Assessing the effect of salinity on relative crop yield through the use of irrigation and drainage model CSUID

Victor Obando

Civil and Geomatics Engineering, California State University, Fresno

WRPI USDA Internship

April 2016 – May 2017

Advisor: Dr. Fayzul K. Pasha

Associate Professor, Civil and Geomatics Engineering

Lyles College of Engineering

California State University, Fresno

Submitted: May 31, 2017

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to the California State University, Fresno for allowing me to fulfill my dream of being a Civil Engineering student here. I would also like to thank Water Resources Policy Initiatives (WRPI) and Civil Engineering Department for providing the necessary resources to complete my internship. To all my friends and family for helping me to keep my stress level low. Most of all, I am fully indebted to Dr. Fayzul Pasha, my internship supervisor and student advisor, for his understanding, patience, and encouragement for pushing me to do better and providing me the opportunity for this internship.

TABLE OF CONTENTS

ABBREVIATIONS

CSUF	California State University Fresno
CSUID	Colorado State University Irrigation & Drainage
EC	Electrical Conductivity
ET	Evapotranspiration
LF	Leaching Fraction
USDA	United States Department of Agriculture
WRPI	Water Resources and Policy Initiatives
UAL	University Agricultural Lab

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Background

Since the San Joaquin River is the main source of water used for irrigation in the Central Valley of California it is important for farmers to understand how the change of salt concentration in the water can influence their crop production. Due to the unique geological conditions in the San Joaquin Valley, the salinity level in the groundwater has risen higher making it difficult to reuse the groundwater without desalination.

When farmers use the water from San Joaquin River to irrigate their crop fields, they need to be aware of the high concentration of salt that the water may contain. The high concentration of salt can reduce the crop yield of specific crops that are not able to tolerate the level of salt concentration in the water. With this in mind, the farmers need to either manage which crops have higher tolerance so that they can use this water to irrigate the crops without effecting the crop yield.

Motivation

Salt management is an alternative to the expensive desalination of the irrigation. Salt management requires identifying the levels of salt tolerance in the crops. This would put crops in categories that would go from crops that are highly sensitive or in other words, has a lower tolerance to salt concentration and others that have higher tolerance to it. This would require studying the tolerance of each crop and how the crop yield would be affected due to each level of salt concentration. This can be done by observing the plant physiology of a crop. The Colorado State University Irrigation & Drainage (CSUID) model provides a way to calculate the relative crop yield at different salinity level. The CSUID can be used to graph the change in the crop yield due to the change in salinity concentration. This model can be used on different crops to view which ones have the highest salt tolerance. This process can identify the most to least salt tolerate crop in terms of their crop yields.

Objective

The objective of this study is to identify the effect of the salinity levels in irrigation water on relative crop yields, specifically, different combinations of salinity level between soil and irrigation water on the relative crop yield. Different simulation models including CSUID, Hoffman, and combinations of them to be run to observe the impacts. The models have been applied to olive field at California State University Agricultural Lab.

LITERATURE REVIEW

Effect of Salinity on Crop Yield

Cobot et al. (2014) made some examinations of signaling mechanisms and major elements involved in the response of the plants to salinity following the pathway of salt footprints from the plant as a whole. The examination took place in a lab at the University of Barcelona. The plants were treated under field condition to view how the plants react to saline conditions. In the lab, they would examine the change in the plants while they adapt to the saline levels or die due to having a low tolerance. The results lead to that saline environment slowing down growth rate and putting stress on the plants depending on their tolerance. Also, the condition other conditions of the environment including amount of sunlight and water can cause the plant to experience more stress. Limitations for this experiment were finding a field condition that would fit to all plants in their different environments.

Eldeiry and Garcia (2013) compared the performance of three nonlinear geostatistical models in developing conditional probabilities, compared alfalfa and corn yield samples with the yield potential that was estimated by the three models, and provided ways for precision management of agriculture by keeping in mind the outputs of the models used. This was all done by using the three models which where Disjunctive Kriging, Indicator Kriging, and Probability Kriging and comparing them together. The sample that they used where gathered from corn and alfalfa fields in the lower Arkansas River Valley of Colorado. They found that the conditional probability maps created by the comparison of the three nonlinear kriging models provided information on the expected yield of fields including the zones of risk for poor yield as a result of soil salinity. Limitations to this experiment would be that the models only took into account for the salinity of the soil but not for other conditions like irrigation, drainage, and fertilizer applications.

Wada et al. (2012) globally quantified the amount of non-sustainable groundwater abstraction to sustain the current irrigation practice. This is being applied globally using the hydrological model PCR-GLOBWB letting them simulate gross crop water demands for irrigated crops and blue and green water that is available to meet the demand. The result showed that nonrenewable groundwater abstraction contributes globally around 20% to the gross irrigation water demand for the year 2000 which has more than tripled since 1960. Limitations are that the global model does not include surface water diversions like aqueducts which can lead to some overestimation of nonrenewable groundwater abstractions in some regions.

Singh and Panda (2011) conducted a study on the effects of different qualities of irrigation water on mustard, yield, crop growth, water use efficiency and salinity if the soils. This study was applied at Shahpur village, India. They conducted the study by examining the crop on the field and using both saline groundwater and clean canal water for irrigation. They then measure and calculate the growth of the plant and the yields. The results of the study show that the use of use of slide groundwater increased the salinity of the upper soil profile which leads to the decrease grain yield in mustard and straw yield. Limitations of this study would be the effects of the seasons because it can lead to leaching of the soil which reduces the salinity of the soil.

Harris et al. (2010) constructed a study to find the effects of soil salinity on the growth and wield of the wheat and barley. Study was in Australia by using the wheat and barley crops and growing them in pots letting them control its growth. They used a combination of four varieties and three salinities soil treatments to show the effects from the different soils. The result led to salinity causing a reduction in the rate of the leaf appearance in all four varieties and a negative effect on the yield. The limitation would be that they used pot plants in a glass house but the results could change when applied to normal conditions in nature.

Malash et al. (2007) did a study to find the best way to reuse water even if it is saline and using the best water management. This experiment was conducted in the fields of the Agricultural Experimental Station of the Faculty of Agriculture of Menoufiya University in Shibin El Kom, Egypt. They tested out the different soils and the two water distribution methods. The results showed the tomato fruit yield was on average one third better in drip than furrow irrigation also the drip irrigation maintained the water levels in the soils keeping it from being over watered

Ashraf and Saeed (2006) examined the effects of the different practices used in irrigation on crop yield and soil salinity under saline groundwater. This study was applied in the Bhalwal area in the Indus Basin of Pakistan. They used two different ways to irrigate the crops one being regular furrow and the other being alternative furrows. When they harvest the crops, they let the soil go through evaporation to increase the salinity of the soil. The result showed that alternative furrow saved the most water while during the irrigation and there was no other difference in the crops production. Limitation includes the amount of rainfall in the year which would affect the salinity in the soils.

Steppuhn et al. (2005) did a study to describe the product yield of agricultural crops being grown while in the condition of having root-zone salinity. This experiment was conducted in Canada’s Salt Tolerance Testing Facility. The study was done by comparing six empirical functions, four being nonlinear functions and examining the data collected of the effects from the root-zones being in saline soil. The results show that the crop yield had a decline in response to increasing root-zone salinity. This means that increasing salinity would have a decreasingly reduced influence on yield. The limitation to this experiment would be that the six functions being compared to not considering any other factor other than the salinity in the soil.

Grattan (2002) viewed the affects Irrigation water salinity has on the crop production. These studies were conducted at University of California Agricultural and Natural Resources. Grattan showed his studies through providing information on which equations to use to find the yield of the crops, salinity of the soil, and even the amount of water needed for irrigation. The results ended up with equations showing that salinity is found in all irrigation and that it only affects the crop when it exceeds the crops salinity tolerance. The limitations would be the type of pesticides used on the soil which can have an effect on the soil.

Hill and Koenig (1999) examined other studies and classified the crops by its tolerance towards the salinity in the soil. The four categories are tolerant, moderately tolerant, moderately sensitive, and sensitive. This study was conducted in Utah State University by testing and graphing the tolerance on several test crops and viewing their results. The testing resulted in finding the tolerance of the crops and categorizing them into the four categories. Their limitation would be the areas in where they received the crops and the salinity in the soils.

Letey and Dinar (1986) provided a study that showed crop-water production functions when irrigating with saline water strategies for different crops. This study was conducted at the California of Agricultural Science Experiment Station. They began by collecting varies of crops from specific areas based on their yield. Then they are run through different models to view their tolerance, yield, and electric current of the water and more. These graphs were created showing varies crops. The limitation would be the technology they have to run the model

Barbagallo et al. (2014) evaluated biomass production of energy crops that are irrigated with low quality water at different evapotranspiration restitution. This study was conducted at an open field located in Eastern Sicily. They conducted their study by using two wetland beds to test for crop irrigation. The results proved to be efficient because the chemical and pollutant have been removed and show that the irrigation using this model proves to be useful. The limitations would be the age of the wetlands and how that would affect the changes shown.

Sammonds et al. (2013) suggested and option to improve the ecological condition of wetlands by using them as temporary off-river water storages so that the water used to inundate them is available for use. This study was conducted by using the Broken River which is found to be in Australia. They used the Broken River and analyzed the wetlands that it creates and the volume it contains to view the irrigation. The results show that the wetland with application of bund walls greatly enhanced the potential storage volumes for irrigation reasons. The limitations in this study would have to be the climate change which affects the river and how much water is transferred to the wetland to hold.

Watson and Byrne (2012) researched on a hypothesize that the rise of salinity on the Estuary Marshes caused a shift in the plants in their tolerance levels, this study was conducted on the San Francisco Estuary marshes. They were able to conduct this study by using the GPS to map the marshes and view the sea levels change which would cause a change in salinity on the marshes. The results showed from comparing changes in plant distributions within the wetlands showed that most of the crops have expanded their range into the brackish portion and decrease on the fresher side of the wetland. The limitation would be cause by the sea level which controls where the salinity would be caused.

Nikouei et al. (2012) presented a model implemented through the creation of an integrated basin framework. This study was conducted in Shiraz University, Iran. For this study, they used the analysis model which integrates the hydrology, institutions, economics, agronomy, and policy choices for the basin. This model would be able to calculate the change of water, irrigation, environment change, and much more about the basin. The results show that the method works and are able to conserve the wetlands for farmers by keeping track of the changes within the wetland. The limitation is that the results are based on the idea that irrigation water use doesn't have negative externalities.

Laibin et al. (2011) conducted a study on the effects on the soil properties in the marshes. The study samples were gathered from marshes around the area that the Yellow River Delta in China flows through. These soil samples are then sent to the lab to get air dried and analyzed. The result of the analyzation of the samples show degradation of the marshes and showed a change in the soil nutrition. A limitation to this study is the lack of fertilizer to the soils causing a small change to it.

Fowler et al. (2014) set up a study to analyze and monitor the abiotic influences on soil salinity of inland managed wetlands and agricultural croplands. This study was conducted at Bosque Del Apache National Wildlife Refuge which lies within the Middle Rio Grande Basin along the Rio Grande River. The study was conducted by taking samples of the soil from the wetlands and monitoring the salinity of the soil after irrigation and flooding of the soil. The result showed that the degree of salt accumulation in semi-arid was influenced by the difference in timing, quality of artificial hydrologic regimes, and volume. The limitation would be the season and effects it can bring to the soil in salinity change.

Goldstein et al. (2001) updated the Watershed Analysis Risk Management Framework (WARMF) which is a system that is designed to help stakeholders follow the watershed management plan. They took samples from different environmental conditions and set up models for the system to recognize so it would be able to find the best way for irrigation and keeping the crops at the highest yield. The results lead to education the stakeholders in the watershed management plan and the new functions the WARMF came with. Limitations are that the system contains uncertainties which are contribution to the controllable risk and the contribution to uncontrollable risk.

Herr et al. (2001) are aiming to improve the WARMF and making it more users friendly and helpful for guiding a person to following the watershed management plan. This is a system in which it helps the user, the stakeholders, in constructing consensus on a watershed management plan. This system is design to calculate everything a stakeholder would need to maintain the watershed management plan by calculating all that is need and making the different models for the watershed you are constructing. The limitation for this would be if you don’t have the technology to support this system.

McEwan et al. (2008) studied the interaction between groundwater and surface water, water and salt balance of wetlands, and the ecological responses to change in salinity as a consequence of the changes in both groundwater and surface water regimes. This study was conducted in River Murray wetlands. They used studies that have been made on groundwater and surface water and compared them to the River that they are using to experiment on. With the studies, they found they were able to conduct graphs showing the levels of salinity and how the water reaches the soil. The results showed that the interaction in wetlands are mostly controlled by other factors like the local geomorphology or the wetland and the wetland and groundwater geometry. The limitations are the amount of water from the rainfall that can change the salinity levels.

