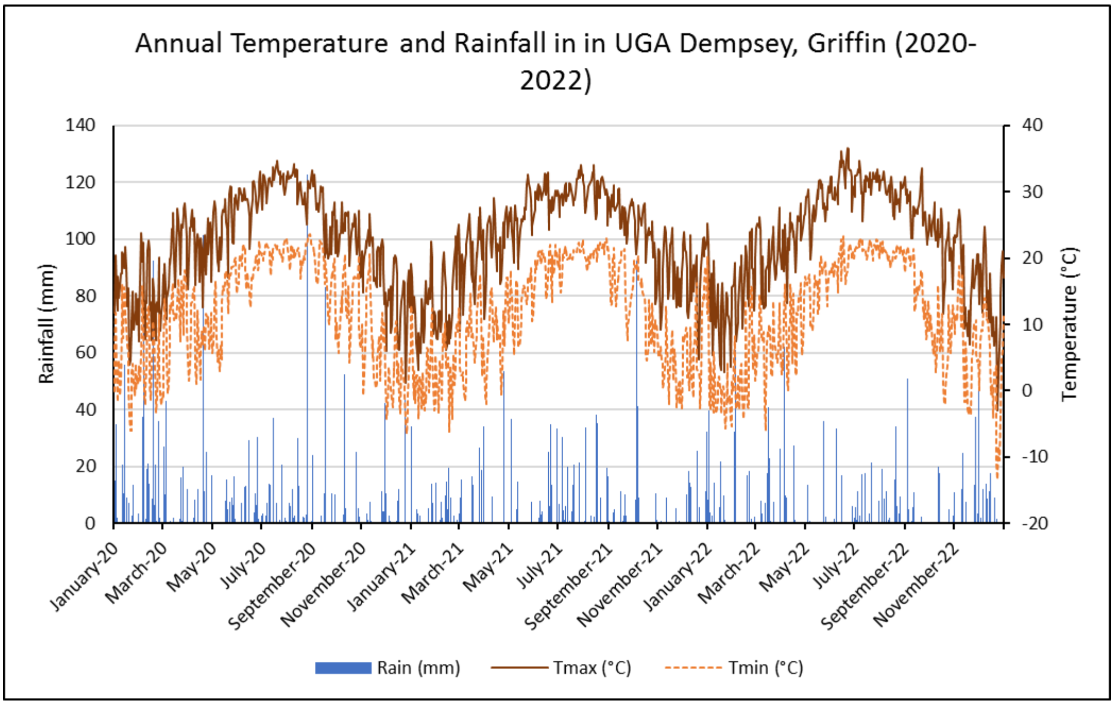



Figure 3.6 Average temperature (°C) and annual precipitation (mm) throughout 2020-2022 along with 20-year historical precipitation average from 1981 to 2010 in UGA Dempsey, Griffin.

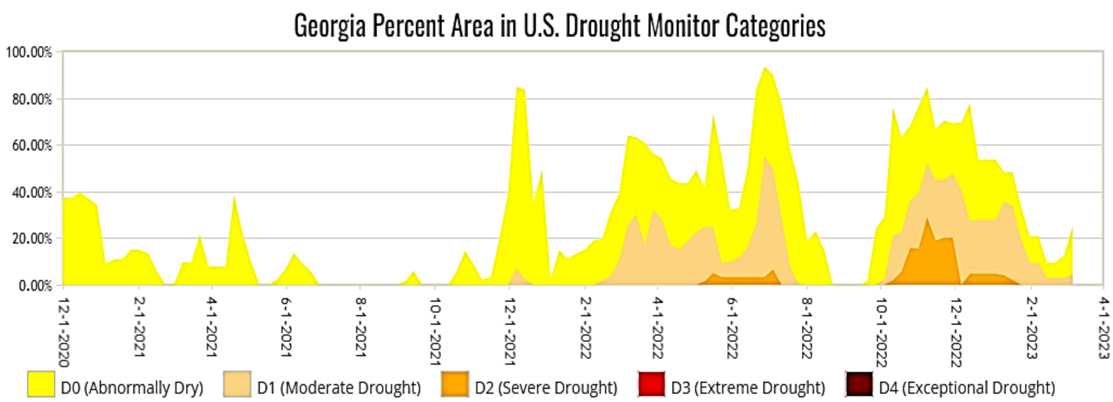
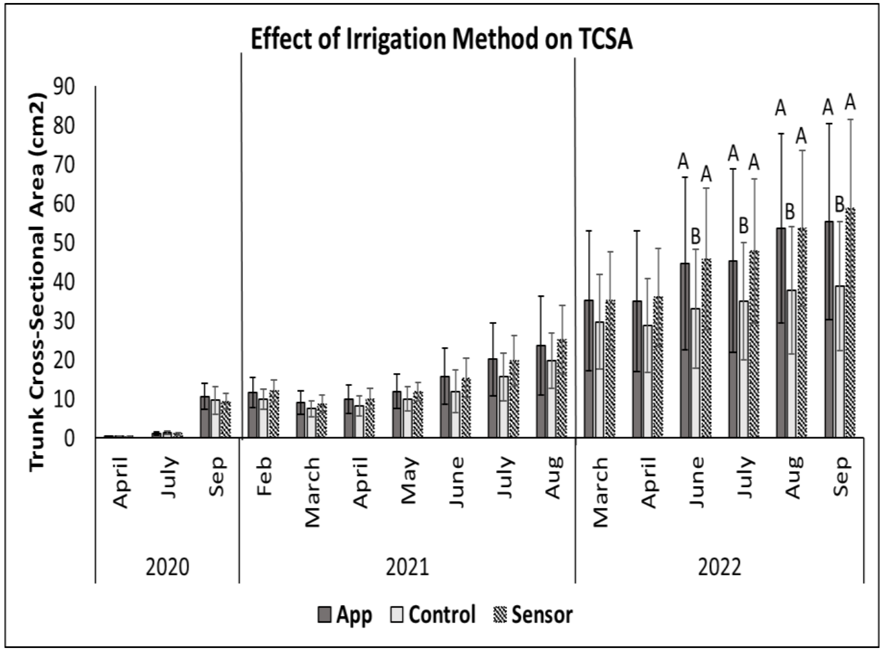



Figure 3.7 Drought monitor indicating moderate to severe drought occurrence in 2021 and 2022 in Georgia. (Source: U.S. Drought Monitor, 2023; https://droughtmonitor.unl.edu/ )



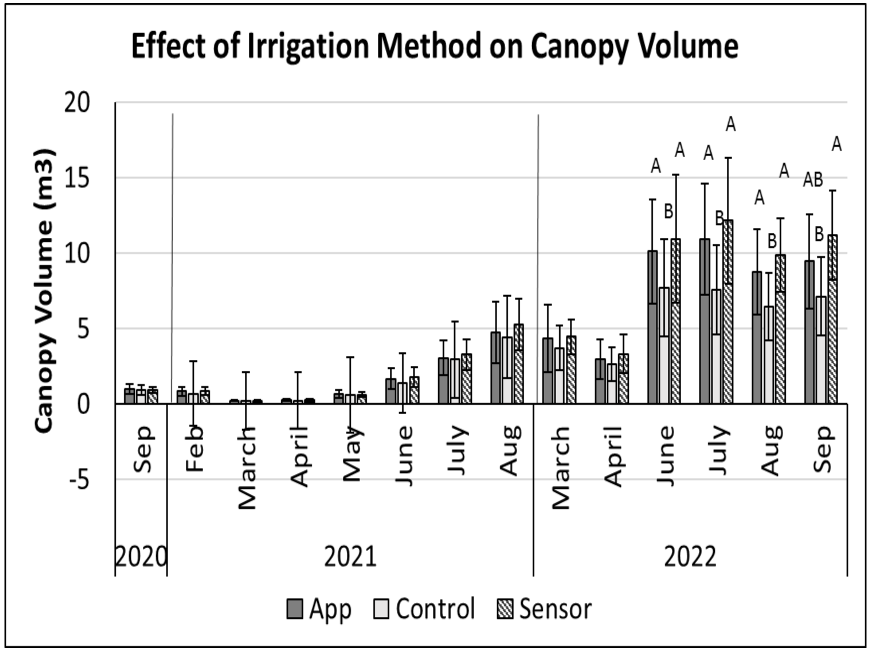




Figure 3.8 Effect of Irrigation methods (App, Control and Sensor) on trunk cross-sectional area (TCSA, $cm^2$) and canopy volume (CV, $m^3$) in 2020, 2021 and 2022 in a young peach orchard.
Different alphabetical letters above bar represent significant differences, *P ≤ 0.05*.

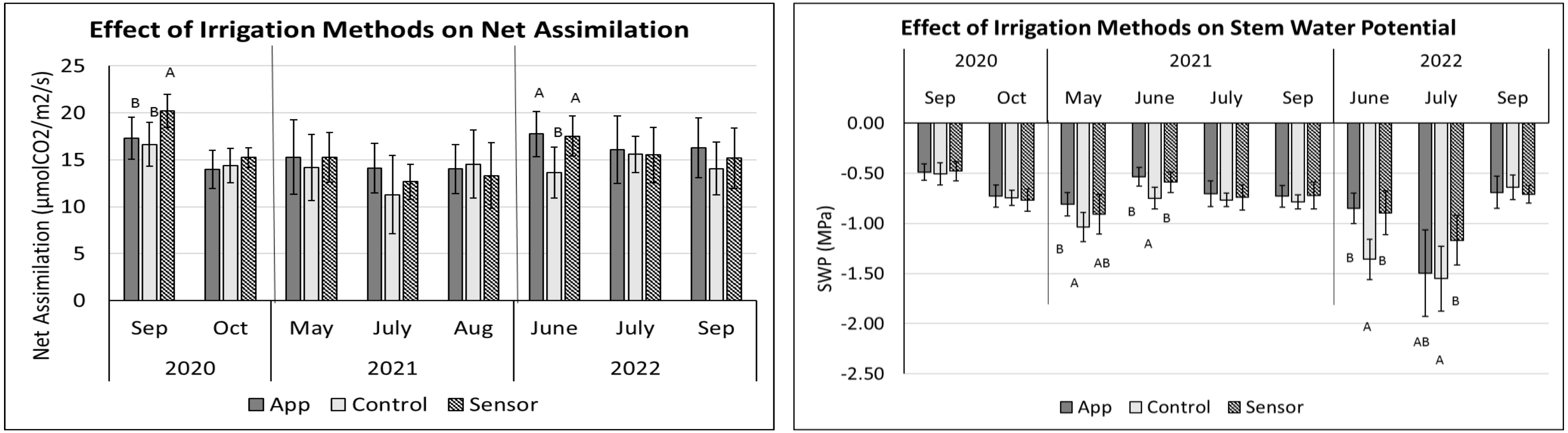



Figure 3.9 Effect of Irrigation methods (App, Control and Sensor) on net assimilation ($A_n$, $\mu molCO_2m^{-2}s^{-1}$) and stem water potential (SWP, MPa) in 2020, 2021 and 2022 in a young peach orchard.
Different alphabetical letters above bar represent significant differences, $P \leq 0.05$.

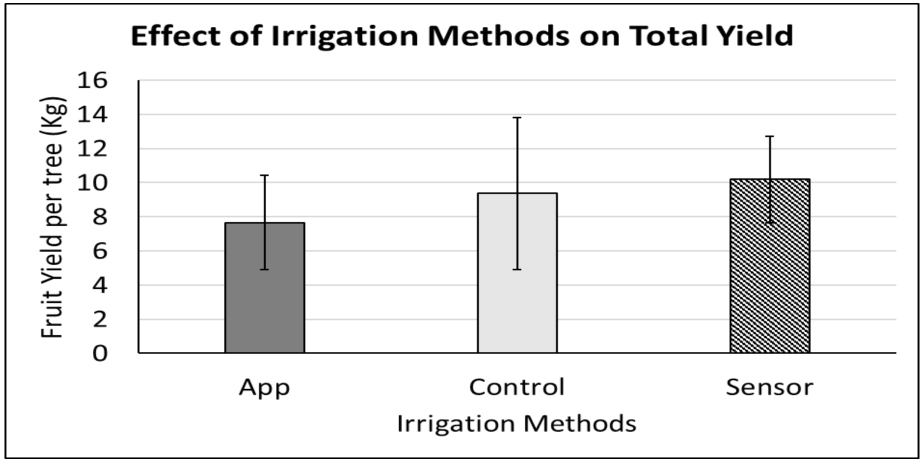



Figure 3.10 Effect of Irrigation methods (App, Control and Sensor) on total yield ($kgtree^{-1}$) in 2022 in a young peach orchard.

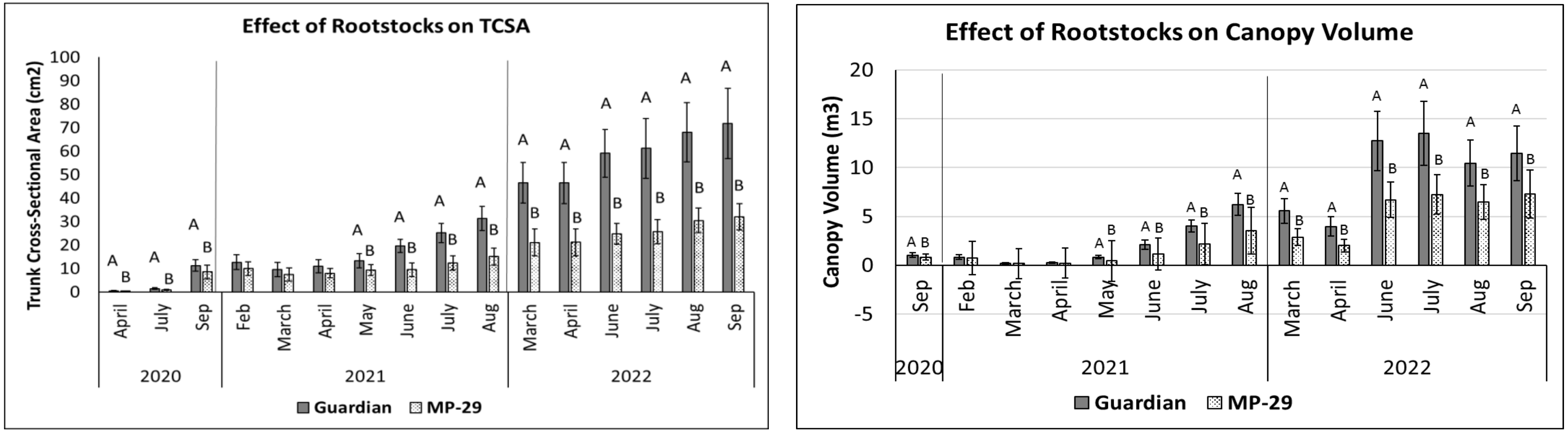



Figure 3.11 Effect of rootstocks (Guardian and MP-29) on trunk cross-sectional area (TCSA, $cm^2$) and canopy volume (CV, m3) in 2020, 2021 and 2022 in a young peach orchard.

Different alphabetical letters above bar represent significant differences, $P \leq 0.05$.

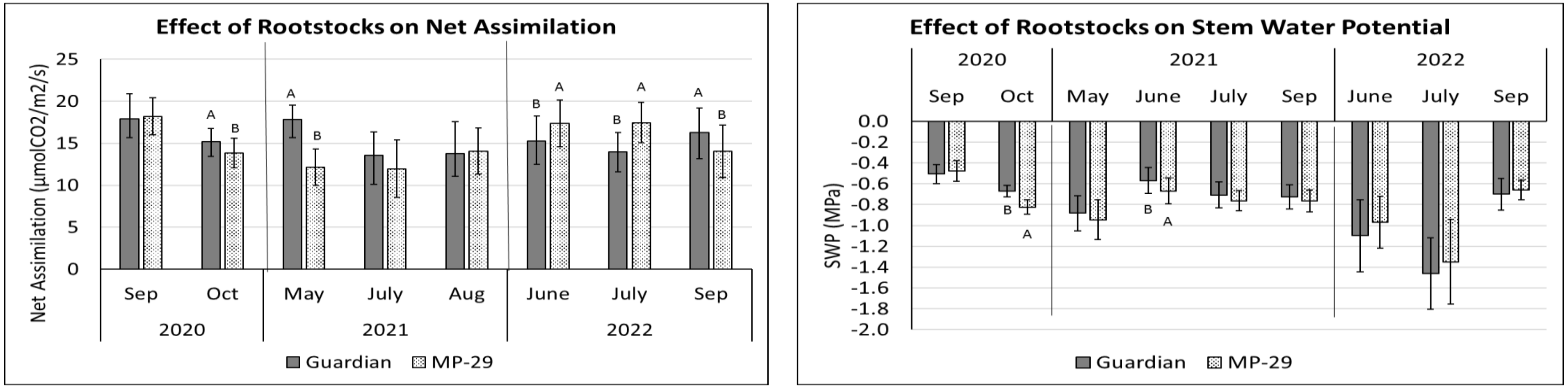



Figure 3.12 Effect of rootstocks (Guardian and MP-29) on net assimilation ($A_n$, $\mu molCO_2m^{-2}s^{-1}$) and stem water potential (SWP, MPa) in 2020, 2021 and 2022 in a young peach orchard.

Different alphabetical letters above bar represent significant differences, $P \leq 0.05$.

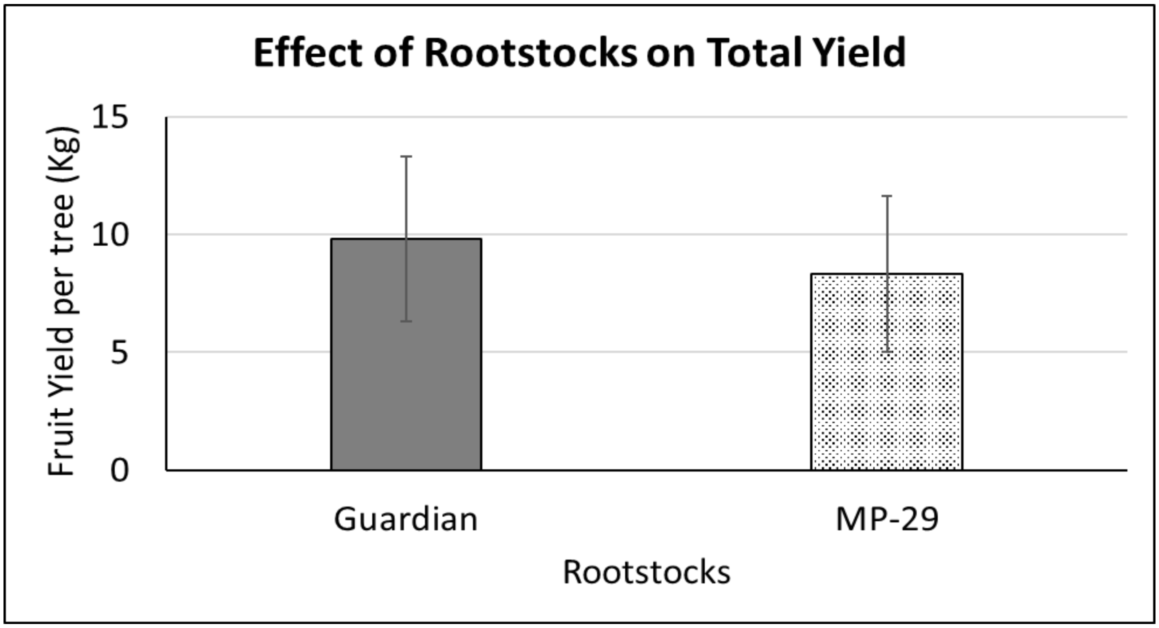


Figure 3.13 Effect of rootstocks (Guardian and MP-29) on total yield of ‘Julyprince’ cultivar in 2022 in a young peach orchard.

# CHAPTER 4

# IRRIGATION SCHEDULING WITH SMARTIRRIGATION APP AND SENSOR-BASED METHOD IN A MATURE PEACH ORCHARD IN GEORGIA

[1]Thapa Magar, S, G. Vellidis, V. Liakos, D.J. Chavez. To be submitted to ***Computers and Electronics in Agriculture*.**

**Abstract**

In Georgia, the absence of proper irrigation tools and the increasing frequency of drought events are a concern for peach growers. Optimal irrigation is essential for promoting plant growth and crop productivity, yet there is currently no irrigation scheduling tool for peach production in Georgia and most of the Southeastern U.S. The University of Georgia Vellidis' Research Group and the Peach Research and Extension program developed a smartphone app known as the SmartIrrigation Peach App. This app creates an up-to-date schedule for irrigation based on the daily water requirements of a peach orchard, based on its evapotranspiration. This research evaluated the performance of the SmartIrrigation Peach App in comparison to a sensor-based irrigation scheduling in a mature peach orchard of the 'Julyprince' cultivar grafted onto 'Guardian' rootstock. In addition, two irrigation systems: drip and micro sprinkler; and two fertilizer rates: 50% and 100% (current recommended rate) were also evaluated. Plant size, photosynthetic assimilation, stem water potential, fruit yield, and several fruit parameters (weight, perimeter) were not statistically different between the two irrigation scheduling methods. The app-based system was found to use only 85, 59, and 72% of the total water used per tree by the sensor-based irrigation in 2020, 2021, and 2022, respectively. On the other hand, trees grown using the drip irrigation system had significantly larger TCSA and higher stem water potential than trees grown with the sprinkler irrigation system. No significant differences were observed between the two fertilizer rates used for all variables measured in this study. Our results indicate that the SmartIrrigation Peach App is an effective tool for scheduling irrigation in mature peach orchards. Furthermore, half of the current recommended fertilizer rate can provide optimal plant growth and yield while reducing

costs. Finally, the drip irrigation system is an effective irrigation system without creating adverse conditions for the growing plant.

**Additional index words**: *Prunus persica*, drought, peach app, tree growth, fruit yield, fruit quality, photosynthetic assimilation, stem water potential, soluble solids concentration, total titratable acidity.

**Introduction**

Georgia is known as the 'peach state'. The first commercial peach cultivar, 'Elberta', was selected and first grown here. Georgia and South Carolina rank 3rd and 2nd in peach production in the U.S., respectively (USDA-NASS, 2022). These two states account for 8,200 and 16,000 bearing acreages with a total production of 35,300 and 87,400 tons, respectively. Georgia's farm gate value was \$35M and South Carolina's farm gate value was \$106M in 2021 (USDA-NASS, 2022). Albeit all the history and tradition of growing peaches in the Southeast, this region does not have a standard irrigation scheduling tool. Similarly, its fertilization practices are outdated and believed to have been derived from Mediterranean regions, therefore they are not suitable for this region and require revision. Irrigation and fertilizer management are fundamental practices in crop production, yet they are frequently neglected. Precision in irrigation and fertilizer management can not only enhance plant growth but also save resources and reduce production's environmental hazards.

The Southeast U.S. lacks irrigation scheduling information for peach production. Most growers do not install irrigation during orchard establishment due to increased establishment costs. Therefore, young peach trees only rely on precipitation until they reach the fruit-bearing stage after four years of establishment. Studies conducted by Layne et al. (2002) and Casamali et al. (2021b) report the positive effects of supplemental irrigation on young peach trees since establishment for plant size and yield. Additionally, it has also been observed that these trees further exhibited residual effects from water stress. Studies by Girona et al. (2005) and Vera et al. (2013) compared the response of peach trees to different deficit irrigation strategies and found that deficit irrigation significantly reduced the vegetative growth of trees as well as decreased fruit set and yield. Several studies have found that deficit irrigation at certain growth stages can optimize yield and improve fruit quality (Du et al., 2017; Kobashi et al., 2000; Thakur and Singh, 2012). Guizani et al. (2019) found that cyclic and sustained deficit irrigation in peach trees in Mid-Western Tunisia significantly reduced vegetative growth but increased fruit sugar content in four peach cultivars (Flordastar, Early Maycrest, Rubirich, and O'Henry). Similarly, Gelly et al. (2004) reported that regulated deficit irrigation during Stage II of peach fruit growth improved fruit quality (high SSC and high SSC/TTA ratio). Li et al. (1989) and Crisosto et al. (1994) reported similar results for fruit quality under different irrigation regimes.

