

Clemson University

TigerPrints

All Theses

Theses

8-2022

The Influence of Water Stress and Rootstocks on Nutrient Uptake and Gas Exchange of Young Peach Trees

Naif Alshammari
nfalsha@g.clemson.edu

Follow this and additional works at: https://tigerprints.clemson.edu/all_theses



Part of the [Agricultural Science Commons](#), [Botany Commons](#), [Horticulture Commons](#), [Other Plant Sciences Commons](#), and the [Plant Biology Commons](#)

Recommended Citation

Alshammari, Naif, "The Influence of Water Stress and Rootstocks on Nutrient Uptake and Gas Exchange of Young Peach Trees" (2022). *All Theses*. 3835.

https://tigerprints.clemson.edu/all_theses/3835

This Thesis is brought to you for free and open access by the Theses at TigerPrints. It has been accepted for inclusion in All Theses by an authorized administrator of TigerPrints. For more information, please contact kokeefe@clemson.edu.

THE INFLUENCE OF WATER STRESS AND ROOTSTOCKS ON NUTRIENT UPTAKE
AND GAS EXCHANGE OF YOUNG PEACH TREES

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Plant and Environmental Sciences

by
Naif Fehaid Alshammari
August 2022

Accepted by:
Dr. Juan Carlos Melgar, Committee Chair
Dr. Sruthi Narayanan
Dr. Dario Chavez

ABSTRACT

Young peach trees are often rainfed in the southeastern U.S. and periods of dry weather can cause tree water deficit that can be detrimental to orchard productivity. There is a lack of understanding of the influence of water regimes and rootstocks on the nutritional status and gas exchange of the peach tree. Most peach growers in Southeastern United States do not irrigate their young peach trees because they do not produce fruit until the third leaf. In this region, peach growers use Guardian as a rootstock, although MP-29 is also interesting for growers with orchards that have Armillaria root rot problems. Nevertheless, growers should understand how both rootstocks uptake nutrients under different water regimes (well-watered conditions or periods of drought stress) to improve tree performance. The experiment was carried out under a screen house at the Musser Fruit Research Farm, located in Seneca, South Carolina, USA. The experiment had a factorial design with two factors: irrigation (well water and drought stress) and rootstock (Guardian and MP-29). All the trees were grown in pots. The first experiment tested the influence of water stress and rootstock on nutritional status of young peach trees and found that nutrient uptake was affected by the main effects of irrigation, rootstock and by their interaction. Over two consecutive years, measuring stem water potential was required to evaluate tree water status throughout the experiment. The interaction between water regime and rootstock showed that drought stress increased the leaf N and K concentrations in trees on MP-29 more than in trees on Guardian, whereas well-watered trees increased leaf Ca and Mg concentration in both MP-29 and Guardian. The second experiment assessed the

effect of water regime and rootstock on gas exchange. Water regime had a significant influence on gas exchange in the two seasons of the study; specifically, drought stress reduced the photosynthesis, leaf transpiration, stomatal conductance, and increased water use efficiency. However, rootstocks or the interaction between water regime and rootstock did not influence gas exchange.

ACKNOWLEDGMENTS

I would like to express my deepest thanks to my advisor, Dr. Juan Carlos Melgar, for being patient with me and helping me to understand and learn. I really appreciate him for his tireless support and guidance from the start of this project until the end. Also, I would like to thank my other committee members, Dr. Sruthi Narayanan and Dr. Dario Chavez, for their cooperation, advice, and motivation to accomplish my degree. Many thanks to Dr. William Bridges for his help with data analysis.

I am thankful to my lab members, Brian Lawrence, Sydney Lykins, and Annie Bruno for their encouragement and support. I would like to thank also my friend Ricardo St Aime, who was always happy to help when I needed him. I want to thank the Clemson University Musser Fruit Research Farm team, especially Luke Dallmann for his help with trees and irrigation management.

I am blessed with a very supportive and loving family. Many thanks to my family for their continuous support and encouragement. I would like to thank each one of them for being so patient with me from the beginning of this journey until the very end.

Finally, I gratefully acknowledge my home university, Jouf University, for offering me a full scholarship through the Saudi Arabian Cultural Mission (SACM).

Thank you, everyone!

TABLE OF CONTENTS

	Page
TITLE PAGE	
ABSTRACT	i
ACKNOWLEDGMENTS	ii
LIST OF TABLES	iii
LIST OF FIGURES	vi
INTRODUCTION	1
CHAPTER	
I. LITERATURE REVIEW	3
Water Deficit in Fruit Tree Production Regions	3
Physiological Effects of Water Stress on Trees	5
Influence of Soil Water Content on Nutrient Availability	8
Role of Rootstocks in Water and Nutrient Uptake	11
Objectives and Hypotheses	12
II. INFLUENCE OF WATER STRESS AND ROOTSTOCK ON NUTRITIONAL STATUS OF YOUNG PEACH TREES	13
Introduction	13
Materials and Methods	14
Results	17
Discussion	38
Conclusion	43

III. INFLUENCE OF WATER STRESS AND ROOTSTOCK ON GAS EXCHANGE OF YOUNG PEACH TREES	45
Introduction	45
Materials and Methods	46
Results	48
Discussion	56
Conclusion	58
REFERENCES	60

LIST OF TABLES

Table		Page
1	The influence of water regime, rootstock, and their interaction on leaf Ca concentration (%) in Fall 2020. The nature of the main effect of the interaction were determined by using LSMeans differences Student. Different letter mean significant differences at $P \leq 0.05$.	22
2	The influence of water regime, rootstock and their interaction on leaf N concentration (%) in Fall 2020. The nature of the main effect of the interaction were determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$.	23

- 3 The influence of water regime, rootstock, and their interaction on leaf K concentration (%) in Spring 2021.
The nature of the main effect of water regime, rootstock and their interactions were determined by using LSMeans differences Student. Different letters mean significant at differences $P \leq 0.05$ 24
- 4 The influence of water regime, rootstock, and their interaction on leaf Mg concentration (%) in Spring 2021. The nature of the main effect of water regime, rootstock and their interactions were determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$. 25
- 5 The influence of water regime, rootstock, and their interaction on leaf Ca concentration (%) in Spring 2021.
The nature of the main effect of water regime, rootstock and their interactions were determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$ 26
- 6 The influence of water regime, rootstock, and their interaction on leaf N concentration (%) in Spring 2021.
The nature of the main effect of water regime, rootstock and their interactions were determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$ 27
- 7 The influence of water regime, rootstock, and their interaction on leaf K concentration (%) in Fall 2021.
The nature of the main effect of water regime, rootstock and their interactions were determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$ 28
- 8 The influence of water regime, rootstock, and their interaction on leaf Mg concentration (%) in Fall 2021.
The nature of the main effect of water regime, rootstock and their interactions were determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$ 29

- 9 The influence of water regime, rootstock, and their interaction on leaf Ca concentration (%) in Fall 2021. The nature of the main effect of water regime, rootstock and their interactions were determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$ 30
- 10 The influence of water regime, rootstock, and their interaction on leaf N concentration (%) in Fall 2021. The nature of the main effect of water regime, rootstock and their interactions were determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$ 31
- 11 The influence of water regime, rootstock, and their interaction on K concentration (%) of dormant tissues (root, portion below the graft union, stem, and one year- old shoots) in winter 2021 and 2022. The nature of the main effect of water regime, rootstock and their interactions were determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$ 32
- 12 The influence of water regime, rootstock, and their interaction on Mg concentration (%) of dormant tissues (root, portion below the graft union, stem, and one year- old shoots) in winter 2021 and 2022. The nature of the main effect of water regime, rootstock and their interactions were determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$ 34
- 13 The influence of water regime, rootstock, and their interaction on Ca concentration (%) of dormant tissues (root, portion below the graft union, stem, and one year- old shoots) in winter 2021 and 2022. The nature of the main effect of water regime, rootstock and their interactions were determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$ 36

- 14 The influence of water regime, rootstock, and their interaction on N concentration (%) of dormant tissues (root, portion below the graft union, stem, and one year- old shoots) in winter 2021 and 2022. The nature of the main effect of water regime, rootstock and their interactions were determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$

37

LIST OF FIGURES

Figure	Page
1 Influence of the interaction water regime and rootstock on SWP throughout fall 2020. Different letters mean significant differences at $P \leq 0.05$. The nature of the main effect of water regime was determined by using LSMeans differences Student.	18
2 Influence of the interaction water regime and rootstock on SWP throughout fall 2020. Different letters mean significant differences at $P \leq 0.05$. The nature of the main effect of water regime was determined by using LSMeans differences Student.	18
3 Influence of the interaction water regime and rootstock on SWP throughout fall 2020. Different letters mean significant differences at $P \leq 0.05$. The nature of the main effect of water regime was determined by using LSMeans differences Student.	19
3 Influence of water regimes on leaf K concentration (%) in Fall 2020. Different letters mean significant differences at $P \leq 0.05$. The nature of the main effect of water regime was determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$	20
4 Influence of water regimes on leaf Mg concentration (%) in Fall 2020.	

	Different letters mean significant differences at $P \leq 0.05$. The nature of the main effect of water regime was determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$	21
6	Influence of water regimes on photosynthesis of young peach trees in Fall 2020. Different letters mean significant differences at $P \leq 0.05$. The nature of the main effect of water regime was determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$	49
7	Influence of water regimes on photosynthesis of young peach trees in Spring 2021. Different letters mean significant differences at $P \leq 0.05$. The nature of the main effect of water regime was determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$	50
8	Influence of water regimes on stomatal conductance of young peach trees in Fall 2020. Different letters mean significant differences at $P \leq 0.05$. The nature of the main effect of water regime was determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$	51
9	Influence of water regimes on stomatal conductance of young peach trees in Spring 2021. Different letters mean significant differences at $P \leq 0.05$. The nature of the main effect of water regime was determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$	52
10	Influence of water regimes on leaf transpiration of young peach trees in Fall 2020. Different letters mean significant differences at $P \leq 0.05$. The nature of the main effect of water regime was determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$	53
11	Influence of water regimes on leaf transpiration of young peach trees	

	in Spring 2021.Different letters mean significant differences at $P \leq 0.05$. The nature of the main effect of water regime was determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$	53
12	Influence of water regimes on water use efficiency of young peach trees in Fall 2020.Different letters mean significant differences at $P \leq 0.05$. The nature of the main effect of water regime was determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$	55
13	Influence of water regimes on water use efficiency of young peach trees in Spring 2021.Different letters mean significant differences at $P \leq 0.05$. The nature of the main effect of water regime was determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$	55
14	Influence of rootstocks on water use efficiency of young peach trees in Spring 2021.Different letters mean significant differences at $P \leq 0.05$. The nature of the main effect of water regime was determined by using LSMeans differences Student. Different letters mean significant differences at $P \leq 0.05$	56

INTRODUCTION

Plant growth and production can be impacted by most environmental factors, including drought and heat, salinity, flooding, or freezing conditions. Some plants are physiologically capable of adapting to increasing stress caused by abiotic factors, other plants may have specific physiological/biochemical traits that allow them to temporarily tolerate stress, and some may have no tolerance at all. Among abiotic stresses, drought stress is one of the most important stresses worldwide as it has a severe influence on plant growth and productivity, and interacts with other factors such as temperature, affecting the availability of water in the soil. Drought stress limits plant growth affects water relations, and plant nutrient availability and uptake. Thus, water deficit is one of the most challenging problems that fruit trees face worldwide. Fruit trees, and specifically peach trees, are sensitive to water deficit and water is not only required for plant and fruit growth but also for nutrient uptake. Furthermore, young peach trees are often rainfed in the southeastern U.S. and, while most of the region has a subtropical humid climate, there are periods of dry weather that can cause tree water deficit that could be detrimental to orchard productivity. Nevertheless, most farmers do not irrigate their young peach trees because young trees do not produce fruits. Another challenge for peach production in the southeastern United States is the presence of diseases, which not affect only the fruit quality but also cause tree decline and death in the Southeastern United States. In the southeastern U.S., most peach growers use Guardian as a rootstock, although MP-29 is also interesting for orchards with Armillaria root rot (ARR) problems. ARR is currently the most relevant threat to peach production and is caused by the fungus *Desarmillaria tabescens* in the Southeastern United States

(Baumgartner, et al. 2011). MP-29 rootstock has improved resistance against ARR and many peach growers realized that peach trees on MP-29 need supplemental irrigation; on the contrary, trees on Guardian rootstock, which does not have resistance against ARR are typically not irrigated until they start producing fruit. Rootstocks may influence tree nutritional status, especially under drought conditions. However, there are no studies that assess the influence of water deficit on the nutritional status of peach trees with different rootstocks. This research will focus on the influence of water stress and rootstocks on tree nutrient uptake and gas exchange performance of young peach trees.

CHAPTER I

LITERATURE REVIEW

Water Deficit in Fruit Tree Production Regions

Fruit trees are grown commercially in countries around the world, and irrigation is a critical practice in most regions, particularly in arid and semiarid regions, but also in regions with subtropical humid climates that provide uneven distribution of rainfall throughout the year. For fruit tree production in arid and semiarid climates, irrigation management is vital to meet the water requirements of fruit trees (Al-Yahyai, 2012). However, the impact of water deficit depends on the region, plant species, duration, and severity of the deficit. For instance, in some arid and semiarid regions, some fruit trees such as olive trees have been traditionally rainfed (Fraga, et al, 2020). However, the growth and production of most fruit species in these regions significantly respond to irrigation (Fereres and Soriano, 2006), and irrigation in fruit production has been shown to increase yields, and to improve fruit quality (Fereres, et al, 2003).

Peach fruit originated in China with humid conditions more than 4500 years ago (Yu, et al, 2018). Currently, most of the peach production around the world comes from Asian and European countries. China is the leader in peach production with around half of the share of the global production followed by Italy and Spain (Habib, 2015). Most of the orchards in China, as well as around the Mediterranean Basin and other areas with Mediterranean-like climates are located in areas where the climate is seasonally dry, affecting trees throughout their vegetative and reproductive cycles to the final stages of

fruit production, and requiring supplemental irrigation (Wang, et al, 2015). Also, market demands requiring fruit size higher than 2.5 inches as well as sporadic dry periods near harvest make supplemental irrigation of mature orchards an absolute need for growers even in areas with subtropical humid climate such as the southeastern U.S., where average annual precipitation is over 50 inches or 1270 mm) (Zhou, et al, 2017). Also, most of the crops in the Mediterranean region have been struggling with drought stress throughout their vegetative and reproductive cycles to the final stages of fruit production, and that is because water is a limited resource (Bronick, and Lal, 2005).

Irrigation is used to avoid periods of water deficit that can affect tree and fruit growth, yield, and fruit quality. Crop water use has two main components: the first one is to compensate for the evaporation losses that happen from the soil and crop, which is called evapotranspiration (ET), and the others resulting from distribution (Feres and Soriano, 2006). Growers can use different irrigation strategies to increase water use efficiency for fruit trees and to avoid water deficit. For instance, in certain stages, regulated deficit irrigation (RDI) is a strategy that restricts irrigation during stages that do not affect fruit growth or yield (Chai, et al, 2016). RDI is used by fruit growers to enhance vegetative, growth, and to improve fruit quality at certain stages of fruit development (Alcobendas, et al., 2013). Nevertheless, most woody fruit trees can hold water between 20 to 30 % of the irrigation water without reducing or declining the crop yield (Chai, et al, 2016).

Physiological Effects of Water Stress on Trees

Water is often seen as the main climate variable that controls the relationship between plants and their environment. Cell growth is first affected by water deficit (Mingeau, et al. 2001). Then, water deficit affects plant growth by reducing carbon accumulation, tissue expansion, and cell number. Plant responses to water deficit are at various levels, depending on the severity and duration of stress, in addition to plant species and growth stages. Understanding plant responses to water deficit is an essential and one of the most important parts of making crops tolerant of drought conditions (Kumar, et al, 2018). When plants are stressed by water deficit in the field, crop yields decrease around 69% (Bray, 2007). Particularly, in peach trees, vegetative growth is very sensitive to water deficiency (Villena, et al, 2010). Water deficit not only reduces vegetative growth but also it decreases the photosynthesis rate of the leaves. However, growth and photosynthesis respond differently to water deficit. As a matter of fact, the most sensitive physiological process to water deficit is growth and it is influenced directly by the plant water status. Whereas the reduction of the photosynthesis that is interacted with stomatal closure occurs later (Rahmati, et al, 2018). Moreover, the regulation of growth in plants occurs first in the cell and second in the organ. Even so, cell division and cell expansion are always affected by water availability. The flux of water into or out of the cell causes the interactions between the wall and the plasma membrane, and changes in membrane tension. To understand the plant-water relations at the cell scale, it is important to know the mechanism of regulating the water flow, which is determined by the water potential across the

membrane. Water potential is influenced by three parameters: pressure potential, osmotic potential, and matric potential.

An important point of water movement is the cell wall, which is a key to water uptake. Another important point of water movement is turgor pressure (hydrostatic pressure). Moreover, this pressure is exerted on a cell wall by the passage of water into the cell by osmosis. Turgor pressure plays a critical role in cell growth because water availability is one of the most important requirements for cell division and cell expansion (Taiz, et al., 2018). However, water deficit influences the growth by affecting the cell size as it will not be fully turgid. The osmotic potential and the turgor pressure are two important parameters for the water potential of the cell (Bray, 2007). In addition, turgor-time is an expression that represents both the growth rate and the transition rates of the individual leaf zones (Coussement, et al., 2021).