Quinn et al. (2013) were making updates for the WARMF-SIR model by utilizing real-time point source which would provide a more accurate reading of the data collected at the San Joaquin River. This study was conducted at the San Joaquin River. They were able to conduct this study by setting up monitoring stations along minor west side ephemeral streams and drainage which allows them to collect their data on water flow, salinity distribution, can calculate what area it goes to. The results show that with this update there was better accuracy for the mud slough area. The limitation is that it would need more calibration to provide accurate readings.

Nachshon et al. (2014) set up a study to explore the salt dynamics in the prairies to find how recent climate variability has affected the salinity of ponds. This study was conducted at the salt-rich glaciated plains of North America which is also known as the prairie pothole region. They examined snow and rain conditions with respect to their impact on the salt transport, wetland salinization, and salt accumulation. Then they examine the ponds and their change in salinity. The result shows that under wet conditions mainly the rainy summers, large fluxes of salts are flushed into the ponds from the subsurface. The ponds salinity is dependent on the flow of water coming in containing salt which raises the salinity of the ponds. The limitations faced would be predicting the weather which can lead to rain or snow to bring in salt.

Quinn et al. (2012) are working with others to develop wetland simulation models and enhance system wide monitoring to allow the formulation of interim wetland salt load target. This study was conducted at the lower San Joaquin River. They used an electromagnetic instrument to map the near surface soil salinity also used the monitor devises to use the Real- Time point source to have accurate readings. The results lead to new installation of monitoring devises installed to collect data around the area which provided lots of data of flow and water quality. This will allow them to precisely conduct model for the best wetland management plans and improve the quality of water. The limitation of the experiment was that there is a certain timing to conduct this experiment for the best outcome. The best time would be after the initial draw down which provides uniform soil moisture.

Sanchez-Carrillo et al. (2004) were aiming to identify the importance of the variables in the evapotranspiration in different water level scenarios. This study was conducted in a semi-arid, freshwater wetland in Central Spain. They conducted this study by gathering microclimatic data from an automatic weather station located towards the western shoreline of the wetland. The data contains measurements of wind speed, direction, temperature, and dry and wet bulb air temperature. Using this data they then calculated the relationship between the transpiration rats and short wave radiation. The result determines the variability of evapotranspiration during the inundation cycle and indicates that hydrological restoration programs could benefit from vegetation management. Limitation found were the flux of the weather during the seasons.

Olive Field Plant Physiology

Chiraz (2013) conducted an experiment on a variety of olive trees which include Chetoui, Manzanille, Meski, and Picholine. The experiment was conducted to monitor the tree height, shoot length, canopy, and diameters of fruit and trunk changes. This experiment took place in North Tunisia at the research farm of the National Institute of Agronomy where the climate is Mediterranean. The hot and dry climate went from March to September with an annual average rainfall of 450mm. They conducted the experiment by using the variety of trees and closely monitoring their growth while keeping track of the temperature and water input being used throughout the year. More than 30% of the crop water requirement was met during the irrigation period. They found that the tree height growth, lateral shoot length, canopy, trunk and fruit diameter increases during the time they were observing the trees. They also noticed that active growth occurs in April, July, and September but throughout the year it would be dependent on the temperature, pruning, watering condition, fruit load, fruit interferences, and the difference between the types of trees used which were the driving factors controlling the growth. The limitation to the experiment was finding soil types, the best trees to test, the accuracy of the season change.

Fereres (2004) gathered information on the Olive Plant from other sources that were researched and tested by other researchers who have conducted studies on the Olive Plants. In the section about Olives, Fereres wrote about the general information of Olive trees including their general description for what they are used for and how they grow. Fereres also includes stages of development in relation to yield determination, assessment of tree water status, water requirements, water production function, and suggested RDI regimes. In the sections on olives there are many charts and graphs that show well organized information about the Olive Plant. There is a graph that shows the production of Olive Plants in different countries and from the graph Spain has the highest production. There is a bar graph that shows the water deficit of the different parts of olive plant that includes the leaf, shoot, inflorescence and flower development for the different months. There is also a table that shows the water flow of the olive plant that includes the in water and out water. In the chart, you can see the amount of water coming in from rainfall and irrigation as well as the out water which includes the evaporation and water used by the plant from different regions. There is a chart showing the K value used for the different seasons. Limitations would be the reliability of the research used.

Fernandez and Moreno (1999) conducted a study on Olive Trees and the amount of water the tree uses. They gathered information from recent studies and experiments that they themselves have conducted to describe the characteristics and mechanisms conferring drought tolerance on the olive tree. The study would examine the root system functionality, leaf water relations, hydraulic characteristics of the conductive system, and transpiration behaviors. The reason for choosing the olive tree is because of its tolerance to drought, and its capacity to grow in shallow, poor quality soils, makes this tree the best for cultivation in arid and semiarid area.

The Root system of the olive tree seems to be designed to absorb the water of the light and intermittent rainfall that would be usual to its habitat instead of taking water from deep layers like other trees. The small diameter is a high portion of the root length, which favors absorption capacity. The absorption by the tree is also enhanced by the high potential gradients between roots and soil which is caused by osmotic adjustment. The highest root density can be found close to the trunk, although the volume travels by the roots can extend beyond the canopy projection. The distribution of the tree's roots is determined by the soil condition, neighboring trees, and the amount of irrigation. The roots of the olive tree can react quickly even after a long period of drought, absorbing water immediately when it is sensed in the soil. The efficiency of the olive tree root system is contained by the root-canopy ration that is usually bigger in non-irrigated trees than in those that are irrigated. The hydraulic characteristics of the wood for the olive tree have also been researched in this article. The olive tree is a diffuse porous tree which has a dense wood with abundant fibers and little parenchyma. The maximum depth of sapwood is highly heterogeneous, ranging between 12 and 34 mm, averaging around 26.6 mm. The leaves are well adapted to avoid excessive water loss under the highly demanding conditions of the surrounding area. They show several sclerophyllous characteristics, but also active mechanisms controlling water loss. The optical property of the olive leaves has a huge role in controlling the water consumption due to the leaves absorbing more photosynthetically active radiation than the abaxial surface. The tree size and canopy structure depends on pruning practices and plant density. The sap flow measurements are important because they can determine the short-term water use dynamics of the olive tree. The sap flow measurements are taken from the trunk, branches, or roots which this information is essential for a better control of the high frequency irrigation systems normally used in olive orchards. All the methods to find the sap flow use heat as a tracer for the sap movement. The two main methods used to find the sap flow are heat balance and the heat pulse methods. The sap flow can also be used to calculate the transpiration from the branches. The limitations of this study would be the accuracy of the information collected from other research on olive trees. The temperature of each year can have a huge effect on the olive tree and on how much water can be used. The tree itself may contain an unknown substance that may affect the calculations. Also, the soil types used can affect the growing rate of the tree.

Masmoudi et al. (2007) conducted a study on Olive tree and finding the water requirements for the Olive tree. The study was conducted in Tunisia where the Olive trees were able to grow under arid conditions. They analyzed the root growth and distribution which they noticed that starting the second year after the tree was planted the roots grew rapidly in both lateral and vertical directions. The roots would expand one meter cubed every year for the first four years. The canopy development was also analyzed and showed that the canopy would increase between successive pruning's, over a four year range from 0.5 to 1.25 m. the researchers noticed that applied water didn't limit vegetative growth since the trees were observed during the years of the experiment. When there is a high value of root-canopy ratio it may indicate a greater availability of water per unit of the lead area and may be used as an indicator of tree adaptation to water shortage. The results show that the ratio of applied irrigation during the dry season from April to August was low with an increase from 0.02 to 0.14 when the trees grew one to six years. The limitations were the type of soils that was used during the experiment and the temperature during the years.

Masmoudi et al. (2010) conducted a study to analyze the effect of irrigation schedule on water relations for young olive trees that have been cultivated from Chetoui, Chemlaii, Coratina, Picholine, and Manzanille. The study was conducted at the Experimental Field Taoues, southern Tunisia where the climate is arid with a yearly average of 250 mm rainfall. The process they followed were applying different amount of irrigation and examining the soil, lead water potential, stomatal resistance, conductance, and water contents. During the experimental year the total rainfall was about 97 mm which was received between March and October. Most researchers reported that low water potentials in the tissues of trees subjected to increasing water stress. The heterogeneous distribution of water in the root zone can modify the response of the tree to water application. Through this research, you can see that the olive tree response to water regime was largely influenced by irrigation affecting the most physiological parameters that have been monitored. Limitations could be the type of soil as well as the different types of trees used for the experiment may be damaged or defective.

Rahman and Sharkawi (1974) conducted a stud to reseach the response of olive trees to partial irrigation under dry farming in semi-arid regions. They conducted their research in the Burg El-Arab Desert Experiment Station in Egypt where the climate was semi-arid with a mean annual rainfall of 150 mm. the decided to use 15-year-old Olive trees called Shimlali. During this experiment, they would examine the transpiration, leaf number, fresh weight of leaved, relative turgidity, and osmotic pressure of leaf sap. They would use four types of treatments in which there would be ten trees per treatment to examine. For the hanged in the fresh weight of leaved, they would have excised one hundred leaved from the ten trees of the treatment and weight them to find the average single leaf. This data was then used to calculate the amount of total water output was used. The results show that the maximum growth of leaves occurs in early spring which is between February and January and the minimum found to be in July. Water loss was also lower in the natural growing trees that were not irrigated compared to the irrigated ones. The minimal loss occurred during winter while the maximum loss occurred in June. The change in turgidity of the leaves was consistent in all the treatments over the period of the experiment. The limitations of this experiment are full control over the temperature and the quality of the soils which could have an effect on the Olive Trees.

Fernandez et al. (1990) conducted a study on the root distribution and root activity of the Olive tree when influenced by drip irrigation. There were two experiments conducted with a 20-year-old olive tree, one with a sandy loam soil and the other with clay loam. This experiment was conducted in Spain where the climate is arid. There were two methods to finding the root distribution one is cylinder and the other method is the trench method. Root activities have been monitored from during the summer of 1986 and 1987 by tracking the depths and distances from the tree trunk. The results show that from a sub-sample with a 90 piece of root of different diameters and length that showed the total length was 1047 mm. The higher root concentration is found in the deeper layer than the top layer, except for the distances from the tree trunk. The root density near the tree trunks is not higher than in the other positions. Conforming that the cultural practices applied to the first treatment is the reason for the higher root density near the tree trunks. The results obtained for the root activity from the two years were similar meaning that they are consistent. The limitations for this experiment would be the function of the drip system used for irrigation and also the type of soil.

Vertedor et al. (2011) conducted an experiment to characterize the interactions between variable water supply and crop load on vegetative growth and water relations of an olive orchard. The experiment was conducted over a six-year period with two different types of experiment done with four different irrigations. The first experiment was done with younger olive trees while the second was done with more mature olive trees to see the difference between ages. This experiment was conducted in Badajoz, southwest of Spain. They used an automated weather station that was located 800 mm away from the olive orchard. The weather station recorded half-hourly averaged of global radiation, air temperature, wind speed, relative humidity, and rainfall. The results show that the ground coverage, also known as canopy, would increase when the irrigation rate would increase. The tree water status reacted to the variations in irrigations water as well as to the crop load. The branch length decreased as water stress increased. The water deficits have strong influence on tree growth in fruit crops and the water supply have a strong influence on the expansion of both the young and mature olive canopies. Water deficits affected ranch length and internode number showing that the length of the branch was greatest in one of the treatment and decreased as water supply declined in two other experiments. Limitations would be the accuracy of the weather station and the type of soils used in the experiments.

Masmoudi et al. (2011) conducted a study on measuring sap flux from May 2003 to March 2004 on 6-year-old irrigated olive trees of cultivar Chetoui cultivated in Mornag, Northern Tunisia. This study was conducted at an experimental farm of the *Institut National Agronomique de Tunisie*, close to South of Tunis, Northern Tunisia. The region climate is Mediterranean with average annual rainfall of 450 mm and soil is clay loam of about 2 m depth. The purpose of the research is to evaluate the sap flux technique for its applicability with young olive trees and to estimate their water consumptions under the condition of the field being used. They used three thermal sensors that were implanted in the trunk of three olive trees following the North, South-East, and South-West directions. In their research data on prove calibration, wood conductive section estimation and sap flux spatial variability are examined as well as relationships between sap flux measurements, climate and soil water status have been investigated. A weather station was used to obtain the temperature, air relative humidity, wind spread, rainfall and global solar radiation which were used to calculate the evapotranspiration. The results show that sap flux values vary with sensor position, soul water content and climate demand. The correlations between the sap lux index and the actual sap flux densities were obtained and showed that the relationship is highly dependent of the sensor heat power. As the heat power increased, the sap flux densities decreased consistently for the same value of sap flux index. The absolute values of sap flux densities obtained by individual sensor vary due to the environmental conditions which include soil water content and climates. Daily water consumption ranged between 0.13 mm and 1.13 mm which were obtained on February and August. Limitations would include climate, sensors calibrations, soil contents, and the amount of heat used for the process.