Peach growers in Georgia currently follow the fertilizer recommendations outlined in The Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide (Blaauw et al., 2023). However, these recommendations need to be revised to reflect the actual nutritional requirements of the trees. Casamali et al. (2021a, 2021b) tested four different fertilizer rates (25, 50, 100, and 200%), with 100% reflecting the current recommended rate in Georgia), in a young peach orchard with cv. 'Julyprince' grafted onto 'Guardian' and reported that plant growth and yield response to each rate were comparable. He thus suggested for reduced fertilizer application rate for Georgia peach production.

Zhou and Melgar (2018) compared nutrient concentration and partitioning in peach trees from three different ripening seasons and reported that early-season cultivars had higher macronutrient concentration in leaves, wood, and mature fruits than mid and late-season cultivars. They also suggested having specific fertilization programs for cultivars with different ripening periods to be beneficial. Another study by Zhou and Melgar (2020) assessed the influence of tree age on nutrient partitioning in peach trees. They determined that mature peach trees (6-year-old) allocated more macronutrients to pruned wood, and harvested fruit but less N and Ca to senescing leaves compared to old trees (20-year-old). Based on their findings, they suggested that tree age and the proportion of organs (wood, leaves, fruit) removed need to be considered for optimal estimation of tree nutrient requirement. Optimal irrigation and fertilizer application rates based on the crop's actual requirements can result in healthier plant growth and increase productivity/profitability. The common practice of over-applying fertilizer in commercial orchards can lead to increased production costs, soil nutrient loss, and environmental pollution (Carranca et al., 2018). As a result, determining the optimal amount of fertilizer for application is becoming increasingly important.

The adequate management of irrigation and fertilization guidelines in a peach orchard can help the industry in this region by increasing its productivity, efficiency, and sustainability. In addition, the increasing drought incidence in the Southeast possesses a greater risk to the peach trees, particularly young peach trees (Figure. 4.1). Our team at the University of Georgia thus developed SmartIrrigation Peach App, a tool to schedule irrigation based on the peach tree's water requirement. It is useful in scheduling irrigation in a young peach orchard (Thapa Magar et al., 2022). In this study, we are comparing the

SmartIrrigation Peach App to a sensor-based method (UGA Smart Sensor Array) in a mature peach orchard. UGA Smart Sensor Array is a wireless soil moisture sensing system, well designed with a smart sensor node (accommodating up to 3 Watermark sensors) and a gateway to suit any field crops (Vellidis et al., 2013). We are also looking to continue understanding the effect of different fertilizer application rates in peaches to determine an optimal fertilizer rate in the Southeast region.

## Materials and Methods

### *Location and Plant material*

The study was conducted from 2019 to 2022 in a mature peach orchard. This orchard was established in 2015 at the Dempsey Farm at the University of Georgia, Griffin GA. The soil at the site is Cecil sandy loam with pH ~5.9, and organic matter ~1.5%. A total of 236 trees were planted at a spacing of 4.6 m × 6.1 m. Sixty-three trees cv. 'Julyprince' grafted onto 'Guardian' rootstock were selected as data trees for corresponding treatments in 2020. The management practices were followed according to recommended guidelines published in the Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide (Blaauw et al., 2023).

### *Experimental Design*

From establishment in 2015 until 2018, the experiment was designed with three main effects: 1) Irrigation levels (irrigated vs. non-irrigated trees); 2) irrigation systems (drip- vs. micro-sprinkler-irrigated trees); and 3) fertilizer levels (25, 50, 100, and 200%). The 100% fertilizer level refers to the current recommended fertilizer rate for peach production in Georgia based on the recommendations of the Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide (Blaauw et al., 2023). The irrigation was based on the use of soil moisture sensors set to a desired volumetric water content (VWC) specific to the soil moisture release curves for the location (Casamali et al., 2021b). Additional information about experimental design, results, and discussion can be found in Casamali et al. (2019, 2021a, 2021b).

For this research, in 2019, as trees matured, certain modifications were applied to the experimental design. For the fertilizer treatments, the levels were limited to 50 and 100% rates based on findings from a previous study (Casamali, 2019; Casamali et al. 2021a and 2021b). For the irrigation treatments, irrigated trees from the original experiment were kept with the same sensor-based irrigation while the non-irrigated treatments were irrigated following the recommendations from the SmartIrrigation Peach App (referred to as Peach App or App). The Peach App was still in the development phase in 2019 and it did not include a rainfall adjustment feature, which was later added in 2020. Data for 2019 was collected as a buffer year between the main research periods. In 2020, further modifications were done for the irrigation treatments in order to avoid any effect from the original treatments (2015-2018) in the current period of research (for example, the use of non-irrigated plants as sensor-based irrigation in 2019 was modified to non-irrigated plants in sensor-based and app irrigation, Figure. 4.2). In addition, the sensor-based irrigation was also modified where the irrigation recommendations were based on the UGA Smart Sensor Array (Vellidis et al., 2013). It is a wireless system that includes watermark sensors at desired depths to measure the soil water tension and a circuit board with radiofrequency transmitters to relay the measurements wirelessly using a mesh network (Figures 4.3 and

4.4). The watermark sensors are installed in a stainless-steel stake back-to-back at the depths of 20, 40, and 60 cm, considering the majority of root distribution for mature peach trees. The soil water potential values measured by the Watermark sensors at corresponding depths are then considered for the irrigation recommendations based on the weighted average of these three sensors as 20 cm (50%), 40 cm (30%), and 60 cm (20%) respectively. Then, the van Genuchten model is used to convert the soil water potential data to irrigation recommendations in depth which later is converted to irrigation duration using the same method used in the Peach app calculations (Equations. I and II) (Vellidis et al., 2013). Sixteen UGA SSA were installed throughout the research plot with eight of them in the sensor-based treatment and the rest in the app-based treatment to monitor the soil moisture level every hour over the growing season.

$$Irrigation\ Amount = Amount\ in\ hectare \times irrigated\ area\ (ha) \times irrigation\ depth \ldots\ldots \text{Eq. I}$$

$$Irrigation\ duration = \left(\frac{Irrigation\ amount}{Irrigation\ rate}\right) + minutes\ to\ pressurize\ system \ldots\ldots \text{Eq. II}$$

The experimental design of the research plot from 2020 until 2022 was a split split-plot randomized complete block design where the first split is for the irrigation system (drip and micro-sprinkler system) and the second split is for fertilizer doses (50 and 100%) (Figure 4.5). Each treatment combination was randomized and replicated with four blocks. Each block consisted of two irrigation systems (drip and micro-sprinkler), two fertilizer doses (50 and 100% rates), and two irrigation methodologies (SmartIrrigation app and sensor-based irrigation. The irrigation system was arranged such that the micro-sprinkler and drip set-up per tree both delivered 30.4 $L \cdot h^{-1}$ in a diameter of ~3.5 m around the truck.

The drip irrigation system included four emitters (SB-20 Bowsmith; Exeter, CA) placed ~45 cm around the truck. The micro-sprinkler irrigation system consisted of one head (QN-08 Rain Bird; Azusa, CA) located ~10 cm away from the trunk. Flow meters were installed at the entry point of the water source for each irrigation method (SmartIrrigation app vs. sensor-based) and irrigation system (drip vs. micro-sprinkler) to record periodically the water used by each treatment.

*Variables Measured*

The data were collected from a total of 63 trees for various plant, fruit, and physiological parameters such as trunk cross-sectional area (TCSA), canopy volume (CV), net assimilation, stem water potential, yield, fruit size, and fruit quality. Tree height and canopy diameter were measured monthly using a measuring tape. The trunk diameter, ~15 cm above the soil surface, was measured using a caliper (The Mantaz Blue, Haglőf, Sweden). These parameters were then used to calculate TCSA and CV using the equations below (Equations. III and IV). Mid-day photosynthetic net assimilation ($A_n$) data of a mature leaf was measured using a portable LI-COR 6400 (LI-6400XT; LI-COR, Lincoln, NE) where a constant photosynthetic photon flux density of 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and $CO_2$ concentration of 400 $\mu mol \cdot mol^{-1}$ were maintained. The machine also measured leaf transpiration (E); thus, water use efficiency (WUE) can be estimated using Equation V. The mid-day stem water potential of a leaf was measured with a pressure chamber (1505D-EXP; PMS Instrument Company, Albany, OR). A mature leaf was first enclosed in an aluminum foil bag for about 20 minutes. It was then detached from the tree with the leaf still inside the bag and placed in the pressure chamber. The compressed Nitrogen gas was supplied in the pressure chamber and the pressure gauge value was recorded when the sap first oozes out of the petiole.

$$TCSA = \pi \times \left(\frac{average\ trunk\ diameter}{2}\right)^2 \text{.......................................................Eq. III}$$

$$CV = \pi \times \left(\frac{average\ canopy\ diameter}{2}\right)^2 \times \left(\frac{tree\ height}{3}\right) \text{.......................................Eq. IV}$$

$$WUE = An/E \text{..........................................................................Eq. V}$$

The total fruit yield was measured during the harvest period in July. Fruits were classified into commercial and non-commercial categories depending on their size, shape, and others. Non-commercial fruit consisted of smaller, damaged, and misshaped fruits. Once harvested, a sample of 10 commercial fruit was randomly selected from each treatment for further fruit processing. Measurements of fruit weight, size, and quality were taken. The average fruit weight was estimated by measuring the sample weight of the 10 commercial fruit on a digital scale (Ohaus; Parsippany, NJ). Five fruit out of those 10 were further selected to obtain fruit diameter using a fruit sizer (Cranston Machinery Co.; Oak Grove, OR). Additionally, these fruit samples were then cut into slices and a slice from five individual fruits was placed in a one-quart Ziplock bag (Ziploc; SC Johnson, Racine, WI) and frozen at -80 °C (U725 INNOVA; Eppendorf, Hauppauge, NY) until further juice processing at the Peach Research and Extension laboratory at the University of Georgia, Griffin campus, GA. For the juice processing, the fruit slices were first thawed at room temperature and blended into a homogenous purée using a blender (Ultima Blender BL810 30; Ninja, Newton, MA). About 33 g of the purée was poured into a 50-mL Oak ridge centrifuge tube (Oak Ridge Nalgene; Thermo Scientific, Waltham, MA) and centrifuged at 20,000 rpm for 20 min at 5 °C (Model 5810R; Eppendorf, Hauppauge, NY). The supernatant and the juice were then separated, and the juice was filtered into a 15 mL conical tube. The juice was filtered during transference using 95 95 mm two double-layer cheesecloth (VWR, Radnor, PA). The final juice amount was recorded. Tubes were then stored in a -20 °C freezer (VWR, Radnor, PA) until further processing. The frozen juice was thawed at room temperature for a minimum of 1 hr and mixed using a vortex. Soluble solids concentration (SSC) was measured by placing 300 µL juice on a handheld refractometer (Palette PR-32; Atago, Bellevue, WA, U.S.). Total titratable acidity (TTA) was measured as in % Malic acid as described by Mitcham et al. (1996) by first diluting the juice at a 1:50 dilution rate in deionized water. In addition, 0.6 mL of the 1:50 diluted solution was used to measure acidity in a Pocket Brix-Acidity Meter (PAL-BX|ACID F5; Atago, Bellevue, WA, U.S.). Two replications of each juice sample were used for both SSC and TTA measurements. The average value between the two juice reps was further used for analyses.

*Data Analysis*

Analyses of variance were performed using the proc mixed procedure in SAS 9.4 (SAS Institute Inc.; Cary, NC, U.S.). Data were compared to examine the differences between treatments. Differences between means for each treatment and treatment interactions were examined using Tukey's Honest Significant Difference test with a confidence level of 95% ($P \leq 0.05$).

## Results and Discussion

The soil moisture levels for different combinations of irrigation systems with irrigation methods were depicted in Figures 4.6, 4.7, and 4.8 for 2020, 2021, and 2022 respectively. Supplemental irrigation started on April 21, April 27, and May 2 respectively in 2020, 2021, and 2022 and was turned off as the freezing temperatures approached each year. The soil water tension values were comparatively lower in the spring but eventually increased as the active growing season started and lowered again as trees entered the dormancy period. The SWT graph follows a similar pattern as the Kc curve through the growing season. The higher SWT values in summer as a result of higher water uptake by trees and also due to the drought incidence each year implied greater irrigation water application. In 2021, a severe drought occurred resulting in very high SWT values (Figure 4.7). Similarly, in 2022, drought incidence in summer and October resulted in higher SWT values (Figure 4.8). The rise in the SWT graph represented water uptake by peach trees and the fall in the SWT graph corresponded to supplemental irrigation/rainfall throughout the growing season.

Casamali et al. (2019, 2021a) reported that peach trees of 'Julyprince' grafted onto 'Guardian' with no supplemental irrigation since establishment resulted in significantly smaller plant size and lower yield compared to its counterparts after four years of experiment (Casamali et al., 2019; Casamali et al., 2020a). In 2019, this field was repurposed as previously described in the materials and methods section. The non-irrigated plants were switched to app-based irrigation following standard commercial procedures in Georgia. The irrigated plants were kept in sensor-based irrigation. Due to this change, it was necessary to assess if there were any residual effects of the treatments prior to 2019 to the end of the 2019 season that could affect our new experiment. The analyses indicated that previously non-irrigated trees (prior to 2019)/ app-irrigated (in 2019) were comparable in terms of plant size with irrigated trees (sensor-based) at the end of the 2019 season. Furthermore, it was observed that there was a significant difference in terms of fruit yield (commercial and total), with non-irrigated trees (prior to 2019)/ app-irrigated (in 2019) having significantly lower yield compared to irrigated trees (sensor-based) at the end of 2019 (Table 4.1). Based on these results, we proceeded to check the plots for any residual effect from the treatments prior to 2019 and again in 2020. It was found that there was no residual effect in 2020 from the treatments prior to 2019 as previously set by Casamali et al. (2021a and 2021b). In 2020 based on these results, data from 2019 is considered a buffer year between experiments. Hereafter, results will be presented for data from 2020 onward.

*Plant Size and Fruit Yield*

Table 4.2 indicates the effects observed from different irrigation systems, methods, and fertilizer rates on plant size and fruit yield from 2020 to 2022. The results indicated that drip irrigation resulted in significantly larger TCSA compared to the micro-sprinkler system at the end of each year. Bryla et al. (2003) found similar results where peach trees irrigated with microjets were significantly smaller for TCSA compared to trees irrigated by drip and furrow irrigation. Drip irrigation ensures precise water application enhancing nutrient uptake by plants, as observed in the results from Chapter (2). It is a more efficient method compared to micro sprinkler systems because the latter causes water loss through evaporation, leading to a need for a larger amount of water to be applied to achieve similar results as those of the drip irrigation method. Canopy volume and total yield were comparable between the two irrigation systems (Table 4.2). For the comparison between irrigation methods, there were no significant differences for any plant size or fruit yield parameters over three years. The results hold true in the case of the young peach trees irrigated with peach app-based recommendations and sensor-based recommendations by Thapa Magar et al. (2022). Given that the plant size was comparable between the irrigation methods over years, this must have translated to a similar number of fruiting wood numbers, resulting in comparable fruit yield over the years. For the fertilizer rate comparison, TCSA was comparable over three years. Canopy volume however was significantly larger for the current recommended fertilizer rate (Blaauw et al., 2023) for 2020, however, this difference was not consistent in 2021 and 2022. Fruit yield was comparable between the two fertilizer rates, no differences were observed in the 2020 and 2021 seasons, however, in 2022 the 50% fertilizer rate yielded statistically more fruit than the standard fertilizer rate. The comparable plant size and yield across years when comparing the 50% and 100% fertilizer rates suggest that the current recommended rate is more likely above what is needed by the trees. The excess fertilizer is likely used only for luxury consumption by the plants. Similar results were observed by Casamali et al. (2021b) with young peach trees fertilized with 25, 50, 100, and 200% of the current recommended rate for Georgia. Thus, the current recommended fertilizer rate could be reduced by 50% without compromising the peach tree’s growth and production.

*Stem Water Potential*

Table 4.3 indicates the effect of irrigation systems, methods, and fertilizer rates on mid-day stem water potential (SWP) over the growing seasons of 2020 to 2022. This parameter is affected by water availability to plants as well as weather conditions. It is measured in negative values and indicates the level of water stress in plants. The lower the SWP value, the higher the water stress in plants. For peach trees, mid-day SWP values higher than -1 MPa are considered as no water stress conditions (Mahhou et al., 2005; Rahmati et al., 2015). The SWP values of peach trees in this study were within this range until July 2022. The rainfall data for this location supports these results since the average rainfall for these years was greater than the historical average (947 mm) with 2020 having the highest rainfall average (1894 mm) followed by 2021 (1272 mm) and 2022 (1195 mm). However, in 2022, rainfall was minimal in summer and Georgia experienced moderate to severe drought incidence (Figure. 4.1). This resulted in mid-day stem water potential lower than -1 MPa during July 2022 (Table 4.3). Since all our treatments were irrigated, the peach trees recovered from the water stress quickly. When comparing SWP between the irrigation systems, the micro-sprinkler system resulted in a significantly lower SWP in June and September 2021 in comparison with drip irrigation. Basically, this implies that SWP is dependent on water availability to plants rather than the amount of water required by the plant. The amount of water for each irrigation system is the same for the app-based method and is based on the soil moisture sensors readings for the sensor-based method. With the drip irrigation system producing larger trees than the micro-sprinkler system, it is expected that larger trees would have higher water requirements thus higher water stress levels. But since the drip irrigation system is more efficient in terms of water delivery to plants than the micro-sprinkler system, it helps reduce plant water stress and maintain stem water potential at the desired range. Water from the micro-sprinkler system can be affected by evaporation caused by wind and sun exposure, which may have affected the overall delivery of water to the trees.

*Photosynthetic Assimilation and Water Use Efficiency*

Table 4.4 presents the photosynthetic assimilation by the mature peach trees under different irrigation and fertilizer rate treatments compared across seasons. It was only in July 2022 that the drip irrigation system had significantly higher photosynthetic assimilation compared to the sprinkler system. This date aligns with the drought period in this region (Figure. 4.1). A possible explanation is that the micro-sprinkler irrigation system being less efficient than the drip system puts trees under water stress that affects their photosynthetic assimilation, especially during drought conditions. This statement is supported by the SWP values in Table 4.3 where trees under the micro-sprinkler irrigation system had comparatively lower SWP values than those under the drip irrigation system. It was also observed that the photosynthetic assimilation in 2021 was smaller than in the other two years. This was likely due to some technical issues in the LiCOR 6400, recognized and fixed shortly after the two measurements in May and July.

Table 4.5 indicated the water use efficiency (Photosynthetic assimilation/stomatal conductance) results of the mature peach trees under various irrigation practices and fertilizer rates. This parameter was comparable across all treatments for all three years. These results were consistent with other trials reported by Casamali et al. (2021b) and

Haider et al. (2018). Only in September 2022, trees irrigated with a drip system had significantly higher water use efficiency compared to trees irrigated with a micro-sprinkler system. The drought incidence in the summer of 2022 resulting in lower photosynthetic assimilation in the micro-sprinkler system explains the lower water use efficiency in the micro-sprinkler system since water use efficiency is directly proportional to the photosynthetic assimilation.

*Fruit Characteristics*

Table 4.6 presents the physical parameters of ripe fruit harvested from individual treatments. These data include the average fruit weight and perimeter. For different irrigation systems, the average fruit weight and perimeter were significantly larger in the micro-sprinkler-irrigated trees for 2020 and 2021 contrary to what Bryla et al. (2003) reported. In 2022, both parameters were significantly larger in drip-irrigated trees in comparison to micro-sprinkler-irrigated trees. These results could be due to various environmental factors besides the irrigation system used. In 2021, late frost was observed on April 22 (-0.6 °C) respectively. The drip side is situated downhill compared to the micro-sprinkler side, which likely caused the late freeze to have had a significant impact on the fruit found on the drip side leading to lower yields and smaller fruit sizes. The drip side did have a lower yield in comparison with the micro-sprinkler trees in 2021, however, the fruit size was smaller contrary to what would have been expected by a reduction of the crop. For irrigation methods and fertilizer rates, there were no significant differences for any of the fruit parameters similar to results from Thapa Magar et al., 2022 in a young peach orchard comparing sensor- and app-based irrigation methods.

*Fruit Quality*

Table 4.7 presents the chemical parameters of ripe fruit under various irrigation and fertilizer treatments. Results indicated that fruit under a micro-sprinkler irrigation system had significantly higher SSC in two out of three years compared to the drip irrigation system. Trees irrigated with a micro-sprinkler system had higher water stress during the active growing period. This resulted in a limited water supply to tree tissues, concentrating higher sugar content in fruit (Lopez et al., 2010). According to a study by Lo Bianco et al. (2000), trees that are subjected to water stress develop an increased ability to regulate their water balance, known as osmotic adjustment, to cope with the stress. This results in a higher concentration of sugars in the fruit produced by these trees. Fruit under sensor-based irrigation had significantly higher SSC in 2021. For the fertilizer rates, there were no significant differences between the two rates for SSC or TTA. For SSC/TTA, fruit under half of the recommended fertilizer rate had a significantly higher ratio in 2020, however, there were no significant differences thereafter. Similar results were observed by Casamali et al. (2021) with different irrigation systems and fertilizer rates.

*Water Records - Usage*

The Peach app recommends the same amount of water for each irrigation system, the only difference is in terms of irrigation duration due to the irrigation system specifications and delivery efficiency. Therefore, in this section, we focused on the difference in amounts of water used between irrigation systems using the sensor-based irrigation records only. The amount of water used when evaluating the different irrigation systems showed that the drip irrigation system was comparatively using more water than the micro-sprinkler system through the season (Figure 4.9). However, the sensor-based recommendations were high for the micro-sprinkler system in comparison to the drip system, which should have resulted in higher water use than the drip system. The irrigation rate for both systems based on the technical data was 30.2 $L \cdot h^{-1}$, however, the calculated irrigation rate using our water irrigation records showed that the irrigation rate for the drip system was ~ 34 $L \cdot h^{-1}$ contrary to the 26 $L \cdot h^{-1}$ for the micro-sprinkler system.

For the irrigation methods, the app-based method used comparatively less water than the sensor-based method throughout all three years (Figure. 4.9). In 2020, the difference in water use is minimal, but this was a year with ample rainfall. In addition, the Peach app was not equipped with a rainfall adjustment feature. The rainfall adjustment feature accounts for the rainfall observed for the past five days in the location and calculates its equivalent irrigation duration. It then recommends the users adjust irrigation for the equivalent irrigation duration. This feature was added to the Peach app in 2021. This is the reason why a pronounced water use difference was observed between the peach app and the sensor-based irrigation method in 2021 and 2022. The peach app used only 85, 59, and 72% of what sensor-based methods used per tree in 2020, 2021, and 2022 respectively.

## Conclusion

In terms of peach irrigation, the drip irrigation system resulted in higher TCSA than the micro-sprinkler system. All other parameters were comparable and not significantly different between the irrigation systems. Considering that the drip irrigation system was providing a slightly larger amount of water than the micro-sprinkler system in this study, the difference in TCSA might have occurred. But it was also possibly the mode of action that determined the differences in terms of plant size. Regarding the irrigation method, there was no significant difference between any of the plant's physical, physiological, and chemical parameters measured. The only difference observed was in terms of the water used by the trees under each irrigation method. This implies that the peach app-based irrigation method has higher water and yield use efficiency compared to the sensor-based method. Similar to the irrigation methods, different fertilizer rates also did not have any significant difference as such. This translates that the current recommended fertilizer rate could be reduced to half without affecting the tree's health, growth, and productivity.