Water deficit influences the rate of leaf transpiration efficiency in addition to the stomatal density and photosynthetic capacity (Bray, 2007). Water deficit causes a loss in turgor pressure in the plant cells. As a result, the negative effects of canopy development (shoot growth and leaf expansion) are one of the first responses to water deficit before stomata closure and reduction of photosynthesis. Consequently, this should effectively allow for having more carbohydrates ready for the growth of other organs (Johnson, 2000). The mean reduction in plant canopy development is related to the influence of declining turgor pressure, which is represented by cell expansion. As result, cell expansion would be limited by the restriction of water availability which can consequently reduce cell division. However, reducing the growth during the first duration of water deficit is directly related to water status but unrelated to carbon

availability (Woodruff and Meinzer, 2011). Also, during a water deficit period, the root system synthesizes abscisic acid (ABA), which is transported in the xylem to the shoot, where it restricts leaf expansion and induces stomatal closure before detectable changes in leaf water status (Lipiec, et al, 2013). Water deficit also affects the fruit. Overall, in a short period of water deficit, peach fruit growth will be limited by two mechanisms: the first one is the effect of cellular stress on growth by the influence of water stress; the second one is due to carbohydrate reduction in plant tissues due to reduced photosynthesis (Lopez, et al., 2006).

As a result of water deficiency, guard cells control the closure of the stomata, however, it is necessary to optimize water use efficiency and CO₂ absorption by leaves (Gayatri, et al., 2013). Stomata act as channels to control gas exchange and moisture loss. Stomatal closure is mediated by the influx of water and solutes such as K⁺ into the guard cells, and stomata closure is mediated by the efflux of water and solutes (Murata, et al., 2015). Water status (as well as other environmental factors such as light intensity, and CO₂ concentration) play a key role in stomatal aperture (Hetherington and Woodward, 2003). In addition to the influence of water deficit on stomatal movement, there are endogenous factors, like reactive oxygen species (ROS), Ca²⁺, and ABA. These factors will respond differently and that is based on the environmental conditions such as drought (Junsheng, et al., 2018).

Stomatal closure leads to reduced transpiration, which guides to reduced CO₂ assimilation and influences the photosynthesis rate. As a consequence of stomatal closure and reduction in the CO₂ assimilation, water deficit results in biochemical, enzymatic, and metabolic changes. However, the photosynthetic responses to water

deficit are complex, involving different morphological and physiological processes at additional time and growth stages. The intensity, duration, and rate of progression of water deficit have an impact on photosynthetic responses. Water deficit impairs photosynthesis by reducing the availability of carbon dioxide to chloroplasts through stomatal and mesophyll restrictions. As a result of the drought stress, the Calvin–Benson cycle reactions are affected, limiting photosynthetic metabolism. The CO₂ assimilation by the Calvin–Benson reactions is the main source for the NADPH and ATP, delivered by the photosynthetic electron transport (Lima Neto, et al, 2017). Furthermore, water stress damages the essential organizational structure, by reducing carbon assimilation and damaging the photosynthetic apparatus. When plants absorb more light energy than can be consumed by photosynthetic carbon fixation, the excess of light leads to production of ROS, which is critical for the plant's cellular metabolism (Wang, et al, 2018). However, different environmental stresses such as water deficit lead to excessive production of ROS, oxidative damage, and consequently, cell death (Sharma, et al, 2012).

Influence of Soil Water Content on Nutrient Availability

Nutrient availability depends on physical, chemical, and biological soil factors such as pH (Corey, 1990), cation exchange capacity (Jia, et al. 2021), or microbial soil life (Zhong, et al., 2015). While some studies have shown the importance of soil water content (SWC) on plant nutrient uptake, research on the effect on fruit trees is less common. However, many studies have proven that SWC is primarily dependent on precipitation, temperature (Yuste, et al, 2003), and soil characteristics (Soltani, et al, 2018). The interaction between the fluctuating SWC and soil nutrient availability is

poorly understood, which is essential for the nutritional status of plant growth. It has been found that SWC is playing a critical role in increasing or reducing certain nutrients, as well as SWC is affecting the interaction between nutrient cycles and the availability of microorganisms by affecting microbial biomass (Xue, et al, 2017). However, reducing the concentration of any essential element can cause problems in tree health which influences fruit quality, vegetative growth, and production (Layne and Bassi, 2008).

Consequently, soil moisture affects nutrient availability and nutrient uptake through physico-chemical processes and biological processes (Li, et al., 2020). However, very few studies have shown the overlap between physicochemical and biological functions because of the similarity in effect. Among the first ones, the most important impact is on mineralization (Francisco, et al., 2017). For instance, N is the most sensitive nutrient to soil moisture. Furthermore, soil moisture influences the rate of net nitrogen mineralization (Gutiñas, et al, 2012). Also, phosphorus is the second most sensitive nutrient to the soil moisture. Nevertheless, nitrogen and phosphorus are playing a fundamental role in regulating plant biomass production (Menegatti, et al, 2020). In contrast, among biological processes, soil moisture affects root exudation, root growth, and the soil microbial community (Monokrousos, et al., 2019). Microorganisms have important factors for soil quality of both nutrient availability and nutrient cycling (Chen, et al., 2007). For example, microorganisms increase the availability of accumulated phosphorus for growth and plant development. Also, microorganisms improve the efficiency of nitrogen fixation and increase the availability

of other elements and, consequently, enhance growth and plant development (Gyaneshwar, et al., 2002).

The nutrient concentrations of all plant tissues result from their absorption, translocation, and redistribution; however, all these processes are results of the interactions that happen between soil conditions and the root system. Moreover, roots do not only influence nutrient concentrations or water movement, but also it will influence plants' resistance to pathogens (Casamali, et al ,2021), and the availability and distribution of inorganic nutrients in the soil (Forde and Lorenzo, 2002). Also, the interaction between the root system and nutrient availability in soil influences root development processes such as branching, hair production, diameter, growth angle, and nodulation.

Lowering SWC can reduce the rate of diffusion of nutrients from the soil matrix to the absorbed root surface. Moreover, macronutrients such as Ca, N, K, and Mg are taken by the plant through mass flow from the soil solution to the xylem via the transpiration flow. When the plant has absorbed N, K, and Mg, the next process will be redistribution through the phloem. On the other hand, calcium is sensitive to low phloem mobility, and that is why the capacity for redistribution is very limited. Thus, the interaction between SWC and plant water status can play an important role in the translocation of plant nutrients, and any period of water stress will influence this interaction by impacting the transpiration rates and affecting the allocation of mineral nutrients from the root system to other plant tissues (Valverdi, et al, 2019).

Role of Rootstocks in Water and Nutrient Uptake

The rootstock constitutes the lower part of a grafted tree and includes the root system of the tree. Rootstocks are commonly used in fruit trees to control vegetative vigor and provide tolerance to abiotic and biotic factors that would prevent a commercial cultivar from successfully producing high yields of quality fruit. Rootstocks can influence root and shoot hydraulic conductance, which will impact water transport to the shoot, ultimately affecting stomatal conductance, photosynthesis, and shoot growth. The role of rootstocks on water and nutrient uptake has also been studied for decades (Casamali, et al ,2021) and has been reported to have a significant impact on growth, quality, and fruit production (Fazio et al. 2013).

Understanding the effect of rootstocks will lead to knowing the influences on tree adaptability, production, fruit quality, and nutritional status of peach trees. Also, the role of rootstocks responds differently to unstable irrigation conditions and fertilization systems (Giorgi, et al., 2005). Rootstock can improve the fruit quality in different ways such as the uniformity of size and shape, firmness, and maturity. However, every rootstock has a different potential for water and nutrient uptake, and many studies have shown that root size, length, and distribution influence the water and nutrient uptake. Knowledge of the effect of rootstock on the nutritional status of peach trees and peach quality and, specifically, the effect of the interaction of rootstocks with water deficit is limited. Understanding rootstock genotypes and their roles in nutrient uptake under water deficit conditions could lead farmers to know how

much fertilizer they should apply, what kind of fertilizers, and when according to the tree nutritional needs (Fazio et al., 2013).

The variety and the size of roots and rootstocks are the most important factor for water and nutrient uptake (Savvas, et al, 2017). Many studies have shown that root size, length, and distribution influence the water and nutrient uptake, which can affect the diameter of rootstock size. Also, root water absorption is based on plant species because of the differential activity of superficial and deep roots (Leuschner, et al. 2004). In addition, while grafting is commonly used to improve disease resistance, it could be the choice to enhance water and nutrient uptake to those not resistant to water deficit and high temperature (Ismael, et al, 2020).

Objectives and Hypotheses

The objectives of this study were to determine the influence of water regime and rootstock on the concentration of nutrients in leaf and dormant tissues, and gas exchange of young peach trees. My hypotheses were that water stress and rootstocks with lower vigor (MP-29) reduce the concentration of nutrients in plant tissues such as root, rootstock, stem, shoot, and leaves compared to well-watered trees and those on vigorous rootstocks, and that vigorous rootstocks (Guardian) can have a higher gas exchange than rootstocks with lower vigor even under conditions of water stress.

CHAPTER II

THE INFLUENCE OF WATER STRESS AND ROOTSTOCK ON THE NUTRITIONAL STATUS OF THE YOUNG PEACH TREES

Introduction

In the southeastern United States, young peach trees are mostly rainfed and even a short period of dry weather can cause tree water deficit that can be detrimental to orchard productivity and growth. The interaction between water regimes and rootstocks and their influence on the nutritional status of the peach trees is not clear yet. Previous studies have shown that irrigation management and rootstock improve the efficiency of nutrient uptake, accumulation, distribution and use in plant tissues (Aline et al. 2019). However, some rootstocks may reduce the nutrient uptake, concentration, and content during the water deficit; on the contrary, some cultivars have shown that nutritional status increases during the dry period. The role of rootstocks under the drought condition may improve the nutrient uptake; however, it could reduce the growth, development, and fruit production. Selecting the proper rootstock is the most important point to avoid the reduction of water and nutrient uptake. In this experiment, we studied the influence of two water regimes (well-watered trees and drought stress), and their influence on the nutritional status of three-year-old 'Scarletprince' peach trees grafted onto two different rootstocks (Guardian or MP-29).

Materials and Methods

Study Establishment, Location, and Design

This experiment was conducted between fall 2020 and spring 2022 seasons. A total of 60 three-year old 'Scarletprince' peach trees grafted onto two rootstocks (30 on Guardian and 30 on MP-29) were grown in 19.5-L pots containing a mixture of 2:1 potting soil Fafard 3B (Sun Gro, Agawam, MA): sand, and 3.5 g L⁻¹ of lime and 3.5 g L⁻¹ Osmocote 14-14-14. The experiment was carried out under a screen house at the Musser Fruit Research Farm, located in Seneca, South Carolina, USA. The experiment had a factorial design with four treatments, as a result of the combination of two irrigation regimes [well-watered trees (WW) or drought stressed trees (DS)] and two rootstocks [Guardian (G) and MP-29 (M)]. Thus, there were 15 trees in each of the four treatments: WWM, WWG, DSM and DSG. In Fall 2020, evapotranspiration was calculated gravimetrically before the experiment started, and irrigation regimes were set at either 1.5 L/day (WW) or 1 L/day (DS). However, these irrigation regimes were not kept throughout the experiment time (two years). The experiment was exposed to rain and temperature fluctuations. To reduce the influence of rain events, the pots of DS trees were covered with aluminum plates to avoid rainwater. Before spring 2021, trees were transplanted to 7 gallon (26.5 L) pots (lime and fertilizer was added at the same proportion as described before). In addition, during winter, the irrigation regimes were shut off due to the dormancy. After blooming, the irrigation regimes were turned on, all the fruits were thinned in late April. In Spring and Fall 2021, irrigation was shut off for all the treatments when there was heavy rain (more than 12.2 mm/ day). Irrigation of drought stressed trees was cut in half if there was

light rain (less than 12.2 mm/day). After heavy rainfall in spring 2021 and 2022, measurements and plant samplings were stopped until tree water status measurements were indicating that there was a difference between the well-watered trees and the drought stress. After collecting the leaves samples for Spring nutrients analysis, WW and DS trees were all well-watered until late summer. In Fall 2021, the baseline irrigation in the DS trees was decreased to 0.25 L/day whereas, WW trees got the same amount (2 L/day).

Leaf nutrient analysis

Leaf nutrient analyses were performed throughout the three seasons of the experiment (fall 2020, spring 2021 and fall 2021). Samplings were taken at four different dates in fall 2020, six dates in spring 2021, and four dates in fall 2021. At each sampling, three bags containing 10 to 12, randomly chosen, fully formed 4th - 5th node leaves, were collected per treatment. In preparation for leaf analyses, leaves were washed in distilled water, kiln dried for at least three days at 70°C, and ground to powder. 0.25 g of the ground leaves was burned at 600°C in a muffle furnace (LE4/11 RC, Nabertherm®, Lillienthal, Germany) between 12 to 16 hours and, when samples cooled down, nutrients were extracted by adding 10 mL of 0.1 M HCl. The solution was filtered using ashless filter paper (Whatman grade 42, Cytiva, Marlborough, MA, USA), and appropriate dilutions were prepared for each element. Calcium (Ca), magnesium (Mg), and potassium (K) were measured with an atomic absorption spectrophotometer (PinAAcle 500, PerkinElmer, Waltham, MA, USA). The method for analyzing the concentration of Ca, Mg and K was identical to Zhou and Melgar (2020). In addition, 0.1 g of subsample was used

for analyzing the total N concentration using a revised Dumas method (Harry and Jones, 1991) at the Clemson University's Agricultural Service laboratory.

Dormant tissue nutrient analysis

At the end of fall 2020 and fall 2021, when trees were dormant and have lost all their leaves, two and four trees per treatment, respectively (two in fall 2020, four in fall 2021), were selected and harvested. Each tree was separated into shoots, stem, rootstock (tissue below the graft union but above the soil) and roots. Roots were carefully to clean to remove all soil particles. Tissues were cut into pieces and placed in a dryer for two weeks at 70°C. Samples were ground to powder using a Wiley mill (Model 4, Thomas Scientific, Swedesboro, NJ, USA) and nutrient concentration were analyzed as described above for leaf nutrient analysis.

Tree water status

Tree water status was measured throughout the experiment to understand the level of water stress. Tree water status was measured by determining midday stem water potential (SWP) at solar noon (13:00-14:00 h) using six mature, fully developed leaves per treatment. Measurements were taken once every two weeks during the three seasons unless it had rain or that date fell immediately after a change in irrigation. Leaves were enclosed in reflective plastic bags for at least one hour before the measurements. After an hour in the foil wrapping the leaf water potential was equalized with the stem water potential and measurements were taken by placing the leaf in a

pressure chamber (PMS 600, PMS Instruments, Albany, OR, USA) with the cut petiole exposed (Scholander et al., 1965; McCutchan and Shackel, 1992).

Statistical Analysis

The statistical analyses of the study followed a factorial design with two factors, the irrigation regime and the rootstock. The effect of the factors or the interaction of factors on the parameters measured were analyzed using analysis of variance (ANOVA). Comparison between treatments was performed using LSMeans Student's t. Data were analyzed by using JMP® statistical software (Version 16.0.0; SAS institute, Cary, NC).

Results

Tree water status

In Fall 2020 the stress was light (or mild), however, in Spring and Fall 2021 the drought stress trees received less water than before, and the difference in tree water status between WW and DS trees was clear in the second and third season of the experiment. When MP-29 and Guardian were under the drought stress, Guardian showed higher stem water potential than MP-29 In Spring and Fall 2021 ($F = 4.51$, $P \leq 0.0045$; $F = 41.06$, $P \leq 0.0001$). In contrast with well-watered trees MP-29 and Guardian were no different.

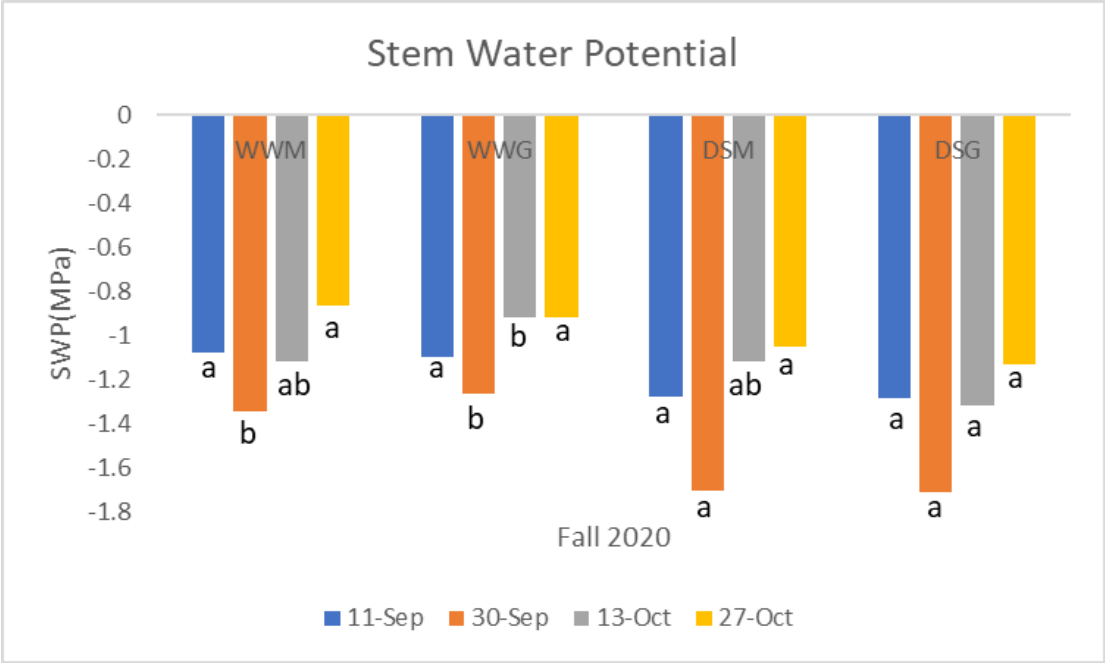


Figure 1. Influence of the interaction water regime and rootstock on SWP throughout fall 2020. Different letters mean significant differences at $P \leq 0.05$.

