HYD 243 Final Project

Modeling of Water Use in the Micro-sprinkler Irrigated Almond Orchard

Liyuan Yang

Abstract: There are growing concerns about excessive water consumption in the highly profitable almond industry. Given the severe droughts in California, the Almond Board of California (ABC) has been investing in efforts to reduce the water consumption in almond production. Since 1982, ABC has studied the use of micro-irrigation in almond orchards and it is then become the main method to water almond trees. There are nearly 80% of California almond orchards use micro-irrigation methods to improve water use efficiency. The focus of this project is to build a model which investigates blue water applied and temporal variability of water balance components in micro-sprinkler irrigated almond orchards.

1. Introduction

Almond is one of the most consumed nuts in the world because of its culinary and nutritional benefits [1, 2]. Almond hulls are also potentially great ingredients for animal feed with a desirable amount of fiber and proteins. California is the major production state in the U.S. and the area for growing almonds has doubled in the past 20 years [3]. However, the excessive water consumption used in the almond industry may raise problems and potentially aggravate the drought situation.

Growing almonds require lots of water. Some reports claimed that almonds use ~3 gallons of water to produce one fruit. On the other hand, almond productions bring significant economic benefits that could offset their environmental impacts [4].

To build a sustainable almond industry, farmers in California have adopted micro-sprinkler irrigation to help improve water use efficiency and reduce water consumption. Micro-sprinkler is a relatively cheap and efficient method, which applies water through an orifice under low pressure and infiltrates water into soils uniformly to regulate the soil moisture. The use of a micro-sprinkler can precisely control how much water is used in almond production but there is still a need to build a mathematical model to predict the ideal water consumption.

This project tries to achieve this goal by estimating annual water applications in the California micro-sprinkler almond orchard with a focus on the volume of surface and groundwater consumed to produce almonds. In short, I studied water applied in an almond orchard, and use HYDRUS-1D to model the temporal variability of soil moisture in a micro-sprinkler irrigated almond orchard in partnership with the University of California. Soil moisture plays an essential part in modulating the hydrologic processes and above-ground activities. It is also an important parameter used to determine irrigation application rate [5]. The main objectives of this project are: (1) to study the temporal variability of applied water in micro-sprinkler irrigated almond orchards, and (2) to analyze the temporal variability of soil moisture in almond orchards using common micro-sprinkler irrigation scheduling practice.

2. Data Sources

The data used in this study were obtained from the following sources. The nearest CIMIS station provides atmospheric information and temporal evapotranspiration at Williams, Colusa. The data is provided by California Irrigation Management Information System online: https://cimis.water.ca.gov/

Site-specific reference evapotranspiration is downloaded from the University of California Integrated Pest Management (IPM) website: http://ipm.ucanr.edu/WEATHER/index.html

The water demand for almond orchard varies by season and growth stages, thus crop different crop coefficient is essential for accurate water demand calculations. An average crop coefficient of each month was reported by the Almond Board of California: https://www.almonds.com/sites/default/files/irrigation_scheduling_using_et%5B1%5D.pdf

3. Methods

3.1 Water Demand

This project focused on Nickel's Ranch in the Sacramento Valley (Figure 1). The orchard has been growing almonds since 1989. Koumanov [6] reported soil compositions of the orchard as a function of depth (Table 1). Using the Soil Water Characteristic Calculator, the general soil type at the ranch is categorized as sandy loam.

Figure 1. Nickel's Ranch located in Colusa County in Evapotranspiration Zone 12.

The irrigation application rate was estimated based on approximated crop evapotranspiration (ETc), and calculated using Equation (1):

$$ETc = Kr * Kc * ETo \quad (1)$$

Where Kr is the reduction coefficient considering the acreage factor; Kc is crop coefficients from ABC's reported monthly average, and ETo is reference evapotranspiration estimated using atmospheric data from the nearest CIMIS station. Kr was taken as 1.0 for 60% canopy coverage of the soil surface for drip-irrigated trees in the Sacramento Valley.