Improved irrigation and fertilization practices can greatly improve peach tree growth and production. SmartIrrigation peach app has been found to be a proper irrigation scheduling tool generating proper irrigation schedules for mature peach trees in Georgia. The app can be a beneficial tool for peach growers in this region. Also, fertilizer rates in this region need to be updated to a lower rate. This can save growers the money to purchase extra fertilizers as well as reduce environmental impacts due to higher fertilizer applications.

**Literature cited:**

Blaauw, B., Brannen, P., Bellinger, B., Lockwood, D., & Ritchie, D. (2023). Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide. University of Georgia Cooperative Extension, Athens, GA.

Bryla, D. R., Trout, T. J., Ayars, J. E., & Johnson, R. S. (2003). Growth and production of young peach trees irrigated by furrow, microjet, surface drip, or subsurface drip systems. *HortScience, 38(6),* 1112-1116.

Carranca, C., Brunetto, G., & Tagliavini, M. (2018). Nitrogen nutrition of fruit trees to reconcile productivity and environmental concerns. *Plants, 7(1),* 4.

Casamali, B. (2019). *Irrigation and fertilization practices for young peach trees in the southeastern United States* (Doctoral dissertation, University of Georgia).

Casamali, B., van Iersel, M. W., & Chavez, D. J. (2021a). Nitrogen Partitioning in Young "Julyprince" Peach Trees Grown with Different Irrigation and Fertilization Practices in the Southeastern United States. *Agronomy, 11(2),* 350.

Casamali, B., van Iersel, M. W., & Chavez, D. J. (2021b). Plant growth and physiological responses to improved irrigation and fertilization management for young peach trees in the southeastern United States. *HortScience, 56(3),* 336-346.

Crisosto, C. H., Johnson, R. S., Luza, J. G., & Crisosto, G. M. (1994). Irrigation regimes affect fruit soluble solids concentration and rate of water loss of O'Henry'peaches. *HortScience, 29(10),* 1169-1171.

Du, S., Kang, S., Li, F., & Du, T. (2017). Water use efficiency is improved by alternate partial root-zone irrigation of apple in arid northwest China. *Agricultural Water Management, 179*, 184-192.

Gelly, M., Recasens, I., Girona, J., Mata, M., Arbones, A., Rufat, J., & Marsal, J. (2004). Effects of stage II and postharvest deficit irrigation on peach quality during maturation and after cold storage. *Journal of the Science of Food and Agriculture, 84(6),* 561-568.

Girona, J., Gelly, M., Mata, M., Arbones, A., Rufat, J., & Marsal, J. (2005). Peach tree response to single and combined deficit irrigation regimes in deep soils. *Agricultural Water Management, 72(2),* 97-108.

Guizani, M., Dabbou, S., Maatallah, S., Montevecchi, G., Hajlaoui, H., Rezig, M., ... & Kilani-Jaziri, S. (2019). Physiological responses and fruit quality of four peach cultivars under sustained and cyclic deficit irrigation in center-west of Tunisia. *Agricultural Water Management, 217*, 81-97.

Haider, M. S., Kurjogi, M. M., Khalil-ur-Rehman, M., Pervez, T., Songtao, J., Fiaz, M., ... & Fang, J. (2018). Drought stress revealed physiological, biochemical and gene-expressional variations in 'Yoshihime'peach (Prunus Persica L) cultivar. *Journal of Plant Interactions, 13*(1), 83-90.

Kobashi, K., Gemma, H., & Iwahori, S. (2000). Abscisic acid content and sugar metabolism of peaches grown under water stress. *Journal of the American Society for Horticultural Science, 125(4),* 425-428.

Layne, D. R., Cox, D. B., & Hitzler, E. J. (2002). Peach systems trial: the influence of training system, tree density, rootstock, irrigation and fertility on growth and yield of young trees in South Carolina. *Acta Horticulturae*, 592.

Li, S. H., Huguet, J. G., Schoch, P. G., & Orlando, P. (1989). Response of peach tree growth and cropping to soil water deficit at various phenological stages of fruit development. *Journal of Horticultural Science, 64(5)*, 541-552.

Lo Bianco, R., Rieger, M., & Sung, S. J. S. (2000). Effect of drought on sorbitol and sucrose metabolism in sinks and sources of peach. *Physiologia Plantarum*, *108(1)*, 71-78.

Lopez, G., Behboudian, M. H., Vallverdu, X., Mata, M., Girona, J., & Marsal, J. (2010). Mitigation of severe water stress by fruit thinning in 'O'Henry'peach: Implications for fruit quality. *Scientia Horticulturae*, *125*(3), 294-300.

Mahhou, A., DeJong, T. M., Cao, T., & Shackel, K. S. (2005). Water stress and crop load effects on vegetative and fruit growth of 'Elegant Lady'peach [Prunus persica (L.) Batch] trees. *Fruits, 60(1),* 55-68.

Mitcham, B., Cantwell, M., & Kader, A. (1996). Methods for determining the quality of fresh commodities. *Perishables handling newsletter*, *85*, 1-5.

Rahmati, M., Davarynejad, G. H., Génard, M., Bannayan, M., Azizi, M., & Vercambre, G. (2015). Peach water relations, gas exchange, growth and shoot mortality under water deficit in semi-arid weather conditions. *PLoS One*, *10*(4), e0120246.

Thapa Magar, S., Vellidis, G., Porter, W., Liakos, V., Andreis, J.H. and Chavez, D. (2022). Development and evaluation of a SmartIrrigation Peach App in a young peach orchard. *Acta Horticulturae, 1352,* 575-582

Thakur, A., & Singh, Z. (2012). Responses of 'Spring Bright'and 'Summer Bright'nectarines to deficit irrigation: Fruit growth and concentration of sugars and organic acids. *Scientia Horticulturae*, *135*, 112-119.

U.S. Department of Agriculture, National Agricultural Statistics Survey (2022). Noncitrus Fruits and Nuts 2021 Summary. U.S. Department of Agriculture, Washington, D.C.

Vellidis, G., Tucker, M., Perry, C., Reckford, D., Butts, C., Henry, H., Liakos, V., Hill, R., and Edwards, W. (2013). A soil moisture sensor-based variable rate irrigation scheduling system. *In Precision agriculture'13*, (Springer), pp. 713-720.

Vera, J., Abrisqueta, I., Abrisqueta, J. M., & Ruiz-Sánchez, M. C. (2013). Effect of deficit irrigation on early-maturing peach tree performance. *Irrigation Science, 31*,747-757.

Zhou, Q., & Melgar, J. C. (2019). Ripening season affects tissue mineral concentration and nutrient partitioning in peach trees. *Journal of Plant Nutrition and Soil Science*, *182*(2),203-209.

Table 4.1. Effects of Irrigation systems, methods, and fertilizer rates in 2019 for a commercial and total yield of 'Julyprince' cultivar grafted onto 'Guardian' rootstock established in 2015.

| Treatments | 2019 | | | |
|---|---|---|---|---|
| | TCSA ($cm^2$) | CV ($m^3$) | Commercial Yield ($kg \cdot tree^{-1}$) | Total yield ($kg \cdot tree^{-1}$) |
| Irrigation System | | | | |
| Drip | 156.6 | 30.7 | 53.5 | 58.6 |
| Micro Sprinkler | 157.3 | 28.7 | 50.4 | 56.7 |
| | | | | |
| Irrigation Method[s] | | | | |
| App | 147.5 | 29.7 | 44.3 b[y] | 49.0 b |
| Sensor | 166.5 | 29.772 | 59.7 a | 66.3 a |
| | | | | |
| Fertilizer | | | | |
| 50% | 159.7 | 29.5 | 52.2 | 57.9 |
| 100% | 154.2 | 29.9 | 51.8 | 57.4 |
| | | | | |
| *P-value* | | | | |
| Irrigation system | 0.957 | 0.336 | 0.507 | 0.680 |
| Irrigation Method | 0.159 | 0.975 | **0.003**[x] | **0.001** |
| Fertilizer | 0.675 | 0.841 | 0.940 | 0.911 |
| Irrigation system × Irrigation method | 0.711 | 0.269 | 0.559 | 0.436 |
| Irrigation system × Fertilizer | 0.180 | 0.101 | 0.460 | 0.441 |
| Irrigation method × Fertilizer | 0.619 | 0.694 | 0.768 | 0.832 |
| Irrigation system × Irrigation method x Fertilizer | 0.718 | 0.935 | 0.315 | 0.480 |

[z]Prior 2019 app-based irrigated trees corresponded to non-irrigated trees. Sensor-based trees were the same as irrigated trees.
[y]Means followed by different letters within a treatment indicate a significant difference, $P \leq 0.05$.
[x]Bold values indicate significant *P* values and a confidence interval of 95%.

Table 4.2. Effects of Irrigation systems, methods, and fertilizer rates on plant size, Trunk cross-sectional area (TCSA) and Canopy volume (CV), and total yield of ‘Julyprince’ cultivar grafted onto ‘Guardian’ rootstocks in 2020, 2021, and 2022.

| Treatments | TCSA ($cm^2$) | | | CV ($m^3$) | | | Total yield ($kg \cdot tree^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| Irrigation system | | | | | | | | | |
| Drip | 192.6 | 231.4 a[z] | 258.2 a | 22.8 | 31.8 | 24.5 | 68.0 | 39.9 | 51.8 |
| Sprinkler | 175.3 | 200.5 b | 233.0 b | 23.8 | 29.1 | 22.4 | 56.9 | 51.1 | 49.3 |
| Irrigation Method | | | | | | | | | |
| App | 182.5 | 216.8 | 240.1 | 22.4 | 29.8 | 22.6 | 64.3 | 45.3 | 50.7 |
| Sensor | 185.6 | 215.7 | 251.4 | 24.2 | 31.1 | 24.3 | 60.9 | 45.6 | 50.5 |
| Fertilizer | | | | | | | | | |
| 50% | 179.8 | 211.3 | 243.5 | 22.2 b | 30.6 | 24.1 | 65.6 | 44.4 | 55.0 a |
| 100% | 188.3 | 221.0 | 248.0 | 24.3 a | 30.4 | 22.9 | 59.6 | 46.4 | 46.3 b |
| *P-value* | | | | | | | | | |
| Irrigation system | 0.051 | **0.025**[y] | **0.040** | 0.339 | 0.084 | 0.084 | 0.830 | 0.052 | 0.538 |
| Irrigation Method | 0.664 | 0.993 | 0.321 | 0.063 | 0.377 | 0.173 | 0.413 | 0.934 | 0.991 |
| Fertilizer | 0.310 | 0.439 | 0.648 | **0.035** | 0.952 | 0.408 | 0.337 | 0.700 | **0.043** |
| Irrigation system × Irrigation method | 0.335 | 0.815 | 0.449 | 0.166 | 0.691 | 0.563 | 0.832 | 0.253 | 0.541 |
| Irrigation system × Fertilizer | **0.034** | 0.073 | 0.058 | **0.026** | 0.346 | 0.421 | 0.932 | 0.148 | 0.547 |
| Irrigation method × Fertilizer | 0.246 | 0.432 | 0.516 | 0.066 | 0.989 | 0.195 | 0.777 | 0.271 | 0.384 |
| Irrigation system × Irrigation method × Fertilizer | 0.723 | 0.739 | 0.527 | 0.936 | 0.729 | 0.771 | 0.291 | 0.891 | 0.575 |

[z]Means followed by different letters within a treatment indicate a significant difference, $P \leq 0.05$.
[y]Bold values indicate significant *P* values and a confidence interval of 95%.

Table 4.3. Effect of irrigation systems, methods, and fertilizer rates on stem water potential of 'Julyprince' cultivar grafted onto 'Guardian' rootstocks in 2020, 2021, and 2022.

| **Treatments** | **Stem water potential (MPa)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **2020** | | | **2021** | | | | **2022** | |
| | **July** | **Sep** | **Oct** | **May** | **June** | **July** | **Sep** | **July** | **Sep** |
| **Irrigation system** | | | | | | | | | |
| Drip | -0.63 | -0.59 | -0.65 | -0.63 | -0.66 b[z] | -0.81 | -0.75 b | -1.03 | -0.84 |
| Micro-Sprinkler | -0.66 | -0.54 | -0.66 | -0.69 | -0.72 a | -0.87 | -0.91 a | -1.09 | -0.89 |
| **Irrigation Method** | | | | | | | | | |
| App | -0.65 | -0.54 | -0.65 | -0.67 | -0.71 | -0.88 | -0.82 | -1.03 | -0.85 |
| Sensor | -0.64 | -0.59 | -0.66 | -0.65 | -0.67 | -0.80 | -0.84 | -1.09 | -0.89 |
| **Fertilizer** | | | | | | | | | |
| 50% | -0.68 | -0.57 | -0.65 | -0.64 | -0.65 b | -0.85 | -0.85 | -1.06 | -0.88 |
| 100% | -0.61 | -0.57 | -0.66 | -0.68 | -0.72 a | -0.83 | -0.81 | -1.06 | -0.86 |
| *P-value* | | | | | | | | | |
| Irrigation system | 0.570 | 0.229 | 0.927 | 0.067 | **0.048**[y] | 0.174 | **<.0001** | 0.496 | 0.518 |
| Irrigation Method | 0.900 | 0.402 | 0.652 | 0.502 | 0.252 | 0.088 | 0.934 | 0.521 | 0.505 |
| Fertilizer | 0.076 | 0.892 | 0.920 | 0.200 | **0.042** | 0.522 | 0.143 | 0.906 | 0.397 |
| Irrigation system × Irrigation method | 0.308 | 0.480 | 0.192 | 0.400 | 0.594 | 0.387 | 0.732 | 0.296 | 0.690 |
| Irrigation system × Fertilizer | 0.377 | 0.212 | 0.374 | 0.706 | 0.738 | 0.642 | 0.215 | 0.441 | 0.414 |
| Irrigation method × Fertilizer | 0.673 | 0.133 | 0.901 | 0.762 | 0.265 | 0.122 | 0.524 | 0.898 | 0.223 |
| Irrigation system × Irrigation method × Fertilizer | 0.562 | 0.480 | 0.518 | 0.117 | 0.611 | 0.853 | 0.278 | 0.037 | 0.203 |

[z]Means followed by different letters within a treatment indicate a significant difference, $P \leq 0.05$.
[y]Bold values indicate significant *P* values and a confidence interval of 95%.

Table 4.4. Effects of irrigation systems, methods, and fertilizer rates on photosynthetic assimilation of 'Julyprince' cultivar grafted onto 'Guardian' rootstock in 2020, 2021, and 2022.

| **Treatments** | **Photosynthetic assimilation (μmol $CO_2 m^{-2} s^{-1}$)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **2020** | | | **2021** | | | **2022** | |
| | **June** | **Aug** | **Sep** | **May** | **July** | **Sep** | **July** | **Sep** |
| **Irrigation system** | | | | | | | | |
| Drip | 15.68 | 17.06 | 13.61 | 8.51 | 9.83 | 14.04 | 14.52 a[z] | 14.28 |
| Micro-Sprinkler | 14.88 | 15.78 | 13.93 | 8.47 | 9.2 | 12.43 | 12.68 b | 13.21 |
| **Irrigation Method** | | | | | | | | |
| App | 15.5 | 15.93 | 13.85 | 8.18 | 10.09 | 13.35 | 13.64 | 13.89 |
| Sensor | 15.32 | 16.92 | 13.69 | 8.79 | 8.98 | 13.15 | 13.59 | 13.63 |
| **Fertilizer** | | | | | | | | |
| 50% | 15.60 | 16.25 | 13.62 | 8.90 | 9.57 | 13.61 | 13.87 | 13.82 |
| 100% | 14.98 | 16.61 | 13.91 | 8.09 | 9.47 | 12.89 | 13.37 | 13.69 |
| *P-value* | | | | | | | | |
| Irrigation system | 0.300 | 0.100 | 0.695 | 0.941 | 0.473 | 0.067 | **0.008**[y] | 0.153 |
| Irrigation Method | 0.887 | 0.191 | 0.853 | 0.247 | 0.182 | 0.988 | 0.983 | 0.726 |
| Fertilizer | 0.451 | 0.584 | 0.738 | 0.217 | 0.890 | 0.546 | 0.493 | 0.851 |
| Irrigation system × Irrigation method | 0.191 | 0.929 | 0.638 | 0.279 | 0.193 | 0.558 | 0.856 | 0.489 |
| Irrigation system × Fertilizer | 0.437 | 0.152 | 0.094 | 0.870 | 0.437 | 0.829 | 0.591 | 0.753 |
| Irrigation method × Fertilizer | 0.117 | 0.384 | 0.126 | **0.041** | 0.735 | 0.504 | 0.146 | 0.530 |
| Irrigation system × Irrigation method × Fertilizer | 0.532 | 0.895 | 0.830 | 0.768 | 0.945 | 0.484 | 0.572 | 0.496 |

[z]Means followed by different letters within a treatment indicate a significant difference, $P \leq 0.05$.
[y]Bold values indicate significant $P$ values and a confidence interval of 95%.

Table 4.5. Effects of irrigation systems, methods, and fertilizer rates on water use efficiency (photosynthetic assimilation/transpiration), measured by LiCOR 6400, of 'Julyprince' cultivar grafted onto 'Guardian' rootstock in 2020, 2021, and 2022.

| **Treatments** | **Water Use Efficiency (mmol.mol$^{-1}$)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **2020** | | | **2021** | | | **2022** | |
| | **June** | **Aug** | **Sep** | **May** | **July** | **Sep** | **July** | **Sep** |
| **Irrigation system** | | | | | | | | |
| Drip | 2.81 | 2.64 | 3.91 | 1.97 | 2.13 | 3.73 | 3.33 | 3.63 a[z] |
| Micro-Sprinkler | 2.88 | 2.60 | 3.87 | 2.03 | 1.93 | 3.94 | 3.40 | 3.13 b |
| **Irrigation Method** | | | | | | | | |
| App | 2.82 | 2.68 | 3.91 | 2.03 | 2.14 | 3.80 | 3.36 | 3.39 |
| Sensor | 2.87 | 2.57 | 3.87 | 1.96 | 1.92 | 3.87 | 3.37 | 3.38 |
| **Fertilizer** | | | | | | | | |
| 50% | 2.86 | 2.64 | 3.86 | 2.03 | 2.04 | 3.78 | 3.31 | 3.35 |
| 100% | 2.83 | 2.60 | 3.91 | 1.97 | 2.02 | 3.89 | 3.43 | 3.42 |
| *P-value* | | | | | | | | |
| Irrigation system | 0.206 | 0.174 | 0.765 | 0.559 | 0.480 | 0.769 | 0.962 | **0.003**[y] |
| Irrigation Method | 0.434 | 0.555 | 0.857 | 0.688 | 0.304 | 0.559 | 0.903 | 0.987 |
| Fertilizer | 0.591 | 0.709 | 0.712 | 0.570 | 0.873 | 0.270 | 0.623 | 0.610 |
| Irrigation system × Irrigation method | 0.796 | 0.737 | 0.307 | 0.237 | 0.742 | 0.635 | 0.824 | 0.851 |
| Irrigation system × Fertilizer | 0.333 | 0.789 | 0.510 | 0.701 | 0.757 | 0.825 | 0.458 | 0.590 |
| Irrigation method × Fertilizer | **0.018** | 0.574 | 0.182 | 0.100 | 0.341 | 0.918 | 0.681 | 0.083 |
| Irrigation system ×Irrigation method × Fertilizer | 0.838 | 0.902 | 0.258 | 0.227 | 0.833 | 0.418 | 0.480 | 0.766 |

[z]Means followed by different letters within a treatment indicate a significant difference, $P \leq 0.05$.

[y]Bold values indicate significant $P$ values and a confidence interval of 95%.

Table 4.6: Effects of irrigation systems, methods, and fertilizer rates on fruit weight and perimeter of the 'Julyprince' cultivar grafted onto 'Guardian' rootstock in 2020, 2021, and 2022.

| Treatments | Average Fruit Wt. (g) | | | Average Fruit Perimeter (mm) | | |
|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **Irrigation system** | | | | | | |
| Drip | 256.87 b[z] | 229.74 b | 252.71 a | 80.50 b | 78.65 b | 78.60 a |
| Micro-Sprinkler | 276.63 a | 257 a | 214.42 b | 82.84 a | 82.62 a | 73.20 b |
| **Irrigation Method** | | | | | | |
| App | 272.22 | 243.09 | 229.21 | 81.36 | 80.37 | 75.34 |
| Sensor | 261.15 | 243.22 | 238.38 | 81.94 | 80.83 | 76.53 |
| **Fertilizer** | | | | | | |
| 50% | 267.73 | 241.81 | 240.96 | 81.35 | 80.20 | 77.07 |
| 100% | 265.49 | 244.46 | 226.99 | 81.95 | 80.99 | 74.85 |
| *P-value* | | | | | | |
| Irrigation system | **0.016**[y] | **0.002** | **<.0001** | **0.010** | **0.001** | **<.0001** |
| Irrigation Method | 0.226 | 0.496 | 0.292 | 0.470 | 0.618 | 0.258 |
| Fertilizer rate | 0.773 | 0.330 | 0.153 | 0.455 | 0.532 | 0.075 |
| Irrigation system × Irrigation method | 0.354 | 0.714 | 0.831 | 0.540 | 0.440 | 0.645 |
| Irrigation system × Fertilizer | 0.193 | 0.106 | 0.673 | 0.854 | **0.045** | 0.594 |
| Irrigation method × Fertilizer | 0.163 | 0.415 | 0.519 | 0.423 | 0.342 | 0.425 |
| Irrigation system × Irrigation method × Fertilizer | 0.125 | 0.461 | 0.632 | 0.152 | 0.936 | 0.771 |

[z]Means followed by different letters within a treatment indicate a significant difference, $P \leq 0.05$.

[y]Bold values indicate significant *P* values and a confidence interval of 95%.

Table 4.7. Effects of irrigation systems, methods, and fertilizer rates on soluble solids concentration (SSC), total titratable acidity (TTA), and SSC/TTA of 'Julyprince' cultivar grafted onto 'Guardian' rootstock in 2020, 2021, and 2022.

| Treatments | SSC (°Brix) | | | TTA (% Malic acid) | | | SSC/TTA | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **Irrigation system** | | | | | | | | | |
| Drip | 8.12 b[z] | 9.48 | 10.42 b | 0.66 | 0.62 a | 0.67 | 12.35 | 15.46 b | 15.52 |
| Micro-Sprinkler | 8.48 a | 9.56 | 11.03 a | 0.66 | 0.59 b | 0.70 | 12.88 | 16.55 a | 15.8 |
| **Irrigation Method** | | | | | | | | | |
| App | 8.41 | 9.34 b | 10.68 | 0.67 | 0.60 | 0.70 | 12.69 | 15.77 | 15.34 |
| Sensor | 8.18 | 9.70 a | 10.74 | 0.66 | 0.61 | 0.68 | 12.54 | 16.21 | 15.94 |
| **Fertilizer** | | | | | | | | | |
| 50% | 8.33 | 9.46 | 10.52 | 0.65 | 0.59 | 0.69 | 12.92 a | 16.25 | 15.42 |
| 100% | 8.26 | 9.58 | 10.93 | 0.67 | 0.61 | 0.69 | 12.31 b | 15.75 | 15.91 |
| *P-value* | | | | | | | | | |
| Irrigation system | **0.021**[y] | 0.655 | **0.049** | 0.790 | **0.048** | 0.122 | 0.072 | **0.023** | 0.752 |
| Irrigation Method | 0.133 | **0.044** | 0.858 | 0.351 | 0.561 | 0.202 | 0.668 | 0.977 | 0.183 |
| Fertilizer | 0.644 | 0.491 | 0.215 | 0.094 | 0.257 | 0.801 | **0.041** | 0.886 | 0.435 |
| Irrigation system x Irrigation method | 0.674 | 0.697 | 0.198 | 0.833 | 0.346 | 0.429 | 0.813 | 0.914 | 0.632 |
| Irrigation system x Fertilizer | 0.472 | 0.707 | 0.245 | 0.221 | 0.802 | 0.377 | 0.566 | 0.495 | 0.973 |
| Irrigation method x Fertilizer | 0.478 | 0.967 | 0.339 | 0.812 | 0.304 | 0.480 | 0.393 | 0.211 | 0.866 |
| Irrigation system x Irrigation method x Fertilizer | 0.091 | 0.972 | 0.064 | 0.098 | 0.402 | 0.324 | 0.738 | 0.465 | **0.013** |

[z]Means followed by different letters within a treatment indicate a significant difference, $P \leq 0.05$.
[y]Bold values indicate significant *P* values and a confidence interval of 95%.