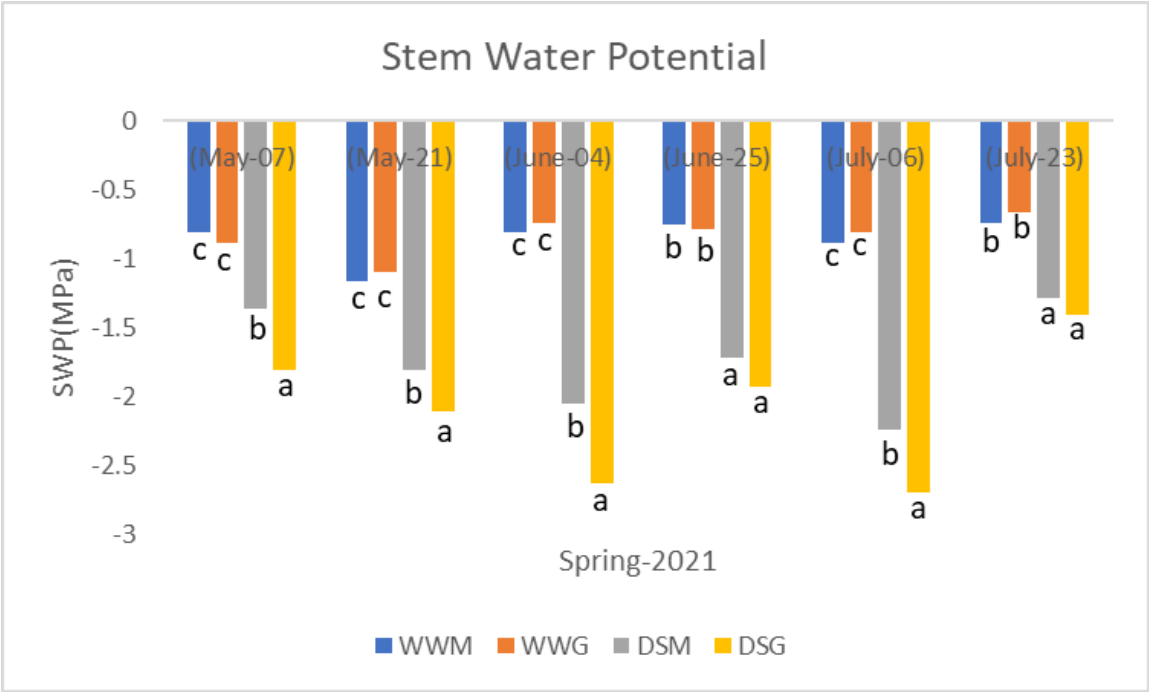


Figure 2. Influence of the interaction water regime and rootstock on SWP throughout spring 2021. Different letters mean significant differences at $P \leq 0.05$.

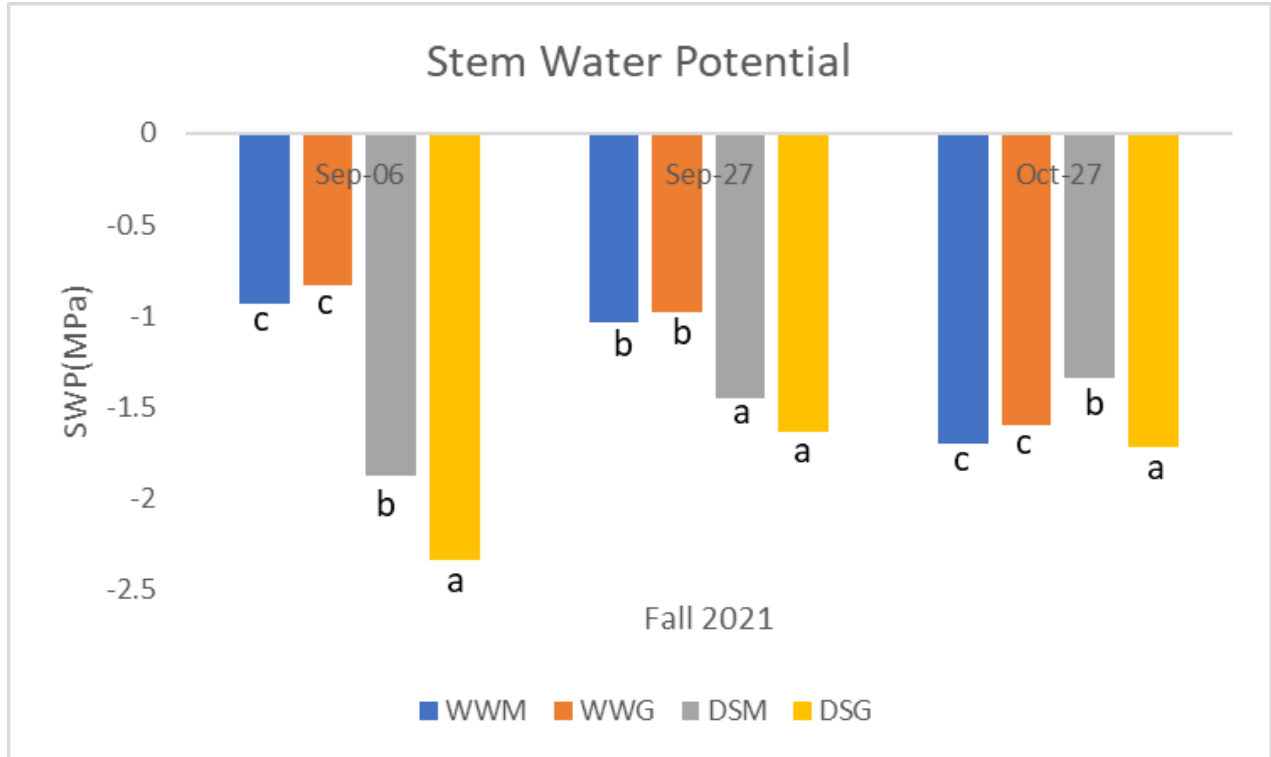


Figure 3. Influence of the interaction water regime and rootstock on SWP throughout fall 2021. Different letters mean significant differences at $P \leq 0.05$.

Leaf nutrients. Fall 2020

In Fall 2020, when the water stress was lighter, the effect of irrigation regime on leaf K concentration was significant only in two of the four measurements taken, specifically the first ($F = 10.74$, $P \leq 0.0066$) and fourth ($F = 5.40$, $P \leq 0.0384$) measurements (Fig. 1). On the first date of the experiment in fall 2020, there was a difference among the four treatment combinations in K concentrations due to the effect of the irrigation ($F = 5.79$, $P \leq 0.0109$). Also, in the last date of the experiment, the main effect of the irrigation showed a significant effect on K concentration ($F = 3.78$, $P \leq 0.0403$). Overall, well-watered trees tended to have a higher K leaf concentration than those from drought

stress. In addition, drought stress reduced K leaf concentration, whereas the well-watered treatment increased it. Lastly, there was not a significant influence of the rootstock or its interaction with irrigation.

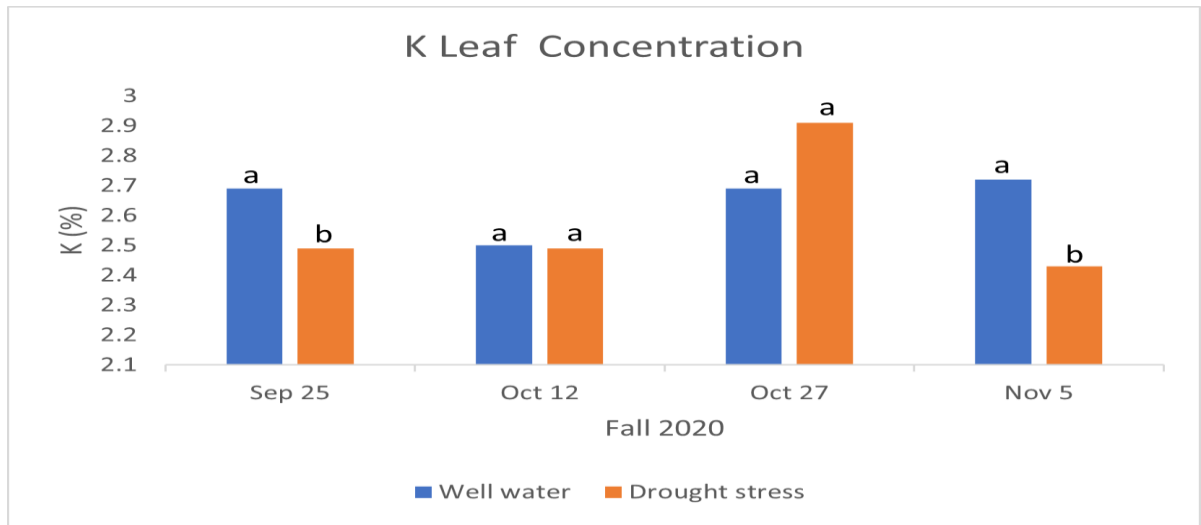


Figure 4. Influence of water regimes on leaf K concentration throughout fall 2020. Different letters mean significant differences at $P \leq 0.05$.

Leaf Mg concentration was not affected by the interaction of water regime and rootstock in Fall 2020. However, well-watered trees had lower leaf Mg concentrations than drought-stressed trees in two of the four measurements, specifically on the second and fourth dates ($F = 11.10$, $P \leq 0.0009$; $F = 46.41$, $P \leq 0.0001$, respectively). However, in the fourth date the influence of the differences was from irrigation regime, rootstock, and the interaction of both factors. The main effect of irrigation was significant ($F = 95.93$, $P \leq 0.0001$), the main effect of rootstock was also significant ($F = 34.43$, $P \leq 0.0001$), in addition the interaction of rootstock and irrigation was significant ($F = 8.88$, $P \leq 0.0115$).

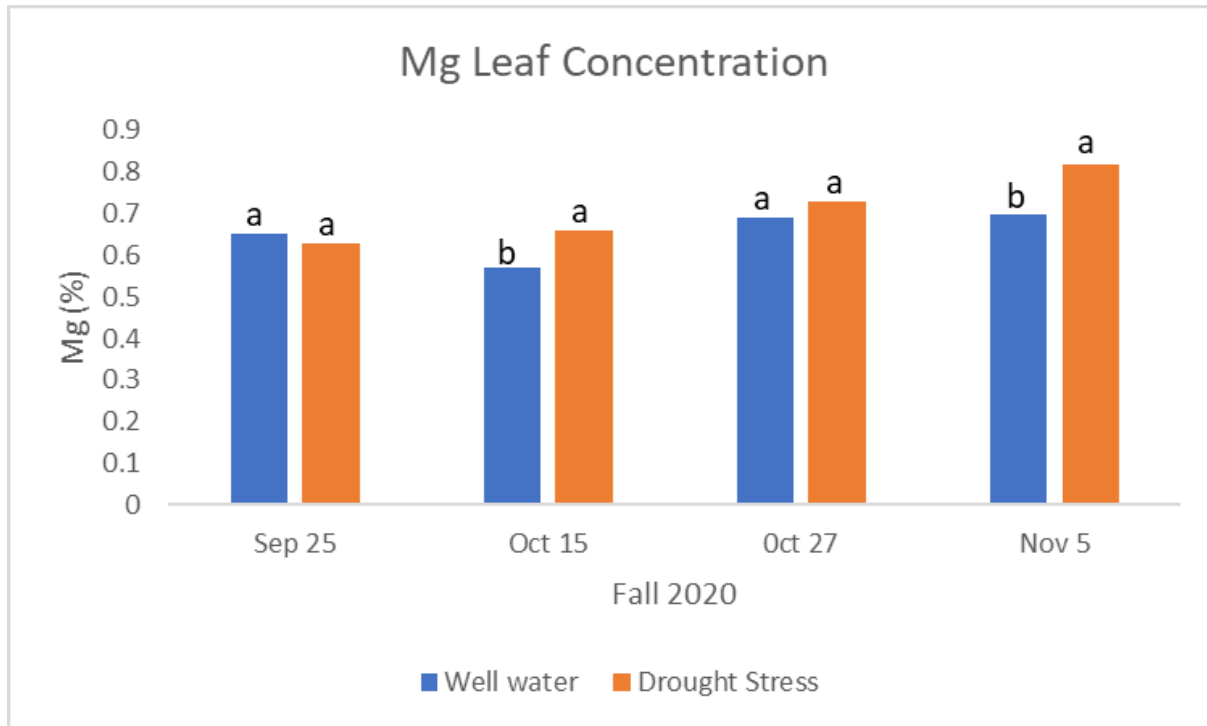


Figure 5. Influence of irrigation regime on leaf Mg concentration in Fall 2020. Different letters mean significant differences at $P \leq 0.05$.

Leaf Ca concentration was influenced by the interaction between irrigation and rootstock in three out of the four different dates (Table 1). Trees on Guardian tended to have higher leaf Ca concentration than trees on MP-29 when they were well-watered; however, there were no clear differences when trees were drought-stressed (trees on MP-29 showed higher leaf Ca values for one of the measurements; no differences found for the other dates). The main effect of the interaction occurred in the first ($F = 7.11$, $P \leq 0.0205$), second ($F = 5.80$, $P \leq 0.0330$), and fourth date of 2020 ($F = 4.79$, $P \leq 0.0490$). However, there was no influence of single factors (water regime or rootstock) for any date.

Table 1. Influence of water regime, rootstock, and their interaction on leaf Ca concentration (%) in Fall 2020.

Main effect	Ca %			
	Date 1	Date 2	Date 3	Date 4
	Water regime			
Well-watered			2.20a	
Drought stress			2.23a	
	Rootstock			
MP-29			2.14a	
Guardian			2.29a	
	Water regime x Rootstock			
Well-watered MP-29	1.30b	1.46b		1.69b
Well-watered Guardian	1.75a	1.52b		2.06a
Drought stress MP-29	1.75a	1.79a		2.08a
Drought stress Guardian	1.80a	1.61b		2.18a

Different letters mean significant differences at $P \leq 0.05$.

Leaf N concentration was influenced by the interaction between water regime and rootstock only in the second part of the season (third and fourth measurement ($F = 11.44$, $P \leq 0.0008$; $F = 9.64$, $P \leq 0.0016$, respectively; Table 2). Specifically, trees on MP-29 had higher leaf N concentration than those on Guardian when they were drought-stressed; however, they had similar or lower leaf N when they were well-watered. The interactions occurred in the third and fourth date ($F = 19.33$, $P \leq 0.0009$, $F = 9.64$, $P \leq 0.0016$). However, the interaction of the fourth date had higher impact on N leaf concentration than the third date ($F = 22.65$, $P \leq 0.0005$).

Table 2. Influence of water regime, rootstock, and their interaction on leaf N concentration (%) in Fall 2020.

Main effect	N%			
	Date 1	Date 2	Date 3	Date 4
	Water regime			
Well-watered	2.70a	2.53a		
Drought stress	2.70a	2.41a		
	Rootstock			
MP-29	2.71a	2.41a		
Guardian	2.72a	2.54a		
	Water regime x Rootstock			
Well-watered MP-29			2.36b	2.58bc
Well-watered Guardian			2.39b	2.75a
Drought stress MP-29			2.58a	2.66ab
Drought stress Guardian			2.29b	2.52c

Different letters mean significant differences at $P \leq 0.05$.

Spring 2021

In Spring 2021, leaf K concentrations were significantly influenced by the interaction between irrigation and rootstock in four of the six measurements taken. Drought stress increased leaf K concentration in MP-29 more than in Guardian (Table 3); however, well-watered trees on both rootstocks had comparable K concentrations (with the exception of the very last measurement, when MP-29 showed higher leaf K concentration than Guardian). Throughout the experiment in Spring 2021, drought-stressed trees had higher leaf K concentration than well-watered trees, and trees on MP-29 had higher leaf K concentration than those on Guardian rootstock.

Table 3. Influence of water regime, rootstock, and their interaction on leaf K concentration (%) in Spring 2021.

Main effect	K%					
	Date 1	Date 2	Date 3	Date 4	Date 5	Date 6
	Water regime					
Well-watered				3.19b		2.97b
Drought stress				3.92a		3.73a
	Rootstock					
MP-29				3.75a		3.56a
Guardian				3.36b		3.14b
	Water regime x Rootstock					
Well-watered MP-29	2.83b	2.79c	2.87c		3.17a	
Well-watered Guardian	2.79b	3.01c	2.81c		2.44b	
Drought stress MP-29	3.43a	3.71a	3.58a		3.36a	
Drought stress Guardian	2.97b	3.32b	3.23b		3.64a	

Different letters mean significant differences at $P \leq 0.05$.

Trees on MP-29 had lower leaf Mg concentration than trees on Guardian when they were well-watered (Table 4). However, when trees were under drought stress, leaf Mg concentration in trees on both rootstocks were comparable, with the exception of the second measurement, when MP-29 had a lower leaf Mg concentration ($F = 45.69$, $P \leq 0.0001$ for the second date; $F = 9.27$, $P \leq 0.0102$ for the fifth date; $F = 20.56$, $P \leq 0.0007$ for the sixth date). When there was no interaction, water regime did not influence leaf Mg concentration; nevertheless, trees on MP-29 had lower leaf Mg concentration than trees on Guardian on two dates (measurements two and three).

Table 4. Influence of water regime, rootstock, and their interaction on leaf Mg concentration (%) in Spring 2021.