Pasquale and Giovanni (2003) conducted a study to estimate sap flow using a new technique in which instead of using a large number of gauges and trees they would only use a few trees and gauges. They used the compensation heat-pulse velocity (CHPV) technique for finding the sap flow. They monitored six CHPV gauges in three well irrigated trees and six CHPV gauges in three rain-fed trees at half hour intervals for 60 days. This study was conducted at the CNR-ISPAIM experimental farm near Benevento, in the Campania region in southern Italy during the summer. The sap flow was estimated by the CHPV technique which each heat-pulse gauge consists of a linear heater and two temperature probes, one installed down-stream and the other up-stream of the heater. The results that were obtained showed that all gauges of both treatments had a good correlation. They show that it would be much more efficient to follow their technique and just use fewer gauges and trees and just scale up to find the sap flow of the different amount of olive trees. Using this approach, you can reduce the complexity of the instrumentation required during the irrigation season. Limitations are the types of soils being used and the gauges being used may be low quality.

Fernandez et al. (2011) conducted a study to find water stress and to evaluate plant water consumption using the measurements of the sap flux and the trunk diameter variation. They analyzed relations between the sap flux, trunk diameter variation, midday stem water potential, relative extractable water and atmospheric demand in an olive orchard of 38-year-old Manzanilla de Sevilla trees. The trees were trained to an open center canopy of about 4.5 m diameter and had a single trunk and two main branches from 0.7 to 1.5 m above ground. The experiments were carried out during the irrigation season of 2006 between May and October, a year with heavy fruit load. The sap flow was measured using the Heat-Pulse velocity probes which were connected to one of each tree per treatment. Three sets of probes were installed into the single trunk of each tree and each set had two temperature probes located upstream and a linear heater probe located downstream. The trunk diameter measurements were taken by using the probes and also tested for expansion which resulted to no expansion at all. During the experiment, there were signs of change in soil water in the three experiments. The results show that one of the treatments showed a constant rate while the other two showed a drastic rate of change. The limitation of this study would be control over the soil conditions, temperature, atmospheric conditions, and the accuracy of the probes placed on the trees.

Fernandez et al. (2001) conducted a study of measuring sap flow using the compensation heat-pulse method testing on olive trees. They did two tests using heat-pulse gear inserted into the stem of 12-year-old Manzanilla olive trees. One of the test used forced flow through a stem section while the other involved measuring water uptake by an excised tree. They conducted a third and fourth experiment, the third was carried out in the field where sap flow from two 29-year-old olive trees were analyzed. One of the two trees were under regular drip irrigation and the other was from dry farming conditions. They used measurements of the sap flow to examine the hydraulic functioning of the tree and to explore some diagnostics of water stress. The fourth experiment was also carried out in the field where sap flow measurements were made at three locations in the trunk as well as in two roots of another 29-year-old olive tree. The two roots of the tree expanded in different directions in which they were differentially wetted by separate irrigation of each side showing that the roots were able to absorb water. The results obtained from the excised tree showed that during the first say of the excision test, the tree consumed water from the reservoir at rates that peak around 3- 4 Lh^{-1}. These rates were expected due to the size of the tree under the condition it was in, but on the second day transpiration decreased markedly and on the third there was a negligible amount of water consumption. The reason for the loss of hydraulic functioning of the vascular system may be due to clogging, by phloem exudates, of the proximal entrance to the xylem vessels at the cut face. The sap velocity to be was greater in the outer annuli and while the atmospheric demand rose towards midday, the velocity steepened so that the bulk of the flow was in the outermost 20 mm. the loss of sap flow is a result of emboli forming in those vessels of the outer annuli, due to the water stress probably caused by blockages to water supply at the entrance to the xylem vessels in the butt. The limitations were the accuracy of the probes, weather conditions, soil contents, and also the heat used in the probes.

Tognetti et al. (2004) conducted an experiment on the effects that irrigations have on whole plant sap flow and lead level water relations in an olive orchard. This experiment was carried out at the experimental farm of CNR-ISAFOM, located near Benevento, a typical olive growing area of southern Italy. The experiment took place between May and October 2002 and the site is characterized by good precipitation in sprung, scarce or no rainfall from mid-June to mid-August, and frequent rain in autumn which it between October and December. The soil used during the experiment was sandy loam with a volumetric water content of 35.6% at field capacity. The sap flow was monitored within the trunk of both irrigated and non-irrigated trees using the heat-pulse technique. Two sets of heat-pulse gauges were placed into parallel holes drilled in radial positions into the semi-trunk of each tree. When the heat-pulse is released they were able to calculate the ideal velocity by measuring the crossing time needed for the up and down pair of thermocouples to reach an equal temperature during the heating. Diurnal time courses of lead water potential were measured on four leaves periodically from three individual plants for each trial with a two-hour interval. The results showed the climatic aridity index was averaged 0.54 for the experimental period. The total precipitation for the irrigation period which was between the first of June and the 30th of September was 225 mm while the average max and min temperature was 13 and 27 C. The soil moisture reduction throughout the growing season showed similar patterns for the different experiments depth, the soil water content decreased progressively near non-irrigated trees and remained below the wilting point threshold throughout the period from early July to late September. The sap flow diurnal patterns showed that a steep morning increase leading to the max rates achieved at about midday. The sap flow activity period showed a reduction from June to October, but rain fed plants showed lower daytime, Sap flow rates than that of the irrigated plants in the summer. The maximum daily leaf conductance decreased with decreasing predawn leaf water potential across treatments, but showed separation between them and a stronger negative relationship with increasing vapor pressure deficit. The limitations are the soil types, temperature, and the accuracy of the probes used to measure the sap flow.

Grattan et al. (2006) conducted a two-year study in the spring of e2002 to identify the optimal level of applied water on a super high density olive orchard. The study was conducted at a large ranch in California’s Sacramento Valley near Groville with 30-month-old olive trees that were irrigated using drip irrigation. They measured the stem water potential by using pressure chambers on leave that were covered with foil faced bags after 15 minutes prior to measurements to allow equilibration. Through field evaluations they found that two leaves per tree were sufficient for quantifying stem water potential in any particular tree. The soil matric potential was also measured in the center block of four treatments by placing nine WaterMark sensors ate each of the four stations. There were measurements made on flowers to estimate fruit density, fruit retention, and fruit set. The measurements were made on each of the tagged branches used to characterized growth. At the end of the season, two separate harvests were made to determine the effects of irrigation treatment on the oil content/extraction and quality in relation to early and late harvests. The results showed that the volume of applied water had a profound influence on branch growth. There was no significant difference within the higher irrigation treatments, but differences were found when trees were given less water. The length of tree branches from the lowest water application treatment was only about half of those from higher water application treatments. While water application treatments increased from 40 to 56% evaporation, branch length increased from 68 to 86% of those from the highest water application treatments. The same affects were also found based on trunk diameter measurements. Plant water relations, who were characterized by mid-day stem water potential, indicated that water potential varied throughout the 2002 and 2003 seasons between -0.2 and -4.1 MPa, but relative differences among stems from different treatment son a particular sampling day were very consistent. The stem water potential differences among treatments were detected at an earlier time which was the main difference between the 2 years. The characteristic changes in soil water potential were synchronized with those changes in stem water potential and root water extractions patterns were relatively the same both years. The different water application treatments affected fruit set in 2002 but not 2003. Some of the difference in yield among treatments can be taken into account by reduced fruit size. The study shows that applied water has a large influence on olive tree growth, tree water relations and fruit production as well as yield, fruit size, and fruit density.

Nadezhdina et al. (2006) conducted a study to investigate radial variability in sap flow in the trunk and branches of mature olive trees and examine how the sap flow radial pattern changed during the day with changing soil water content. This experiment was conducted in an olive orchard located near Andria, Southern Italy. The mean annual rainfall is 530 m, distribute from September to April and the yearly means of minimum and maximum temperature are 11 and 21 Celsius. The soil water content was measured once or twice daily by time domain reflectometry probes at eight positions in the orchard. The sap flow was measured by the heat field deformation method (HFD). Thirteen mature olive trees were used for the study and 12 of them had HFD sensors for short term measurements of sap flow radial pattern from July 23 to August 2, 2002. Each tree trunk was measured from opposite sides as well as main branches from one to three cardinal directions in four of the sampled trees. There were two asymmetric types of sap flow rail patterns that were observed: type 1, rising to a maximum near the mud-point of the sapwood: and type 2, falling continuously from a maximum just below cambium to zero at the inner boundary of the sapwood. The results show that the shape of the sap flow radial pattern recorded on the same side of the trunk remained constant during the daytime. Sap flow density was similar on the north side of the trunk in the morning and afternoon, but in the south and west sides it was at least twice as high in the afternoon as in the morning. The sap flow radial patterns recorded in the branches were similar to what was found in the trunks. They found that by using the ration of daily values of sap flow densities in the inner to the outer stem xylem can become an indicator for water stress for automatic irrigation control. Limitations include errors during flow integration from single point measurements also accuracy from the measurements done throughout the study.

Iniesta et al. (2009) conducted a study to find the effect of regulated and continuous deficit irrigation on the water use, growth and yield of olive trees. This experiment was conducted between 2004 and 2006 in and experimental olive orchard located at the CIFA Experimental Station, Cordoba, Spain. The soil is a typic Xerofluvent of sandy loam texture. There were three treatments that were tested, on being control treatment, second being continuous deficit irrigation, and the third being regulated deficit irrigation. There were three replications with each of the 9 plots consisting of 12 trees in 3 adjacent rows. The evapotranspiration was obtained by water balance, measuring the soil water content with a neutron probe. Leaf water potential was measured during midday with a pressure chamber in two leaves per tree. The vegetative and fruit growth were also measured every 2 weeks during the season. The canopy volume of each tree was calculated from the coordinates of the tree silhouette. The results show that the first treatment leaf water potential values were between -0.5 and -1.7 MPa throughout the 3 years of the experiment while in the other two it decreased during irrigation seasons reached values of -2.9 and -3.6 MPa. The third treatment showed the minimum values of leaf water potential values at the end of the no irrigation period. The third treatment recovered from stress once irrigation restarted and reached similar values as the first treatment. A strong effect of growth reduction was shown in the third and second treatment with the highest value shown in the first and the lowest shown in the third treatment. Canopy volume and leaf area index were lower in the deficit treatments than in the first treatment. Canopy volume increase was directly associated with plan water status throughout the experiment with the first treatment being the highest and the deficit treatment being lowest with the worst water status during the dry season. The controlled treatment showed the highest fruit yields while the third treatment produced slightly more than the second treatment. Limitations are the soil water content and on how much water were contained within the soils.

Palese et al. (2010) conducted an experiment that was carried out in a young high density olive grove located in Southern Italy to evaluate the effect of different soil water availability on the vegetative and productive performance of olive trees as well as looking into the quality of the resulting oils. The experiment was carried out over a three- year period on trees that were subjected to irrigation and grown under rain fed conditions. The climate of the area where the experiment took place is classified as semi-arid, with an average annual rainfall of 578 mm, mostly concentrated in the October-February period. The monthly average annual temperature can range from 5.2 to 24.1 Celsius and the soil is loamy with no groundwater table. When finding the measurements for vegetative and growth they would choose 41 trees at random from the group of trees being observed. There were 18 gypsum blocks that was used to measure the soil matric potential by placing the blocks into the soil at an angle of 45 degrees. Weather stations were used to find the meteorological variables which were placed close to the trial field. The weeds growth was controlled by regular shallow tilling as the pest and diseases control was performed according to the regional service recommendations for commercial olive grove. The trunk diameter measurements were taken along the growing season of each experimental year which was measured using calipers. The results showed a difference within the studied years of the annual precipitation. Over the three years the calculated average climatic aridity index was 0.27 in the April-October period, but differences were shown as well. Irrigation showed a significant effect on the current year shoot growth in 1997 while the final current shoot length was reduced by 81% under the non-irrigated treatment with respect to the irrigated one. The irrigated trees showed higher trunk diameter values than that of the non-irrigated.

Mezghani et al. (2012) carried out an experiment to study the behaviour of local and foreigner varieties like Chetoui, Chemlali, Coratina, Picholine ad Manzanilla under climatic conditions of central Tunisia. There were three irrigation treatments that were applied during two growing seasons with water amounts of 20%, 50%, and 100% crop evapotranspiration. The growth parameters were measured regularly and the flowering and fruit set were monitored on the same trees. In the area were the experiment took place, annual rainfall was equal to 155 and 288 mm. The soil used was silty, calcareous, and poor in organic matter with a pH of 8.7. Water requirements were determined by using the K_c and were irrigated twice a week. Measurements were taken on three trees per treatment and variety of olive trees. The number of flowers per tagged shoot was counted at full bloom stage during the first experimental year in 2008. The results showed a significant difference between years, with greater values observed during the second year of the experiment and an effect on variety. There was no significant effect of irrigation on final shoot elongation but it varied consistent following water application with values ranging between 33 mm and 353 mm for the treatment with the 20% evapotranspiration. Results found a linear relationship between the final basal diameter and the length increment. The number of flowers developed per unit of length increased with the increased amount of water applied for most varieties except for Coratina with higher numbers of flowers. The maximum fruit densities were found on the treatments with 100% evapotranspiration for both Coratin and Chemlali reaching 0.6 and 1.2 fruit per cm^{-1}. There were differences of individual fruit sizes on both years due to the treatment and variety. Shoot elongation seems to be more affected by the plant bearing conditions than by water applications.