The irrigation efficiency for the micro-sprinkler system was between 85-90%. This study uses 87% as the application efficiency. The amount of water applied seasonally to the field from the micro-sprinkler system was calculated from effective evapotranspiration Equation (2) and applied water (AWt) Equation (3) from January 2021 to December 2021.

$$ETt^{C,Effective} = ETc - Precipitation \ (2)$$

$$AWt = \frac{ETt^{C,Effective} * Area\_t^{Production}}{ApplicationEfficiency\_t^{c}} \quad (3)$$

Table 1. Soil characteristics at Nickel's ranch

Depth(cm)	Soil texture(%, by weight)			Volumetric gravel content(m^3 m^{-3})	Bulk density(kg m^{-3})	Soil moisture at FC (m^3 m^{-3})
	Sand	Silt	Clay			
15				0.25	1,598	0.196
30	53.0	41.0	6.0	0.29	1,610	0.185
45				0.29	1,646	0.214
60	58.0	32.5	9.5	0.40	1,738	0.252
75				0.31	1,807	0.272
90	67.0	25.0	8.0	0.30	1,790	0.229

3.2 Model Simulation

HYDRUS-1D model is commonly used for simulating water movement by solving the Richards equation (Equation 4) with numerical method [7]. In this study, the model was applied to estimate the soil moisture at different depths with measured precipitation and estimated irrigation.

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial Z}\left[K(h)\left(\frac{\partial h}{\partial Z} + 1\right)\right] - S \quad (4)$$

Where θ is the soil moisture (cm^3 cm^{-3}), *t* is the time (day), *Z* is the spatial coordinate (cm) in the upward direction, *K*(*h*) is the unsaturated hydraulic conductivity function (cm d^{-1}) , *h* is the soil water pressure head (cm), and *S* is the sink term denoting water uptake by plant roots ($cm^3 cm^{-3} day^{-1}$) calculated from the Feddes root water uptake reduction model (substituting Po= -10cm, POpt = -600cm, P2H = -8000cm, P2L = -10000cm in HYDRUS 1D root water uptake parameter from Baram's nitrate leaching study in one of the almond orchard in California [8]).

The soil hydraulic properties for sandy loam were modeled using van Genuchten's K(h) and θ (h) relationships in HYDRUS-1D [9].

The soil profile was wetted with micro-sprinkler irrigation and evaporation. The initial soil water condition was the soil water content. The upper boundary condition was the boundary atmospheric conditions with the surface layer assuming no water ponding on the soil surface. The lower boundary was set with free drainage. This simulation was run to simulate 1-m soil depth domain using estimated soil hydraulic parameters. Evaporation and transpiration were calculated separately from crop evapotranspiration as inputs to HYDRUS 1D using Equation 5 [10].

$$Ep = ETc * e^{-Kgr * LAI}$$

$$Tp = ETc - E \quad (5)$$

Here Kgr is an extension coefficient for global solar radiation, and it is estimated at 0.463 for mature almond trees. LAI used the annual average of 2.040 reported by Maldera for high-density almond orchard [11].

The daily irrigations were added to measured precipitations in the time variable condition table in HYDRUS-1D as a combined input. Figure 2 shows the amount of water applied by irrigation for the almond orchard each day using irrigation schedule spreadsheet modified from the spreadsheet in Irrigation Drainage Engineering Book [12]. The maximum allowable depletion rate was set at 30% and the available water holding capacity (AWC = 11.7%) was estimated using permanent wilting point and field capacity calculated using Soil Water Characteristics Calculator. The root distribution for almond tree was set to follow the linear distribution in 1-m depth. Soil moisture in the soil profile was observed at the soil surface, 34cm, 69cm and 100cm below the soil surface.

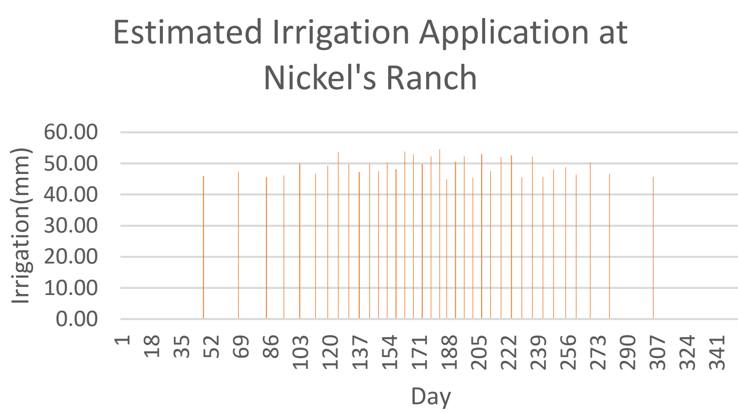

Figure 2. Daily irrigation requirement calculation.