Main effect	Mg %					
	Date 1	Date 2	Date 3	Date 4	Date 5	Date 6
	Water regime					
Well-watered	0.38a		0.44a	0.49a		
Drought stress	0.39a		0.46a	0.53a		
	Rootstock					
MP-29	0.37a		0.42b	0.48b		
Guardian	0.40		0.48a	0.54a		
	Water regime x Rootstock					
Well-watered MP-29			0.32c			0.45b 0.54c
Well-watered Guardian			0.48ab			0.57a 0.64a
Drought stress MP-29			0.45b			0.52a 0.61ab
Drought stress Guardian			0.50a			0.54a 0.56bc

Different letters mean significant differences at $P \leq 0.05$.

Leaf Ca concentration was influenced by the interaction of water regime and rootstock in half of the dates when samples were collected (Table 5). Trees on Guardian had higher leaf Ca concentrations than those on MP-29 when trees were well-watered. However, trees on Guardian and MP-29 have similar (or only slightly higher) concentrations when they were water-stressed ($F = 99.83$, $P \leq 0.0001$, $F = 124.61$, $P \leq 0.0001$, $F = 9.22$, $P \leq 0.0103$). On the third and fifth measurement dates, there were some effects of single factors (water regime and rootstock) on leaf Ca, but they were not conclusive as their influence were different for each date.

Table 5. Influence of water regime, rootstock, and their interaction on leaf Ca concentration (%) in Spring 2021.

Main effect	Ca%					
	Date 1	Date 2	Date 3	Date 4	Date 5	Date 6
	Water regime					
Well-watered			1.23a		1.37b	1.59a
Drought stress			1.13b		1.52a	1.59a
	Rootstock					
MP-29			1.14a		1.36b	1.59a
Guardian			1.22a		1.53a	1.59a
	Water regime x Rootstock					
Well-watered MP-29	0.58c	0.75c		0.93c		
Well-watered Guardian	1.02a	1.20a		1.27b		
Drought stress MP-29	0.88b	1.11a		1.49a		
Drought stress Guardian	0.95ab	1.24a		1.43a		

Different letters mean significant differences at $P \leq 0.05$.

The effect of the interaction of water regime and rootstock on leaf N concentration occurred in four different dates in spring 2021 (Table 6). Drought stressed trees had higher leaf N concentration than well-watered ones; when trees were well-watered, those on MP-29 rootstock had higher leaf N than those on Guardian for the four sample dates, but when they were drought stressed, trees on MP-29 had higher leaf N concentration than trees on Guardian only at half of the sampling times and there were no differences the other times. When there were no interactions, water stressed trees had higher leaf N concentration than well-watered trees, and trees on MP-29 also had higher leaf N concentration than those on Guardian rootstock ($F = 12.71$, $P \leq 0.0005$, $F = 40.48$, $P \leq 0.0001$).

Table 6. Influence of water regime, rootstock, and their interaction on leaf N concentration (%) in Spring 2021.

Main effect	N%					
	Date 1	Date 2	Date 3	Date 4	Date 5	Date 6
	Water regime					
Well-watered	3.71b		3.10b			
Drought stress	3.93a		3.75a			
	Rootstock					
MP-29	3.98a		3.64a			
Guardian	3.66b		3.22a			
	Water regime x Rootstock					
Well-watered MP-29	3.27c		3.28c		3.05a	2.94b
Well-watered Guardian	3.12d		2.68d		2.54b	2.53c
Drought stress MP-29	4.08a		3.88a		3.33a	3.41a
Drought stress Guardian	3.73b		3.46b		3.34a	3.34a

Different letters mean significant differences at $P \leq 0.05$.

Fall 2021

In Fall 2021, drought stress trees on both rootstocks had a similar leaf K concentration, and similar to well-watered trees on MP-29, but well-watered trees on Guardian had a lower leaf K concentration than the other three treatments (Table 7). This effect was seen only on the third ($F = 10.45$, $P \leq 0.0012$), ($F = 63.33$, $P \leq 0.0001$) but not during the first two measurements ($F = 1.75$, $P \leq 0.2095$), ($F = 2.01$, $P \leq 0.1662$). In the last (fourth) measurement date, drought-stressed trees had a higher leaf K concentration than well-watered trees ($F = 24.43$, $P \leq 0.0003$), and trees on MP-29 had a higher leaf K concentration than trees on Guardian ($F = 165.39$, $P \leq 0.0001$).

Table 7. Influence of water regime, rootstock, and their interaction on leaf K concentration (%) in Fall 2021

Main effect	K%			
	Date 1	Date 2	Date 3	Date 4
	Water regime			
Well-watered	3.33a	3.38a		4.04b
Drought stress	3.65a	3.67a		4.44a
	Rootstock			
MP-29	3.64a	3.69a		4.76a
Guardian	3.34a	3.36a		4.72b
	Water regime x Rootstock			
Well-watered MP-29			4.18a	
Well-watered Guardian			3.16b	
Drought stress MP-29			4.36a	
Drought stress Guardian			4.08a	

Different letters mean significant differences at $P \leq 0.05$.

The interactions of irrigation and rootstock on Mg leaf concentrations were significantly different in the second and third date ($F = 24.21$, $P \leq 0.0004$; $F = 109.34$, $P \leq 0.0001$, respectively; Table 8). Well-watered trees on Guardian had a higher leaf Mg concentration than the other three treatments; however, drought stress on Guardian showed the lowest leaf Mg concentration. MP-29 on both treatments had a similar leaf Mg concentration. Well-watered trees of both rootstocks had a higher concentration than the drought stress in the first date ($F = 66.11$, $P \leq 0.0001$).

Table 8: Influence of water regime, rootstock, and their interaction on leaf Mg concentration (%) in Fall 2021

Main effect	Mg%			
	Date 1	Date 2	Date 3	Date 4
	Water regime			
Well-watered	0.46a			0.44a
Drought stress	0.29b			0.44a
	Rootstock			
MP-29	0.35a			0.44a
Guardian	0.39a			0.44a
	Water regime x Rootstock			
Well-watered MP-29		0.40b	0.47b	
Well-watered Guardian		0.51a	0.66a	
Drought stress MP-29		0.38b	0.37c	
Drought stress Guardian		0.33c	0.33c	

Different letters mean significant differences at $P \leq 0.05$

The interaction between irrigation and rootstock on leaf Ca concentration occurred once only in the beginning of the season ($F = 8.69$, $P \leq 0.0122$; Table 9). MP-29 had lower leaf Ca concentrations than those on Guardian when trees were well-watered. However, drought stress trees on both rootstocks had a similar leaf Ca concentration. In the last three measurements, well-watered trees had a higher Ca concentration than drought stress. In addition, the influence of the rootstock illustrates that MP-29 had a higher Ca concentration than those on Guardian.

Table 9. Influence of water regime, rootstock, and their interaction on leaf Ca concentration (%) in Fall 2021.

Main effect	Ca			
	Date 1	Date 2	Date 3	Date 4
	Water regime			
Well-watered		1.61a	1.87a	1.54a
Drought stress		1.10b	1.21b	1.09b
	Rootstock			
MP-29		1.50a	1.66a	1.36a
Guardian		1.21b	1.42b	1.26a
	Water regime x Rootstock			
Well-watered MP-29	1.34b			
Well-watered Guardian	1.54a			
Drought stress MP-29	0.88c			
Drought stress Guardian	0.71c			

Different letters mean significant differences at $P \leq 0.05$

The influence of the interaction of irrigation and rootstock on leaf N concentration in all four different dates, throughout fall 2021 ($F = 262.33$, $P \leq 0.0001$, $F = 128.86$, $P \leq 0.0001$, $F = 83.02$, $P \leq 0.0001$, and $F = 160.70$, $P \leq 0.0001$; Table 10). Well-watered trees had a lower leaf N concentration than drought stressed trees. Trees on MP-29 had a higher leaf N concentration than trees on Guardian when they were under the drought stress. In contrast, trees on Guardian had lower leaf N concentration than trees on MP-29 when they were well-watered. Overall, trees on MP-29 in all treatments (under drought stress or being well-watered) had higher leaf N concentration than those on Guardian.

Table 10. Influence of water regime, rootstock, and their interaction on leaf N concentration (%) in Fall 2021.

Main effect	N%			
	Date 1	Date 2	Date 3	Date 4
Well-watered Drought stress	Water regime			
MP-29 Guardian	Rootstock			
	Water regime x Rootstock			
Well-watered MP-29	2.83b	2.77c	2.71b	2.80c
Well-watered Guardian	2.14c	2.15d	2.21c	2.29d
Drought stress MP-29	3.58a	3.23a	3.30a	3.49a
Drought stress Guardian	3.63a	3.07b	3.28a	3.17b

Different letters mean significant differences at $P \leq 0.05$

Nutrients in Dormant Tissues

The influence of water regime, rootstock, or their interaction on the accumulation of K in different dormant tissues (roots, portion below the rootstock, stems, or one-year shoots) were not consistent in both years. Shoot K concentration was influenced by the interaction between water regime and rootstock, as trees on Guardian rootstock had higher shoot K concentration than those on MP-29 after they went through a light drought stress period in 2021 ($F = 10.10$, $P \leq 0.0079$; Table 11). However, when trees were well-watered, no differences were observed. No differences were found in 2022 either. The MP-29 rootstock accumulated more K in the rootstock tissue than Guardian in 2021 ($F = 15.51$, $P \leq 0.0020$), although differences were not significant in 2022. On the other hand, water-stressed trees accumulated more K in their rootstock tissues than

well-watered trees in 2022 ($F = 30.45$, $P \leq 0.0001$), but no significant effect was found in 2021.

Table 11. Influence of water regime, rootstock, and their interaction on K concentration (%) of dormant tissues (roots, portion below the graft union, stem, and one-year-old shoots), in winter 2021 and 2022.

Main effect	K%			
	Root	Rootstock	Stem	Shoot
2021				
Water regime				
Well-watered	0.42a	0.27a	0.37a	
Drought stress	0.42a	0.27a	0.38a	
Rootstock				
MP-29	0.41a	0.30a	0.40a	
Guardian	0.41a	0.25b	0.35a	
Water regime x Rootstock				
Well-watered MP-29				0.74b
Well-watered Guardian				0.73b
Drought stress MP-29				0.77b
Drought stress Guardian				0.88a
2022				
Water regime				
Well-watered	0.39a	0.25b	0.33a	0.72a
Drought stress	0.45a	0.33a	0.39a	0.74a
Rootstock				
MP-29	0.40a	0.30a	0.37a	0.77a
Guardian	0.45a	0.28ab	0.35a	0.69a
Water regime x Rootstock				
Well-watered MP-29				
Well-watered Guardian				
Drought stress MP-29				
Drought stress Guardian				

Letters identify significant differences using LSMeans Differences Student's *t* at $P \leq 0.05$

The effect of irrigation, rootstock, or their interaction on the accumulation of Mg in different dormant tissues (roots, portion below the rootstock, stems, or one-year shoots) were not consistent in both years (Table 12). Rootstock Mg concentration were

influenced by the main effect water regime, as drought stress trees had a higher leaf Mg concentration than well water trees in 2021 and 2022 ($F = 5.36$, $P \leq 0.0351$; $F = 14.12$, $P \leq 0.0027$). On the other hand, trees on Guardian rootstock accumulated more Mg in the rootstock tissue than those on MP-29 in 2021 ($F = 5.26$, $P \leq 0.0406$). Nevertheless, the opposite was seen in the dormancy season of 2022 ($F = 24.64$, $P \leq 0.0003$).

Rootstock Mg concentration was not influenced by the interaction between irrigation and rootstock in 2021 or 2022. Also, shoot concentration had significant differences of the main effect of the water regime and rootstock in 2021. Hence, trees under a light stress had a higher Mg concentration than those with well-watered trees ($F = 6.72$, $P \leq 0.0235$). Whereas the main effect of the rootstock showed trees on Guardian accumulated more Mg in the shoot tissue than MP-29. However, the effect of the treatments did not occur on the shoot Mg concentration in 2022.

Table 12. Influence of water regime, rootstock, and their interaction on Mg concentration (%) of dormant tissues (roots, portion below the graft union, stem, and one-year-old shoots, in winter 2021 and 2022.

Main effect	Mg%			
	Root	Rootstock	Stem	Shoot
2021				
Water regime				
Well-watered	0.10a	0.06b	0.09a	0.22b
Drought stress	0.10a	0.07a	0.08a	0.24a
Rootstock				
MP-29	0.09a	0.06b	0.08a	0.21b
Guardian	0.10a	0.07a	0.09a	0.25a
Water regime x Rootstock				
Well-watered MP-29				
Well-watered Guardian				
Drought stress MP-29				
Drought stress Guardian				
2022				
Water regime				
Well-watered	0.17a	0.12b	0.10a	0.06a
Drought stress	0.16a	0.14a	0.09a	0.06a
Rootstock				
MP-29	0.17a	0.14a	0.10a	0.06a
Guardian	0.16a	0.12b	0.09a	0.06a
Water regime x Rootstock				
Well-watered MP-29				
Well-watered Guardian				
Drought stress MP-29				
Drought stress Guardian				

Letters identify significant differences using LSMeans Differences Student's t at $P \leq 0.05$

Root Ca concentration was influenced by the interaction between water regime and rootstock in 2021 and 2022 ($F = 6.40$, $P \leq 0.0264$; $F = 11.94$, $P \leq 0.0047$; Table 13). In 2021, trees on MP-29 had a higher root Ca concentration than Guardian, but a difference was not seen between well-watered and drought-stressed of MP-29 whereas

drought stressed trees on Guardian showed had higher root Ca concentration than those of well-watered trees. In 2022, the well-watered trees on MP-29 accumulated more Ca in their roots than those under the drought stress but trees Guardian rootstock had similar root Ca concentration, independently of the irrigation treatment. Rootstock Ca concentrations in 2021 and 2022 were influenced by the main effect of rootstock, as trees on MP-29 rootstock had higher rootstock Ca concentration than those on Guardian ($F = 9.53, P \leq 0.0004$; $F = 9.21, P \leq 0.0104$). However, the main effect of the irrigation did not show differences between well-watered and drought stress. In addition, shoot Ca concentration was influenced by the main effect water regime, as well-watered trees in 2021 and 2022 had a higher shoot Ca concentration than drought stress ($F = 9.67, P \leq 0.0090$; $F = 8.48, P \leq 0.013$).

Table 13. Influence of water regime, rootstock, and their interaction on Ca concentration (%) of dormant tissues (roots, portion below the graft union, stem, and one-year-old shoots, in winter 2021 and 2022.

Main effect	Ca%			
	Root	Rootstock	Stem	Shoot
2021				
Water regime				
Well-watered		0.50a	0.38a	1.66a
Drought stress		0.53a	0.44a	1.43b
Rootstock				
MP-29		0.58a	0.37a	1.52a
Guardian		0.45b	0.45a	1.57a
Water regime x Rootstock				
Well-watered MP-29	0.28a			
Well-watered Guardian	0.13c			
Drought stress MP-29	0.25a			
Drought stress Guardian	0.17b			
2022				
Water regime				
Well-watered		0.70a	0.5a	1.57a
Drought stress		0.67a	0.4a	1.23b
Rootstock				
MP-29		0.77a	0.5a	1.46a
Guardian		0.60b	0.5a	1.34a
Water regime x Rootstock				
Well-watered MP-29	0.42a			
Well-watered Guardian	0.16c			
Drought stress MP-29	0.24b			
Drought stress Guardian	0.14c			

Letters identify significant differences using LSMeans Differences Student's t at $P \leq 0.05$

N concentration in dormant tissues was not influenced by any of the treatments or their interaction in 2021; however, dormant tissues were affected by the water regime and rootstock in 2022 (Table 14). As drought stressed trees consistently had higher N concentration in their dormant tissues than well-watered trees. Also, rootstock and stem N concentration were influenced by the main effect of the rootstock, as trees on MP-29

rootstock accumulated more N in their rootstock and stem tissues than trees on Guardian ($F = 4.85$, $P \leq 0.0479$; $F = 14.67$, $P \leq 0.0024$).

Table 14. Influence of water regime, rootstock, and their interaction on N concentration (%) of dormant tissues (roots, portion below the graft union, stem, and one-year-old shoots, in winter 2021 and 2022).

Main effect	N %			
	Root	Rootstock	Stem	Shoot
2021				
Water regime				
Well-watered	106a	0.56a	0.50a	1.32a
Drought stress	1.023a	0.53a	0.61a	1.55a
Rootstock				
MP-29	1.15a	0.57a	0.57a	1.40a
Guardian	1.15a	0.52a	0.54a	1.48a
Water regime x Rootstock				
Well-watered MP-29				
Well-watered Guardian				
Drought stress MP-29				
Drought stress Guardian				
2022				
Water regime				
Well-watered	0.68b	0.48b	0.54b	1.46b
Drought stress	1.40a	0.81a	0.93a	1.78a
Rootstock				
MP-29	1.05a	0.70a	0.82a	1.59a
Guardian	1.03a	0.59b	0.65b	1.33a
Water regime x Rootstock				
Well-watered MP-29				
Well-watered Guardian				
Drought stress MP-29				
Drought stress Guardian				

Letters identify significant differences using LSMeans Differences Student's t at $P \leq 0.05$

Discussion

The nutritional status of the peach tree was affected by the interaction between water regime and rootstock. Peach trees are known for high water consumption and a short period of drought can reduce the peach production rate (Layne and Bassi, 2008), but choosing the right rootstock can improve tree size, fruit quality, and crop load (Nimbolkar et al. 2016). and nutrient dynamics can be influenced by the rootstock and drought conditions (Lawrence and Melgar, 2018). During fall 2020, trees on MP-29 had a higher leaf Ca concentration than trees on Guardian when they were under drought stress; whereas trees on Guardian had a higher leaf Ca concentration than those on MP-29 when they were well-watered trees. Under drought stress, N concentration was reduced in all the plant tissues; as a result, water deficit can decrease growth by reducing N uptake transport and redistribution (He and Dijkstra, 2014). Previous studies have reported that drought stress increases nutrient uptake quickly, especially in the first week of the drought, and after that, nutrients uptake decreases remarkably (Zhang, et al, 2010). In contrast, drought stress on MP-29 had a higher leaf N concentration than the other treatments including the well-watered trees, throughout 2022. However, the influence of the interaction on the N concentration of the dormant tissues did not match with what was observed in leaf tissue.