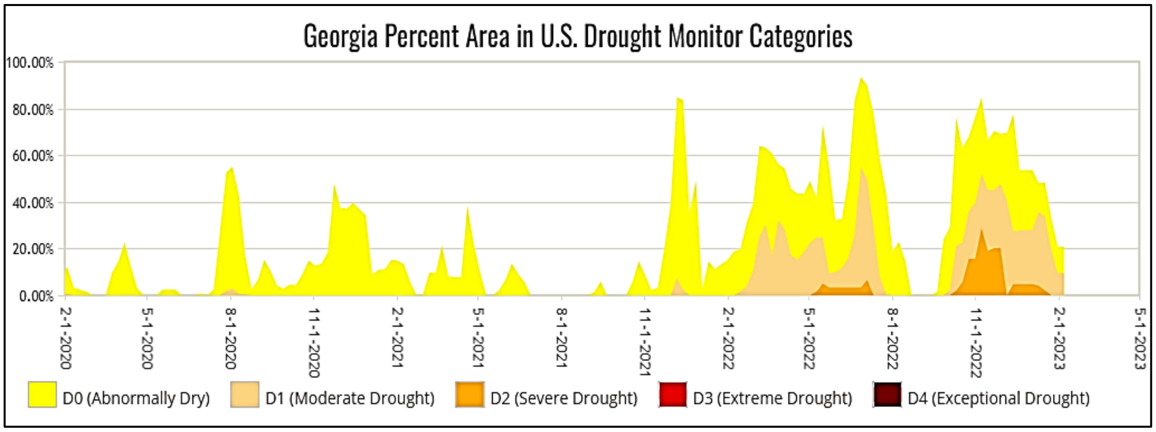



Figure 4.1. Time series of drought status for the state of Georgia indicating moderate to severe drought since 2020 (Source: U.S. Drought Monitor, 2023; https://droughtmonitor.unl.edu/ ).

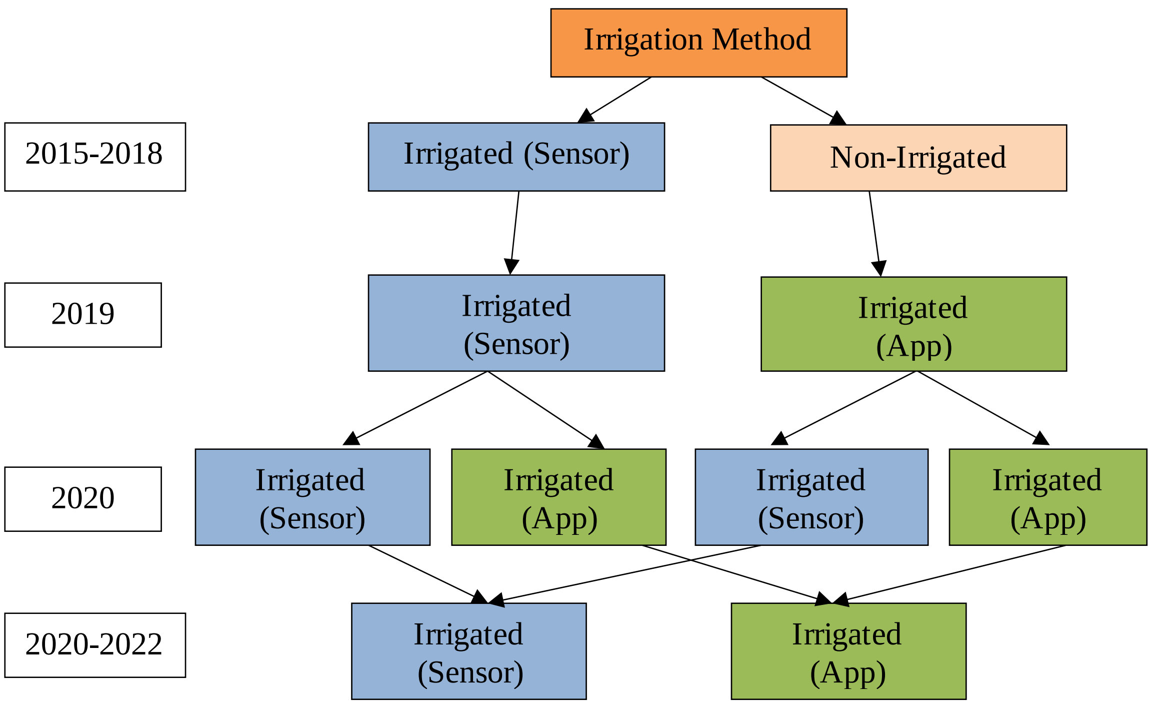



Figure 4.2. Flow chart of irrigation methods treatment followed from 2015 to 2022, indicating how irrigation methods were modified to repurpose research needs over years.

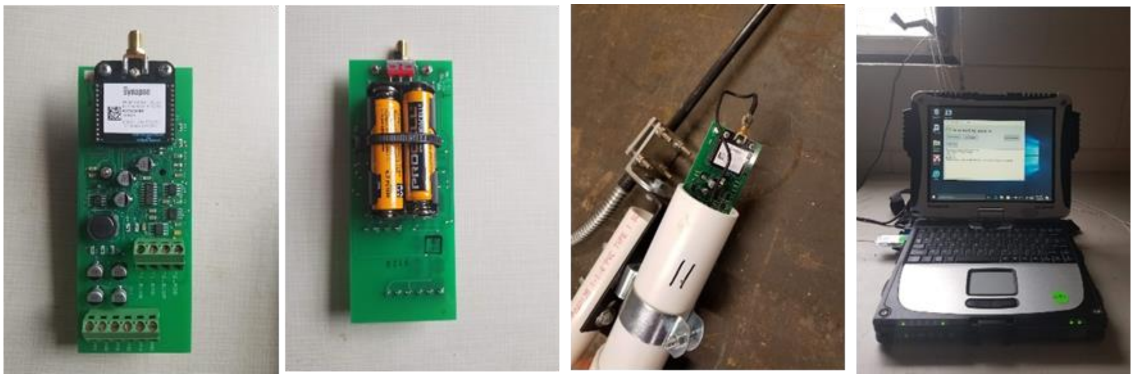


Figure 4.3. A circuit board with a radio transmitter and two AA batteries placed inside a protective PVC coating and the base station that receives and stores all the soil moisture data transferred by the soil moisture sensors through a wireless mesh network in UGA Smart Sensor Array (UGA SSA).

Figure 4.4. Demonstration of UGA SSA with a smart sensor node (with 3 Watermark Sensors at the depth of 20, 40, and 60 cm), its total configuration with the antenna used for wireless mesh networking among sensors and the base station, the installation process and final setup in the experimental plot, located in UGA Peach Research and Extension Farm, Griffin Georgia.

| | | DRIP | | | | | | | | SPRINKLER | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BLOCK 1 | 1 | 8.3 | 1.2 | 2.2 | 3.4 | 1.1 | 3.2 | 6.3 | 6.4 | 8.4 | 3.1 | 6.4 | 2.1 | 7.2 | 6.1 | 4.1 | 1.1 |
| | 2 | 3.1 | 5.4 | 7.3 | 8.2 | 2.4 | 6.2 | 2.1 | 7.2 | 8.2 | 4.4 | 2.2 | 8.3 | 5.4 | 7.4 | 4.2 | 3.4 |
| | 3 | 3.3 | 8.4 | 6.1 | 1.3 | 5.3 | 7.1 | 7.4 | 5.2 | 3.2 | 5.2 | 6.3 | 7.1 | 1.3 | 4.3 | 1.2 | 5.3 |
| | 4 | 4.2 | 5.1 | 4.4 | 2.3 | 8.1 | 4.1 | 1.4 | 4.3 | 3.3 | 2.4 | 8.1 | 6.2 | 7.3 | 1.4 | 5.1 | 2.3 |
| BLOCK 2 | 5 | 3.3 | 2.3 | 2.1 | 8.3 | 1.1 | 6.2 | 1.4 | 5.3 | 7.3 | 6.3 | 6.1 | 7.1 | 8.3 | 6.2 | 8.2 | 1.2 |
| | 6 | 6.4 | 8.4 | 7.3 | 3.4 | 7.4 | 7.2 | 1.3 | 1.2 | 2.3 | 2.4 | 7.2 | 3.2 | 8.4 | 3.3 | 5.3 | 3.4 |
| | 7 | 4.4 | 3.2 | 6.3 | 2.4 | 8.2 | 5.2 | 8.1 | 5.4 | 3.1 | 4.4 | 4.3 | 4.2 | 5.2 | 1.4 | 5.1 | 2.2 |
| | 8 | 7.1 | 2.2 | 5.1 | 4.2 | 4.3 | 3.1 | 4.1 | 6.1 | 7.4 | 1.1 | 5.4 | 8.1 | 1.3 | 4.1 | 6.4 | 2.1 |
| BLOCK 3 | 9 | 8.2 | 6.4 | 7.1 | 8.3 | 6.2 | 1.1 | 3.4 | 7.3 | 3.2 | 1.2 | 7.1 | 4.1 | 3.1 | 3.3 | 6.2 | 6.1 |
| | 10 | 2.3 | 2.2 | 2.1 | 3.2 | 7.2 | 5.3 | 4.1 | 7.4 | 8.1 | 5.3 | 6.4 | 5.1 | 4.3 | 8.3 | 8.2 | 1.4 |
| | 11 | 2.4 | 4.3 | 3.3 | 6.3 | 8.4 | 5.2 | 4.2 | 4.4 | 2.4 | 7.3 | 6.3 | 8.4 | 1.1 | 3.4 | 4.4 | 2.2 |
| | 12 | 8.1 | 3.1 | 1.4 | 5.1 | 1.2 | 6.1 | 1.3 | 5.4 | 2.1 | 1.3 | 5.2 | 5.4 | 4.2 | 2.3 | 7.2 | 7.4 |
| BLOCK 4 | 13 | 5.3 | 1.1 | 2.3 | 8.1 | 5.1 | 6.2 | 6.3 | 7.1 | 4.2 | 8.2 | 8.1 | 6.1 | 8.3 | 6.2 | 7.3 | 2.3 |
| | 14 | 5.2 | 7.3 | 3.3 | 2.1 | 8.3 | 4.2 | 1.3 | 7.2 | 3.1 | 4.1 | 1.1 | 1.2 | 5.2 | 7.1 | 7.2 | 5.1 |
| | 15 | 6.1 | 1.2 | 2.2 | 4.1 | 3.1 | 8.2 | 3.2 | 4.3 | 2.2 | 3.3 | 4.3 | 3.2 | 5.3 | 1.3 | 2.1 | 6.3 |

| Combination | Fertilizer | Irrigation Method |
|---|---|---|
| Plants initiating with 1,2,5 and 6 | 50 | Sensor-based (Brown/Blue) |
| Plants initiating with 1,2,5 and 6 | 100 | Sensor-based (Brown/Blue) |
| Plants initiating with 3,4, 7 and 8 | 50 | App-based (Red/Purple) |
| Plants initiating with 3,4, 7 and 8 | 100 | App-based (Red/Purple) |

Figure 4.5 Split-split plot randomized complete block experimental design of the research plot from 2020-2022 with first split for irrigation system and second split for fertilizer rates. Each block had one replicate of irrigation systems (Drip vs. Micro-sprinkler), two replicates of fertilizer rates (50% vs. 100%), and eight replicates of irrigation methodologies (Peach app vs. Sensor-based method).✦ indicates the sensor placement within the plot.

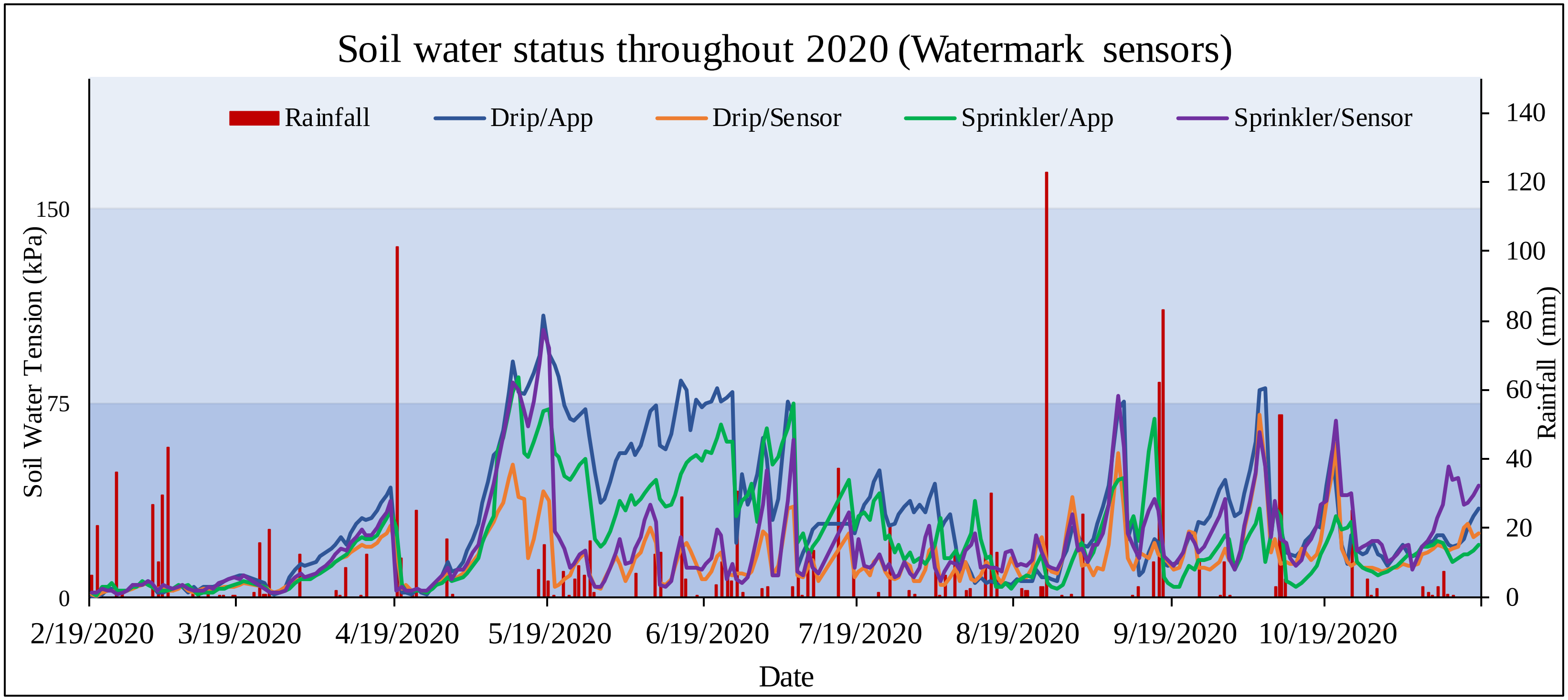



Figure 4.6. Soil water tension (SWT), measured in kPa, indicates the soil moisture level in 2020 for different combinations of irrigation systems (drip and micro-sprinkler) with different irrigation methods (peach app and sensor-based). Rainfall events, measured in mm, are represented by vertical red bars. UGA SSA was installed in the second week of February 2020. April 21 was the date when supplemental irrigation started until November 11. Irrigation was turned off after this point as freezing temperatures approached, and trees entered the dormant stage. Values are the average of four UGA SSA, each with three watermark sensors at the depth of 20, 40, and 60 cm. The weighted average of each sensor [(50% of the sensor at 20 cm) + (30% of the sensor at 40 cm) + (20% of the sensor at 60 cm)] was considered for irrigation recommendations.

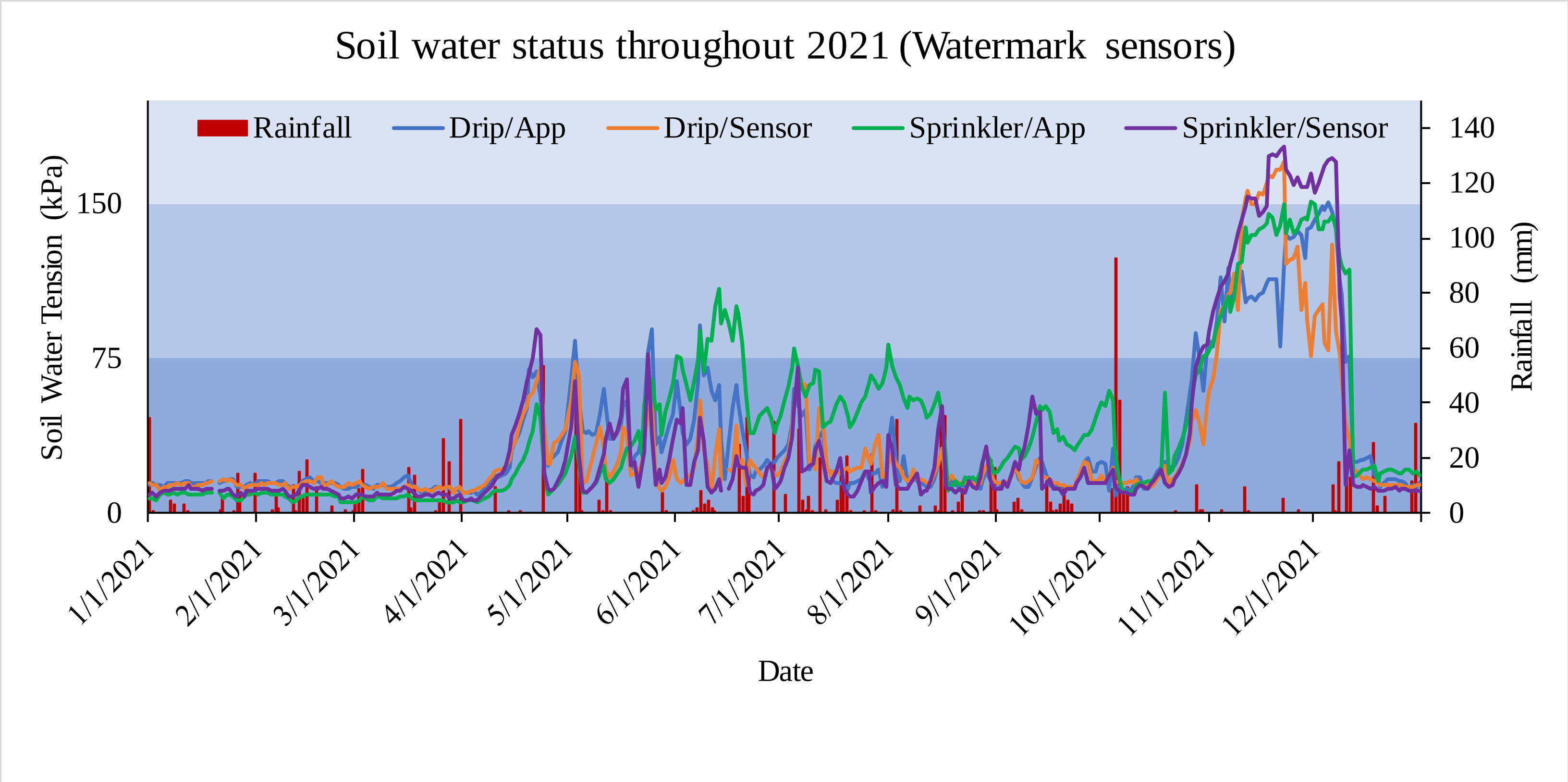



Figure 4.7. Soil water tension (SWT), measured in kPa, indicates the soil moisture level in 2021 for different combinations of irrigation systems (drip and micro-sprinkler) with different irrigation methods (peach app and sensor-based). Rainfall events, measured in mm, are represented by vertical red bars. April 27 was the date when supplemental irrigation started until October 20. Irrigation was turned off after this point as freezing temperatures approached, and trees entered the dormant stage. Moderate to severe drought occurred in December 2021 as indicated by the sensor values as well. Values are the average of four UGA SSA, each with three watermark sensors at the depth of 20, 40, and 60 cm. The weighted average of each sensor [(50% of the sensor at 20 cm) + (30% of the sensor at 40 cm) + (20% of the sensor at 60 cm)] was considered for irrigation recommendations.

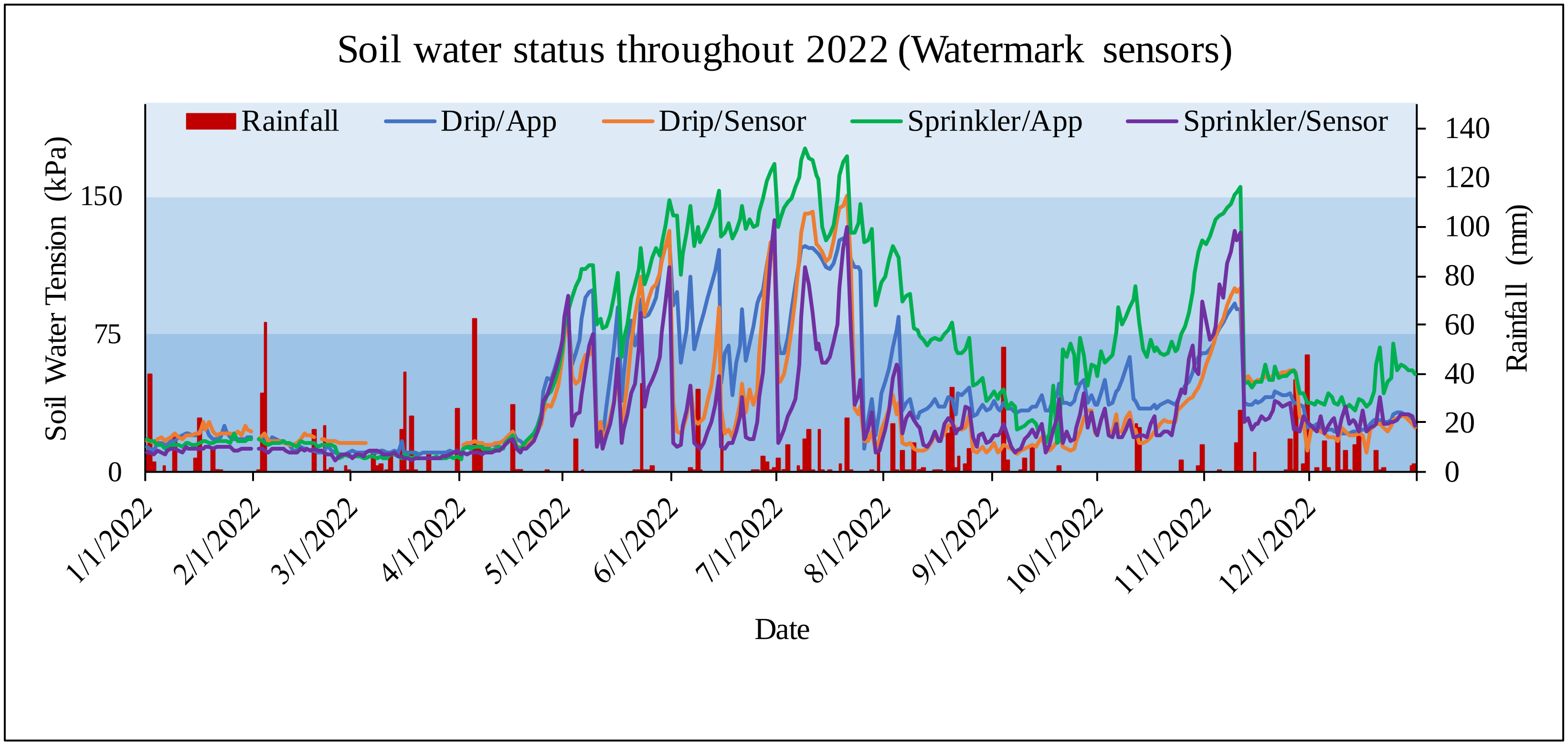



Figure 4.8. Soil water tension (SWT), measured in kPa, indicates the soil moisture level in 2022 for different combinations of irrigation systems (drip and micro-sprinkler) with different irrigation methods (peach app and sensor-based). Rainfall events, measured in mm, are represented by vertical red bars. May 2 was the date when supplemental irrigation started until October 20. Irrigation was turned off after this point as freezing temperatures approached, and trees entered the dormant stage. Moderate to severe drought occurred from April until August and again in October 2022 as indicated by the sensor values as well. Values are the average of four UGA SSA, each with three watermark sensors at the depth of 20, 40, and 60 cm. The weighted average of each sensor [(50% of the sensor at 20 cm) + (30% of the sensor at 40 cm) + (20% of the sensor at 60 cm)] was considered for irrigation recommendations.