4. Results and Discussion

4.1 Water application in micro-sprinkler irrigated orchard

The differences in monthly crop coefficients for mature almonds vary with growth stage (Figure 3). Almond growth undergoes five stages, and the crop coefficient continues to rise in its growth stage, and it reaches a maximum during hull split. Monthly crop evapotranspiration (Figure 4) varies similarly to the crop coefficients. ETc estimated from Nickel's soil lab station is higher than the nearest CIMIS station and 30-year monthly average estimates from the growth stage. ETc calculated using the Nickel's soil lab reflects site-specific atmospheric conditions and it is believed to be the most accurate reference to calculate the water applied for the almond orchard. The nearest CIMIS station is more than 10 miles north of the orchard, and this distance could result in weather variabilities. Monthly applied water volumes for an acre of micro-sprinkler irrigated almond orchard and monthly precipitation are presented in Figure 5. Applied water increased significantly from April to September which corresponds to the months with little rainfall, with maximum value of 0.57 acre-feet per acre in July 2021. In October, December and January, precipitations were sufficient to sustain the Almond's dormancy and no applied water was provided to the orchard.

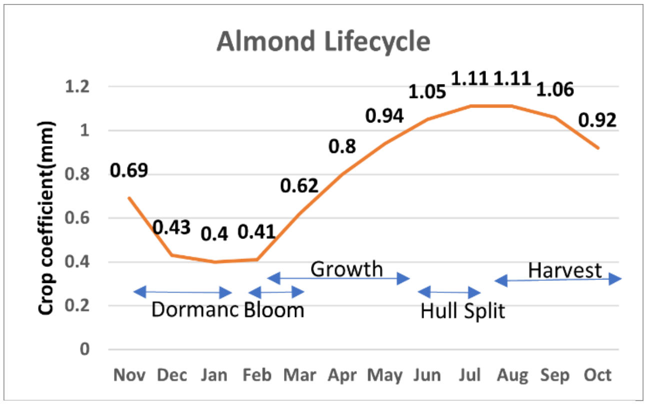

Figure 3. Crop coefficient for a full almond lifecycle. Crop season for March to Nov 15, and non-crop season for January, February, November 16-30, and December.

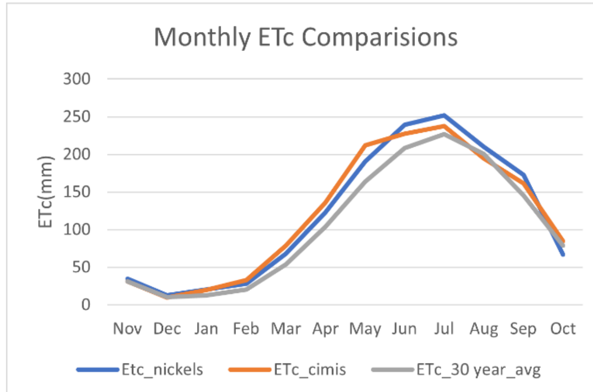

Figure 4. Comparing ETc values calculated using ETo values from nearest CIMIS station, 30-year average Zone 12 evapotranspiration values, and Nickel's soil lab station.