Larbi et al. (2014) conducted an experiment in a high-density olive orchard located in Mornag, Northern east of Tunisia, to find the effects of light on leaves and how they have an effect on canopy light distribution, leaf anatomy, gas exchanges, chlorophyll fluorescence, and pigment composition. The area has an average rainfall of 450 mm $year^{-1}$ average mean, maximum and minimum temperatures were 17.5, 24.2, and 13.9 ^{o}C. The soil type used for this experiment was clay loamy. The leaves that were completely developed were measured from the middle part of the marked branch at each height. The leaf angle was found manually using an angle hook by measuring the insertion angle of leaves on marked branches at each canopy height. Leaf gas exchanges were performed on fully expanded leaves by using a LI-6200 portable photosynthesis system. The measurements were done on cloudless, sunny days. Results show that the average light interception from March o October decreased significantly from upper canopy to the central and lower ones in both cultivars. The leaf angle increased in the upper canopy and lower. The leaf area was higher in the lower canopy of Arbequina cultivar when compared to the rest of the sampled leaved. The leaves from the lower and central canopy were higher than the leaves in the upper. The leaf anatomical characteristics of both cultivars varied significantly with their position into the canopy. Leaf tissue thickness decreased in the lower as compared to the central and upper canopy for both cultivars. The photosynthetic rates were similar in both cultivars, but decreased from the upper and the central canopy. The limitation would be the amount of light that is provided by the sun.

Quinn et al. (2016) conducted a study that identifies the relationships between agricultural applied water salinity leaching fraction, and soil salinity. They were able to find the relationships through two models one being the Hoffman model and the second one being the CSUID. They needed only the parameters of the crops that they were using and the soils initial state as well as the status of the farm. The data received from the models shows that there was an impact on the crop yield due to the level of the salinity. Singh and Benes (2016) conducted a study to monitor the soil salinity in Alfalfa and 'Jose' tall wheatgrass fields. This research was conducted on the campus of Fresno State. To monitor these crops the CSUID model was used as well as the EM-38 soil surveys. The surveys were used to measure the salinity properties on the crop. The results revealed that there is an impact from the soil salinity has over the given crops which should be shown on both models.

Singh et al. (2017) conducted a study to analyze the soil salinity after being irrigation with the water obtained from the San Joaquin Valley. The study was conducted at CSU Fresno and the way this study was conducted is by using the CSUID model. The goal is to use the CSUID as a supporting tool for decision support so that there could be an improvement. The result of the project came out to become a great way to support one's decision to manage the salt concentration in the water used for irrigation and to consider different crops for different levels of salinity.

STUDY AREA

The University Agricultural Lab (UAL) at Fresno State can be found behind the school with the fields being about 760 acres. The Olive Fields, show in Figure 2 and Figure 3, was used to test the high tolerance it has toward the high salinity.

***Figure 1**: Fresno State University Agricultural Laboratory (Source: Google Earth)*

***Figure 2:** Study Area - Olive Fields (Source: Google Earth)*

Figure 3: *Olive Field Close-Up (Source: Google Earth)*

The Olive field at CSU Fresno is divided by a path that runs in the middle as shown in Figure 3. The top section has 73 rows and the bottom has 52 rows of olive trees for a total of 125 rows. There is a pond where the irrigation water is stored and is distributed to the olive trees through a pump that can be seen in Figure 4. The olive trees go through a drip irrigation method which has a small line with holes along the hose that releases water for the crop.

Figure 4: *Irrigation Pump at Olive Field*

Figure 5: *Single Olive Tree at the Olive Field*

The olive trees stand just about 6’5” tall and has many green leaves surrounding it making it look bushy as shown in figure 5. They are all evenly spaced by an area of 12” X 6” so that each individual tree can grow freely. The trees are replaced once they reach a certain age when they do not produce the same amount of crops and are replaced with a 6-year old tree.

Figure 6: *Olive Trees in a Row*

APPLICATION OF CSUID TO OLIVE

CSUID Model Description

Colorado State University Irrigation & Drainage (CSUID) model is well known as well as peer-reviewed agricultural hydrology and salinity model that simulates the dynamic of a variably saturated flow in porous media that focuses on irrigation, drainage, and the impact on soil chemistry. This model analyzes the groundwater as well as the crop yield when all the parameters are entered into the model (Quinn 2015)

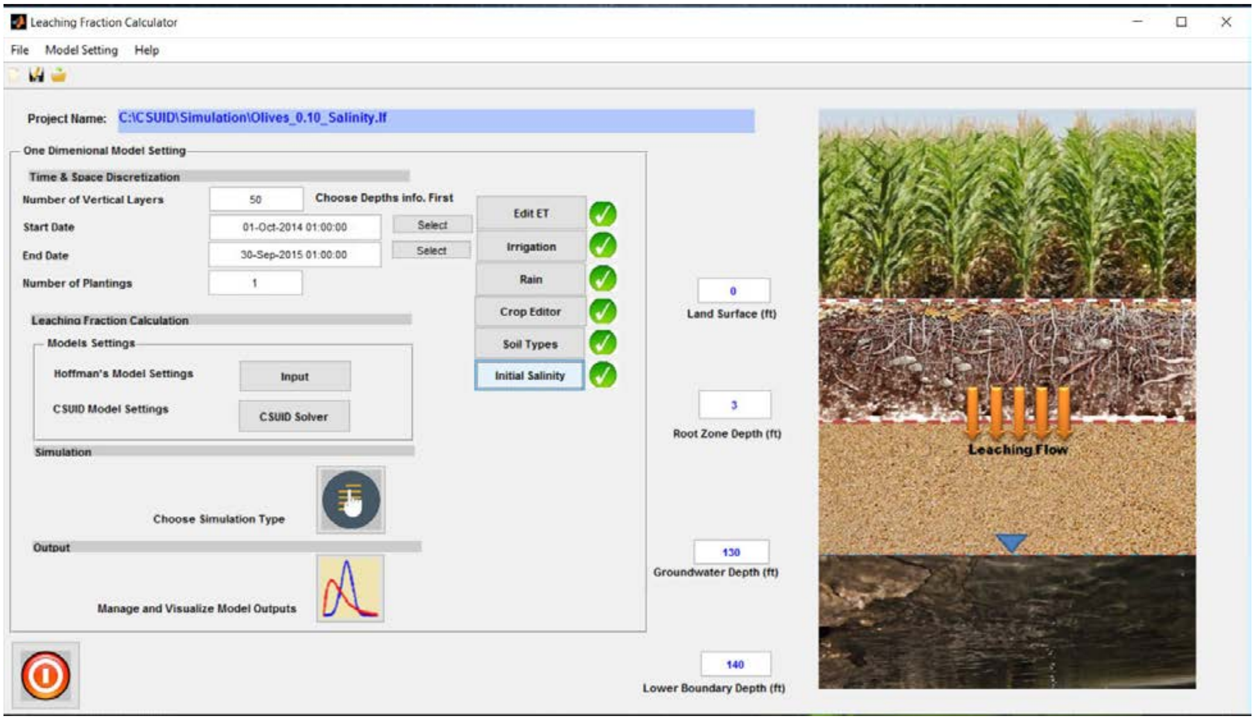
The parameters the model requires are topology, period, coefficients, and information of the area. The topology section asks for the root zone depth, total soil thickness, water table elevation, and lower boundary depth. The period is the time the experiment is being run and which seasons are included. The coefficients needed are the crop growth rate that changes with each crop and each season. Information of the area includes the rate of evaporation, irrigation, rain, crop type, soil type, and the initial salinity found in the soil that is present.

While using the CSUID, you have an option to run both the analysis by the CSUID model or the Hoffman's Model. There is also an option to compare the results from both models. The difference is that the Hoffman's model requires additional parameters that include the temperature, radiation, and salt tolerance threshold. There is a third model where the Hoffman model is used while apply the leaching factor that is calculated through the CSUID model. The fourth model is the comparison between both the CSUID model and the Hoffman model. These two models are them compared and graphed to show the difference between the results of the affect that he salinity levels has on the crop yield (Quinn 2015)

Model Development for Olive Field

The model that was created for the Olive Field that has 125 rows total that is divided into two sections one with 73 rows and the other with 53 rows and a period that was a year-long from October 1st to September 30th (2014-2015). The olive plant would have experienced all four seasons since it is a year-long experiment the model considers Fall, Spring, Winter, and Summer. The topology for the olive plant are shown in Figure 4 with the land surface starting at zero, root zone depth being at 3ft, groundwater depth at 130ft and lower boundary depth at 140ft.

The irrigation rate and salinity were determined by a report from the Fresno Irrigation System. They provided the flow rate of the water used from the San Joaquin River, and then to find Irrigation rate the flow was divided by the area of the fields to find the rate of irrigation. The salinity of the water used for irrigation was given in the report being between 0.50 dS/m and 0.75 dS/m, but since we are finding the affect that salinity has on crop yield then the salinity levels were changing with each run to analyze the affect it had as it rises. Since the soil of the olive fields is Hanford sandy loam soil it was found, by a chart that was provided by the CSUID model as shown in figure 5, that the hydraulic conductivity is 3.2870 in/day and the porosity being 0.3870 in/in. Using the CIMIS station 80, the temperature, precipitation, radiation, evaporation, and rainfall were given for the olive fields. CIMIS uses stations with different sensors that detect the activities of the plant itself.



Project Name: C:\CSUID\Simulation\Olives_0.10_Salinity.lf

Number of Vertical Layers: 50

Start Date: 01-Oct-2014 01:00:00

End Date: 30-Sep-2015 01:00:00

Number of Plantings: 1

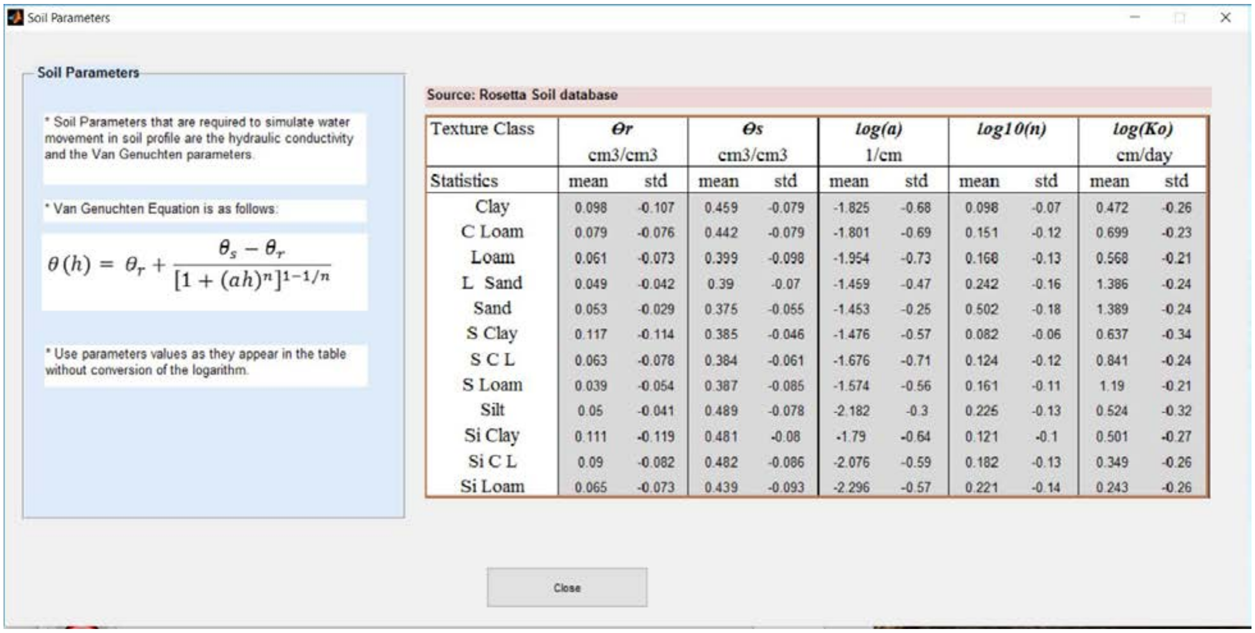
Land Surface (ft): 0

Root Zone Depth (ft): 3

Groundwater Depth (ft): 130

Lower Boundary Depth (ft): 140

Figure 7: *CSUID Main Window*



* Soil Parameters that are required to simulate water movement in soil profile are the hydraulic conductivity and the Van Genuchten parameters.