In addition, trees on MP-29 under water stress showed a higher Ca concentration than well-watered trees in fall 2020 and spring 2021, but the opposite was seen in fall 2021. In contrast, all trees on Guardian rootstock had almost similar results when they were well-watered or water-stressed throughout the first two seasons. However, the well-watered trees had higher concentrations than trees on drought condition, and the leaf

Ca concentration decreased as expected. When the trees were under the shade house, and the drought trees were covered, water could be seeping in when it was raining. In fall 2021, leaf Ca concentration was lower in DS than well-watered trees on MP-29, whereas leaf Ca concentrations in trees on Guardian were comparable in DS and well-watered trees.

Leaf K concentration was increased by the interaction of water regime and rootstock in spring 2021 (four times out of six) and in fall 2021 (once out of four different times).

Drought stress increased leaf K concentration in MP-29 and Guardian more than in well-watered trees in spring 2021. In addition, trees on Guardian under drought stress had a higher leaf K concentration than when they were well-watered trees, but similar between both treatments of MP-29 trees in fall 2021. Understanding the influence of drought stress on mineral nutrition is challenging because depends on the duration of stress and plant species (Ge, et al. 2012). Drought stress reduces soil moisture which can guarantee K uptake and concentration due to the decrease in soil nutrient diffusion capacity, activities of soil enzymes, and plant root enzymes. It is well known that K is highly mobile in the plant; thus, water stress may decrease K concentration, but it depends on drought duration. It was reported that drought stress affects K accumulation in the aboveground biomass (Sardans, et al. 2008). In addition, the increased concentration and uptake of K can be a tolerance mechanism since K plays an essential role in stomatal regulation and controls water balance even under water stress (Ashraf, et al. 2002). The opposite of leaf K concentration was seen in leaf Mg concentration; drought stress trees had a higher Mg concentration than well-watered trees in spring 2021; however, the influence of interaction had reduced the leaf Mg concentration,

especially when the trees were under drought stress in fall 2021. Trees on Guardian had a higher leaf Mg concentration than those on MP-29 when they were all well-watered trees throughout 2021. Several studies have shown that leaf Mg concentration can be increased by the rootstock species' ability to absorb even if they are under drought stress (Fallahi, et al. 2013).

The water regime influenced the nutritional status of young peach trees. Water availability plays a critical role in nutrient uptake and concentration in peach trees (Casamali et al, 2021), and, specifically, drought stress in long term can reduce the concentration and/or content of nutrients in peach trees, especially mobile nutrients (Thapa-Magar et al, 2020). In Fall 2020, water stress did not reduce leaf nutrient concentration as expected due to water stress being mild and short. Potassium and Mg leaf concentration were affected by the irrigation, specifically, well-watered trees had higher leaf K concentration than drought stress, and the opposite was seen in Mg leaf concentration. Several studies have shown that short periods of drought can reduce N leaf concentration (Casamali et al, 2021; He and Dijkstra, 2014), and Ca leaf concentrations (Layne and Bassi, 2008). However, this level of stress was enough to affect nutrient concentration in dormant tissues. In addition, the competition between root and shoot suggests that shoot K, Mg, Ca, and N concentrations depend on root uptake and the conditions of the root system (Baldi et al. 2010). These effects are usually reduced by water stress. In our study, dormant shoots collected in winter 2021 from well-watered trees had a higher concentration of Ca than those from DS, but the opposite was seen for shoot Mg concentration. During dormancy, the young peach trees were transplanted to bigger pots (26.5 L). In spring and fall 2021, trees under

water stress had a higher leaf K and N concentration than those from well-watered trees which was the opposite of fall 2020. In contrast, other studies had shown that water stress reduces the K leaf concentration due to the reduction of the soil water content (Sardans et al, 2008). Potassium and Nitrogen are highly mobile nutrients and it is an obvious clue that plant water status is important to improve the nutrient concentrations. The influence of the drought stress on the nutrient uptake of peach trees could be apparently reduced during the fruit production and before the following dormancy; however, some of the nutrients can remain stable during the initial drought period (Layne and Bassi, 2008). On the contrary, the leaves of DS trees had lower Ca and Mg concentrations than those from well-watered trees. However, the Mg reduction was not consistent, whereas the reduction of leaf Ca concentration was consistent. Additionally, the reduction of nutrient uptake that is caused by drought stress could result in delayed senescence time (Estiarte and Peñuelas, 2015). And the opposite was found, the leaves of well-watered trees dropped earlier than those from DS in 2022 compared to 2021.

Rootstocks influenced peach tree nutrient content, and environmental conditions can improve the rules of the rootstocks. The most critical factor in enhancing nutrient uptake is selecting the suitable rootstock and scion cultivar combination for improving peach tree growth (Efstathios, et al. 2021). Rootstock plays an important role in the translocation of nutrients, under drought stress. The influence of rootstocks has shown that MP-29 and Guardian had significant effects on the leaf nutrient concentrations and in the dormant tissues, but the effects were not consistent among nutrients in dormancy tissues collected and analyzed in both winters. In spring 2021, MP-29 rootstock had

higher leaf K, Ca, and N concentrations than those from Guardian. Other authors have also reported that MP-29 rootstock under different irrigation regimes showed higher leaf N and K concentrations (Thapa-Magar et al., 2022) and lower leaf Mg concentrations (Clavijo-Herrera et al., 2022) than Guardian. In contrast, MP-29 had a lower leaf Mg concentration than Guardian in the spring of 2021. In my study, the influence of the main effect of rootstock was not consistent throughout the seasons; however, the water regime had a higher impact on the nutritional status of peach trees throughout 2021.

Drought stress during fall season increased K and Mg concentrations in the rootstock during dormancy. In addition, N was more remobilized to all dormant tissues under drought stress conditions compared to well-watered trees (second year, when stress was more pronounced). A similar result was seen the water deficit increased not only N concentration but also potassium (Lawrence and Melgar. 2018). In contrast, the reduction of nutrient uptake may lead to strong nutrient resorption under drought stress conditions which is seen as a high concentration but is temporary and the concentration will be decreased by the drought (Zhao et al. 2017). In contrast, the effect on previous drought stress on K, Ca, and Mg concentrations in dormant tissues was less important (only low Ca and high Mg concentrations in shoots and rootstock, respectively, of DS trees compared to WW trees were observed). Overall, the nutritional concentration of rootstock and shoot tissues was more sensitive than other tissues to the influence of rootstock, which is a clue for the influence of the interaction between rootstock and shoot on growth and productivity. Across all the dormant tissues, the nutritional status of the root system nutrients has been affected by the interaction of the rootstock and water regime in 2021 and 2022. It could be a respond of the influence of the soil moisture

(Tworkoski et al., 2016), or the change of the soil temperature (Dong, et al. 2001) since trees were grown in the pots-culture study.

Conclusion

This study provides evidence that nutritional status of the young peach trees was influenced by the water regime and rootstock as well as their interactions. The water regime had a higher impact on the nutritional status of peach trees throughout the experiment whereas the influence of the rootstock was not consistent throughout the seasons. Drought stress may temporarily increase some of the nutrient concentration of both Guardian and MP-29 rootstocks; however, water stress and rootstocks with lower vigor (MP-29) could reduce the concentration of nutrients in plant tissues if the experiment was longer than two years. More research is needed to determine the influence of water regime and rootstock on the nutrient concentrations, but the stress should be increased as needed from the beginning of the experiment.

CHAPTER III

INFLUENCE OF WATER STRESS AND ROOTSTOCK ON GAS EXCHANGE OF YOUNG PEACH TREES

Introduction

Peach trees are sensitive to water stress during certain phenological stages, such as flowering, fruiting, and stem expansion. Additionally, the peach tree is native to humid and temperate climates (Mellisho, et al. 2011). Water stress reduce the growth by decreasing the rate of leaf gas exchange and water relations. It is very known that water stress reduces the physiological processes and functions. However, the role of rootstock may improve tree water status during drought stress. Rootstocks play essential roles in peach tree productivity because they enhance the mechanisms for drought resistance, including reduced root hydraulic conductance and effects on stomatal conductance. The most apparent effect of rootstocks is improving the scion behavior and the scion water relations, such as water use efficiency and drought tolerance (Hamlyn, 2012). However, previous studies have shown that rootstock improves leaf gas exchange under different irrigation conditions (Paranychianakis, et al. 2004; Frioni, et al. 2020). In the Southeastern United States, where drought periods have frequently occurred over the last two decades, growers do not irrigate their young peach trees since they do not produce fruit. Nevertheless, they realized that young trees on MP-29 need supplemental irrigation; on the contrary, trees on more vigorous Guardian rootstock need less irrigation, and the reason is still unclear. This study aims

to analyze the influence of water regimes and rootstock on the gas exchange of young peach trees and to understand the response to drought conditions.

Materials and Methods

Study Establishment, Location, and Design

This experiment was conducted between fall 2020 and spring 2022 seasons. A total of 60 three-year old 'Scarletprince' peach trees grafted onto two rootstocks (30 on Guardian and 30 on MP-29) were grown in 19.5-L pots containing a mixture of 2:1 potting soil Fafard 3B (Sun Gro, Agawam, MA): sand, and 3.5 g L⁻¹ of lime and 3.5 g L⁻¹ Osmocote 14-14-14. The experiment was located under a screen house at the Musser Fruit Research Farm, located in Seneca, South Carolina, USA. The experiment had a factorial design with four treatments, as a result of the combination of two irrigation regimes [well-watered trees (WW) or drought stressed trees (DS)] and two rootstocks [Guardian (G) and MP-29 (M)]. Thus, there were 15 trees in each of the four treatments: WWM, WWG, DSM and DSG. In Fall 2020, evapotranspiration was calculated gravimetrically before the experiment started, and irrigation regimes were set at either 1.5 L/day (WW) or 1 L/day (DS). However, these irrigation regimes were not kept throughout the experiment time (two years). The experiment was exposed to rain and temperature fluctuations. To reduce the influence of rain events, the pots of DS trees were covered with aluminum plates to avoid rainwater. Before spring 2021, trees were transplanted to 7-gallon (26.5 L) pots and soil mix, fertilizer and lime was added at the same rate as they were at the beginning of the experiment. In addition, during winter, the irrigation regimes were shut off due to the dormancy. After blooming, the irrigation regimes were turned on, all the fruits were thinned in late April. In Spring and Fall 2021, irrigation was shut off for all the treatments

when there was heavy rain (more than 12.2 mm/ day). Irrigation of drought stressed trees was cut in half if there was light rain (less than 12.2 mm/day). After heavy rainfall in spring 2021 and 2022, measurements and plant samplings were stopped until tree water status measurements were indicating that there was a difference between the well-watered trees and the drought stress. After collecting the leaves samples for Spring nutrients analysis, WW and DS trees were all well-watered until late summer. In Fall 2021, the stressed was decreased to 0.25 L/day whereas, well-watered trees got the same amount (2 L/day).

Tree water status

Tree water status was measured throughout the experiment to understand the level of water stress of each treatment. Measurements were taken once every two weeks during the three seasons unless it rains or that date fell immediately after a change in irrigation. Tree water status was measured by determining midday stem water potential (SWP) at solar noon (13:00-14:00 h) using six mature, fully developed leaves per treatment. Leaves were enclosed in reflective plastic bags for at least one hour before the measurements. After an hour in the foil wrapping the leaf water potential was equalized with the stem water potential and measurements were taken by placing the leaf in a pressure chamber (PMS 600, PMS Instruments, Albany, OR, USA) with the cut petiole exposed (Scholander et al., 1965; McCutchan and Shackel, 1992).

Gas exchange

Gas exchange parameters were determined in the morning (8:00–11:00) to avoid midday depression of net gas exchange (Jifon and Syvertsen, 2003). Measurements

were performed every two weeks unless we had rain or a cloudy day. Net CO₂ assimilation rate (A_{CO_2}), stomatal conductance (g_s), leaf transpiration (E_{leaf}) and leaf water use efficiency (WUE_{leaf} , calculated as A_{CO_2} / E_{leaf}) were measured with a photosynthesis system (LI-6400XTR; Licor, Lincoln, NE, USA) in a healthy, fully expanded leaf in the mid-stem of six replicate trees per treatment. All these measurements were taken at a photosynthetically active radiation of 1,000 mmol m⁻² s⁻¹. Measurements were taken in fall 2020 and spring 2021.

Statistical Analysis

The statistical analyses of the study followed a factorial design with two factors, the irrigation regime and the rootstock. The effect of the factors or the interaction of factors on the parameters measured were analyzed using analysis of variance (ANOVA). Comparison between treatments was performed using LSMeans Student's t. Data were analyzed by using JMP® statistical software (Version 16.0.0; SAS institute, Cary, NC).

Results

Fall 2020

For the first date, the treatment differences were partitioned into the main effect of irrigation, the main effect of rootstock, and the interaction effect of both irrigation and rootstock. The main effect of irrigation was significant ($F = 17.90$, $P \leq 0.0001$) (Figure 3), the main effect of rootstock was weakly significant ($F = 3.88$, $P \leq 0.0627$), and the interaction of rootstock and irrigation were not significant ($F = 1.21$, $P \leq 0.2843$). The mean value for photosynthesis for DS was 7.67 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ whereas the mean

value for well-watered trees was $11.41 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ and they were significantly different. However, water regimes did not show any significant differences on the other dates. In spring 2021, well-watered trees had a higher photosynthesis rate than those from drought stress trees (Figure 4). The main effect of the irrigation had significant differences in all sampling dates during the spring of 2021 ($F = 12.40, P \leq 0.0001$). The main effect of irrigation was significant ($F = 295.86, P \leq 0.0001$), the main effect of rootstock was not significant ($F = 0.2887, P \leq 0.5918$), and the interaction of rootstock and irrigation did not occur ($F = 0.7748, P \leq 0.3801$). The mean photosynthesis for DS was $4.13 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ and the mean photosynthesis for well-watered trees was $10.01 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$, and they were significantly different.

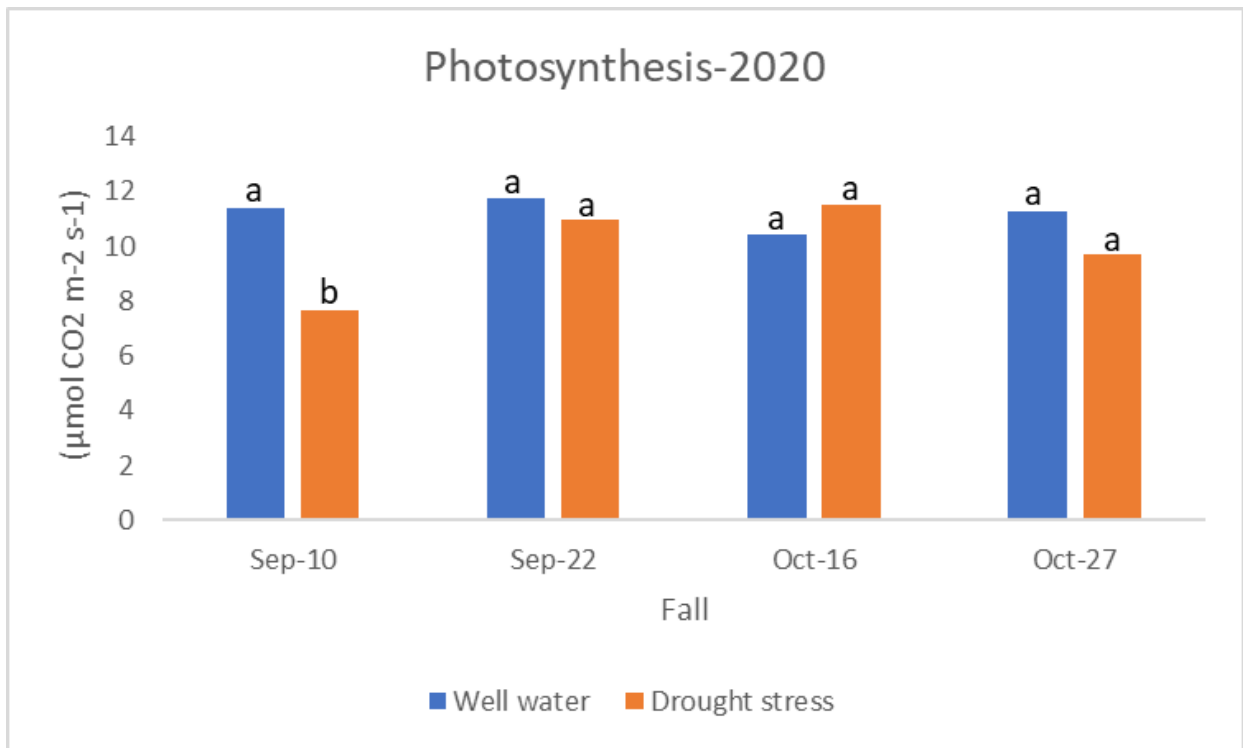


Figure 6. The influence of water regimes on photosynthesis of young peach trees in (Fall 2020). Different letters show significance using LSMeans Differences Student's *t* at $P \leq 0.05$