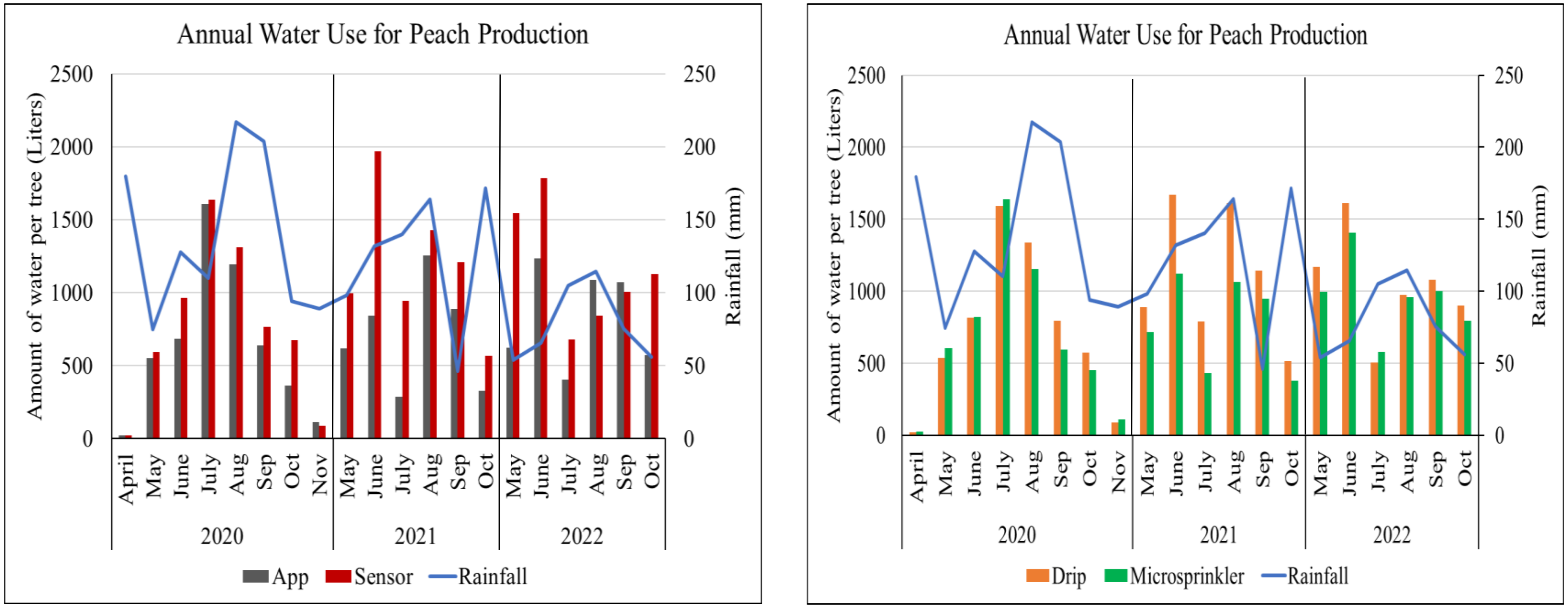



Figure 4.9. Irrigation records (liters per tree) for a mature orchard established in 2015 of 'Julyprince' grafted onto 'Guardian' at the University of Georgia Peach Research orchard in Griffin, GA. A) SmartIrrigation vs. sensor-based irrigation and B) Drip vs. micro-sprinkler irrigation.

CHAPTER 5

# NUTRIENT PROFILES OF A YOUNG AND A MATURE PEACH ORCHARD UNDER DIFFERENT IRRIGATION SCHEDULING AND FERTILIZATION TREATMENTS

[1]Thapa Magar, S, G. Vellidis, V. Liakos, D.J. Chavez. To be submitted to ***Agronomy.***

**Abstract**

Different irrigation and fertilization management guidelines have been evaluated in Georgia peach production in the last few years. However, only a few have included thoughtful consideration of the nutrient profile effect of these treatments. It is important to understand their impact on nutrient uptake and distribution patterns in peach trees to ensure proper fertilization and resource optimization. In this study, we evaluated the nutrient profile of young and mature peach trees in soil, leaf, and fruit nutrient levels in two different experimental plots at the Peach Research and Extension Orchard in Griffin, GA. The young peach orchard consisted of 'Julyprince' grafted onto two rootstocks: 'Guardian' and 'MP-29'; and three irrigation methods: SmartIrrigation Peach app, sensor-based, and no-irrigation. The mature orchard consisted of two irrigation methods: SmartIrrigation Peach app and sensor-based; two irrigation systems: drip and micro-sprinkler; and two fertilizer rates: 50 and 100% of the current recommended annual rate. Soil samples were collected and analyzed for all nutrients, pH, and CEC at 0-20 cm depth in March. Leaf and fruit samples were collected and analyzed in June and July, respectively. The overall nutrient analyses of soil, leaf, and fruit indicated significant differences across the years. Soil nutrient analyses indicated the soil pH value below 6.0 for the young orchard but 6.5 for the mature orchard. In terms of the rootstock's comparison, the nutrient concentration varied greatly, mainly in the leaf. While Mg, Ca, and B concentrations in the leaf were higher in 'Guardian'; P, K, Zn, Mn, and Cu concentrations were higher in 'MP-29'. The irrigation improved nutrient uptake in young peach trees. The drip irrigation system in the mature orchard enhanced higher nutrient uptake and distribution in leaves and fruits. The

current recommended fertilizer rate resulted in lower soil pH but did not necessarily promote nutrient uptake or distribution compared to half this rate. Our results provided insight into how modern irrigation and fertilization practices affect the nutritional status of peach trees in Georgia. This can be useful in determining the nutrient deficiencies and thereafter modifying the management practices to meet the nutrient requirements of peach trees.

**Keywords**: *Prunus persica*; nutrients, nutrient uptake, nutrient distribution; young peach trees, mature peach trees, nutrient balance, peach app, rootstocks

**Introduction**

Peach (*Prunus persica* L.) is an economically important tree fruit in Georgia. Georgia peach production accounts for ~10,000 acres, contributing to a $36 million farm gate value (USDA-NASS, 2021). Georgia's soil and weather conditions are favorable for peach production, but growers are adapting to modern technologies to increase their productivity. These modern technologies include improved irrigation, fertilization, dwarfing rootstocks, pesticide/herbicide spray, new scion cultivar trials, etc. As these technologies impact plant growth and development, they will likely affect the way these plants absorb nutrients from the soil and allocate those nutrients to different plant parts (Shah and Shahzad, 2008). Plants, in order to support their vigor, absorb nutrients at a much faster rate, leading to nutrient deficiencies at the latter stages. For a perennial fruit crop like the peach, effective nutrient management is thus of high importance to maintain tree nutrient balance to maximize resource-use efficiency and improve crop health, productivity, and fruit quality. It is thus important to understand the nutrient distribution in fruit crops with respect to the management practices adopted in order to avoid nutrient deficiency.

Peach trees are perennial woody plants and have two basic cycles: annual cycle and life cycle (Zhang et al., 2021). The annual cycle refers to the period within a year where the peach tree goes through dormancy, active vegetative phase, reproductive phase, and back to dormancy. Each phase has its nutrient requirements to support the plant's physiological processes. Proper irrigation and fertilization management at the right timing thus play a crucial role in nutrient uptake and distribution. Optimal irrigation helps maintain soil moisture, ensures nutrient availability and movement in the root zone, and assists in the nutrient application (fertigation). Plants primarily obtain macronutrients from the soil through mass flow from the soil solution, which occurs in response to transpiration. Therefore, even if nutrients are abundant in the soil, a lack of water can limit nutrient uptake. This has been supported by Casamali et al. (2021a), who found that irrigated trees removed more nitrogen than non-irrigated trees when evaluating summer pruning nutrient removal from leaves and branches. Over-irrigation however results in nutrient leaching and negatively affects plant growth. The application of an optimal fertilizer rate at optimal timing is equally important to ensure nutrient availability to plants. Excess fertilizer application, common in orchards (Carranca et al., 2018), does not ensure nutrient availability to plants. It instead can result in plant toxicity, nutrient losses, increased cost, and environmental pollution (Zhou and Melgar, 2020). It is important to understand the peach tree's nutritional status to determine optimal irrigation and fertilization management for efficient orchard management. However, the guidelines available for both these practices in Georgia need revisions. Casamali et al. (2021b) determined that irrigating young peach trees from the establishment enhances tree growth and also results in higher yield in Georgia. The authors also evaluated different fertilizer rates and concluded that the current fertilizer rate recommended for Georgia peach production can be cut in half, while still maintaining the same tree size and yield. Thapa Magar et al. (2022) developed a new irrigation scheduling tool, called the SmartIrrigation Peach app, hereafter described as the Peach app. The authors determined that the peach app was more water-use efficient for young peach trees compared to sensor-based irrigation. With the advent of these new irrigation and fertilizer management practices for Georgia and the Southeastern U.S., likely to be adopted by the growers, it is important to check their effect on the nutrient uptake, distribution, and allocation in the young and mature peach trees.

Besides, irrigation and fertilization, nutrient distribution can be affected by other factors such as tree age, scion and rootstock cultivars, soil type, environmental conditions, etc. Zhou and Melgar (2020) discovered that the age of a peach tree determined how nutrients were distributed in the tree's aboveground organs. Specifically, mature 6-year-old peach trees allocated more nutrients to pruned wood and fruit than to leaves compared to 20-year-old trees. Similar results were reported in pears, where N fertilization had a greater impact on leaf growth in young trees compared to mature trees (Sanchez et al., 1992; Quartieri et al., 2002). Furthermore, Carranca et al. (2018) found that young non-fruiting trees had different nutrient uptake patterns and requirements than mature trees because mature trees have a larger storage pool and, thus, higher nutrient resorption, storage, and remobilization. Policarpo et al. (2002) researched the distribution of nitrogen in early and late-maturing peach cultivars and found that leaves were the main nitrogen sink throughout the growing season. Başar (2006) compared the leaf and fruit nutrients in three different peach cultivars (Redhaven, Glohaven, and J.H. Hale) and found significant differences in terms of leaf nutrient concentrations (N, Ca, Mg, Fe, Mn, and Zn), however, the nutrient concentrations in fruit flesh and peel were similar among cultivars. He also identified the presence of deficiency for some of the nutrients such as N, K, Fe, and Zn in the leaf and N and K deficiency in fruit. Shah et al. (2013) indicated that abundant soil nutrients do not translate to optimal nutrient translocation in plants. Soil test results, mainly the top 30 cm, do not properly represent the nutrient availability in perennial trees since most of the roots are at a greater depth than that (Heckman, 2001). In summary, various factors can result in a nutrient imbalance and ultimately lead to nutrient deficiency in plants. A proper evaluation of nutrient distribution in soil and plant itself can help identify a such deficiency.

The objective of this study was to compare the nutrient levels of a young and a mature peach orchard at the soil, leaf, and fruit levels, considering the newly updated irrigation and fertilization practices in Georgia (Casamali et al., 2021a and 2021b, Thapa Magar et al. 2022). The results of this study can be useful in optimizing water and nutrient management for peach production in Georgia and the Southeastern U.S. by providing insight into the impact of these practices on peach tree nutrition at different plant levels.

## MATERIALS AND METHODS

### *Plant Material and Field Conditions*

This study was conducted in two different orchards, a young peach orchard established in 2020 and a mature peach orchard established in 2015, both located at the University of Georgia Peach Research and Extension Orchard in Griffin, Georgia, USA. Both orchards were planted in a Cecil sandy loam soil. A commercial cultivar ‘Julyprince’ grafted onto ‘Guardian’ and ‘MP-29’ rootstocks was used in the young orchard and only ‘Julyprince’ grafted onto ‘Guardian’ rootstock in the mature orchard, both planted at a density of 4.5 m × 6 m (358 trees per ha). ‘Julyprince’ is a commercial peach cultivar widely grown in Georgia. ‘Guardian’ is a standard rootstock in the Southeast, known for its vigor and disease resistance/tolerance. It is however susceptible to Armillaria root rot (ARR), a devastating disease resulting in tree mortality. ‘MP’-29’ is a semi-dwarf rootstock that is known to be resistant to ARR. It was released in 2012 and its use in commercial production continues to increase. The orchard management practices followed were as recommended by the Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide (Blaauw et al., 2023).

### *Experimental Design*

#### i. *Young Orchard*

The experimental design of this plot was a split-plot randomized complete block design with rootstock as the main plot. There were two main treatment levels: (1) Rootstocks (Guardian and MP-29); and (2) Irrigation methods (app, control, and sensor-based). There were three blocks (reps), with each block having six treatment combinations. Each individual replicate was formed by a four-tree plot, in which the middle trees were used for data collection to avoid any border effect from adjacent treatments. A total of 36 data trees were evaluated.

The irrigation was scheduled based on recommendations from the Peach app for the app-based method and the UGA Smart Sensor Array for the sensor-based method. The control treatment lacked any supplemental irrigation besides rainfall. For fertilizer application, only 50% of the current recommended rate was applied in this plot based on Casamali et al. (2021a and 2021b) results. For the first two years, the first fertilizer application was 10.0N-10.0P-10.0K (Farmers Favorite Fertilizer; Agri-AFC, Evergreen, AL, USA) applied in March followed by two applications of 15.5N-0P-0K (Yara Live Tropicote, Yara, Tampa, FL, USA) in May and July. From the third year onward, there were only two applications, March (10.0N-10.0P-10.0K) and August (15.5N-0P-0K). 15.5N-0P-0K was a high-quality Calcium Nitrate product and included 19% Ca.

*ii. Mature Orchard*

The experimental design of this plot was a split split-plot randomized complete block design with irrigation systems (Drip and Micro-sprinkler) and fertilizer rates (50 and 100%) as main plots. There were three main treatment levels: (1) Irrigation systems (drip vs. micro-sprinkler), (2) Irrigation methods (app and sensor-based), and (3) Fertilization rates (50, 100%). There were four blocks, with each block having eight treatment combinations. There were two replicates (data trees) for each treatment combination in a block. The irrigation systems were set up to provide 30.4 $L \cdot h^{-1}$ of water per tree, covering an area of approximately 3.5 meters in diameter around the base of the trunk. The drip irrigation system utilized four emitters (SB-20 Bowsmith; Exeter, CA) spaced around 45 cm apart from each other, while the sprinkler irrigation system only used one sprinkler head (QN-08 Rain Bird; Azusa, CA) positioned about 10 cm from the trunk. For irrigation methods, the app-based method followed the recommendations from the peach app and the sensor-based method followed the recommendations of the UGA Smart Sensor Array (Vellidis et al., 2013). The trees were fertilized with either the current recommended rate (100%) or half the recommended rate (50%). There were only two applications, the first in March (10.0N-10.0P-10.0K) and the second in August (15.5N-0P-0K). 15.5N-0P-0K was a high-quality Calcium Nitrate product and included 19% Ca.

*Nutrient Analysis*

Before applying fertilizer each year in early spring, soil samples were taken using a soil probe from the top 20 cm of soil by collecting four cores per tree as far as the tree's canopy diameter from the tree trunk. These four cores were mixed together and placed into a paper bag. Afterward, the samples were dried for two days at 65 °C in a large capacity bench oven (Model 323, GRIEVE, Round Lake, IL) For leaf analysis, approximately 30 leaf samples were collected from each of the data trees following the harvest in July. The samples were taken from the mid-section of the canopy and from a current season fruiting wood (mid-way from the end). These leaves were put into a paper bag and left to dry for two days at a temperature of 65 °C. The fruit samples were gathered from each of the data trees. These individual samples were stored in grocery bags inside a cooler with ice and taken to a laboratory for size measurements. A total of ten fruit samples were utilized for the measurements, and out of these, five fruit from each data tree were quartered. Small parts of the flesh from each fruit were collected and mixed together. These mixed flesh samples were then dried for two days at 65 °C inside a 100 mL Erlenmeyer flask. Afterward, the dried samples were transferred to a paper bag. All the dried soil, leaf, and fruit samples were then sent to Waters Agricultural Laboratories in Camilla, Georgia, USA for nutrient analysis.

*Data Analysis*

This study examined all the macro- and micro-nutrients in soil, leaf, and fruit from two different orchards for 2020, 2021, and 2022. Macronutrients included Nitrogen (N), Phosphorus (P), Potassium (K), Magnesium (Mg), and Calcium (Ca), while micronutrients included Boron (B), Zinc (Zn), Manganese (Mn), Iron (Fe), and Copper (Cu). For soil nutrients, N was measured as $NO_3$-N and $NH_4$-N. The soil pH and cation exchange capacity (CEC) was also measured, with soil pH indicating the acidity or alkalinity of the soil affecting nutrient availability (Havlin et al., 2016). CEC measures the total negative charges within the soil that adsorb plant nutrient cations. The nutrient data were analyzed using SAS 9.4 (SAS Institute Inc., Cary, NC), and Tukey's Honest Significant Difference method was used to separate treatment means with a significance level of $P \leq 0.05$. The data were first compared across years to determine if there were any significant differences. If significant differences were found, the data were then analyzed within each year to determine how each treatment influenced the nutrient concentration in the soil, leaf, and fruit of young peach trees.

## RESULTS AND DISCUSSION

The plant growth aspect of the data trees in both the young and mature peach orchards was previously described in Chapters 3 and 4 respectively. For the young trees, the trees grafted onto 'Guardian' rootstock were significantly larger (57% more canopy volume and 125% more trunk cross-sectional area) than the ones grafted onto 'MP-29' rootstocks since establishment (Figures 5.1 and 5.2). The yield however was comparable between the two rootstocks, suggesting that high-density planting on 'MP-29' rootstock could result in higher productivity (Figure 5.3). In terms of the effect of the irrigation method treatments, the tree size was comparable along with the yield between app- and sensor-based irrigation (Figures 5.4 and 5.5). As for the non-irrigated trees, these started to lag in growth since establishment until eventually, they were significantly smaller than the irrigated trees (app- and sensor-based). The main difference between the irrigation methods was in terms of water used where the app-based method used less (~27 to ~55% per tree per season) than the sensor-based method in the second and third years of planting (Figure 5.6). The yield was comparable among the irrigation treatments.

In the mature plot, the plant size and yield were comparable between the app and sensor-based irrigation methods, however, the app-based system used less water compared to the sensor-based method (Figure 5.7). The trunk cross-sectional area of the trees irrigated by the drip system was significantly larger than that in the micro-sprinkler system. Between the current recommended fertilizer rate and half this rate, there were no significant differences observed in terms of plant size or yield.

The results from both experimental plots indicated that irrigating young peach trees and reducing the recommended fertilizer rates are beneficial for optimal growth and yield. It is important to determine the relationship between these plant growth parameters with the nutrient soil, leaf, and fruit status under different treatments. The results of this research are presented below.

*Soil Nutrient Profile*

The soil nutrient analysis results across three years (2020, 2021, and 2022) indicated significant differences for all the nutrients in the young orchard as well as in the mature orchard ($NO_3$ significant at $P \leq 0.1$) (Tables 5.1 and 5.2). Thus, the nutrient analysis within each year was performed to determine the nutrient status under each treatment.

Results from analysis of soil samples in the young orchard (Table 5.3) indicated that soil pH was maintained below 6.0 over years and the rootstock or irrigation method did not result in any significant difference except for the irrigation method in 2021. The soil pH in the non-irrigated treatment (control) was significantly lower than in the sensor-based treatment. CEC overall was within the optimal range of 5-10 meq per 100 g as indicated by Sonon et al. (2022). CEC was significantly lower in the app-based method compared to control and sensor in 2020 and control in 2022. Rootstock treatments produced comparable CEC over the years.

The soil pH in the mature orchard was 6.5 on average (Table 5.4). Comparatively higher Ca accumulation in the soil in mature orchards observed over years could have resulted in higher soil pH in the mature orchard compared to the young orchard (Tables 5.7

and 5.8). Soil pH was significantly higher in the micro-sprinkler system each year compared to a drip system. Contrary to soil pH, CEC was significantly higher in the drip system each year in comparison to the micro-sprinkler system (Table 5.4). Similar patterns for soil pH and CEC were observed in the results from Chapter 2 (Table 2.3). Irrigating over a long period of time leads to minerals and salt accumulation on the soil surface, increasing the soil pH over time (Smedema and Shiati, 2002). Irrigation with a micro-sprinkler system for a long duration often leads to runoff, causing nutrients, mostly nitrogen form to leach, contributing to higher soil pH. A significantly lower amount of $NH_4$ and $NO_3$ in the micro-sprinkler irrigated system as indicated in Table 5.6 in the mature peach orchard supports this statement. Soil pH was also significantly higher in the sensor-based method than the app-based method in 2020, possibly due to leaching caused by a larger water supply. But no significant differences were observed in 2021 and 2022. The current recommended fertilizer rate resulted in lower soil pH than half the recommended rate in 2020 and 2022. The use of high nitrogen-based fertilizers results in soil acidification (low soil pH) due to the release of hydrogen ions in the process of conversion of ammonium to nitrate in soil (Ge et al., 2018). There were no significant differences within irrigation methods and within fertilizer rates used for CEC data.

*iii. Macronutrients*

Overall, the soil nutrient analyses suggested that macronutrients in the soil were comparable for any rootstock with the same scion (Julyprince), or the irrigation methods used in the young peach orchard (Table 5.5 and 5.7). $NH_4$ was found to be significantly higher in the soil samples collected in the 'Guardian' rootstock treatment plants whereas

Mg was found to be significantly higher in the 'MP-29' rootstock treatment in 2021 only. The P level in soil was significantly lower in the control treatment compared to the sensor-based treatment in 2020 but the result was not consistent in other years. $NO_3$ level in 2020 was significantly higher than levels in 2021 and 2022, probably because this field was a pasture for several years before the orchard was established and soil supplemental fertilization and amendments for planting peaches were made prior to 2020. Tables 5.6 and 5.8 suggested higher macronutrient concentrations ($NH_4$, $NO_3$, and K significantly higher) in the soil under the drip system compared to a micro-sprinkler system in a mature peach orchard. A micro-sprinkler irrigation system uses more water over a period of time and distributes water broadly resulting in nutrient losses through evaporation and runoff (Bryla et al., 2003; Casamali et al., 2021b). The highly mobile soil nutrients like $NO_3$ concentration are thus lost through leaching in the micro-sprinkler system. P concentration was significantly higher in the micro-sprinkler system in 2020 and 2021. The drip irrigation system allows for slow and consistent application of water right in the plant root zone, making the nutrients readily available to the plants. Most of the macronutrients were comparable between the irrigation methods used except for Mg which was significantly higher in the sensor-based method than the app-based method. Higher Mg concentration in sensor-based method is likely related to higher soil pH in the sensor-based system (Table 5.4). The macronutrients across different fertilizer rates used were comparable (Table 5.6 and 5.8).