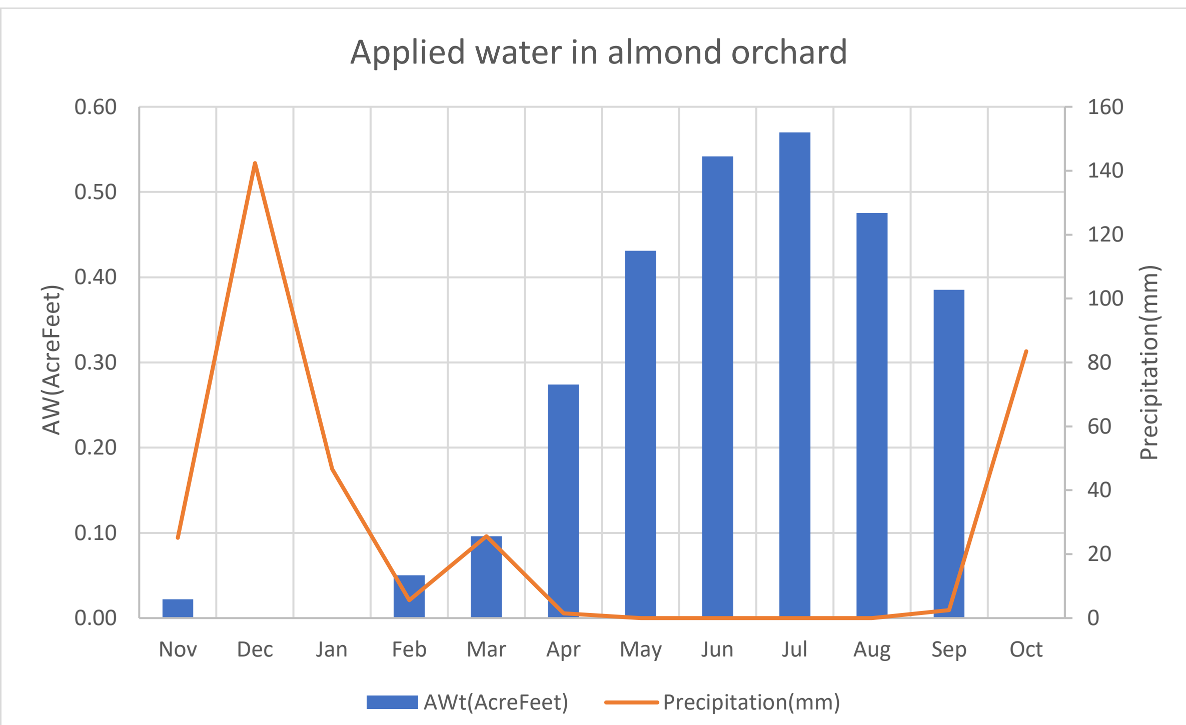

Figure 5. Seasonal water application amount in one acre of almond using micro-sprinkler at Nickel's soil lab.

4.2 *Soil moisture dynamics*

Figure 6 shows the time series of soil moisture at different depths simulated using HYDRUS-1D at four soil depths. Precipitation and irrigation occasions above 10mm resulted in a drastic increase in soil moisture. The soil water content in the upper soil layers produced more changes than in the deeper soil layers. The reason might be that the soil was not fully covered. Besides the topsoil surface, soil moisture between -34cm and -100cm varied slightly between 15 and 23 cm^3cm^{-3} with the impact of precipitation and estimated irrigation. Changes in soil moisture content was more intensive between Day 109 and 290, which corresponded to almond's growth and hull split season.