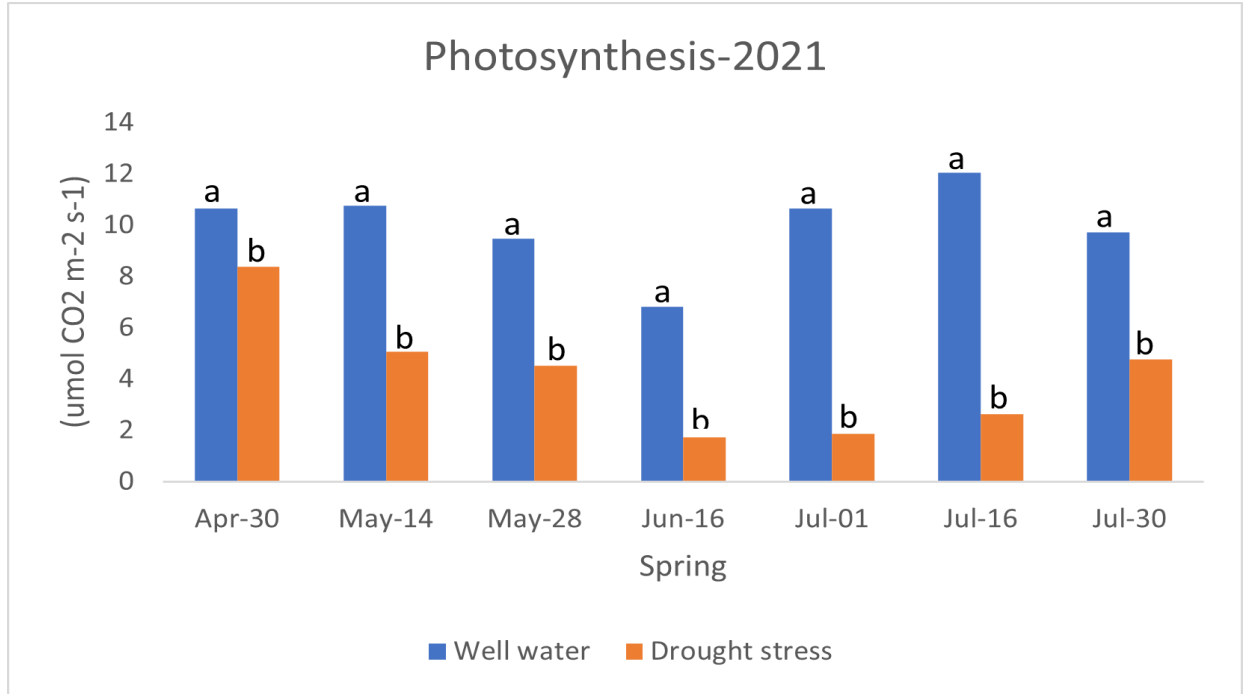


Figure 7. The influence of water regimes on photosynthesis of young peach trees in (Spring 2021). Different letters show significance using LSMeans Differences Student's t at $P \leq 0.05$

In addition, the rate of the stomatal conductance was affected by the water regime in fall 2020 and spring 2021. In first date of fall 2020, there was a difference among the four treatment combinations ($F = 13.68$, $P \leq 0.0002$). The main effect of irrigation was only the significant factor ($F = 39.50$, $P \leq 0.0001$) (Figure 5). The mean stomatal conductance for DS trees was $0.09 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$ and the mean stomatal conductance for well-watered trees was $0.2 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$ and they were significantly different. Across all dates in spring 2021, the interaction between water regime and rootstock did not occur. However, the main effect of the irrigation had significant impact on the treatments ($F = 28.49$, $P \leq 0.0001$) (Figure 6 below). The main effect of irrigation was significant ($F = 170.94$, $P \leq 0.0001$), the main effect of rootstock was not significant ($F = 2.90$, $P \leq$

0.0901), and the interaction of rootstock and irrigation was not significant ($F = 0.66$, $P \leq 0.4155$). Average value of stomatal conductance for DS trees was $0.04 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$ and the mean stomatal conductance for well-watered trees was $0.15 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$ and they were significantly different.

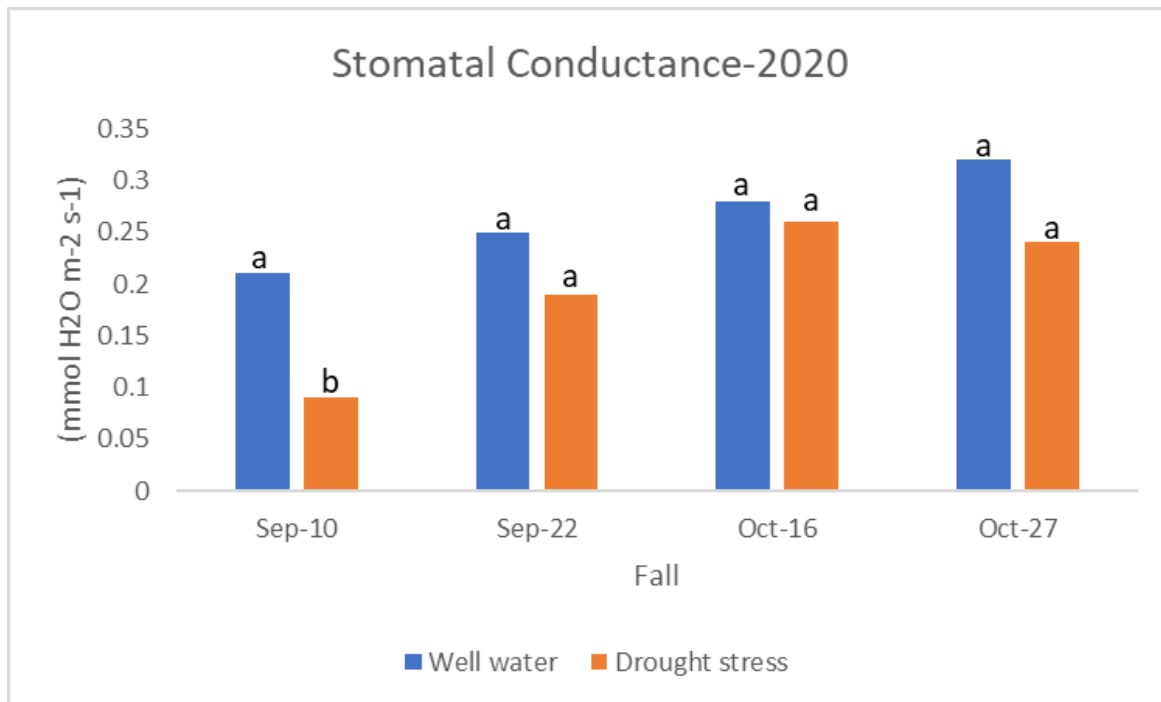


Figure 8. The influence of water regimes on stomatal conductance of young peach trees in (Fall 2020). Different letters show significance using LSMeans Differences Student's t at $P \leq 0.05$

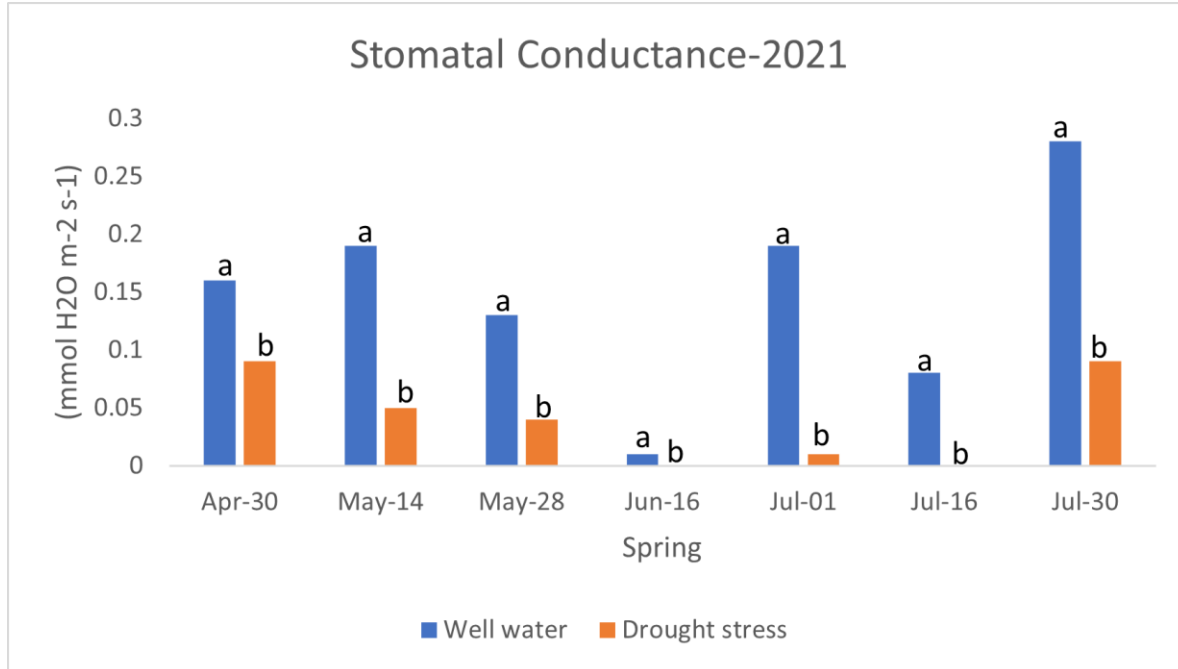


Figure 9. The influence of water regimes on stomatal conductance of young peach trees in (Spring 2021). Different letters show significance using LSMeans Differences Student's t at $P \leq 0.05$

The performance of leaf transpiration was similar; the main effect of irrigation was significant ($F = 28.63$, $P \leq 0.0001$) (Figure 7 below), the main effect of rootstock was not significant ($F = 0.90$, $P \leq 0.3522$), and the interaction of rootstock and irrigation was not significant ($F = 0.03$, $P \leq 0.8521$). The mean leaf transpiration for DS trees was $1.86 \text{ mmol/m}^2/\text{s}$ and the mean leaf transpiration for well-watered trees was $3.61 \text{ mmol/m}^2/\text{s}$, and they were significantly different. In spring 2021, only the main effect of the irrigation had significant impact between well-watered trees and drought stress trees ($F = 227.36$, $P \leq 0.0001$). Average value of leaf transpiration for DS was $1.04 \text{ mmol/m}^2/\text{s}$, and in comparison, to well water was $3.09 \text{ mmol m}^2/\text{s}$ and they were significantly different (Figure 8 below).

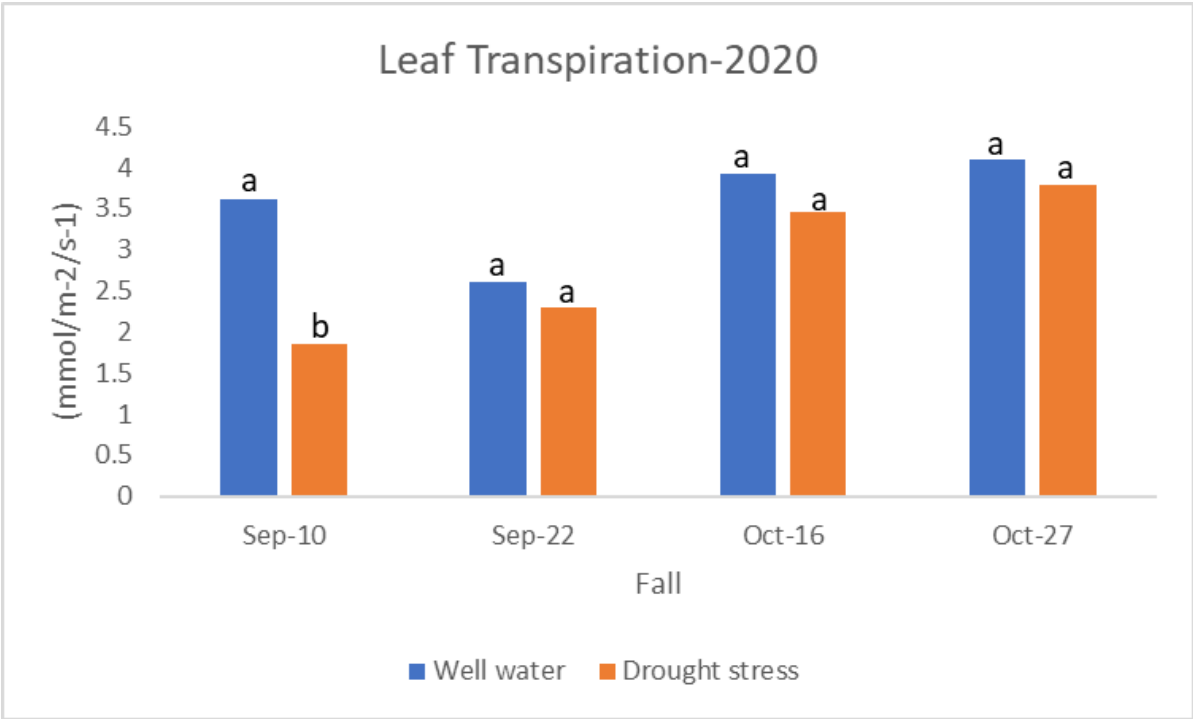


Figure 10. The influence of water regimes on leaf transpiration of young peach trees in (Fall 2020). Different letters show significance using LSMeans Differences Student's t at $P \leq 0.05$

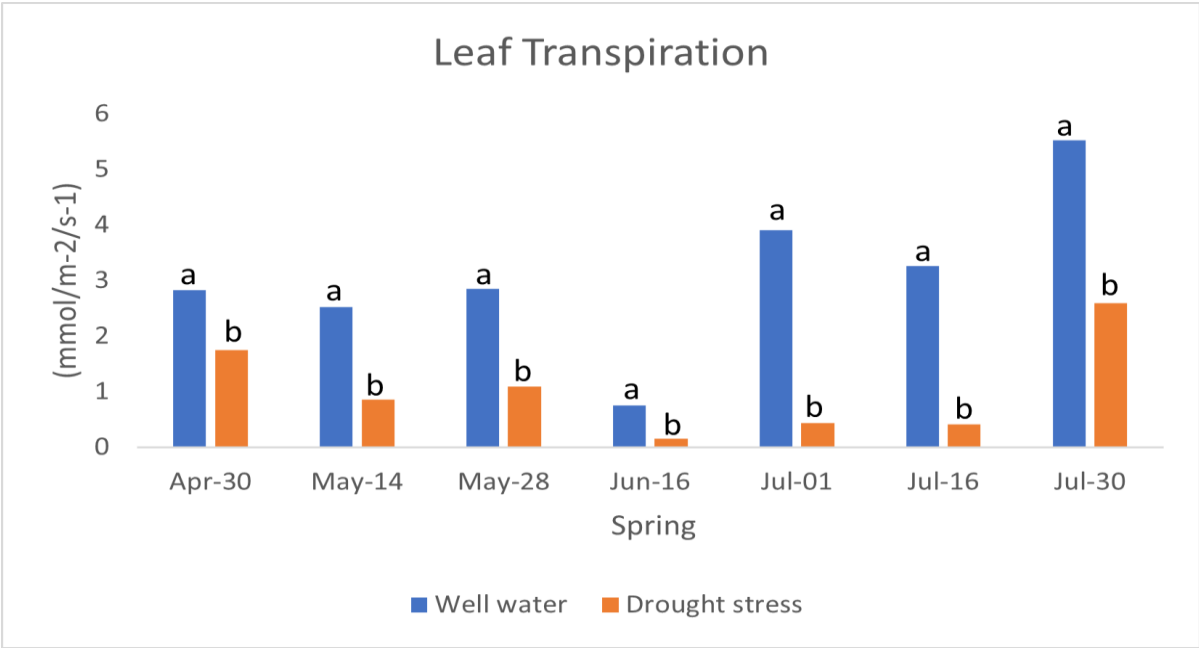


Figure 11. The influence of water regimes on leaf transpiration of young peach trees in (Spring 2021). Different letters show significance using LSMeans Differences Student's t at $P \leq 0.05$

The influence of water regime, rootstock, and their interaction on WUE was also assessed. Only in the first and third date there were significant among the four treatment combinations ($F = 8.23, P \leq 0.0009$) and ($F = 3.11, P \leq 0.0491$). In the second and the last date of the experiment in fall 2020, there were no differences ($F = 0.12, P \leq 0.9468$) and ($F = 1.09, P \leq 0.3731$). The main effects of irrigation were significant ($F = 20.64, P \leq 0.0002$) and ($F = 8.11, P \leq 0.0099$). In the first date, the mean water use efficiency for DS trees was $4.27 \mu\text{mol CO}_2/\text{mol H}_2\text{O}$ and the mean WUE for well-watered trees was $3.20 \mu\text{mol CO}_2/\text{mol H}_2\text{O}$ and they were significantly different (Fig. 9). Also, in the last date, the mean water use efficiency for DS trees was higher ($3.42 \mu\text{mol CO}_2/\text{mol H}_2\text{O}$) than well-watered trees ($2.70 \mu\text{mol CO}_2/\text{mol H}_2\text{O}$). Across all dates, the main effect of irrigation was significant in fall 2020 ($F = 27.54, P \leq 0.0001$). In Spring 2021, the average value of each treatment is showing drought stress had a higher water use efficiency $5.68 \mu\text{mol CO}_2/\text{mol H}_2\text{O}$, whereas well-watered trees had $4.20 \mu\text{mol CO}_2/\text{mol H}_2\text{O}$ and they were significantly different (**Figure 10** below). In Spring 2021, the influence of the rootstock had a significant impact on the water use efficiency, and it showed Guardian had a higher WUE than MP-29 ($F = 4.95, P \leq 0.0376$) but it was not consistent throughout the experiment. There was no influence of the interaction of water regime x rootstock on any gas exchange parameter.