On comparing the soil nutrients in a young and mature peach orchard, we observed that most of the macronutrients accumulated in soil over years. In the young peach orchard, concentration of $NH_4$ and Ca increased over the years whereas the concentration of all the macronutrients except for $NO_3$ increased over years in the mature peach orchard. An increase in $NH_4$ and Ca concentration is supported by the use of fertilizer (YaraLive Tropicote) with higher concentrations of both these nutrients in the orchard. $NO_3$, being a highly mobile soil nutrient, is likely to have been lost through leaching or plant uptake over years.

*Micronutrients*

Tables 5.9 and 5.10 present the micronutrient concentrations in soil for a young and mature peach orchard over 2020, 2021, and 2022 seasons. Consistently over the years, B and Cu concentrations were significantly higher under the 'MP-29' rootstock treatment while Mn concentration was significantly higher in the 'Guardian' rootstock treatment in the young peach orchard (Table 5.9). B concentration in the control treatment was significantly higher than in the app-based treatment, inversely Zn concentration was lower in the control treatment than in the irrigated treatments. Mn, Fe, and Cu soil concentrations were not significantly different across irrigation methods.

In the mature peach orchard, Zn concentration was consistently higher in the drip system compared to the micro-sprinkler system (Table 5.10). No significant differences were observed for other soil nutrients across irrigation systems. Similarly, micronutrient concentrations when comparing the irrigation methods and fertilizer levels were not significantly different within each factor evaluated, except for B soil concentration being higher in the current recommended fertilizer rate (100%) compared to the half rate for the

2020 and 2022 seasons. Fe soil concentration in 2020 for the fertilizer 100% rate was significantly higher than half the rate, however, it was not consistent in the following years (Table 5.10). The Fe concentration in the years prior to this research was found to be consistently higher at 100% so the Fe concentration in 2020 could likely be the residual effect that dissipated in the second season.

*Leaf Nutrient Profile*

Leaf nutrient concentrations for trees were compared across three seasons (2020, 2021, and 2022). Yearly differences were reported for both young and mature peach orchards (Table 5.11 and 5.12). Therefore, the analyses of leaf nutrients within each year were performed to determine the nutrient status under each treatment. Hereafter, those results are presented.

*i. Macronutrients*

Tables 5.13-5.16 presented the results of all leaf nutrients, which all were within the sufficiency range (Johnson, 2008). Variations across years in leaf nutrient concentration were observed. In the young orchard, leaf N concentration in 'Guardian' was significantly higher than 'MP-29' in 2021 but was significantly lower in 2022. Similarly, K was significantly higher in 'MP-29' in 2020 and 2021 but lower in 2022 compared to 'Guardian'. P was significantly higher in 'MP-29' in comparison to 'Guardian' in the 2020 and 2022 seasons. Mg and Ca were significantly higher in the 'Guardian' rootstock in the 2021 and 2022 seasons in comparison with the 'MP-29' rootstock. Ca accumulation in the leaf is mainly attributed to transpiration (Kalcsits et al., 2020). The tree with higher plant vigor results in higher transpiration and thus accumulates higher Ca concentration.

‘Guardian’ had larger vegetative growth compared to ‘MP-29’ (Figures 5.1 and 5.2). In 2022, the trunk cross-sectional area in ‘Guardian’ was 125% larger that of ‘MP-29’. It may imply that ‘Guardian’ rootstock has higher storage/ translocation capacity of nutrients in trunk and roots, which may result in higher nutrient concentration in plant parts the following season in comparison with ‘MP-29’ trees. In the case of irrigation methods, the leaf nutrient concentration was comparable across the irrigation methods except for P which was significantly lower in the non-irrigated (control) trees compared to the sensor-based irrigated trees. Nutrient concentrations of N, P, K, and S were comparatively lower in 2022, perhaps because this was the first year of fruit production, and nutrients were being partitioned in a major portion towards wood and fruit as suggested by Carranca et al. (2018) and Zhou and Melgar, (2020).

In the mature orchard, N, K, and S concentrations in the leaf were comparatively higher in the drip system in comparison with the micro-sprinkler irrigated plants. Mg and Ca were significantly higher in the micro-sprinkler system compared to its counterpart (Tables 5.15 and 5.16). Similar trends were observed in the results from Chapter 2. The higher N and K uptake can negatively affect the Mg and Ca uptake (Havlin et al., 2016) which is probably why we are observing higher N and K, and lower Mg and Ca with drip irrigation, as previously reported by Başar (2006). There were no significant differences for most of the leaf nutrients between the peach app and sensor-based irrigation methods, except Ca which was significantly higher for the sensor-based method in 2021 and 2022. The current recommended fertilizer rate (100%) resulted in higher N and S concentrations in leaf, but lower Mg compared to half the recommended rate (50%). The different fertilizer rates did not result in significant differences for the other nutrients, except Ca in 2022 when half of the recommended rate had a significantly higher Ca leaf concentration than the 100% fertilizer recommended rate (Table 5.16).

*ii. Micronutrients*

Tables 5.17 and 5.18 present the micronutrient leaf concentrations in 2020, 2021, and 2022. Some of the micronutrients like B, Zn, and Fe were deficient in both young and mature trees based on the sufficiency range suggested by Johnson (2008). The young trees comparatively had higher concentrations of Zn, Mn, Fe, and Cu in leaves compared to mature trees. These differences may be due to an increase in nutrient translocation/use by different plant parts as the trees mature and become productive. In the young trees, B concentration was significantly higher in ‘Guardian’, contrary to Zn, Mn, and Cu, which were significantly higher in ‘MP-29’ grafted plants. ‘MP-29’ is found to be efficient at micronutrient distribution in leaves compared to ‘Guardian’ rootstock. Given that ‘Guardian’ results in larger plant size, the total nutrient concentration might be higher in ‘Guardian’ rootstocks.

For irrigation in young trees, B in the non-irrigated treatment was significantly lower than the leaf concentration of irrigated trees, despite the methods used. The drier the soil conditions in a non-irrigated treatment, the lower the mineralization of B occurs thus making it less available for plant uptake (Havlin et al., 2016). In the mature trees, no significant differences were observed across all methods for all the micronutrients except for B. Boron leaf concentration was significantly higher in the drip irrigation system than in micro-sprinkler irrigation. For the irrigation methods, all the micronutrients were not statistically different within each year. Finally, in the case of the different fertilizer rates, Zn, Mn, and Cu concentrations were significantly higher in the current recommended rate in comparison with the reduced rate (Table 5.18).

*Fruit Nutrient Profile*

The season 2022 was the first year of harvest for the young trees and certain nutrients were significantly different across the treatments (Tables 5.19). For the mature trees, significant differences were reported for the nutrients in the fruit when comparing data across years (Table 5.20). Hereafter, each nutrient was analyzed within each year and across different treatments (Tables 5.21, 5.22, and 5.23). Ca, Mn, and Fe concentrations in fruit from the young orchard were below the sufficiency range while others were within the sufficiency range (Johnson and Uriu, 1989). Fe was found to be sufficient in fruit from mature trees in 2020 but the fruit concentration eventually dropped below the sufficiency range in 2021 and 2022. The immobile nature of these nutrients within plants limits their transport to fruit, storage organs, and young roots (Havlin et al., 2016).

*i. Macronutrients*

In young trees, N and S were significantly higher in 'MP-29' rootstock compared to 'Guardian' while other nutrients were not significantly different between rootstocks. For the irrigation methods, P concentration in fruit was higher in the irrigated treatment than in the non-irrigated trees (Table 5.21). In the mature orchard, N, K, and S concentrations in fruit were significantly higher in the drip system compared to the micro-sprinkler system. The amount of water used and the efficient delivery to plants by drip system contributed to higher nutrient concentrations in fruits. There were no significant differences between treatments for the irrigation methods and the fertilizer rates when evaluating the fruit nutrients (Tables 5.22 and 5.23).

*ii. Micronutrients*

All the micronutrients were not statistically significant between the two rootstocks in the young orchard. B, Fe, and Cu concentrations in fruit were significantly lower in the non-irrigated treatment compared to irrigated treatment, independent of being sensor- or app-based irrigation method (Table 5.24). In the mature trees, micronutrients B and Zn were significantly higher in the drip system when compared to the micro-sprinkler irrigation (Table 5.25). The irrigation methods and fertilizer rates in the older trees did not result in any consistent differences for the fruit micronutrients.

Our overall results indicated that irrigation and fertilization affected nutrients distribution in young and mature peach trees. The soil analysis results indicated abundant nutrients available to the plant, however, uptake and allocation to leaf and fruit were not adequate for certain nutrients. One of the major reasons for this is the mobility of the nutrients in soil as well as the plants. Some nutrients such as N, S, and B are mobile in soil, thus readily available for plant uptake. But nutrients like P, Cu, Fe, and Zn are immobile in soil, limiting their availability to plants. Similarly, some of these nutrients are immobile in plants like Ca, B, Cu, Fe, Mn, and Zn thus their translocation from roots to leaves, fruit, or storage organs is limited, resulting in their deficiency (Havlin et al., 2016). These nutrients bind to clay particles and become unavailable for plant uptake. Upon comparing the leaf and fruit nutrient distribution, tree age also seemed to have affected nutrient distribution in plants similar to Zhou and Melgar (2020). The nutrient concentration in the initial three years of the leaf was higher but it dropped later as trees started bearing fruits. This might suggest that the tree is allocating nutrients toward fruit and wood development at a later stage. In this study, the nutrient uptake and removal by pruned wood was not considered. This information could have given clarity to differences in nutrient distribution between young and mature peach trees. As the tree matures, the tree size increases, and it starts bearing more fruit, creating a natural competition for available nutrients. If not assessed properly, these trees will likely suffer nutrient deficiency.

**CONCLUSION**

This study aimed to assess the nutrient levels of young and mature peach trees in soil, leaves, and fruit under different irrigation and fertilization practices in Georgia. Irrigation, despite the irrigation scheduling method (app or sensor-based irrigation method), improved higher uptake and distribution of some of the nutrients in peach trees. This also corresponded with the larger plant size and yield in the irrigated trees (despite irrigation method) when compared to the non-irrigated trees (Figure 3.8). Similarly, the drip irrigation system proved to be more efficient than the micro-sprinkler system in terms of nutrient allocation in leaves and fruits, which contributed to larger trunk size and yield in drip-irrigated trees (Table 4.2). Thus, irrigating peach trees with a drip irrigation system is useful to ensure higher nutrient uptake and support better plant growth and development. Furthermore, the use of half the current recommended fertilizer rate was equally efficient as the current recommended rate in terms of nutrient allocation as well as plant vigor and yield (Table 4.2). Thus, cutting off the current fertilizer rate to half is recommended by this study. Between the two rootstocks, the nutrient uptake and distribution pattern varied for each nutrient. Their difference in plant size, root depth, density, and response to management practices is likely to have influenced these results, so a deeper understanding of these parameters in response to nutrient uptake needs to be carried out.

Although nutrients were abundant in the soil, optimal nutrient allocation to peach trees was not achieved over time. Leaves and fruit in both young and mature peach trees were deficient in some nutrients (mainly micronutrients) despite any irrigation or fertilization practices followed. The immobile nature of most of the micronutrients restricts their translocation to leaves and fruits thus resulting in a deficiency. Their deficiency can adversely affect fruit set, production, and postharvest quality. A probable solution is the foliar application of immobile micronutrients like B, Cu, Fe, Mn, and Zn that could address their deficiencies in peach trees. Further study on the nutrient distribution in young and mature peach trees is of high value to have better understanding.

**Literature cited**

Başar, H. (2006). Elemental composition of various peach cultivars. *Scientia horticulturae*, *107*(3), 259-263.

Blaauw, B., Brannen, P., Bellinger, B., Lockwood, D. and Ritchie, D. (2023). Southeastern peach, nectarine, and plum pest management and culture guide. University of Georgia Cooperative Extension, Athens, GA.

Bryla, D. R., Trout, T. J., Ayars, J. E., & Johnson, R. S. (2003). Growth and production of young peach trees irrigated by furrow, microjet, surface drip, or subsurface drip systems. *HortScience, 38*(6), 1112-1116.

Casamali, B., van Iersel, M. W., & Chavez, D. J. (2021a). Nitrogen Partitioning in Young "Julyprince" Peach Trees Grown with Different Irrigation and Fertilization Practices in the Southeastern United States. *Agronomy, 11(2),* 350.

Casamali, B., van Iersel, M. W., & Chavez, D. J. (2021b). Plant Growth and Physiological Responses to Improved Irrigation and Fertilization Management for Young Peach Trees in the Southeastern United States. *HortScience, 56(3),* 336-346.

Carranca, C., Brunetto, G., & Tagliavini, M. (2018). Nitrogen nutrition of fruit trees to reconcile productivity and environmental concerns. *Plants, 7(1),* 4.

Havlin, J. L., Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (2016). *Soil fertility and fertilizers*. Pearson Education India.

Heckman, J. R. (2001). Leaf Analysis for Fruit Trees. New Jersey Agricultural Experiment Station. New Brunswick.

Johnson, R. S. (2008). Nutrient and water requirements of peach trees. In *The peach: botany, production and uses* (pp. 303-331). Wallingford UK: CABI.

Johnson, R. S., & Uriu, K. (1989). Mineral nutrition. *Growing and handling for fresh market: Division of Agriculture Resource; Larue J, Johnson RS (eds.). pp*, 68-81.

Kalcsits, L., Lotze, E., Tagliavini, M., Hannam, K. D., Mimmo, T., Neilsen, D., ... & Valverdi, N. A. (2020). Recent achievements and new research opportunities for optimizing macronutrient availability, acquisition, and distribution for perennial fruit crops. *Agronomy*, *10*(11), 1738.

Policarpo, M., Di Marco, L., Caruso, T., Gioacchini, P., & Tagliavini, M. (2002). Dynamics of nitrogen uptake and partitioning in early and late fruit ripening peach (Prunus persica) tree genotypes under a Mediterranean climate. *Plant and soil*, *239*, 207-214.

Quartieri, M., Millard, P., & Tagliavini, M. (2002). Storage and remobilisation of nitrogen by pear (Pyrus communis L.) trees as affected by timing of N supply. *European Journal of Agronomy*, *17*(2), 105-110.

Sanchez, E. E., Righett, T. L., Sugar, D., & Lombard, P. B. (1992). Effects of timing of nitrogen application on nitrogen partitioning between vegetative, reproductive, and structural components of mature 'Comice'pears. *Journal of Horticultural science*, *67*(1), 51-58.

Samiullah, Z. S., Tariq, M., Shah, T., Latif, A., & Shah, A. (2013). Micronutrients status of peach orchards in Swat valley. *Sarhad J. Agric*, *29*(4), 485-493.

Shah, Z., & Shahzad, K. (2008). Micronutrients status of apple orchards in Swat valley of North West frontier province of Pakistan. *Soil Environ*, *27*(1), 123-130.

Smedema, L. K., & Shiati, K. (2002). Irrigation and salinity: a perspective review of the salinity hazards of irrigation development in the arid zone. *Irrigation and drainage systems*, *16*(2), 161-174.

Sonon, L. S., Kissel, D. E., & Saha, U. (2022). Cation Exchange Capacity and Base Saturation. *UGA Extension Circular*, University of Georgia, Extension, Athens, Georgia

Tariq, M., Shah, Z., & Ali, A. (2008). Micronutrients status of plum orchards in Peshawar valley. *Soil and Environment*, *27*, 223-227.

Thapa Magar, S., Vellidis, G., Porter, W., Liakos, V., Andreis, J.H., & Chavez, D.J. (2022). Development and evaluation of a SmartIrrigation peach app in a young peach orchard. *Acta Horticulturae. 1352*, 575-582.

U.S. Department of Agriculture, National Agricultural Statistics Service (2021). Noncitrus Fruits and Nuts 2020 Summary. U.S. Department of Agriculture, Washington, D.C.

Vellidis, G., Tucker, M., Perry, C., Reckford, D., Butts, C., Henry, H., ... & Edwards, W. (2013). A soil moisture sensor-based variable rate irrigation scheduling system. In *Precision agriculture'13* (pp. 713-720). Wageningen Academic Publishers.

Zhang, Y., Luo, J., Peng, F., Xiao, Y., & Du, A. (2021). Application of bag-controlled release fertilizer facilitated new root formation, delayed leaf, and root senescence in peach trees and improved nitrogen utilization efficiency. *Frontiers in Plant Science*, *12*, 627313.

Zhou, Q., & Melgar, J. C. (2020). Tree Age Influences Nutrient Partitioning among Annually Removed Aboveground Organs of Peach. *HortScience*, *55*(4), 560-564

Table 5.1 ANOVA table with p-values indicating significance of nutrients in soil against different treatments in young peach orchard.

| Factors | pH | P | K | Mg | Ca | B | Zn | Mn | Fe | Cu | CEC | NH4 | NO3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **<.0001**[y] | **0.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **0.0003** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** |
| **Rootstock** | 0.1081 | 0.6864 | 0.2342 | 0.2022 | **0.0289** | **0.0065** | 0.8178 | **0.0349** | 0.7977 | **0.0121** | 0.2538 | 0.2252 | 0.1098 |
| **Year*Rootstock** | 0.3782 | 0.8357 | 0.7569 | 0.1264 | 0.5038 | 0.9483 | 0.9396 | 0.4226 | 0.2908 | 0.4285 | 0.4295 | 0.2577 | 0.2243 |
| **Method** | 0.1596 | 0.1076 | 0.4708 | **0.0397** | **0.0001** | **0.0014** | **0.0006** | 0.1084 | 0.7921 | 0.8194 | **0.0012** | 0.5566 | 0.3064 |
| **Year*Method** | 0.2364 | 0.4138 | 0.2324 | 0.3173 | 0.9086 | 0.7215 | 0.6079 | 0.322 | 0.9165 | 0.8282 | 0.4529 | 0.2963 | 0.7937 |
| **Rootstock*Method** | **0.0044** | 0.4441 | **0.0006** | 0.0831 | **0.0028** | **0.0037** | **0.0384** | 0.3159 | 0.8837 | 0.0869 | **0.0145** | **0.0194** | 0.1908 |
| **Year*Rootstoc*Method** | 0.2364 | 0.6437 | **0.0081** | 0.6946 | 0.0733 | 0.2308 | 0.0725 | 0.4323 | 0.7515 | 0.8621 | 0.201 | **0.0119** | 0.3219 |

[y]Bold values indicate significant *P* values and a confidence interval of 95%.

Table 5.2 ANOVA table with p-values indicating significance of nutrients in soil against different treatments in mature peach orchard.

| Factors | pH | P | K | Mg | Ca | B | Zn | Mn | Fe | Cu | CEC | $NH_4$ | $NO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **0.0039** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | 0.0689 |
| **System** | **<.0001** | **<.0001** | **0.0063** | **0.0063** | **0.0255** | 0.1382 | **<.0001** | 0.4191 | 0.2513 | 0.0554 | **<.0001** | **<.0001** | **<.0001** |
| **Year*System** | 0.4514 | 0.4714 | 0.1183 | 0.1183 | 0.195 | 0.9739 | 0.8312 | **0.0003** | **0.0094** | 0.8977 | 0.8002 | 0.2368 | **0.003** |
| **Method** | **0.0337** | **0.0023** | 0.133 | 0.133 | 0.3988 | 0.1269 | 0.3097 | 0.8139 | 0.8785 | 0.4151 | 0.5277 | 0.6276 | **0.0402** |
| **Year*Method** | 0.2473 | 0.7581 | 0.4001 | 0.4001 | 0.1312 | 0.4564 | 0.6123 | 0.4594 | 0.6557 | 0.8059 | 0.8654 | **0.345** | 0.0517 |
| **System*Method** | 0.1817 | **0.0206** | **0.011** | **0.011** | 0.1582 | 0.75 | 0.0589 | **0.0147** | **0.0204** | 0.0944 | 0.1647 | 0.0525 | 0.8218 |
| **Year*System*Method** | 0.6707 | 0.9272 | 0.1685 | 0.1685 | 0.2568 | **0.029** | 0.7465 | **0.047** | 0.8434 | 0.6602 | 0.8375 | 0.4542 | 0.9091 |
| **Fertilizer** | **<.0001** | 0.5886 | **0.0066** | **0.0066** | 0.4731 | **0.0379** | 0.997 | 0.1883 | 0.1068 | 0.1777 | 0.1566 | **0.0025** | **0.0321** |
| **Year*Fertilizer** | 0.9958 | 0.5721 | 0.5557 | 0.5557 | 0.3696 | **0.0195** | 0.751 | 0.9661 | 0.3407 | 0.7982 | 0.9952 | 0.6862 | 0.8768 |
| **System*Fertilizer** | 0.0942 | **0.0003** | 0.7682 | 0.7682 | 0.3685 | 0.6162 | **<.0001** | 0.9473 | **<.0001** | 0.0048 | 0.174 | 0.7216 | 0.5148 |
| **Year*System*Fertiliz** | 0.4266 | 0.9358 | 0.2276 | 0.2276 | 0.9472 | 0.0489 | 0.8219 | 0.9306 | 0.1972 | 0.5456 | 0.8268 | 0.2217 | 0.6438 |
| **Method*Fertilizer** | 0.3048 | 0.4472 | 0.3251 | 0.3251 | 0.1373 | 0.5169 | 0.2847 | 0.9563 | 0.0805 | 0.5517 | 0.8569 | **0.0311** | 0.9649 |
| **Year*Method*Fertiliz** | 0.9746 | 0.4271 | 0.9586 | 0.9586 | 0.1597 | 0.5011 | 0.5415 | 0.8487 | 0.5282 | 0.6294 | 0.7125 | 0.8661 | 0.3023 |
| **System*Method*Fertil** | 0.7823 | 0.3224 | 0.3858 | 0.3858 | 0.3886 | 0.2782 | 0.0644 | 0.9354 | 0.5906 | 0.5985 | 0.2468 | 0.6136 | 0.6942 |
| **Year*Syst*Meth*Ferti** | 0.6405 | 0.6858 | 0.7415 | 0.7415 | 0.8048 | 0.4796 | 0.5733 | 0.9302 | 0.7901 | 0.7983 | 0.9939 | 0.9166 | 0.713 |

[y]Bold values indicate significant *P* values and a confidence interval of 95%.