* Van Genuchten Equation is as follows:

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{[1 + (ah)^n]^{1-1/n}}$$

* Use parameters values as they appear in the table without conversion of the logarithm.

Source: Rosetta Soil database

Texture Class	*Θr* cm3/cm3		*Θs* cm3/cm3		*log(a)* 1/cm		*log10(n)*		*log(Ko)* cm/day	
Statistics	mean	std	mean	std	mean	std	mean	std	mean	std
Clay	0.098	-0.107	0.459	-0.079	-1.825	-0.68	0.098	-0.07	0.472	-0.26
C Loam	0.079	-0.076	0.442	-0.079	-1.801	-0.69	0.151	-0.12	0.699	-0.23
Loam	0.061	-0.073	0.399	-0.098	-1.954	-0.73	0.168	-0.13	0.568	-0.21
L Sand	0.049	-0.042	0.39	-0.07	-1.459	-0.47	0.242	-0.16	1.386	-0.24
Sand	0.053	-0.029	0.375	-0.055	-1.453	-0.25	0.502	-0.18	1.389	-0.24
S Clay	0.117	-0.114	0.385	-0.046	-1.476	-0.57	0.082	-0.06	0.637	-0.34
S C L	0.063	-0.078	0.384	-0.061	-1.676	-0.71	0.124	-0.12	0.841	-0.24
S Loam	0.039	-0.054	0.387	-0.085	-1.574	-0.56	0.161	-0.11	1.19	-0.21
Silt	0.05	-0.041	0.489	-0.078	-2.182	-0.3	0.225	-0.13	0.524	-0.32
Si Clay	0.111	-0.119	0.481	-0.08	-1.79	-0.64	0.121	-0.1	0.501	-0.27
Si C L	0.09	-0.082	0.482	-0.086	-2.076	-0.59	0.182	-0.13	0.349	-0.26
Si Loam	0.065	-0.073	0.439	-0.093	-2.296	-0.57	0.221	-0.14	0.243	-0.26

Figure 8: *Soil Parameters (Quinn 2015)*

Model Runs

There were two sets of model runs conducted. First set included five runs with irrigation water salinity level from 0.1 dS/m to 0.5 dS/m with increments of 0.1 dS/m and the second set included 10 runs with irrigation water salinity level ranging from 0.5 dS/m to 5 dS/m at increment of 0.5 dS/m. The impact of salinity at different magnitudes were tested using these two sets of runs. While the first set was used to show how a smaller change in salinity impacted the crop yield, the second set determined how a larger change in the salinity level impacted the crop yield. The Ec_e/Es_W and plant salinity tolerance were set to 2.0 dS/m and 0.1 dS/m respectively.

The models tested the impacts of salinity on relative crop yield by running different combinations of salinity levels which are shown in Table 1. The irrigation water salinity was changed by an increment (Table 1). Both soil salinity and the initial salinity of the water were first kept same and then irrigation water salinity was incrementally changed to observe the impact.

***Table 1**: List of Combinations*

Set	Combination #	Salinity Level in Irrigation Water (ds/m)	Simulation Models Runs
Set 1: 0.1 – 0.5@0.1ds/m increment	Comb 1	0.1	CSUID, Hoffman, Hoffman with Leaching
	Comb 2	0.2	CSUID, Hoffman, Hoffman with Leaching, Model comparison
	Comb 3	0.3	CSUID, Hoffman, Hoffman with Leaching, Model comparison
	Comb 4	0.4	CSUID, Hoffman, Hoffman with Leaching, Model comparison
	Comb 5	0.5	CSUID, Hoffman, Hoffman with Leaching, Model comparison
Set 2: 0.5 – 5.0@0.5ds/m increment	Comb 6	0.5	CSUID, Hoffman, Hoffman with Leaching
	Comb 7	1.0	CSUID, Hoffman, Hoffman with Leaching, Model comparison
	Comb 8	1.5	CSUID, Hoffman, Hoffman with Leaching, Model comparison
	Comb 9	2.0	CSUID, Hoffman, Hoffman with Leaching, Model comparison
	Comb 10	2.5	CSUID, Hoffman, Hoffman with Leaching, Model comparison
	Comb 11	3.0	CSUID, Hoffman, Hoffman with Leaching, Model comparison
	Comb 12	3.5	CSUID, Hoffman, Hoffman with Leaching, Model comparison
	Comb 13	4.0	CSUID, Hoffman, Hoffman with Leaching, Model comparison
	Comb 14	4.5	CSUID, Hoffman, Hoffman with Leaching, Model comparison
	Comb 15	5.0	CSUID, Hoffman, Hoffman with Leaching, Model comparison

Impacts of Salinity

The impact of salinity on relative crop yield has been observed in the following figures. As shown, minimum impact has been observed. This was based on the assumption that the tolerance of the crop would be 0.1 dS/m. The minimum impact means the olive plants may have a higher tolerance. In this case, the model had a 0.01% decrease on its crop yield while the salinity in the root zone increased. Using the CSUID, there was a 0.03% decrease in crop yield. With a crop like this, one wouldn't need to use desalination of the water because the crop yield will still be at a high percentage for framers to still grow a substantial amount of produce.

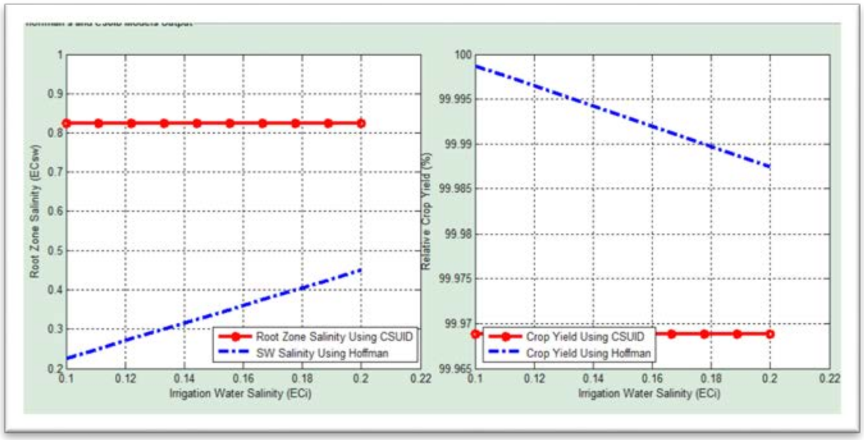


Figure 9: *Model using 0.2 dS/m*

Irrigation water with higher salinity level such as 5 dS/m, as shown in figure 10, the impact increase. The crop yield for the CSUID has dropped by 0.55% while the Hoffman Model shows a decrease of 0.95% in crop yield. With the increase of salinity, it can be seen that the crop yield decrease in a linear manner. In both models the crop yield decreases.