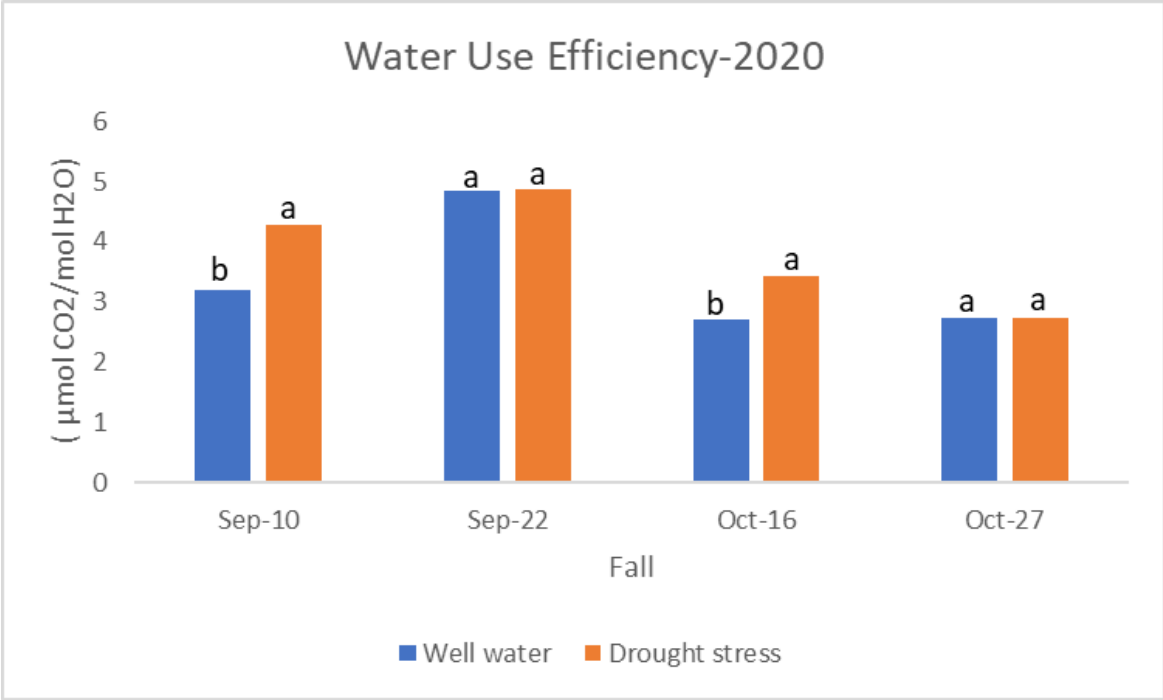


Figure 12. Different letters show significance using LSMeans Differences Student's t at $P \leq 0.05$

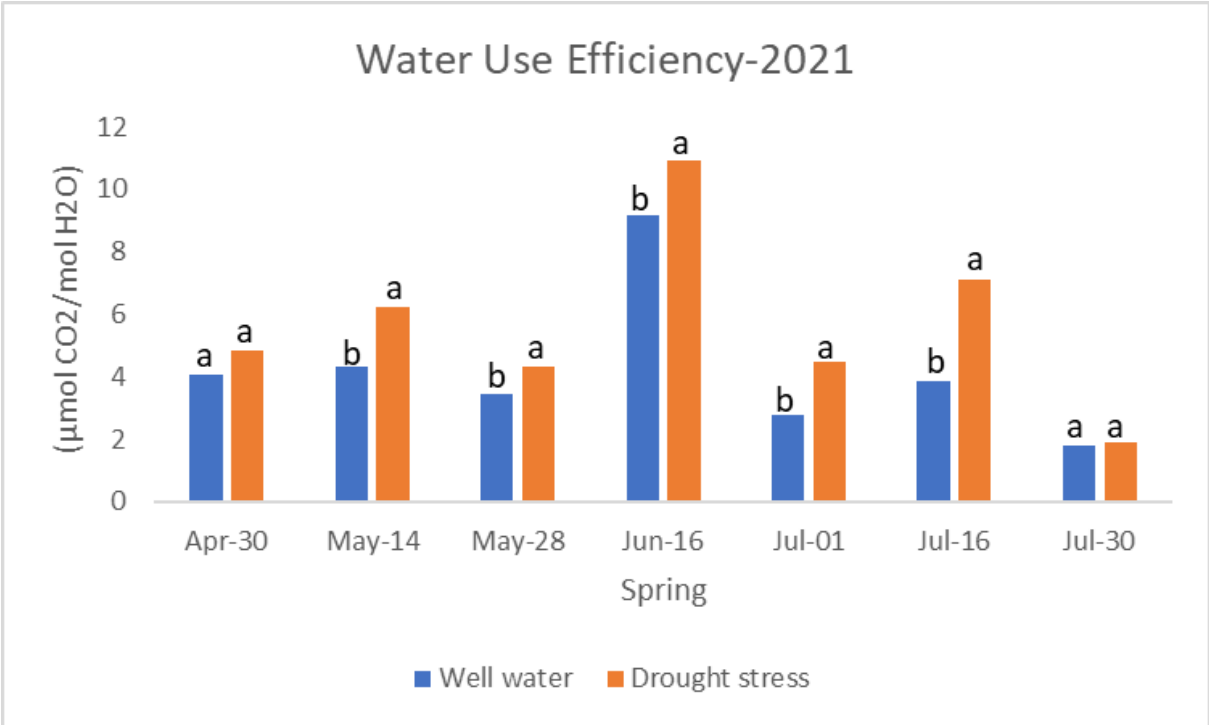


Figure 13. Different letters show significance using LSMeans Differences Student's t at $P \leq 0.05$

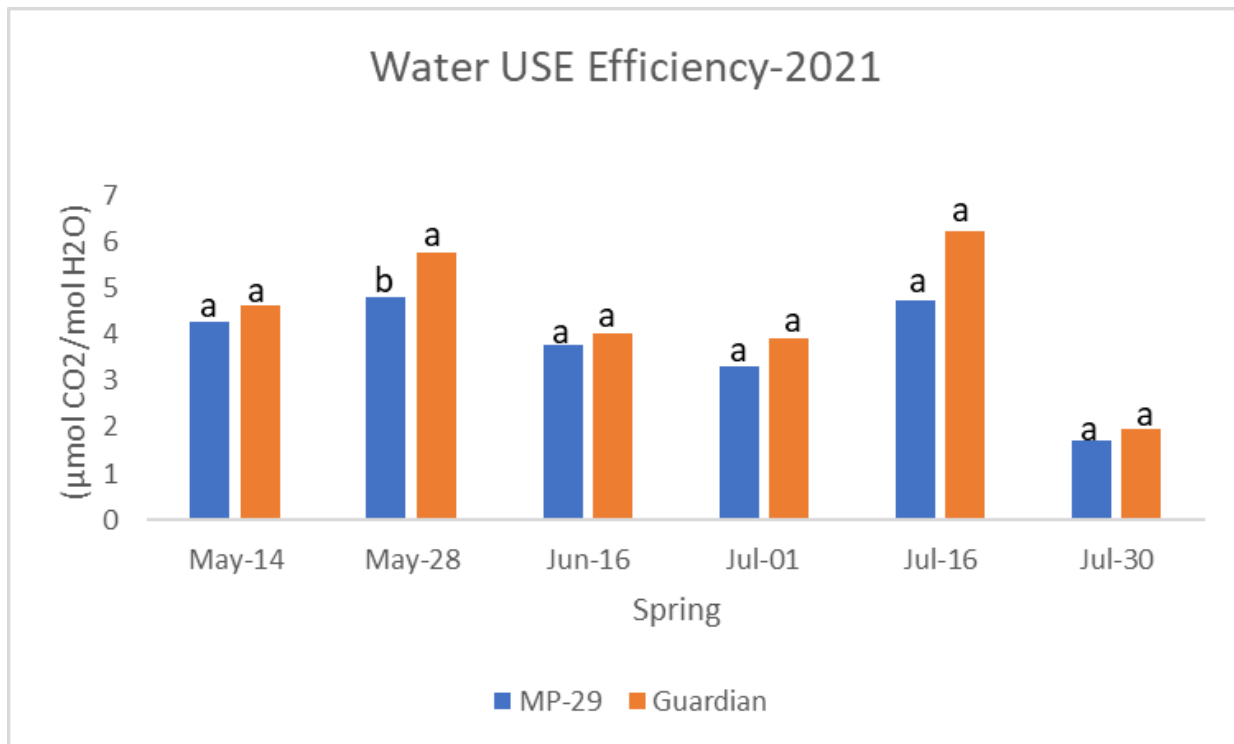


Figure 14. Different letters show significance using LSMeans Differences Student's t at $P \leq 0.05$

Discussion

As expected, the irrigation treatments had a considerable impact on leaf gas exchange. In fact, photosynthesis, stomatal conductance, and leaf transpiration were reduced by drought stress compared to well-watered trees during Fall 2020 and Spring 2021. Previous studies have shown that the young peach tree is one of the most sensitive fruit trees to water stress (Rahmati, et al. 2015). In Fall 2020, photosynthesis, stomatal conductance, and leaf transpiration were reduced by mild drought conditions, although the reductions were not as consistent as for the measurements taken in Spring 2021. Since the main effect was due to the irrigation regime, the well-watered trees had higher

photosynthesis, stomatal conductance, and leaf transpiration than those on drought stress. It was reported that water status of the plant is the key for the gas exchanges (Bray, 2007). Other authors have also reported that drought stress reduces the photosynthesis, stomatal conductance, and the leaf transpiration (Woodruff and Meinzer, 2011). In Spring, the influence of the water regime was reduced by temperature since the trees were under a shadow house, and the temperature was not controlled. It could be the reason to see different effects of irrigation on gas exchange. As a result of the reduction of the photosynthesis, stomatal conductance, and the leaf transpiration, the WUE was increased under the water deficit. Previous studies have also shown that water deficit increases water use efficiency (Sun, et al. 2013; Jaleel, et al. 2008).

On the other hand, leaf gas exchange was not influenced by the rootstock or the interaction between water regime and rootstock in Fall 2020 or Spring 2021. However, other authors have reported that leaf gas exchange and water status can be improved by selecting the suitable rootstock for the growth conditions, enhancing drought tolerance (Frioni, et al. 2020). Studies in different fruit species have reported that rootstock improved leaf gas exchange under drought stress. For example, grapevine rootstock can resist drought stress for two weeks without showing a reduction in the assimilation rate (Paranychianakis, et al. 2004). In contrast, when the drought stress was applied in Spring 2021, the reduction in the assimilation rate was significant on young peach trees. In Spring 2021, WUE was significant by the rootstock and showed Guardian had a higher WUE than MP-29. Additionally, the influence of the rootstock was not consistent as the influence of the irrigation on gas exchange and water use

efficiency. Rootstocks under drought stress can show different water uptake and water consumption (Sun, et al. 2013), since trees on different rootstocks may show differences in shoot extension growth rate, leaf conductance, leaf transpiration, and net CO₂ exchange rate (Solari, et al. 2006). Nevertheless, the effects of the interaction between water regime and peach rootstock interactive have been scarcely studied, and more studies could lead to improved productivity and vegetative growth.

Conclusion

The influence of the irrigation was the most influential factor on gas exchange and water use efficiency. In my study, the water regime had a higher impact on gas exchange than the main effect of the rootstocks of peach trees throughout the experiment. The main effect of the rootstock did not show any significant difference between Guardian and MP-29 on gas exchange in Fall 2020; however, WUE seemed to be affected by the rootstock in Spring 2021, although significant differences were not consistent throughout the entire duration of the experiment.

REFERENCES

- Al-Yahyai, R. "Managing Irrigation of Fruit Trees Using Plant Water Status." *Agricultural Sciences*, Scientific Research Publishing, 5 Jan. 2012, <https://www.scirp.org/journal/PaperInformation.aspx?PaperID=16851>.
- Alcobendas, R., J.M. Mirás-Avalos, J.J. Alarcón, E. Nicolás. "Effects of Irrigation and Fruit Position on Size, Colour, Firmness and Sugar Contents of Fruits in a Mid-Late Maturing Peach Cultivar." *Scientia Horticulturae*, vol. 164, 2013, pp. 340–347., <https://doi.org/10.1016/j.scienta.2013.09.048>.
- Ashraf, M. M. Ashfaq, and M.Y. Ashraf. "Effects of Increased Supply of Potassium on Growth and Nutrient Content in Pearl Millet under Water Stress." *Biologia Plantarum*, vol. 45, no. 1, 2002, pp. 141–144., <https://doi.org/10.1023/a:1015193700547>.
- Aline das G. Souza, Cristina W. Ritterbusch, Renata D. Menegatti, Oscar J. Smiderle, and Valmor J. Bianchi." Nutritional Efficiency and Morphophysiological Aspects With Growth in the 'Okinawa Roxo' Peach Rootstock". *Journal of Agricultural Science*, 2019. <https://doi.org/10.5539/jas.v11n9p221>
- Bronick, C.J., and R. Lal. "Soil Structure and Management: A Review." *Geoderma*, vol. 124, no.1-2, 2005, pp. 3–22., <https://doi.org/10.1016/j.geoderma.2004.03.005>.
- Bray, E. A. "Plant Response to Water-Deficit Stress." *Encyclopedia of Life Sciences*, 2007, <https://doi.org/10.1002/9780470015902.a0001298.pub2>.
- Baldi, Elena, M. Toselli, and B. Marangoni. "Nutrient Partitioning in Potted Peach (*Prunus Persica* L.) Trees Supplied with Mineral and Organic Fertilizers." *Journal of Plant Nutrition*, vol. 33, no. 14, 2010, pp. 2050–2061., <https://doi.org/10.1080/01904167.2010.519080>.
- Chai, Q., Y. Gan, C. Zhao, H.L. Xu, R.M. Waskom, Y. Niu, and K.H.M. Siddique. "Regulated Deficit Irrigation for Crop Production under Drought Stress. A Review." *Agronomy for Sustainable Development*, vol. 36, no. 3, 2016, <https://doi.org/10.1007/s13593-015-0338-6>.
- Casamali, B. Marc W. van Iersel, and Dario J. Chavez. "Nitrogen Partitioning in Young 'Julyprince' Peach Trees Grown with Different Irrigation and Fertilization Practices in the Southeastern United States." *Agronomy*, vol. 11, no. 2, 2021, p. 350., <https://doi.org/10.3390/agronomy11020350>.
- Coussement, J. R., S.L.Y. Villers, H. Nelissen, D. Inzé, and K. Steppe. "Turgor-Time Controls Grass Leaf Elongation Rate and Duration under Drought Stress." *Plant, Cell & Environment*, vol. 44, no. 5, 2021, pp. 1361–1378., <https://doi.org/10.1111/pce.13989>.

- Corey, Richard B. "Physical-Chemical Aspects of Nutrient Availability." *SSSA Book Series*, 1990, pp. 11–24., <https://doi.org/10.2136/sssabookser3.3ed.c2>.
- Chen, M.-M., Y.-G. Zhu, Y. -H. Su B.-D. Chen B.-J. Fu P. Marschner. "Effects of Soil Moisture and Plant Interactions on the Soil Microbial Community Structure." *European Journal of Soil Biology*, vol. 43, no. 1, 2007, pp. 31–38., <https://doi.org/10.1016/j.ejsobi.2006.05.001>.
- Estiarte, M., and J. Peñuelas. "Alteration of the Phenology of Leaf Senescence and Fall in Winter Deciduous Species by Climate Change: Effects on Nutrient Proficiency." *Global Change Biology*, vol. 21, no. 3, 2015, pp. 1005–1017., <https://doi.org/10.1111/gcb.12804>.
- Efstathios, N. A. Annie, R. A. Petros. "Cultivar-Rootstock Interactions on Growth, Yield and Mineral Nutrition of Newly Planted Peach Trees in a Pot Experiment." *Emirates Journal of Food and Agriculture*, 2021, p. 149., <https://doi.org/10.9755/ejfa.2021.v33.i2.2250>.
- Fraga, H, J.G. Pinto, and J.A. Santos. "Olive Tree Irrigation as a Climate Change Adaptation Measure in Alentejo, Portugal." *Agricultural Water Management*, vol. 237, 2020, p. 106193., <https://doi.org/10.1016/j.agwat.2020.106193>.
- Fereres, E., and M. A. Soriano. "Deficit Irrigation for Reducing Agricultural Water Use." *Journal of Experimental Botany*, vol. 58, no. 2, 2006, pp. 147–159., <https://doi.org/10.1093/jxb/erl165>.
- Fereres, E., D.A. Goldhamer, and L.R. Parsons. "Irrigation Water Management of Horticultural Crops." *HortScience*, vol. 38, no. 5, 2003, pp. 1036–1042., <https://doi.org/10.21273/hortsci.38.5.1036>.
- Francisco, Jeane, et al. "Soil Factors Effects on the Mineralization, Extractable Residue, and Bound Residue Formation of Aminocyclopyrachlor in Three Tropical Soils." *Agronomy*, vol. 8, no. 1, 2017, p. 1., <https://doi.org/10.3390/agronomy8010001>.
- Forde, Brian, and Helena Lorenzo. "The Nutritional Control of Root Development." *Interactions in the Root Environment: An Integrated Approach*, 2002, pp. 51–68., https://doi.org/10.1007/978-94-010-0566-1_6.
- FAZIO, GENNARO, D. KVIKLYS , M. A. GRUSAK, and T. ROBINSON. *Phenotypic Diversity and QTL Mapping of Absorption and Translocation of Nutrients by Apple Rootstocks*. Jan. 2013, https://www.researchgate.net/publication/261103062_Phenotypic_diversity_and_QTL_mapping_of_absorption_and_translocation_of_nutrients_by_apple_rootstocks