Table 5.3 Soil pH and CEC under different treatments for 3 years (2020, 2021 and 2022) in a young peach orchard.

| Treatments | pH | | | CEC[3] (meq/100g) | | |
|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **Rootstock** | | | | | | |
| Guardian | 5.44 | 5.69 | 5.92 | 7.06 | 5.97 | 7.28 |
| MP-29 | 5.52 | 5.82 | 5.91 | 7.00 | 6.12 | 7.66 |
| **Method** | | | | | | |
| App | 5.45 | 5.70 ab[z] | 5.93 | 6.54 b | 5.88 | 7.08 b |
| Control | 5.53 | 5.68 b | 5.86 | 7.27 a | 6.17 | 7.92 a |
| Sensor | 5.47 | 5.88 a | 5.97 | 7.27 a | 6.09 | 7.41 ab |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.4 Soil pH and CEC under different treatments for 3 years (2020, 2021 and 2022) in a mature peach orchard.

| Treatments | pH | | | CEC[1] (meq/100g) | | |
|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **System** | | | | | | |
| Drip | 6.57 b[z] | 6.39 b | 6.51 b | 6.36 a | 6.49 a | 7.67 a |
| Micro-sprinkler | 6.76 a | 6.65 a | 6.65 a | 5.55 b | 5.75 b | 6.69 b |
| **Method** | | | | | | |
| App | 6.58 b | 6.48 | 6.57 | 6.06 | 6.13 | 7.27 |
| Sensor | 6.73 a | 6.55 | 6.58 | 5.87 | 6.13 | 7.10 |
| **Fertilizer** | | | | | | |
| 50% | 6.75 a | 6.61 | 6.67 a | 5.86 | 6.01 | 7.08 |
| 100% | 6.57 b | 6.42 | 6.49 b | 6.06 | 6.24 | 7.28 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

[3] CEC: Cation Exchange Capacity

Table 5.5 Relative concentrations of $NH_4$, $NO_3$, P, and K in soil under different treatments in 2020, 2021, and 2022 in young peach orchard.

| Treatments | $NH_4$ (kg.ha$^{-1}$) | | | $NO_3$ (kg.ha$^{-1}$) | | | P (kg.ha$^{-1}$) | | | K (kg.ha$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **Rootstock** | | | | | | | | | | | | |
| Guardian | 9.9 | 10.5 a$^z$ | 13.7 | 107.4 | 4.1 | 5.5 | 31.7 | 20.0 | 35.1 | 237.3 | 162.0 | 207.0 |
| MP-29 | 7.1 | 7.9 b | 13.9 | 96.9 | 5.9 | 6.4 | 32.0 | 23.6 | 47.5 | 238.7 | 178.3 | 219.8 |
| **Method** | | | | | | | | | | | | |
| App | 6.9 | 10.7 | 12.7 | 87.1 | 4.9 | 4. 9 | 32.9 ab | 20.8 | 42.6 | 239.7 | 164.6 | 197.4 |
| Control | 10.1 | 8.7 | 14.5 | 120.5 | 5.4 | 6.4 | 23.2 b | 21.6 | 42.2 | 231.2 | 169.6 | 239.3 |
| Sensor | 8.6 | 8.3 | 14.2 | 98.9 | 4.6 | 6.5 | 39.6 a | 23.1 | 39.2 | 243.0 | 176.3 | 203.5 |

$^z$Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.6 Relative concentrations of $NH_4$, $NO_3$, P, and K in soil under different treatments in 2020, 2021, and 2022 in mature peach orchard.

| Treatments | $NH_4$ (kg.ha$^{-1}$) | | | $NO_3$ (kg.ha$^{-1}$) | | | P (kg.ha$^{-1}$) | | | K (kg.ha$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **System** | | | | | | | | | | | | |
| Drip | 15.0 a$^z$ | 13.8 a | 23.9 a | 6.6 a | 8.7 a | 6.9 a | 70.4 b | 77.45 b | 120.3 | 182.1 | 204.8 a | 269.6 a |
| Micro-sprinkler | 12.4 b | 11.2 b | 16.0 b | 5.2 b | 3.4 b | 3.4 b | 101.2 a | 102.9 a | 133.6 | 182.5 | 184.0 b | 241.1 b |
| **Method** | | | | | | | | | | | | |
| App | 14.0 | 12.4 | 20.8 | 6.1 | 5.7 | 5.1 | 96.4 a | 95.2 | 136.0 | 179.7 | 184.3 | 255.3 |
| Sensor | 13.4 | 12.6 | 19. 2 | 5.7 | 6.5 | 5.2 | 75.0 b | 84.9 | 118.0 | 184.8 | 204.5 | 255.9 |
| **Fertilizer** | | | | | | | | | | | | |
| 50% | 12.8 b | 12.0 | 21.0 | 5.4 b | 5.2 | 4.7 | 85.8 | 94.9 | 124.1 | 171.8 b | 190.9 | 245.1 |
| 100% | 14.6 a | 13.0 | 19.1 | 6.3 a | 6.9 | 5.6 | 85.3 | 85.2 | 129.5 | 192.4 a | 198.1 | 265.8 |

$^z$Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.7 Relative concentrations of Mg and Ca in soil under different treatments in 2020, 2021 and 2022 in young peach orchard.

| Treatments | Mg ($kg.ha^{-1}$)) | | | Ca ($kg.ha^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **Rootstock** | | | | | | |
| Guardian | 240.1 | 152. 1 b | 167.5 | 1191.2 | 1149.2 | 1556.6 |
| MP-29 | 245.0 | 182.2 a | 161.0 | 1250.3 | 1210.0 | 1724.2 |
| **Method** | | | | | | |
| App | 218.7 b[z] | 162.5 | 152.3 | 1048.3 b | 1065.9 | 1517.6 |
| Control | 261.6 a | 158.9 | 169.3 | 1312.0 a | 1225.7 | 1725.6 |
| Sensor | 247.3 ab | 179.9 | 171.2 | 1301.9 a | 1247.3 | 1677.9 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.8 Relative concentrations of Mg and Ca in soil under different treatments in 2020, 2021 and 2022 in mature peach orchard.

| | Mg ($kg.ha^{-1}$) | | | Ca ($kg.ha^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Treatments** | **2020** | **2021** | **2022** | **2020** | **2021** | **2022** |
| **System** | | | | | | |
| Drip | 159.8 | 177.3 a | 187. 5 | 1499.1 | 1615.7 | 2085.4 a |
| Micro-sprinkler | 146.4 | 152.1 b | 185.8 | 1397.4 | 1530.2 | 1801.1 b |
| **Method** | | | | | | |
| App | 140.3 b[z] | 150.1 b | 181.5 | 1479.8 | 1561.5 | 2003.4 |
| Sensor | 165.7 a | 179.2 a | 191.7 | 1419.3 | 1585.4 | 1889.4 |
| **Fertilizer** | | | | | | |
| 50% | 155.4 | 173.1 | 192.9 | 1429.4 | 1598.9 | 1942.7 |
| 100% | 151.1 | 156.9 | 180.7 | 1468.1 | 1549.1 | 1948.2 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.9 Relative concentrations of micronutrients in soil under different treatments in 2020, 2021 and 2023 in young peach orchard.

| Treatments | B ($kg.ha^{-1}$) | | | Zn ($kg.ha^{-1}$) | | | Mn ($kg.ha^{-1}$) | | | Fe ($kg.ha^{-1}$) | | | Cu ($kg.ha^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **Rootstock** | | | | | | | | | | | | | | | |
| Guardian | 0.55 b[z] | 0.55 b | 0.71 | 6.02 | 5.78 | 7.88 | 16.05 a | 20.84 a | 31.48 | 39.88 | 29.87 | 68.88 | 1.08 b | 0.98 b | 1.50 |
| MP-29 | 0.62 a | 0.63 a | 0.77 | 6.56 | 5.75 | 7.39 | 13.44 b | 18.79 b | 31.24 | 33.35 | 26.13 | 66.83 | 1.16 a | 1.15 a | 1.56 |
| **Method** | | | | | | | | | | | | | | | |
| App | 0.52 b | 0.53 | 0.68 b | 7.58 ab | 6.33 a | 8.50 | 14.65 | 19.97 | 30.05 | 32.20 | 28.65 | 64.03 | 1.12 | 1.11 | 1.51 |
| Control | 0.64 a | 0.62 | 0.81 a | 4.91 b | 4.91 b | 6.78 | 12.79 | 18.85 | 32.11 | 43.21 | 25.667 | 73.17 | 1.09 | 1.02 | 1.55 |
| Sensor | 0.59 ab | 0.63 | 0.72 ab | 6.39 a | 6.06 ab | 7.64 | 16.80 | 20.63 | 31.92 | 34.44 | 29.68 | 66.36 | 1.15 | 1.06 | 1.52 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.10 Relative concentrations of micronutrients in soil under different treatments in 2020, 2021 and 2023 in mature peach orchard.

| Treatments | B ($kg.ha^{-1}$) | | | Zn ($kg.ha^{-1}$) | | | Mn ($kg.ha^{-1}$) | | | Fe ($kg.ha^{-1}$) | | | Cu ($kg.ha^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **System** | | | | | | | | | | | | | | | |
| Drip | 0.51 | 0.62 | 0.74 | 6.22 a | 6.30 a | 8.37 a | 10.22 b | 28.07 | 41.97 a | 46.03 | 45.08 | 73.96 | 0.93 | 1.23 | 1.40 |
| Micro-sprinkler | 0.49 | 0.57 | 0.71 | 3.24 b | 3.72 b | 5.07 b | 13.80 a | 26.30 | 38.55 b | 41.66 | 51.53 | 70.85 | 1.13 | 1.30 | 1.14 |
| **Method** | | | | | | | | | | | | | | | |
| App | 0.51 | 0.58 | 712.00 | 4.86 | 4.75 | 6.99 | 12.21 | 26.52 | 40.10 | 45.38 | 49.89 | 72.37 | 1.08 | 1.25 | 1.41 |
| Sensor | 0.50 | 0.61 | 0.74 | 4.65 | 5.30 | 6.51 | 11.76 | 27.86 | 40.46 | 42.42 | 46.76 | 72.49 | 0.98 | 1.28 | 1.14 |
| **Fertilizer** | | | | | | | | | | | | | | | |
| 50% | 0.48 b[z] | 0.62 | 0.67 b | 4.77 | 4.92 | 6.76 | 11.60 | 26.74 | 39.67 | 47.37 a | 51.52 | 72.76 | 1.15 | 1.27 | 1.12 |
| 100% | 0.53 a | 0.57 | 0.79 a | 4.73 | 5.13 | 6.73 | 12.36 | 27.65 | 40.88 | 40.50 b | 45.19 | 72.10 | 0.92 | 1.26 | 1.41 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.11 ANOVA table with p-values indicating significance of nutrients in leaf against different treatments in young peach orchard.

| Factors | N | P | K | Mg | Ca | S | B | Zn | Mn | Fe | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | **<.0001**[y] | **<.0001** | **0.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** |
| Rootstock | **0.0034** | **<.0001** | **0.0045** | **0.0001** | **0.0032** | **0.0001** | **<.0001** | **<.0001** | **<.0001** | 0.7901 | **<.0001** |
| Year*Rootstock | **<.0001** | **<.0001** | **<.0001** | 0.3584 | **0.0054** | **0.0002** | **0.0008** | **0.0043** | 0.081 | 0.1855 | **<.0001** |
| Method | 0.6545 | **0.0002** | **0.0003** | **0.0326** | 0.85 | 0.9601 | **<.0001** | 0.5709 | **0.015** | **0.0404** | 0.0564 |
| Year*Method | **0.0297** | 0.7368 | 0.132 | 0.5269 | 0.4894 | 0.3071 | 0.2504 | 0.0975 | **0.0032** | 0.5386 | 0.4639 |
| Rootstock*Method | 0.3669 | 0.4992 | 0.8953 | **0.006** | **0.0259** | 0.3796 | 0.7701 | 0.7494 | **0.0014** | 0.7367 | 0.7466 |
| Year*Rootstoc*Method | 0.0891 | 0.3548 | 0.2613 | 0.7982 | 0.5462 | **0.0212** | **0.003** | 0.0917 | 0.1971 | 0.3968 | 0.0899 |

[y]Bold values indicate significant *P* values and a confidence interval of 95%.

Table 5.12 ANOVA table with p-values indicating significance of nutrients in leaf against different treatments in mature peach orchard.

| Factors | N | P | K | Mg | Ca | S | B | Zn | Mn | Fe | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | **<.0001**[y] | **<.0001** | **<.0001** | **0.0007** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** |
| System | **0.0154** | 0.2249 | **<.0001** | **0.0005** | **0.0003** | **0.0009** | **<.0001** | **0.0002** | **0.0064** | 0.1668 | 0.0947 |
| Year*System | 0.1712 | 0.0996 | 0.0521 | **0.0262** | 0.2235 | 0.0989 | **0.0013** | **0.012** | 0.1149 | 0.6994 | 0.8084 |
| Method | 0.058 | 0.085 | **0.0079** | 0.8341 | **0.0003** | 0.1453 | 0.1397 | 0.828 | 0.6697 | 0.5742 | 0.5071 |
| Year*Method | 0.1892 | **0.0205** | 0.2268 | 0.1127 | 0.3908 | **0.0048** | 0.5467 | 0.0534 | 0.6347 | 0.3569 | 0.4209 |
| System*Method | 0.4087 | 0.6878 | 0.3139 | 0.9992 | 0.6417 | 0.5519 | 0.7868 | 0.257 | 0.2057 | 0.921 | 0.3064 |
| Year*System*Method | 0.8281 | 0.3284 | 0.4399 | 0.554 | 0.9788 | 0.7561 | 0.9338 | 0.9869 | 0.6955 | 0.943 | 0.7288 |
| Fertilizer | **<.0001** | 0.3301 | 0.2204 | **<.0001** | **0.021** | **<.0001** | 0.8907 | **<.0001** | **<.0001** | 0.4341 | **0.0014** |
| Year*Fertilizer | 0.6051 | 0.9861 | 0.4526 | 0.8989 | 0.7953 | 0.9057 | 0.2511 | 0.5375 | 0.5967 | 0.9176 | 0.1246 |
| System*Fertilizer | 0.5243 | 0.422 | 0.6133 | 0.2356 | 0.1026 | 0.8388 | 0.9112 | 0.5126 | 0.0994 | 0.4119 | **0.0174** |
| Year*System*Fertiliz | **0.0222** | **0.0389** | 0.2025 | 0.5717 | 0.2067 | 0.0376 | 0.6386 | 0.1773 | 0.2885 | 0.5025 | 0.7507 |
| Method*Fertilizer | 0.7948 | 0.1886 | 0.4467 | 0.4718 | 0.7763 | 0.5268 | 0.6978 | 0.6643 | 0.008 | **0.011** | 0.3665 |
| Year*Method*Fertiliz | 0.4891 | **0.021** | 0.369 | 0.3858 | 0.419 | 0.7634 | 0.8954 | 0.3173 | 0.9407 | 0.2231 | 0.0702 |
| System*Method*Fertil | 0.1874 | 0.2525 | 0.6135 | **0.0295** | 0.0624 | 0.254 | 0.7446 | 0.6087 | 0.8142 | 0.0947 | 0.3273 |
| Year*Syst*Meth*Ferti | 0.5353 | 0.2636 | 0.8721 | 0.3738 | 0.2225 | 0.7341 | 0.3115 | 0.3119 | 0.8453 | 0.6667 | 0.187 |

[y]Bold values indicate significant *P* values and a confidence interval of 95%.

Table 5.13 Relative concentrations of macronutrients N, P, and K in leaves under different treatments in 2020, 2021 and 2022 in young peach trees.

| Treatments | N (%) | | | P (%) | | | K (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **Rootstock** | | | | | | | | | |
| Guardian | 3.91 | 4.51 a[z] | 3.31 b | 0.19b | 0.32 | 0.19 b | 1.94 b | 2.29 b | 2.29 a |
| MP-29 | 4.20 | 4.32 b | 3.72 a | 0.23 a | 0.32 | 0.22 a | 2.33 a | 2.42 a | 2.13 b |
| **Method** | | | | | | | | | |
| App | 4.10 | 4.40 | 3.55 | 0.21 ab | 0.32 | 0.20 ab | 2.20 | 2.36 | 2.37 a |
| Control | 3.89 | 4.55 | 3.44 | 0.20 b | 0.31 | 0.19 b | 1.99 | 2.29 | 2.06 b |
| Sensor | 4.17 | 4.303 | 3.55 | 0.22 a | 0.33 | 0.22 a | 2.23 | 2.41 | 2.19 ab |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.14 Relative concentrations of macronutrients Mg, Ca, and S in leaves under different treatments in 2020, 2021 and 2022 in young peach trees.

| Treatments | Mg (%) | | | Ca (%) | | | S (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **Rootstock** | | | | | | | | | |
| Guardian | 0.45 | 0.35 a[z] | 0.47 a | 1.67 | 1.19 a | 1.61 a | 0.24 | 0.21 | 0.17 b |
| MP-29 | 0.43 | 0.30 b | 0.43 b | 1.75 | 0.86 b | 1.43 b | 0.26 | 0.21 | 0.19 a |
| **Method** | | | | | | | | | |
| App | 0.45 | 0.32 | 0.43 b | 1.74 | 1.03 | 1.49 | 0.25 | 0.21 | 0.18 |
| Control | 0.45 | 0.34 | 0.49 a | 1.61 | 1.03 | 1.57 | 0.24 | 0.22 | 0.18 |
| Sensor | 0.43 | 0.32 | 0.43 b | 1.79 | 1.01 | 1.50 | 0.25 | 0.21 | 0.18 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.15 Relative concentrations of macronutrients N, P, and K in leaves under different treatments in 2020, 2021 and 2022 in mature peach trees.

| Treatments | N (%) | | | P (%) | | | K (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **System** | | | | | | | | | |
| Drip | 3.02 | 3.42 a | 3.05 | 0.21 | 0.22 | 0.20 | 2.56 a | 2.91 a | 2.59 a |
| Micro-sprinkler | 2.985 | 3.22 b | 3.00 | 0.21 | 0.21 | 0.20 | 2.36 b | 2.48 b | 2.37 b |
| **Method** | | | | | | | | | |
| App | 2.99 | 3.40 a | 3.07 | 0.21 | 0.22 a | 0.20 | 2.44 | 2.60 b | 2.45 |
| Sensor | 3.01 | 3.24 b | 2.98 | 0.21 | 0.21 b | 0.20 | 2.47 | 2.80 a | 2.51 |
| **Fertilizer** | | | | | | | | | |
| 50% | 2.89 b[z] | 3.26 | 2.93 b | 0.21 | 0.22 | 0.20 | 2.44 | 2.71 | 2.42 |
| 100% | 3.11 a | 3.38 | 3.11 a | 0.21 | 0.22 | 0.20 | 2.47 | 2.69 | 2.54 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.16 Relative concentrations of macronutrients Mg, Ca, and S in leaves under different treatments in 2020, 2021 and 2022 in mature peach trees.

| Treatments | Mg (%) | | | Ca (%) | | | S (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **System** | | | | | | | | | |
| Drip | 0.49 | 0.50 b | 0.50 b | 2.64 | 2.17 | 1.94 b | 0.16 a | 0.17 a | 0.16 |
| Micro-sprinkler | 0.49 | 0.54 a | 0.55 a | 2.74 | 2.30 | 2.22 a | 0.15 b | 0.16 b | 0.16 |
| **Method** | | | | | | | | | |
| App | 0.49 | 0.53 | 0.52 | 2.67 | 2.14 b | 1.96 b | 0.15 b | 0.17 a | 0.16 |
| Sensor | 0.50 | 0.51 | 0.53 | 2.70 | 2.32 a | 2.19 a | 0.16 a | 0.16 b | 0.16 |
| **Fertilizer** | | | | | | | | | |
| 50% | 0.51 a[z] | 0.54 a | 0.55 a | 2.75 | 2.291 | 2.17 a | 0.15 b | 0.16 b | 0.16 b |
| 100% | 0.48 b | 0.50 b | 0.51 b | 2.63 | 2.17 | 1.99 b | 0.16 a | 0.17 a | 0.17 a |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.17 Relative concentrations of micronutrients B, Zn, and Mn in leaves under different treatments in 2020, 2021 and 2022 in young peach trees.

| Treatments | B (ppm) | | | Zn (ppm) | | | Mn (ppm) | | | Fe (ppm) | | | Cu (ppm) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **Rootstock** | | | | | | | | | | | | | | | |
| Guardian | 27.11 | 39.89 a | 29.67 a | 31.89 b | 30.67 b | 19.39 b | 81.11 | 54.89 b | 38.78 b | 125.67 | 68.72 | 75.72 | 9.00 b | 10.44 | 7.39 b |
| MP-29 | 26.89 | 34.94 b | 26.89 b | 47.67 a | 37.50 a | 27.83 a | 98.33 | 89.83 a | 50.89 a | 130.78 | 66.44 | 73.83 | 11.33 a | 10.50 | 9.56 a |
| **Method** | | | | | | | | | | | | | | | |
| App | 27.50 a[z] | 38.75 a | 30.08 a | 41.33 | 34.00 | 23.25 | 99.83 | 71.83 a | 48.58 | 131.33 | 66.17 | 71.33 b | 10.67 | 10.67 a | 8.42 |
| Control | 26.00 b | 34.83 b | 25.42 b | 36.17 | 35.58 | 23.42 | 78.50 | 92.17 a | 44.42 | 122.67 | 70.33 | 80.58 a | 9.83 | 9.92 b | 8.17 |
| Sensor | 27.50 a | 38.67 a | 29.33 a | 41.83 | 32.67 | 24.17 | 90.83 | 53.08 b | 41.50 | 130.67 | 66.25 | 72.42 ab | 10.00 | 10.833 a | 8.83 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.18 Relative concentrations of micronutrients B, Zn, and Mn in leaves under different treatments in 2020, 2021 and 2022 in mature peach trees.

| Treatments | B (ppm) | | | Zn (ppm) | | | Mn (ppm) | | | Fe (ppm) | | | Cu (ppm) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| **System** | | | | | | | | | | | | | | | |
| Drip | 37.78 a | 35.72 a | 30.16 | 14.94 a | 18.88 | 16.31 | 50.69 b | 45.22 | 42.34 | 77.06 | 87.50 | 85.88 | 6.63 | 7.75 | 6.47 |
| Micro-sprinkler | 32.87 b | 31.77 b | 29.61 | 13.07 b | 18.10 | 15.65 | 73.32 a | 48.90 | 50.97 | 93.48 | 89.03 | 92.03 | 6.29 | 7.58 | 6.10 |
| **Method** | | | | | | | | | | | | | | | |
| App | 35.68 | 33.48 | 29.65 | 13.65 | 18.65 | 15.97 | 53.39 | 46.48 | 45.23 | 73.07 | 90.16 | 90.52 | 6.19 | 7.65 | 6.16 |
| Sensor | 35.06 | 34.06 | 30.13 | 14.38 | 18.34 | 16.00 | 70.00 | 47.56 | 47.91 | 96.84 | 86.41 | 87.34 | 6.72 | 7.69 | 6.41 |
| **Fertilizer** | | | | | | | | | | | | | | | |
| 50% | 34.36 | 34.19 | 29.42 | 13.48 b | 17.68 b | 15.58 | 57.48 b | 39.19 b | 39.84 b | 94.71 | 88.07 | 88.00 b | 5.97 b | 7.68 | 6.07 b |
| 100% | 36.34 | 33.38 | 30.34 | 14.53 a | 19.28 a | 16.38 | 66.03 a | 54.63 a | 53.13 a | 75.88 | 88.44 | 89.78 a | 6.94 a | 7.66 | 6.50 a |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.19 ANOVA table with p-values indicating significance of nutrients in fruit against different treatments in young peach orchard.

| Factors | N | P | K | Mg | Ca | S | B | Zn | Mn | Fe | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Rootstock** | **0.043**[y] | 0.9095 | 0.372 | 0.5945 | 0.6113 | **0.008** | 0.0748 | 0.7179 | 0.9561 | 0.9181 | 0.2174 |
| **Method** | 0.2834 | **0.0005** | 0.9098 | 0.567 | 0.3515 | 0.1742 | **0.0037** | 0.1153 | 0.1993 | **0.0017** | **0.0271** |
| **Rootstock*Method** | 0.9233 | 0.0576 | **0.0169** | 0.6678 | 0.2737 | 0.6155 | 0.5783 | 0.3483 | 0.554 | 0.7815 | 0.4011 |

[y]Bold values indicate significant *P* values and a confidence interval of 95%.