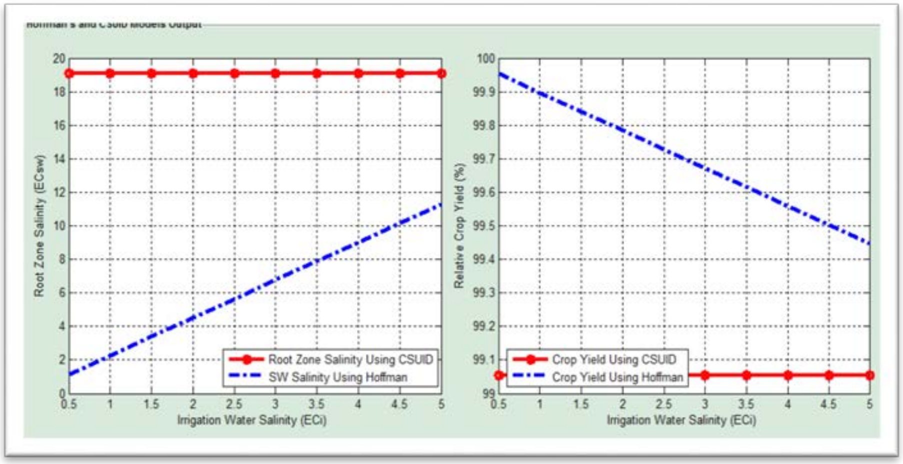


Figure 10: *Model using 5 dS/m*

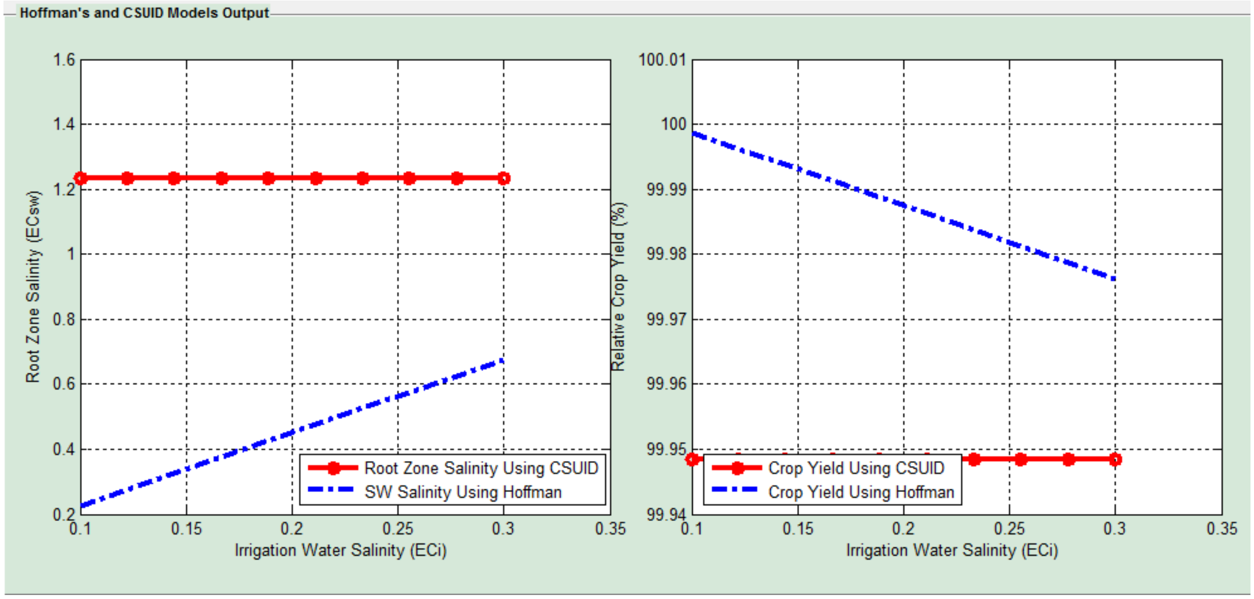


Figure 11: *Model Using 0.3 dS/m*

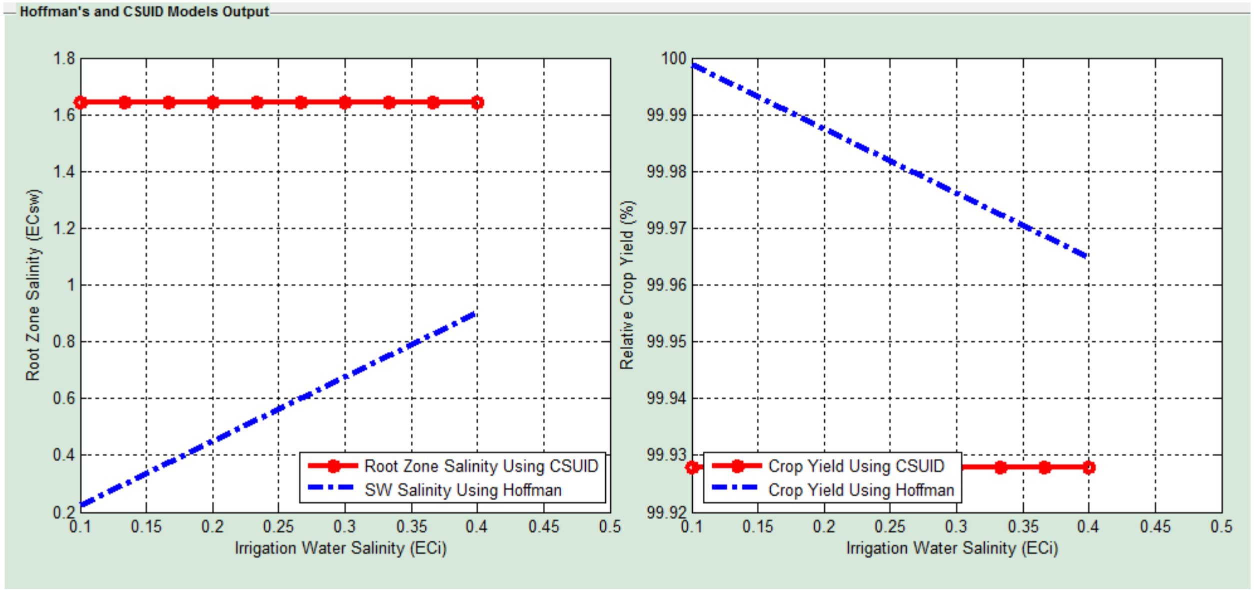


Figure 12: *Model Using 0.4 dS/m*

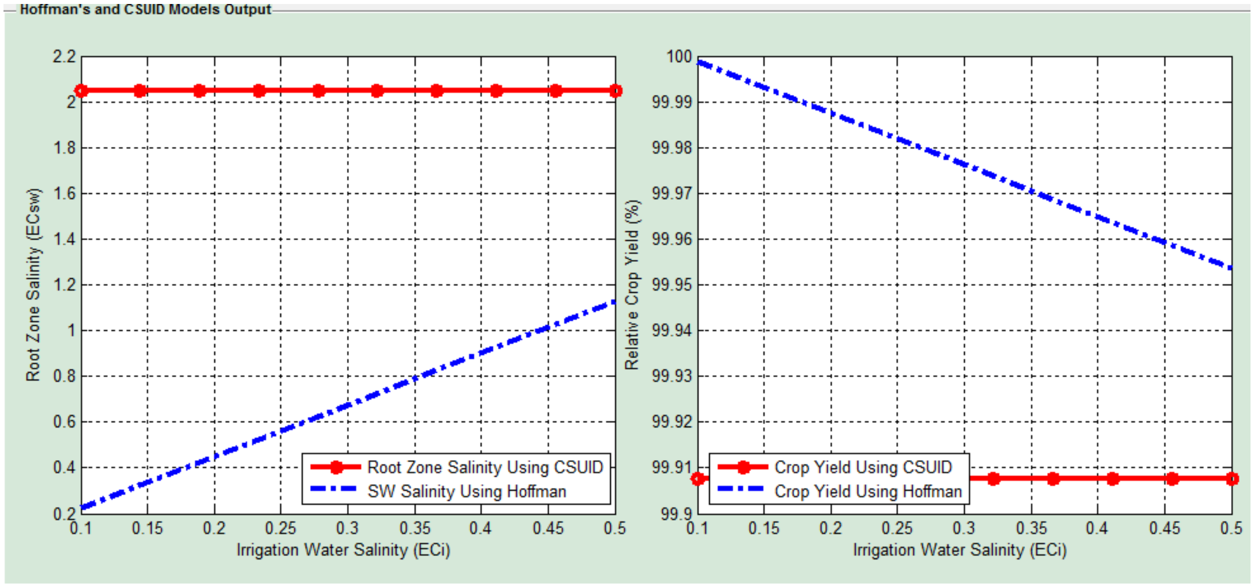


Figure 13: *Model Using 0.5 dS/m*

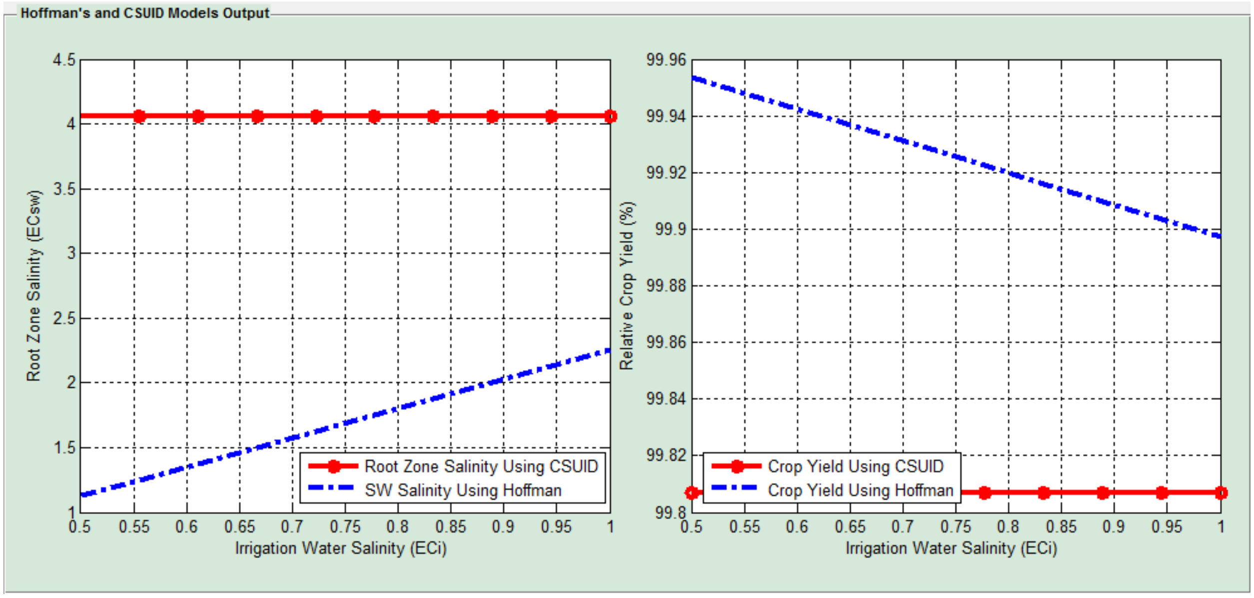


Figure 14*: Model Using 1.0 dS/m*

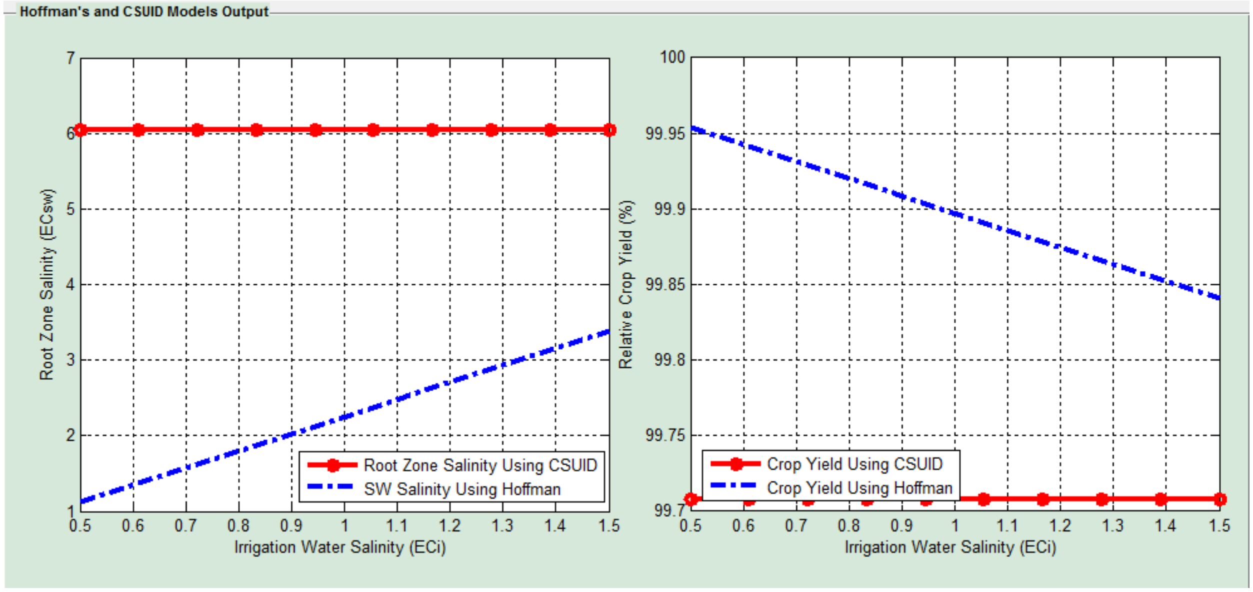


***Figure 15:** Model Using 1.5 dS/m*

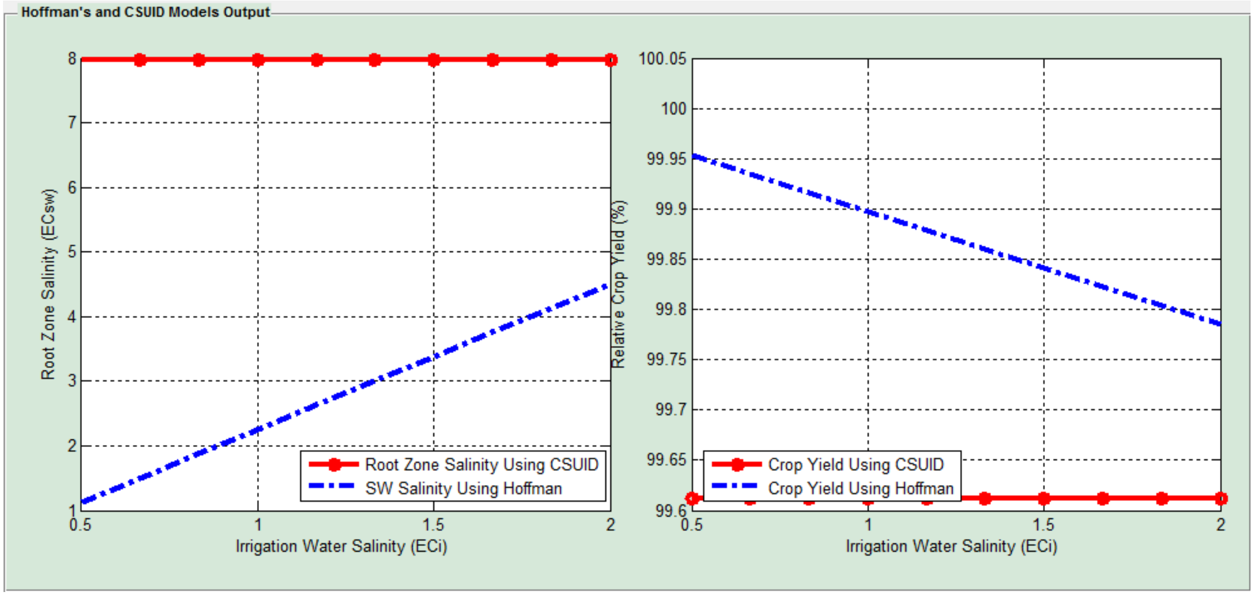


***Figure 16:** Model Using 2.0 dS/m*

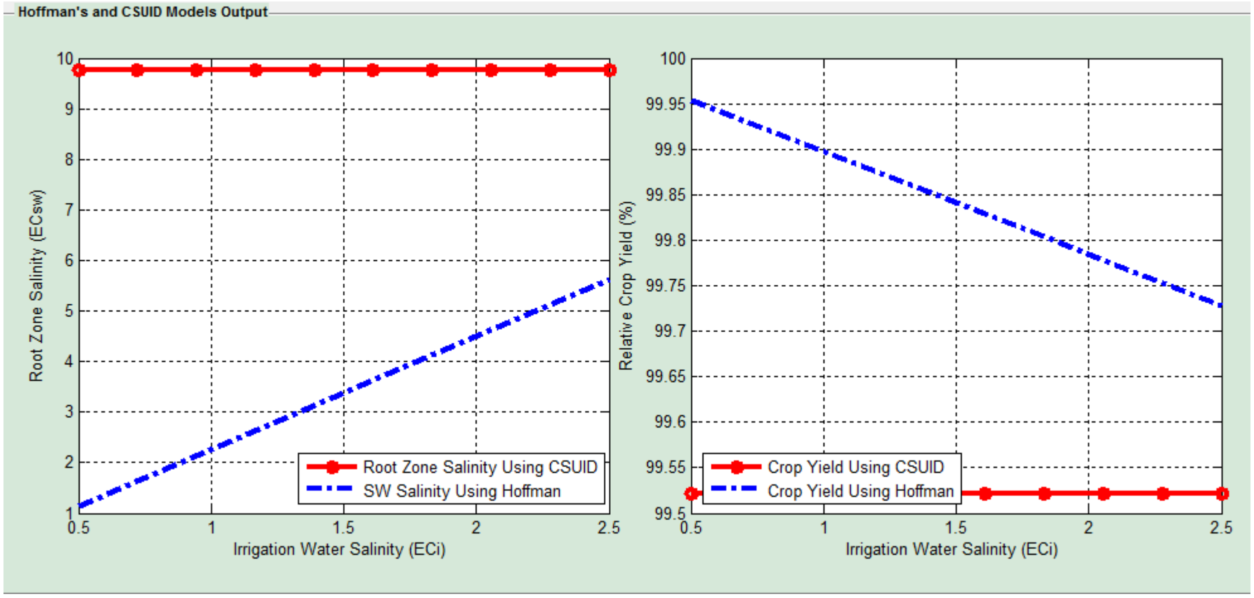


***Figure 17**: Model Using 2.5 dS/m*

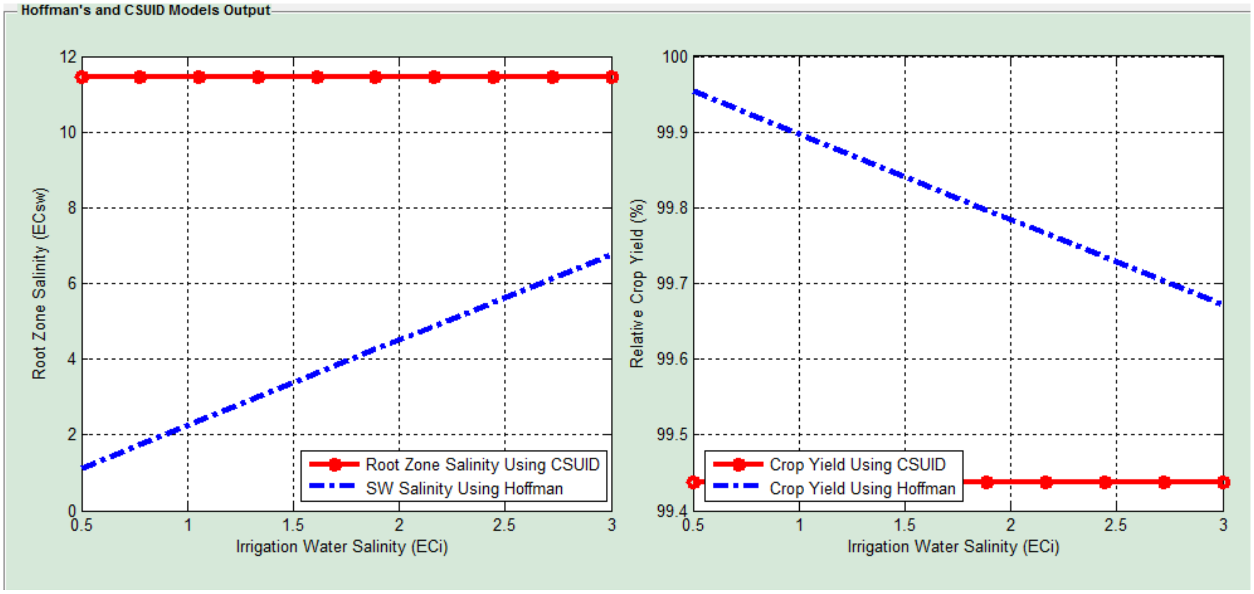


***Figure 18:** Model Using 3.0 dS/m*

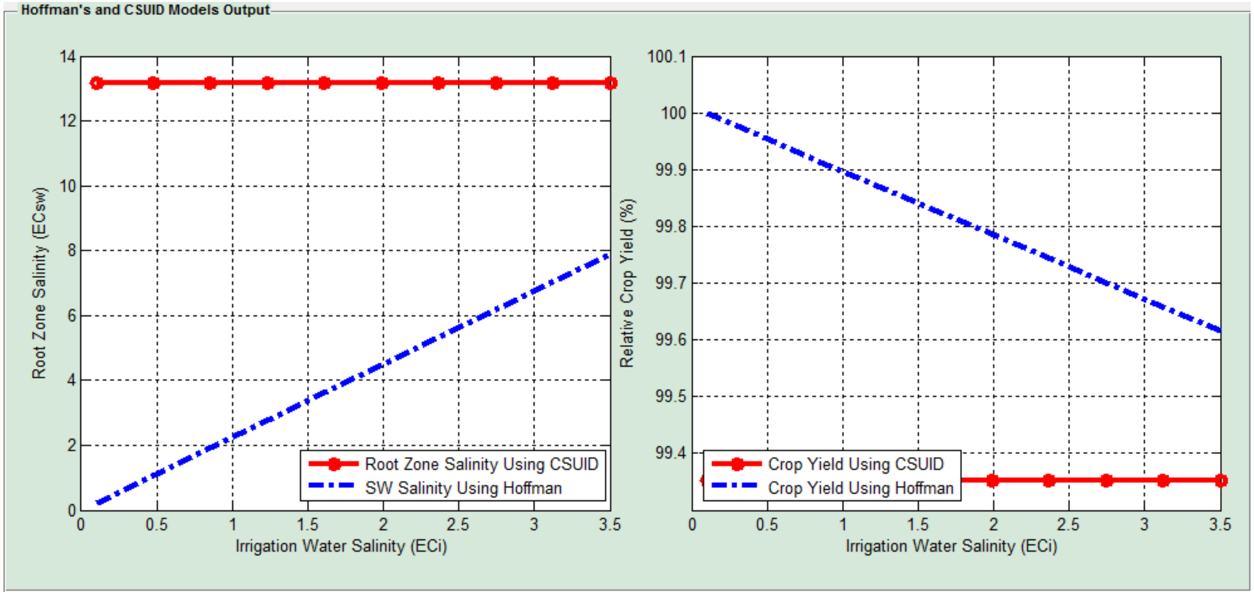


Figure 19: *Model Using 3.5 dS/m*