- Fallahi, E., K. Arzani, and B. Fallahi. "Long-Term Leaf Mineral Nutrition in 'Pacific Gala' Apple (*Malus domestica* Borkh.) as Affected by Rootstock Type and Irrigation System during Six Stages of Tree Development." *The Journal of Horticultural Science and Biotechnology*, vol. 88, no. 6, 2013, pp. 685–692., <https://doi.org/10.1080/14620316.2013.11513025>.
- Frioni, T., A. Biagioni, C., Squeri, S. Tombesi, M. Gatti and S. Poni . "Grafting CV. Grechetto Gentile Vines to New M4 Rootstock Improves Leaf Gas Exchange and Water Status as Compared to Commercial 1103P Rootstock." *Agronomy*, vol. 10, no. 5, 2020, p. 708., <https://doi.org/10.3390/agronomy10050708>.
- Gayatri, G., S. Agurla, and A.S. Raghavendra. "Nitric Oxide in Guard Cells as an Important Secondary Messenger during Stomatal Closure." *Frontiers in Plant Science*, vol. 4, 2013, <https://doi.org/10.3389/fpls.2013.00425>.
- Gutiñas, M.E., M.C. Leirós, C. Trasar-Cepeda, F. Gil-Sotres. "Effects of Moisture and Temperature on Net Soil Nitrogen Mineralization: A Laboratory Study." *European Journal of Soil Biology*, vol. 48, 2012, pp. 73–80., <https://doi.org/10.1016/j.ejsobi.2011.07.015>.
- Gyaneshwar, P., G. Naresh Kumar, L. J. Parekh, and P. S. Poole. "Role of Soil Microorganisms in Improving p Nutrition of Plants." *Food Security in Nutrient-Stressed Environments: Exploiting Plants' Genetic Capabilities*, 2002, pp. 133–143., https://doi.org/10.1007/978-94-017-1570-6_15.
- Giorgi, M., F. Capocasa, J. Scalzo, G. Murri. M. Battino, B. Mezzetti. "The Rootstock Effects on Plant Adaptability, Production, Fruit Quality, and Nutrition in the Peach (Cv. 'Suncrest')." *Scientia Horticulturae*, vol. 107, no. 1, 2005, pp. 36–42., <https://doi.org/10.1016/j.scienta.2005.06.003>.
- Ge, Ti-Da, Ning-Bo Sun, Li-Ping Bai, Chen-Li Tong, Fang-Gong Sui. "Effects of Drought Stress on Phosphorus and Potassium Uptake Dynamics in Summer Maize (*Zea Mays*) throughout the Growth Cycle." *Acta Physiologiae Plantarum*, vol. 34, no. 6, 2012, pp. 2179–2186., <https://doi.org/10.1007/s11738-012-1018-7>.
- Habib, S. "Peach: Queen of fruits." *Pakistan Food Journal* (2015): 26-27. <http://www.foodjournal.pk/2015/September-October-2015/PDF-September-October-2015/Exclusive-on-Peach.pdf>
- Hetherington, A.M., and F.I. Woodward. "The Role of Stomata in Sensing and Driving Environmental Change." *Nature*, vol. 424, no. 6951, 2003, pp. 901–908., <https://doi.org/10.1038/nature01843>.
- He, M and F, A. Dijkstra. "Drought Effect on Plant Nitrogen and Phosphorus: A Meta-Analysis." *New Phytologist*, vol. 204, no. 4, 2014, pp. 924–931., <https://doi.org/10.1111/nph.12952>.

- Hamlyn G. Jones. "How Do Rootstocks Control Shoot Water Relations?" *The New Phytologist*, vol. 194, no. 2, 2012, pp. 301–03. *JSTOR*, <http://www.jstor.org/stable/newphytologist.194.2.301>. Accessed 3 Jul. 2022.
- Johnson, R.S., and D.F.H. "Using Water Stress to Control Vegetative Growth and Productivity of Temperate Fruit Trees." *HortScience*, vol. 35, no. 6, 2000, pp. 1048–1050., <https://doi.org/10.21273/hortsci.35.6.1048>.
- Jia, S, X. Li, W. Sun, Q. Wang, H. Liu, C. Zhou, W. Zhang, and F. Li . "Fine Root Traits of *Pinus Koraiensis* Varied with Soil Cation Exchange Capacity in Natural Forests." *Land*, vol. 10, no. 4, 2021, p. 363., <https://doi.org/10.3390/land10040363>.
- Jonathan Clavijo-Herrera, Lorenzo Rossi, and Ali Sarkhosh. Influence of rootstock on leaf nutrient content in young low-chill peaches under subtropical climate University of Florida. The Southern Region - American Society for Horticultural Science Annual Conference, in New Orleans, LA, Feb. 11-13, 2022.
- Kumar, S., S. Sachdeva, K. V. Bhat, S. Vats. "Plant Responses to Drought Stress: Physiological, Biochemical and Molecular Basis." *Biotic and Abiotic Stress Tolerance in Plants*, 2018, pp. 1–25., https://doi.org/10.1007/978-981-10-9029-5_1.
- Lawrence, Brian T., and J. C. Melgar. "Variable Fall Climate Influences Nutrient Resorption and Reserve Storage in Young Peach Trees." *Frontiers in Plant Science*, vol. 9, 2018, <https://doi.org/10.3389/fpls.2018.01819>.
- Lipiec, J., C. Doussan, A. Nosalewicz, and K. Kondracka. "Effect of drought and heat Stresses on Plant Growth and Yield: A Review." *International Agrophysics*, vol. 27, no. 4, 2013, pp. 463–477., <https://doi.org/10.2478/intag-2013-0017>.
- Lopez, G., M. Mata, A. Arbones, J.R. Solans, J. Girona, J. Marsal. "Mitigation of Effects of Extreme Drought during Stage III of Peach Fruit Development by Summer Pruning and Fruit Thinning." *Tree Physiology*, vol. 26, no. 4, 2006, pp. 469–477., <https://doi.org/10.1093/treephys/26.4.469>.
- Lima Neto, M.C., J.A.G. Silveira, J.V.A. Cerqueira, and J.R. Cunha. "Regulation of the Photosynthetic Electron Transport and Specific Photoprotective Mechanisms in *Ricinus Communis* under Drought and Recovery." *Acta Physiologiae Plantarum*, vol. 39, no. 8, 2017, <https://doi.org/10.1007/s11738-017-2483-9>.
- Layne, Desmond R., and Daniele Bassi. *The Peach: Botany, Production and Uses*, CABI, Wallingford, Oxfordshire, UK, 2008.
- Li, Jinquan, M. Nie, J. R Powell, A. Bissett, and E. Pendall1 "Soil Physico-Chemical Properties Are Critical for Predicting Carbon Storage and Nutrient Availability across Australia." *Environmental Research Letters*, vol. 15, no. 9, 2020, p. 094088., <https://doi.org/10.1088/1748-9326/ab9f7e>.

- Leuschner, C., H. CONERS, and R. ICKE. "In Situ Measurement of Water Absorption by Fine Roots of Three Temperate Trees: Species Differences and Differential Activity of Superficial and Deep Roots." *Tree Physiology*, vol. 24, no. 12, 2004, pp. 1359–1367., <https://doi.org/10.1093/treephys/24.12.1359>.
- Mellisho, C. D., Z. N. CRUZ, W. CONEJERO, M. F. ORTUÑO, and P. RODR ÍGUEZ. "Mechanisms for Drought Resistance in Early Maturing Cvar Flordastar Peach Trees." *The Journal of Agricultural Science*, vol. 149, no. 5, 2011, pp. 609–616., <https://doi.org/10.1017/s0021859611000141>.
- Mingeau, M., C. Perrier T. AmeÂglioc. "Evidence of Drought-Sensitive Periods from Flowering to Maturity on Highbush Blueberry." *Scientia Horticulturae*, vol. 89, no. 1, 2001, pp. 23–40., [https://doi.org/10.1016/s0304-4238\(00\)00217-x](https://doi.org/10.1016/s0304-4238(00)00217-x).
- Murata, Y., I.C. Mori, and S. Munemasa. "Diverse sStomatal Signaling and the Signal Integration Mechanism." *Annual Review of Plant Biology*, vol. 66, no. 1, 2015, pp. 369–392., <https://doi.org/10.1146/annurev-arplant-043014-114707>.
- Menegatti, R. D., D. Graças Souza and V. J. Bianchi. "Nutritional Efficiency for Nitrogen, Phosphorus and Potassium in Peach Rootstocks." *Journal of Plant Nutrition*, vol. 44, no. 2, 2020, pp. 228–237., <https://doi.org/10.1080/01904167.2020.1806306>.
- Monokrousos, N. E. M. Papatheodorou, M. Orfanoudakis D. Gwynn Jones "The Effects of Plant Type, AMF Inoculation and Water Regime on Rhizosphere Microbial Communities." *European Journal of Soil Science*, vol. 71, no. 2, 2019, pp. 265–278., <https://doi.org/10.1111/ejss.12882>.
- Nimbolkar P. K, C Awachare, Y.T.N Reddy, S Chander and F. Hussain ."Role of Rootstocks in Fruit Production–A Review." *Journal of Agricultural Engineering and Food Technology*. 2016 pp. 183-188.
- Opazo, I., G. Toroa, A. Salvatierra, C. Pastenes, P. Pimente,. "Rootstocks Modulate the Physiology and Growth Responses to Water Deficit and Long-Term Recovery in Grafted Stone Fruit Trees." *Agricultural Water Management*, vol. 228, 2020, p. 105897., <https://doi.org/10.1016/j.agwat.2019.105897>.
- Paranychianakis, N. V., K. S. Chartzoulakis, A. N. Angelakis et al. "Influence of Rootstock, Irrigation Level and Recycled Water on Water Relations and Leaf Gas Exchange of Sultana Grapevines." *Environmental and Experimental Botany*, vol. 52, no. 2, 2004, pp. 185–198., <https://doi.org/10.1016/j.envexpbot.2004.02.002>.
- Qi, J., C.P. Song, B. Wang, J. Zhou, J. Kangasjärvi, J.K. Zhu, and Z. Gong. "Reactive Oxygen Species Signaling and Stomatal Movement in Plant Responses to Drought

Stress and Pathogen Attack.” *Journal of Integrative Plant Biology*, vol. 60, no. 9, 2018, pp. 805–826., <https://doi.org/10.1111/jipb.12654>.

Rahmati, M., G.H. Davarynejad, M. Génard, M. Bannayan, M. Azizi, and G. Vercambre. “Peach Water Relations, Gas Exchange, Growth and Shoot Mortality under Water Deficit in Semi-Arid Weather Conditions.” *PLOS ONE*, vol. 10, no. 4, 2015, <https://doi.org/10.1371/journal.pone.0120246>.

Sharma, P., A.B. Jha, R.S. Dubey, and M. Pessaraki. “Reactive Oxygen Species, Oxidative Damage, and Antioxidative Defense Mechanism in Plants under Stressful Conditions.” *Journal of Botany*, vol. 2012, 2012, pp. 1–26., <https://doi.org/10.1155/2012/217037>.

Soltani, I., et al. “A Near Infrared Index to Assess Effects of Soil Texture and Organic Carbon Content on Soil Water Content.” *European Journal of Soil Science*, vol. 70, no. 1, 2018, pp. 151–161., <https://doi.org/10.1111/ejss.12725>.

Savvas, D., G. Bahar Öztekin, M. Tepecik, A. Ropokis, Y. Tüzel, G. Ntatsi, and D. Schwarzl. “Impact of Grafting and Rootstock on Nutrient-to-Water Uptake Ratios during the First Month after Planting of Hydroponically Grown Tomato.” *The Journal of Horticultural Science and Biotechnology*, vol. 92, no. 3, 2017, pp. 294–302., <https://doi.org/10.1080/14620316.2016.1265903>.

Sardans, J., J. Peñuelas, P. Prieto, and M. Estiarte. “Drought and Warming Induced Changes in P and K Concentration and Accumulation in Plant Biomass and Soil in a Mediterranean Shrubland.” *Plant and Soil*, vol. 306, no. 1-2, 2008, pp. 261–271., <https://doi.org/10.1007/s11104-008-9583-7>.

Thapa Magar, S., G. Vellidis, W. Porter, V. Liakos, J.H. Andreis, and D.J. Chavez. “Nutritional Status of Young Peach Plants on Guardian and MP-29 Rootstocks Under Different Irrigation Scheduling Practices”. The Southern Region - American Society for Horticultural Science Annual Conference, in New Orleans, LA, Feb. 11-13, 2022.

Sun, X. P., H.L. YAN, X.Y. KANG, and F.W. MA. “Growth, Gas Exchange, and Water-Use Efficiency Response of Two Young Apple Cultivars to Drought Stress in Two Scion-One Rootstock Grafting System.” *Photosynthetica*, vol. 51, no. 3, 2013, pp. 404–410., <https://doi.org/10.1007/s11099-013-0040-3>.

Solari, L. I., S. Johnson, T M. “Relationship of Water Status to Vegetative Growth and Leaf Gas Exchange of Peach (*Prunus Persica*) Trees on Different Rootstocks.” *Tree Physiology*, vol. 26, no. 10, 2006, pp. 1333–1341., <https://doi.org/10.1093/treephys/26.10.1333>.

Taiz, Lincoln. *Plant Physiology and Development*. Oxford University Press, 2018.

- Tworowski, T. G. Fazio, D. Micheal Glenn. "Apple Rootstock Resistance to Drought." *Scientia Horticulturae*, vol. 204, 2016, pp. 70–78., <https://doi.org/10.1016/j.scienta.2016.01.047>.
- Villena, I. A., L. M. Tapia, W. C. Puente, M. I. Toribio, J. M. A. Garcia, J. V. Munoz, M. C. R. Sanchez. "Response of Early-Peach [*Prunus Persica* (L.)] Trees to Deficit Irrigation." *Spanish Journal of Agricultural Research*, vol. 8, no. S2, 2010, p. 30., <https://doi.org/10.5424/sjar/201008s2-1345>.
- Valverdi, Nadia A., L. Cheng, and L. Kalcsits. "Apple Scion and Rootstock Contribute to Nutrient Uptake and Partitioning under Different Belowground Environments." *Agronomy*, vol. 9, no. 8, 2019, p. 415., <https://doi.org/10.3390/agronomy9080415>.
- Wang, H., C. Wang, X. Zhao, and F. Wang. "Mulching Increases Water-Use Efficiency of Peach Production on the Rainfed Semiarid Loess Plateau of China." *Agricultural Water Management*, vol. 154, 2015, pp. 20–28., doi:10.1016/j.agwat.2015.02.010.
- Woodruff, D.R. and F.C. MEINZER. "Water Stress, Shoot Growth and Storage of Non-Structural Carbohydrates along a Tree Height Gradient in a Tall Conifer." *Plant, Cell & Environment*, vol. 34, no. 11, 2011, pp. 1920–1930., <https://doi.org/10.1111/j.1365-3040.2011.02388.x>.
- Wang, Z., G. Li, H. Sun, L. Ma, Y. Guo, Z. Zhao, H. Gao, and L. Mel. "Effects of Drought Stress on Photosynthesis and Photosynthetic Electron Transport Chain in Young Apple Tree Leaves." *Biology Open*, 2018, <https://doi.org/10.1242/bio.035279>.
- Xue, Ran, Y. Shen, P. Marschner. "Soil Water Content during and after Plant Growth Influence Nutrient Availability and Microbial Biomass." *Journal of Soil Science and Plant Nutrition*, vol. 17, no. 3, 2017, pp. 702–715., <https://doi.org/10.4067/s0718-95162017000300012>.
- Yuste, J. C., I. A. JANSSENS, A. CARRARA, L. MEIRESONNE, and R. CEULEMANS . "Interactive Effects of Temperature and Precipitation on Soil Respiration in a Temperate Maritime Pine Forest." *Tree Physiology*, vol. 23, no. 18, 2003, pp. 1263–1270., <https://doi.org/10.1093/treephys/23.18.1263>.
- Yu, Yang, Jun Fu, Yaoguang Xu, Jiewei Zhang, Fei Ren , Hongwei Zhao, et al. "Genome Re-Sequencing Reveals the Evolutionary History of Peach Fruit Edibility." *Nature Communications*, vol. 9, no. 1, 2018, <https://doi.org/10.1038/s41467-018-07744-3>.
- Zhou, H.M., F.C. Zhang, K. Roger, L.F. Wu, D.Z. Gong, N. Zhao, D.X. Yin, Z.J. Li "Peach Yield and Fruit Quality Is Maintained under Mild Deficit Irrigation in Semi-Arid China." *Journal of Integrative Agriculture*, vol. 16, no. 5, 2017, pp. 1173–1183., doi:10.1016/s2095-3119(16)61571-x.

Zhong, Y., W, Yan Z. Shangguan. "Impact of Long-Term n Additions upon Coupling between Soil Microbial Community Structure and Activity, and Nutrient-Use Efficiencies." *Soil Biology and Biochemistry*, vol. 91, 2015, pp. 151–159., <https://doi.org/10.1016/j.soilbio.2015.08.030>.

Zhang Jie, 2010. "Influence of soil drought stress on photosynthesis, carbohydrates and the nitrogen and phosphorus absorb in different section of leaves and stem of Fuji/M.9EML, a young apple seedling." *African Journal of Biotechnology* Vol. 9(33), pp. 5320-5325, 16 August 2010, <http://www.academicjournals.org/AJB>

Zhao, G., Shi, P., Wu, J., Xiong, D., Zong, N., and Zhang, X. (2017). Foliar nutrient resorption patterns of four functional plants along a precipitation gradient on the Tibetan Changtang Plateau. *Ecol. Evol.* 7, 7201–7212. doi: 10.1002/ece3.3283