Table 5.20 ANOVA table with p-values indicating significance of nutrients in fruit against different treatments in young peach orchard.

| Factors | N | P | K | Mg | Ca | S | B | Zn | Mn | Fe | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **<.0001**[y] | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** | **<.0001** |
| **System** | **0.0033** | 0.0729 | 0.1088 | 0.3541 | **0.0398** | **0.0005** | **<.0001** | **<.0001** | **0.0023** | **0.0074** | 0.1621 |
| **Year*System** | 0.5903 | 0.5255 | 0.1396 | 0.0682 | **<.0001** | 0.286 | 0.5562 | 0.6657 | 0.8371 | 0.7794 | 0.1017 |
| **Method** | 0.5849 | 0.1248 | 0.5293 | 0.9331 | 0.8878 | 0.2636 | 0.2721 | 0.5445 | 0.1336 | 0.2736 | **0.0026** |
| **Year*Method** | 0.4472 | 0.1109 | 0.7827 | 0.8044 | 0.9327 | 0.1217 | 0.8592 | 0.0697 | 0.5755 | 0.0521 | 0.2143 |
| **System*Method** | 0.6808 | 0.7116 | 0.4611 | 0.8691 | 0.1902 | 0.7983 | 0.3838 | 0.9013 | 0.8922 | 0.7618 | 0.3173 |
| **Year*System*Method** | 0.7518 | 0.4348 | 0.3313 | 0.3143 | 0.3984 | 0.3183 | 0.8113 | 0.3418 | 0.5341 | 0.4945 | 0.7384 |
| **Fertilizer** | 0.1069 | 0.3174 | 0.424 | 0.2475 | 0.3586 | 0.5614 | 0.3049 | 0.3306 | **0.0112** | 0.9523 | 0.2574 |
| **Year*Fertilizer** | 0.8752 | 0.7408 | 0.8867 | 0.6126 | 0.8209 | 0.7134 | 0.5415 | 0.9926 | 0.4071 | 0.3845 | 0.178 |
| **System*Fertilizer** | 0.1339 | 0.1779 | 0.6646 | 0.4276 | 0.7268 | 0.1639 | 0.7366 | 0.6558 | 0.4349 | 0.4949 | 0.602 |
| **Year*System*Fertiliz** | 0.5592 | **0.0004** | 0.2301 | 0.2199 | 0.4699 | 0.0213 | 0.1114 | 0.1491 | 0.286 | 0.0722 | **0.0091** |
| **Method*Fertilizer** | 0.1685 | 0.8955 | 0.0836 | 0.0991 | 0.6811 | 0.4124 | 0.1356 | 0.7227 | 0.0606 | 0.2699 | 0.469 |
| **Year*Method*Fertiliz** | 0.4722 | 0.0059 | 0.172 | 0.1469 | 0.0851 | 0.1481 | 0.3679 | 0.7307 | 0.8668 | 0.0814 | 0.9508 |
| **System*Method*Fertil** | 0.3309 | 0.782 | 0.4987 | 0.8015 | 0.8222 | 0.4124 | 0.9848 | 0.8183 | 0.3696 | 0.172 | 0.7507 |
| **Year*Syst*Meth*Ferti** | 0.4934 | 0.2802 | 0.3823 | 0.334 | 0.5853 | 0.5276 | 0.4391 | 0.3574 | 0.703 | 0.151 | 0.1216 |

[y]Bold values indicate significant *P* values and a confidence interval of 95%.

Table 5.21 Relative concentrations of macronutrients in fruit under different treatments in 2022 in young peach trees.

| Treatments | N (%) | P (%) | K (%) | Mg (%) | Ca (%) | S (%) |
|---|---|---|---|---|---|---|
| **Rootstock** | | | | | | |
| Guardian | 1.02 b[z] | 0.18 | 1.69 | 0.08 | 0.04 | 0.04 b |
| MP-29 | 1.08 a | 0.18 | 1.68 | 0.08 | 0.04 | 0.05 a |
| **Method** | | | | | | |
| App | 1.06 | 0.18 a | 1.70 | 0.08 | 0.04 | 0.05 |
| Control | 1.07 | 0.17 b | 1.67 | 0.08 | 0.04 | 0.04 |
| Sensor | 1.03 | 0.18 a | 1.68 | 0.08 | 0.039 | 0.05 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.22 Relative concentrations of N, P and K in fruit under different treatments in 2020, 2021 and 2022 in mature peach trees.

| | N (%) | | | P (%) | | | K (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Treatments** | **2020** | **2021** | **2022** | **2020** | **2021** | **2022** | **2020** | **2021** | **2022** |
| **System** | | | | | | | | | |
| Drip | 1.69 | 1.24 a | 1.23 a | 0.28 | 0.19 | 0.22 | 2.55 a | 1.97 a | 1.97 |
| Micro-sprinkler | 1.54 | 1.12 b | 1.04 b | 0.27 | 0.19 | 0.21 | 2.37 b | 1.87 b | 1.95 |
| **Method** | | | | | | | | | |
| App | 1.54 | 1.19 | 1.12 | 0.27 | 0.19 | 0.21 | 2.47 | 1.93 | 1.96 |
| Sensor | 1.68 | 1.17 | 1.16 | 0.28 | 0.19 | 0.22 | 2.45 | 1.92 | 1.97 |
| **Fertilizer** | | | | | | | | | |
| 50% | 1.51 b[z] | 1.16 | 1.09 | 0.27 | 0.19 | 0.21 | 2.44 | 1.95 | 1.95 |
| 100% | 1.72 a | 1.20 | 1.19 | 0.27 | 0.19 | 0.21 | 2.47 | 1.90 | 1.98 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.23 Relative concentrations of N, P and K in fruit under different treatments in 2020, 2021 and 2022 in mature peach trees.

| | Mg (%) | | | Ca (%) | | | S (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Treatments** | **2020** | **2021** | **2022** | **2020** | **2021** | **2022** | **2020** | **2021** | **2022** |
| **System** | | | | | | | | | |
| Drip | 0.11 | 0.09 | 0.09 | 0.06 | 0.05 | 0.04 b | 0.08 | 0.05 a | 0.57 a |
| Sprinkler | 0.10 | 0.08 | 0.09 | 0.06 | 0.05 | 0.05 a | 0.07 | 0.04 b | 0.05 b |
| **Method** | | | | | | | | | |
| App | 0.11 | 0.09 | 0.09 | 0.06 | 0.05 | 0.05 | 0.07 b | 0.05 | 0.05 |
| Sensor | 0.11 | 0.09 | 0.09 | 0.06 | 0.05 | 0.05 | 0.08 a | 0.05 | 0.05 |
| **Fertilizer** | | | | | | | | | |
| 50% | 0.11 | 0.09 | 0.09 | 0.059 | 0.05 | 0.05 | 0.07 | 0.05 | 0.05 |
| 100% | 0.11 | 0.08 | 0.089 | 0.056 | 0.05 | 0.05 | 0.08 | 0.05 | 0.05 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.24 Relative concentrations of micronutrients in fruit under different treatments in 2022 in young peach orchard.

| Treatments | B (ppm) | Zn (ppm) | Mn (ppm) | Fe (ppm) | Cu (ppm) |
|---|---|---|---|---|---|
| **Rootstock** | | | | | |
| Guardian | 35.00 | 10.36 | 4.14 | 17.500 | 7.71 |
| MP-29 | 32.29 | 10.71 | 4.14 | 18.07 | 8.14 |
| **Method** | | | | | |
| App | 36.63 a[z] | 10.63 | 4.50 | 18.25 a | 8.13 ab |
| Control | 30.33 b | 9.44 | 3.89 | 16.78 b | 7.22b |
| Sensor | 34.18 a | 11.36 | 4.09 | 18.27 a | 8.364 a |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.

Table 5.25 Relative concentrations of micronutrients in fruit under different treatments in 2020, 2021 and 2022 in mature peach orchard.

| | B (ppm) | | | Zn (ppm) | | | Mn (ppm) | | | Fe (ppm) | | | Cu (ppm) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatments** | **2020** | **2021** | **2022** | **2020** | **2021** | **2022** | **20202** | **2021** | **2022** | **2020** | **2021** | **2022** | **2020** | **2021** | **2022** |
| **System** | | | | | | | | | | | | | | | |
| Drip | 38.64 a[z] | 32.53 a | 32.60 a | 13.36 | 9.41 a | 12.41 a | 7.44 | 5.28 a | 5.31 | 22.64 | 18.50 | 20.28 a | 8.68 | 7.44 | 7.93 |
| Micro-sprinkler | 34.41 b | 29.50 b | 28.00 b | 13.33 | 8.50 b | 9.444b | 6.78 | 4.89 b | 4.889 | 22.19 | 17.25 | 17.93 b | 8.89 | 7.64 | 7.00 |
| **Method** | | | | | | | | | | | | | | | |
| App | 37.16 | 31.87 | 30.32 | 13.00 b | 9.20 | 10.44 | 6.84 | 5.07 | 5.00 | 21.16 | 17.97 | 18.92 | 8.28 | 7.47 | 7.00 b |
| Sensor | 35.78 | 30.37 | 30.45 | 13.67 a | 8.77 | 11.42 | 7.33 | 5.13 | 5.19 | 23.56 | 17.87 | 19.32 | 9.26 | 7.60 | 7.87 a |
| **Fertilizer** | | | | | | | | | | | | | | | |
| 50% | 36.67 | 31.25 | 31.04 a | 13.00 | 8.96 | 10.66 | 6.74 b | 4.96 | 5.00 | 22.48 | 17.79 | 19.07 | 8.70 | 7.65 | 7.69 |
| 100% | 36.20 | 31.00 | 29.70 b | 13.72 | 9.00 | 11.33 | 7.48 a | 5.22 | 5.22 | 22.32 | 18.03 | 19.22 | 8.88 | 7.59 | 7.26 |

[z]Means followed by a different lowercase letter within a year and treatment effect are significantly different by Tukey's HSD test, $P \leq 0.05$. Means without letters indicate no significant differences.


Figure 5.1 Visual difference between 3-year-old peach trees cv. ‘Julyprince’ grafted onto ‘Guardian’ and ‘MP-29’ rootstocks in July 2022, established in 2020 in the UGA Peach Research and Extension Farm, Griffin, Georgia.

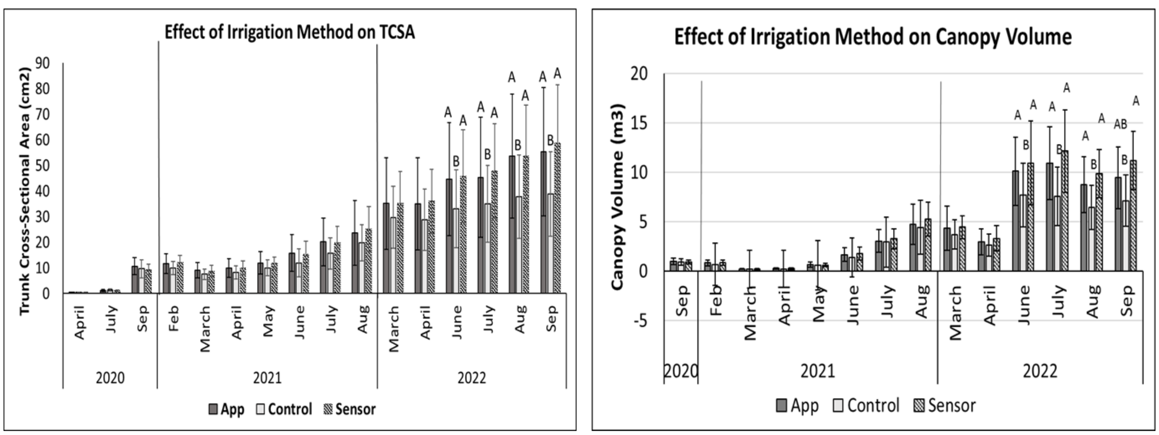



Figure 5.2 Effect of rootstocks ‘Guardian’ and ‘MP-29’ on trunk cross-sectional area (TCSA) and canopy volume (CV) of peach tree cv. ‘Julyprince’, established in 2020 in the UGA Peach Research and Extension Farm, Griffin, Georgia.
Different alphabetical letters above bar represent significant differences, $P \leq 0.05$.

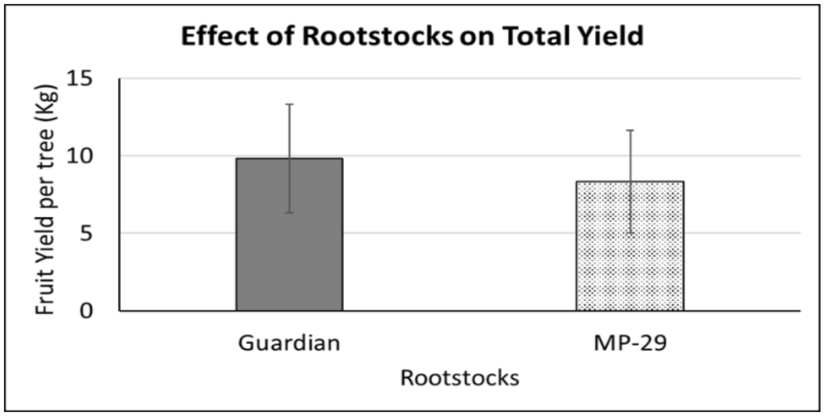



Figure 5.3 Effect of rootstocks (Guardian and MP-29) on total yield of 'Julyprince' cultivar in 2022 in a young peach orchard in Griffin Georgia.

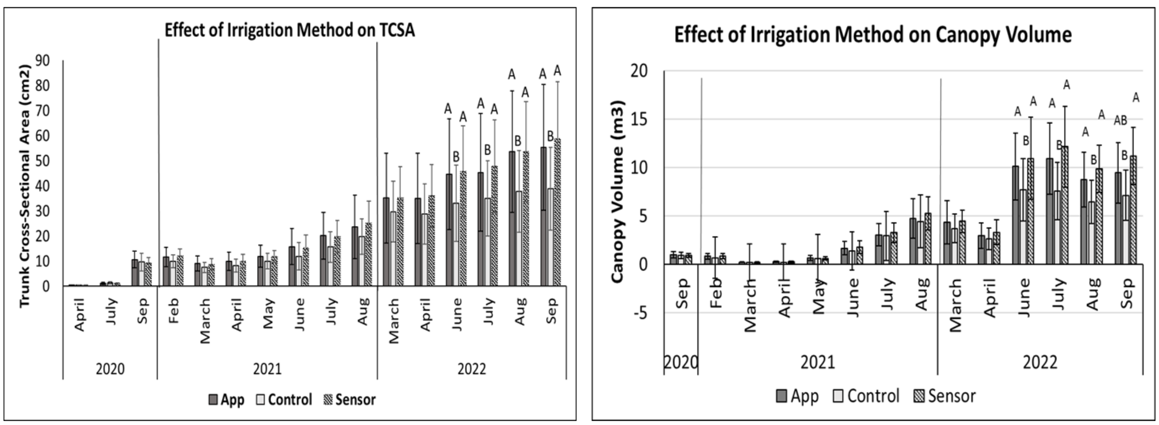



Figure 5.4 Effect of Irrigation methods (App, Control and Sensor) on trunk cross-sectional area (TCSA) and canopy volume (CV) in 2020, 2021 and 2022 in a young peach orchard in Griffin Georgia.
Different alphabetical letters above bar represent significant differences, $P \leq 0.05$.

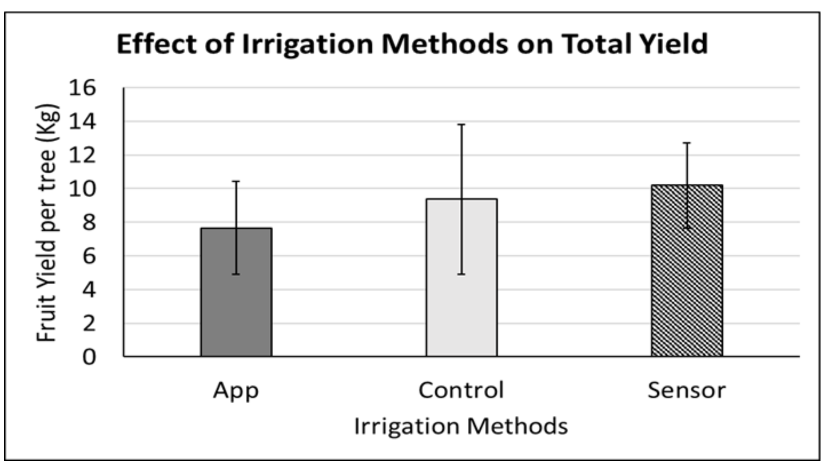



Figure 5.5 Effect of Irrigation scheduling methods (App, control and sensor) on total yield in 2022 in a young peach orchard in Griffin Georgia.

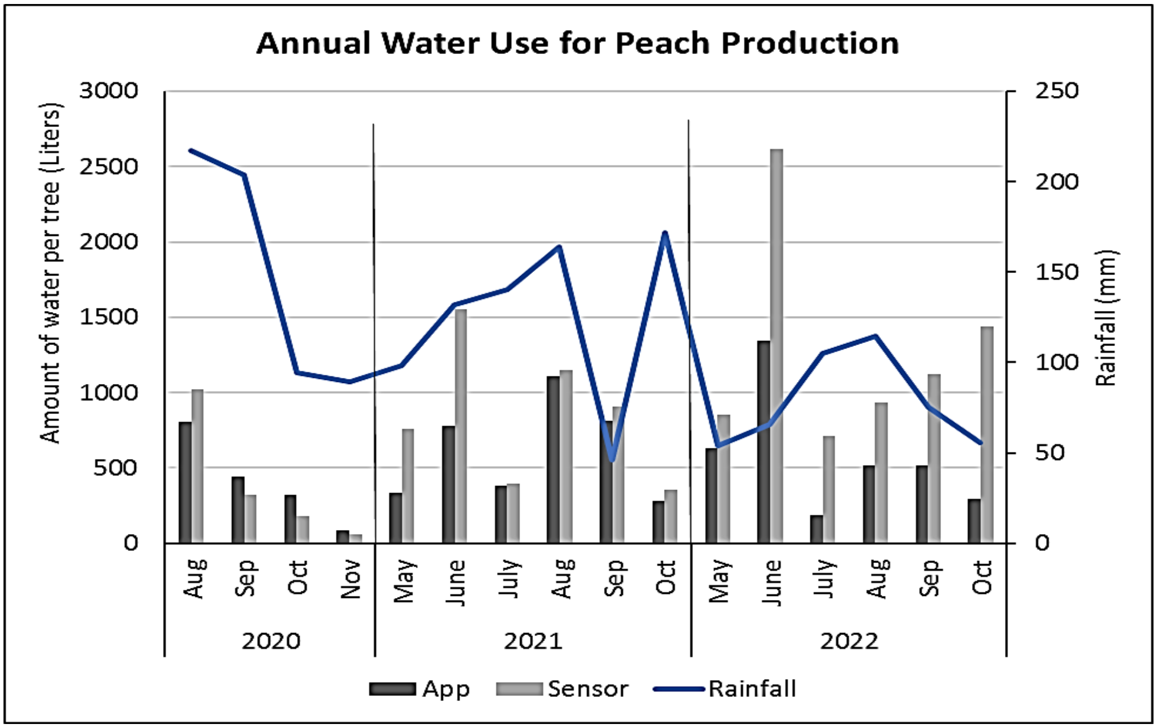



Figure 5.6 Amount of water used by a young peach tree under different irrigation scheduling methods (app and sensor) over the growing season in 2020, 2021 and 2022 in a young peach orchard in Griffin Georgia. Irrigation setup was installed in August 2020 and the values were recorded from that point based on the readings from flowmeter.

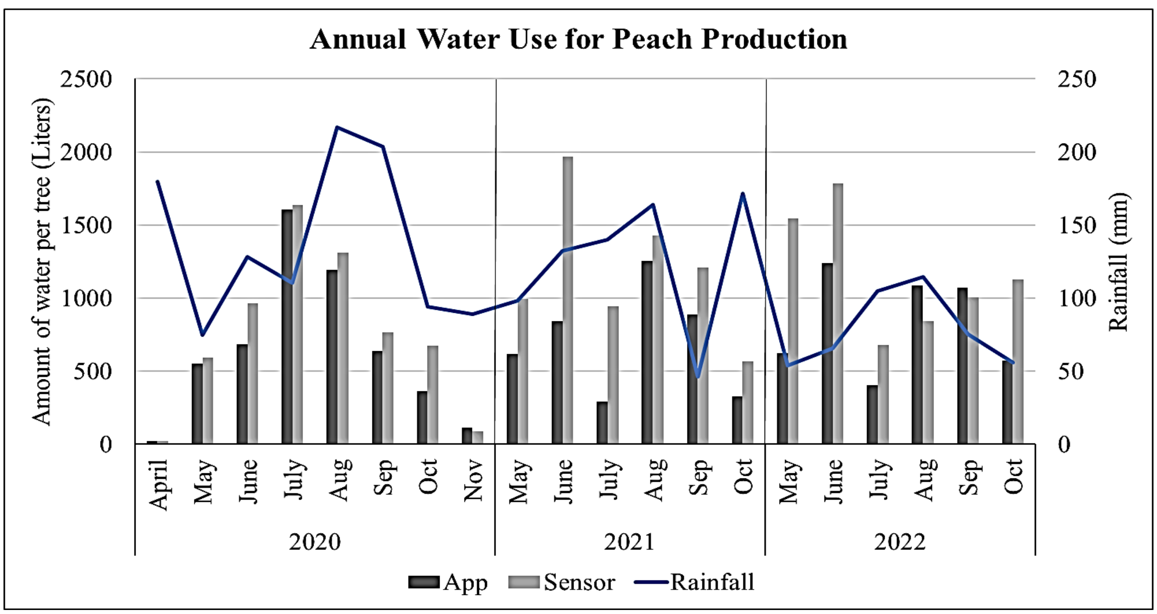



Figure 5.7 Amount of water used by the mature peach trees under different irrigation scheduling methods (app and sensor) over the growing season in 2020, 2021 and 2022 in Griffin Georgia.

## Chapter 6

## CONCLUSION

Recent studies on irrigation and fertilization practices and their impact on peach production have made peach growers in the Southeast aware of their importance for plant growth. In addition, crop loss due to drought incidence has emphasized how a proper irrigation scheduling tool can ensure tree survival and enhance productivity. The traditional practice of not irrigating young peach trees is thus changing gradually. In this study, we investigated the impact of irrigation and fertilization practices on peach production in Georgia and the Southeast US. We developed the SmartIrrigation Peach App, a smartphone-based irrigation scheduling tool, and evaluated its effectiveness in young and mature peach orchards for three consecutive years. We also examined the nutrient uptake and distribution in peach trees and identified factors that affect nutrient allocation within trees.

Our findings suggest that the SmartIrrigation Peach App is an efficient tool for managing irrigation in peach orchards, reducing water usage, and improving crop yield and quality in Georgia. Furthermore, the addition of a national weather data service in the app has widened the geographical footprints of the Peach app, making it a useful tool for the Southeast US. We also recommend reducing the current recommended fertilizer rate for this region, as our results show that the same growth and productivity can be achieved at half the recommended rate. This could help reduce input costs and minimize negative environmental impacts.

Our study also highlighted the importance of nutrient management in peach production. With the new recommendations in terms of irrigation and fertilizer management for Georgia, it was important to understand how they affected the overall nutrient distribution in peach trees. Irrigation with a drip system, despite the method used, enhanced nutrient distribution in peach trees. Increasing the fertilizer rate did not necessarily ensure higher nutrient uptake or distribution. Despite soil nutrient abundance, optimal allocation of nutrients to trees was not always achieved, resulting in deficiencies in micronutrients that can negatively impact fruit yield and quality. We thus recommend optimal irrigation, treating excess calcium in the soil, using the foliar application of immobile micronutrients, and investigating the rootstock's parameters in response to nutrient uptake.

Overall, our study provides valuable recommendations for sustainable peach production in Georgia and the Southeast US. By implementing these practices, growers can improve water and nutrient management, reduce costs, and produce high-quality fruit while minimizing environmental impact.