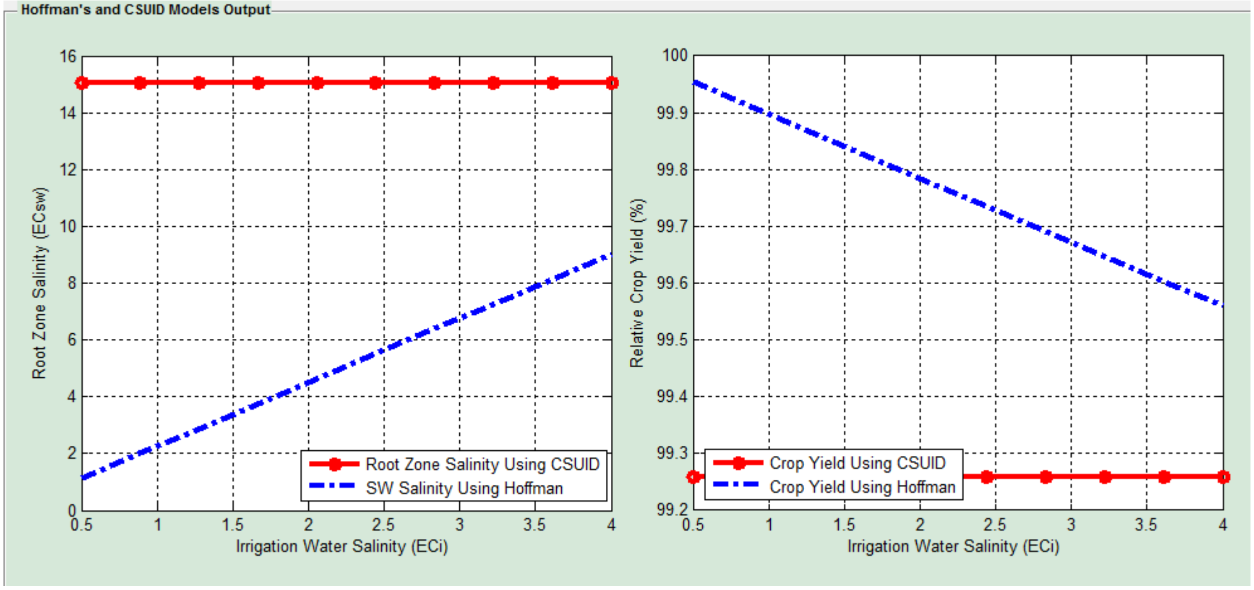


Figure 20: *Model Using 4.0 dS/m*

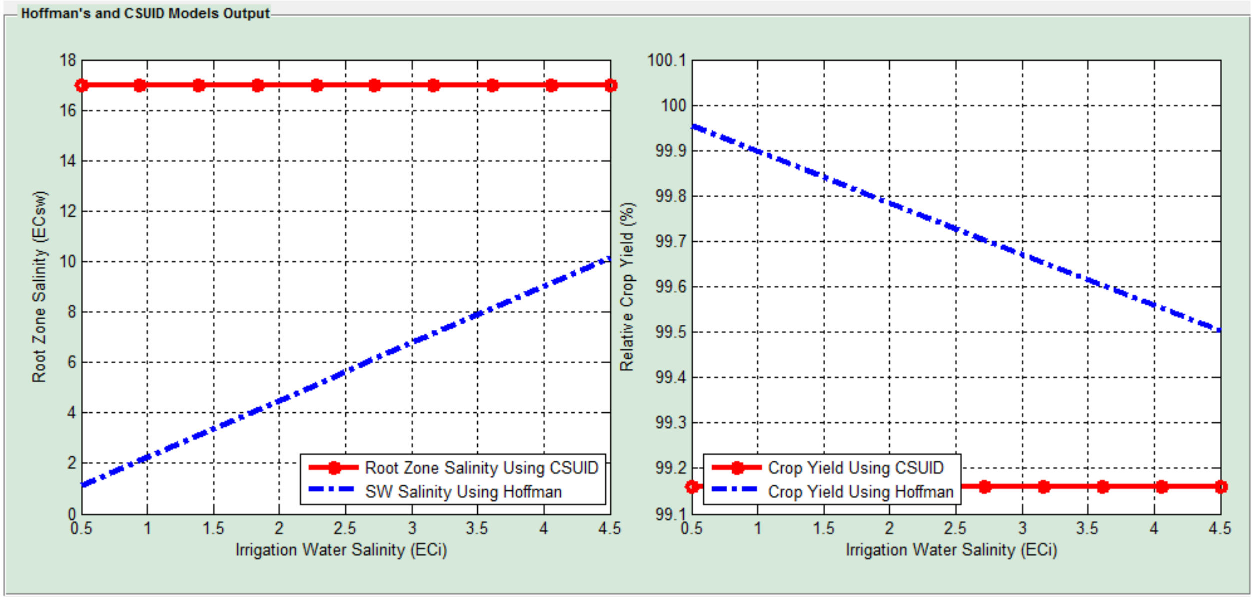


***Figure 21**: Model Using 4.5 dS/m*

***Table 2:** Relative Crop Yields at Different Combinations of Salinity Levels*

Combination #	Salinity Level (ds/m)	Relative crop yield (%)	
		CSUID	Hoffman
Comb 1	0.1	100%	100%
Comb 2	0.2	99.97%	99.997%
Comb 3	0.3	99.95%	99.75%
Comb 4	0.4	99.93%	99.65%
Comb 5	0.5	99.91%	99.57%
Comb 6	0.5	100%	100%
Comb 7	1.0	99.81%	99.90%
Comb 8	1.5	99.71%	99.88%
Comb 9	2.0	99.62%	99.76%
Comb 10	2.5	99.52%	99.75%
Comb 11	3.0	99.43%	99.68%
Comb 12	3.5	99.35%	99.61%
Comb 13	4.0	99.25%	99.56%
Comb 14	4.5	99.15%	99.50%
Comb 15	5.0	99.05%	99.44%

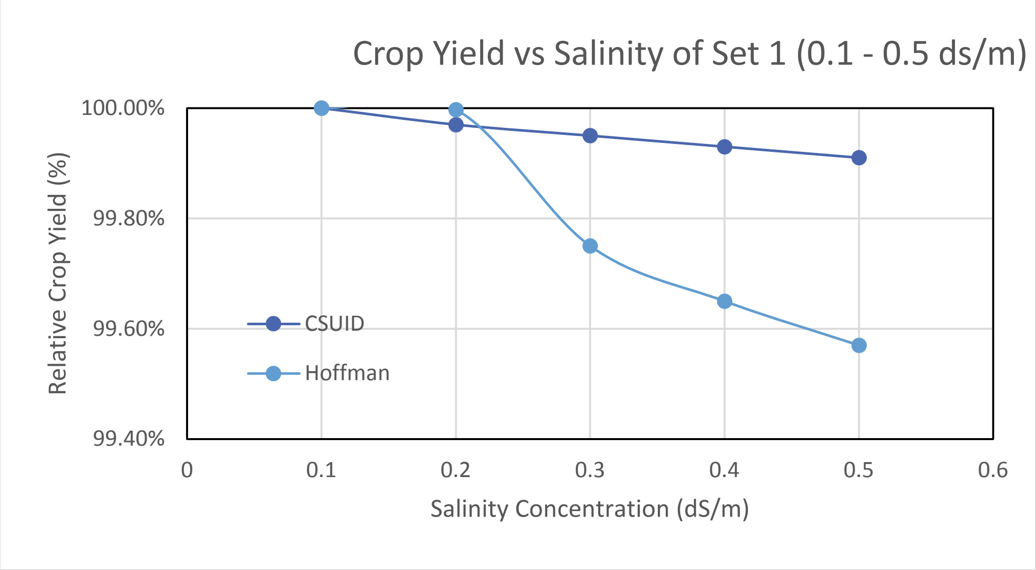


Figure 22: *Impact of Irrigation Salinity on Relative Crop Yield vs Salinity for Set 1*

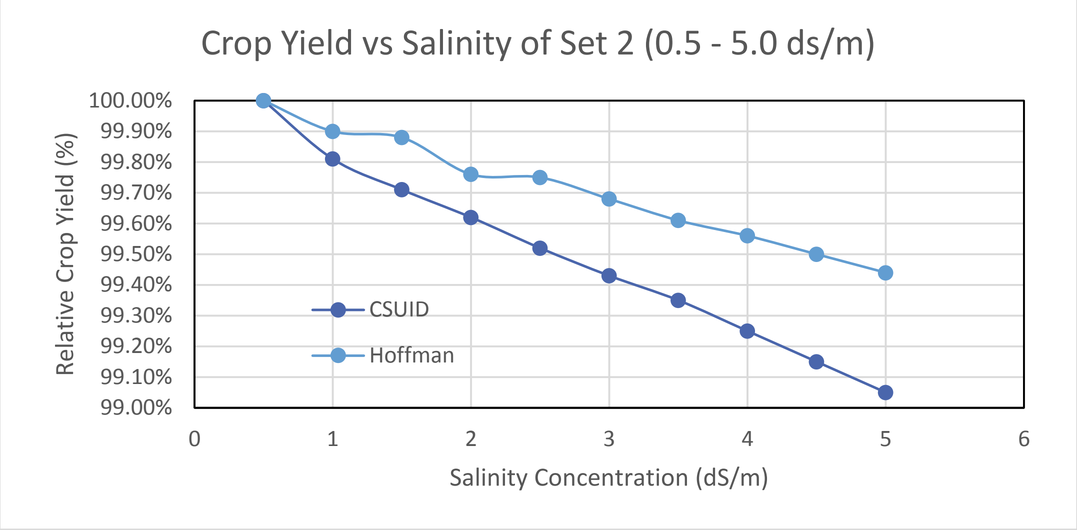


Figure 23: *Impact of Irrigation Salinity on Relative Crop Yield vs Salinity for Set 2*

Based on the graphs shown above, it is easily seen that the salinity levels influence the crop yield, although the relative crop yield change is very minimum (Figures 22 and 23). As seen, the CSUID model finds more linear impact than the Hoffman model. At the lower salinity level (i.e., Set 1) Hoffman model finds the impact more prominent than the CSUID model. However at the higher salinity level (i.e., Set 2) CSUID model finds more prominent impact than the Hoffman model. The change in relative crop due to salinity from Set 1 to Set 2 is found to be minimum.

CONCLUSION

A pre-developed model to simulate irrigation and drainage process known as CSUID has been used in this study to observe the impact of salinity in irrigation water on relative crop yield. Considering salinity in the irrigation water and soil different combinations of model runs have been developed. These combinations have been run using CSUID model suit which uses CSUID and Hoffman models. The models have been applied to an olive field at the California State University Fresno. Results show that relative crop yield reduces as the irrigation salinity level increases. However, the change in relative crop yield due to irrigation salinity is found to be significantly small.

.

REFERENCE

Abdel-Rahman, A. A., and El-Sharkawi, H. M. (1974). “Response of Olive and Almond Orchards to partial irrigation under dry-farming practices in semi-arid regions II. Plant-soil water relations in almond during the growing season.” *Plant and Soil* 41(1), 13-31.

Arrue, J.L., Cabrera, F., Fernandez, J.E., Martin-Aranda, J., and Moreno, F. (1991). “Drip irrigation, soil characteristics and the root distribution and root activity of olive trees.” *Plant and Soil* 133, 239-251.

Ashraf, M. and Saeed, M. M. (2006). “Effect of improved cultural practices on crop yield and soil salinity under relatively saline groundwater applications”. Irrigation and Drainage System 20:111-124

Barbagallo, S., Barbera, A. C., Cirelli G. L., Milani, M., Toscano, A. (2014). “Reuse of constructed wasteland effluents for irrigation of energy crops”. Water Science & Technology

Burt, C. M. and Anderson, S. S. (2002). “Energy, Climate, Environment and Water- Issues and Opportunities for Irrigation and Drainage”. U.S. Committee on Irrigation and Drainage.

Cabot, C., Sibole, J. V., Barcelo, J., Poschenrieder, C. (2014). “Lesson from crop plants struggling with salinity”. Plant Science 226:2-13

Chiraz, Masmoudi-Charfi., (2013). “Growth of young olive trees: Water requirements in relation to canopy and root development”. American Journal of Plant Science 4:1316-1344

Clothierb, B.E., Diaz-Espejo , A., Fernandez, J.E., Giron, I.F., Green, S.R., Moreno, F., Palomo, M.J. (2001). *“Heat-pulse measurements of sap flow in olives for automating irrigation: tests, root flow and diagnostics of water stress.” Agricultural Water Management* 51(2), 99–123.

Eldeiry, A. A. and Garcia, L. A. (2013). “Using nonlinear geostatistical models in estimating the impact of salinity on crop yield variability”. Soil Science Society of America Journal

Fernandez, J.E., and Moreno, F. (1999). “Water Use by the Olive Tree.” *Journal of Crop Production* 2(2), 101-162.

Fernandez, J. E., Moreno, F., Martin-Palomo, M. J., Cuevas, M. V., Torres-Ruiz, J. M., Moriana, A. (2011). “Combining sap flow and trunk diameter measurements to assess water needs in mature olive orchards” Environmental and Experimental Botany 72:330-338

Fereres, E. (2004). “Fruit trees and vines” Crop Yield Response to Water 300-313

Fowler, D. N., Kind, S. L., and Weindorf, D. C. (2014). Evaluating abiotic influences on soil salinity of inland managed wetlans and agricultural croplands in a semi-arid environment. Wetlands 34:1229-1239

Goldstein, R.S., C. Chen, J. Herr, and L. H. Z. Weintraub. (2001). Watershed analysis risk management framework (WARMF): Update One: A decision support system for watershed analysis and total maximum daily load calculation, allocation and implementation. EPRI, Palo Alto, CA:1005181

Grattan, S. R. (2002). “Irrigation water salinity and crop production”. ANR Publication 8066

Grattan, S.R., Berenguer, M.J., Connell J.H., Polito V.S., and Vossen P.M. (2006). “Olive oil production as influenced by different quantities of applied water.” *Agriculture Water Management* 85(1-2), 133-140.

Harris, B. N., Safra, V. O., Tester, M. (2010). “A water-centered framework to assess the effects of salinity on the growth and yield of wheat and barley”. Plant Soil 336:377-389

Herr, J., Weinraub, L., Chen, C. W. (2001). “User’s guid to WARMF”. Electric Power Research Institute.

Hill, R. and Koenig, R. T. (1999). “Water salinity and crop yield”. AG-425.3

Huang, L., Bai, J., Chen, B., Zhang, K., Huang, C., Liu, P. (2012). “Two-decade wetland cultivation and its effects on soil properties in salt marshes in the Yellow River Delta, China”. Ecological Informatics 10:49-55

Iniesta, F., Testi, L., Orgaz, F., and Villalobos, F.J. (2009). “The effects of regulated and continuous deficit irrigation on the water use, growth and yield of olive trees.” *European Journal of Agronomy* 30(4), 258-265.

Jolly, I. D., McEwan, K. L. and Holland, K. L. (2008). A review of groundwater-surface water interactions in arid/semi-arid wetlands and the consequences of salinity for wetland ecology. Ecohydrology 1:43-58.

Larnbi, A., Vazquez, S., El-Jendoubi, H., Msallem, M., Abadia, J., Abadia, A., Morales, F. (2014). “Canopy light heterogeneity drives leaf anatomical, eco-physiological, and photosynthetic changes in olive trees grown in a high-density plantation”. Photosynth Res 123:141-155

Letey, J. and Dinar, A. (1986). “Simulated crop-water production functions for several crops when irrigated with saline waters”. The California Agricultural Experiment Station 54:1

Malash, N. M., Flowers, T. J., Ragab, R. (2008). “Effect of irrigation methods, management and salinity of irrigation water on tomato yield, soil moisture and salinity distribution”. Irrigation Science 26:313-323

Masmoudi, M.M., Masmoudi-Charfi, C., Mahjoub, I., and Ben Mechlia, N. (2007). “Water requirements of individual olive trees in relation to canopy and root development.” *Water saving in Mediterranean agriculture and future research needs* 56(1), 73-80.

Masmoudi, C. C., Ayachi, M. M., Gouia, M., Laabidi, F., Reguaya, S. B., Amor, A. O., Bousnina, M. (2010). “Water relations of olive trees cultivated under deficit irrigation regimes”. Scientia Horticulturae 125:573-578

Martin-Vertedor, A. I., Rodriguez, J. M. P., Losada, H. P., Castiel, E. F., (2011). “Interactive responses to water deficits and crop load in olive (olea europaea L., cv Morisca) I.- Growth and water relations” Agricultural Water Management 98:941-949

Masmoudi, C. C., Masmoudi, M., Abid-Karray, J., Mechlia, N. B., (2011). “Sap flow measurements in young olive trees (Olea europaea L.) cv. Chetoui under Tunisian conditions” Scientia Horticulturae 129:520-527

Mezghani, M. A., Charfi, C. M., Gouiaa, M., Labidi, F., (2012). “Vegetative and reproductive behavior of some olive tree varieties (Olea europaea L.) under deficit irrigation regimes in semi-arid conditions of Central Tunisia. Scientia Horticulturae 146:143-152

Nachshon, U., A. Ireson, G. van der Kamp, and H. Wheater.(2014). Sulfate salt dynamics in the glaciated plains of North America journal of Hydrology 499:188-199.

Nadezhdina, Nadezhda, Nadezhdin, Valeriy, Ferreira, Maria Isabel, and Pitacco, Andrea (2007). “Variability with xylem depth in sap flow in trunks and branches of mature olive trees.” *Tree Physiology* 27(1), 105-113.

Nikouei, A., Zibaei, M., Ward, F. A. (2012). “Incentives to adopt irrigation water saving measures for wetlands preservation: An integrated basin scale analysis”. Journal of Hydrology 464-465, 216-232

Palese , Assunta Maria, Nuzzo, Vitale, Favati , Fabio, Pietrafesa , Angiolina, Celanoa, Giuseppe, and Xiloyannis , Cristos (2010). “Effects of water deficit on the vegetative response, yield and oil quality of olive trees (Olea europaea L., cv Coratina) grown under intensive cultivation.” *Scientia Horticulturae* 125(3), 222-229.

Pasquale, Giorio, and Giovanni, Giorio (2003). “Sap flow of several olive trees estimated with the heat-pulse technique by continuous monitoring of a single gauge.” *Environmental and Experimental Botany* 49(1), 9-20.

Quinn, N. W. T., Alzraiee, A. H., Mathiot, C., Longley, K. E. (2016). “Developing water quality objectives for diversions to agriculture from the San Joaquin River using steady-state (Hoffman) and transient (CSUID) models”. Conference Paper · April 2016,

Quinn, N.W.T., Connor, T., Borel, N., Bergstorm, Herr, H. J., Murakami, T. and van Werkhoven., K. (2013). Opportunistic real-time management of saline drainage conjoined with San Joaquin River restoration regents of the University of California Agreement 442140-NQ-18214

Quinn, N.W.T., Ortega, R. Rahily, P. and Johnson, C.B. (2011). Wetland flow and salinity budgets and elements of decision support system toward implementation of real-time seasonal wetland salinity management

Quinn, N. W. T., Alzraiee, A., Mathiot, C. (2015). “CSUID User manual”.

Sammonds, M. J., Vietz, G. J., Costelloe, J. F. (2013). “Using water destined for irrigation to conserve wetland ecosystems: A basis for assessing feasibility”. Water Resource Research Vo. 49:4662-4671

Sanchez-Carillo, S., Angeler, D.G., Sanchez-Andres, R., Alvarez-Cobelas, M., and Garatzua-Payan, J. (2004). Evapotranspiration in semi-arid and arid wetlands: Relationships between inundation and the macrophyte-cover: open-water ratio. Advances in Water Resources 27:643-655

Singh, A., Benes, S. E., Quinn, N., Cassel-Sharma, F. (2017). "Development of validation data sets for a transient hydro-salinity model using EM-38 Soil surveys, irrigation water monitoring and forage analysis"

Singh, A. and Panda, S. N. (2012). "Effect of saline irrigation water on mustard (Brassica Jungea) crop yield and soil salininty in a semi-arid area of North India". 48:99-110

Steppuhn, H., van Genuchten, M., Grieve, C. M. (2005). "Crop ecology, management & quality". Crop Science Vol.45

Van Werkhoven, K. (2015). Technical Memorandum: WARMF Model Upgrade to Simulate Managed Operations.

Wada, Y., van Beek, L. P. H., Bierkens, M. F. P. (2012). "Nonsustainable groundwater sustaining irrigation: A global assessment". Water Resource Research, Vol. 48

Watson, E, B., and Byrne, R. (2012). "Recent (1975-2004) vegetation change in the San Francisco Estuary, California, Tidal Marshes". 138.8.242.67