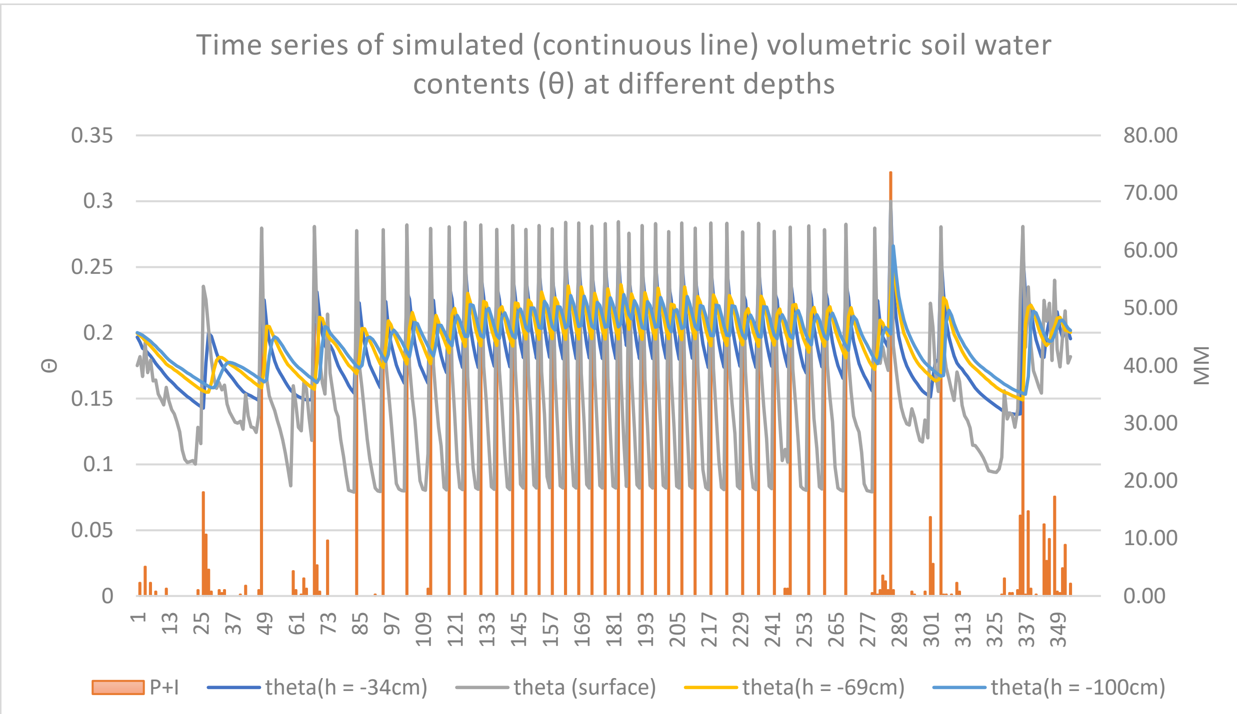

Figure 6. Temporal distribution of soil moisture and the sum of irrigation and precipitation from January 2021 to December 2021.

5. Conclusions

This project focused on one almond orchard that uses micro-sprinkler irrigation, and the annual applied water for one acre of Nickel's ranch is approximately 2.74-4.74 acre-feet. The amount of water applied was estimated using crop-water evapotranspiration (ET) collected from its own weather station. The result is site-specific, but it is only representative of its water demand in 2021. More years of different atmospheric conditions from orchards in different evapotranspiration zones and soil characteristics should be included for a more comprehensive model to estimate water use in micro-sprinkler irrigated orchards. The irrigation schedule was estimated using ETc and maximum allowable water content, and the model simulation shows such irrigation management in micro-sprinkler irrigated fields can maintain the soil moisture at an ideal level for almonds. I assumed a uniform soil composition in 1-m depth for HYDRUS-1D simulation. However, the soil is complex, and its properties can vary greatly within inches. Thus, soil heterogeneity could be essential in the soil moisture model. In addition, the LAI value is directly related to canopy size, tree health status, and growth stage, which will affect the rate of evaporation and transpiration. Monthly LAI specifically from the orchard should be investigated for HYDRUS-1D time-variable boundary conditions input.

References

[1] D.A. Hyson, B.O. Schneeman, P.A. Davis. Almonds and almond oil have similar effects on plasma lipids and LDL oxidation in healthy men and women. J. Nutr., 132 (4) (2002), pp. 703-707.

[2] C.Y. Chen, K. Lapsley, J. Blumberg. A nutrition and health perspective on almonds. J. Sci. Food Agric., 86 (14) (2006), pp. 2245-2250.

[3] Goettsch, Jeffery. Contributions of the California Almond Industry to the California Economy. Agricultural Issues Center, University of California. August 19, 2020.

[4] Julian Fulton, Michael Norton, Fraser Shilling. Water-indexed benefits and impacts of California almonds, Ecological Indicators, Volume 96, Part 1, 2019, Pages 711-717.

[5] Silva Ursulino, Bruno, et al. "Modelling Soil Water Dynamics from Soil Hydraulic Parameters Estimated by an Alternative Method in a Tropical Experimental Basin." *Water*, vol. 11, no. 5, 2019, p. 1007., https://doi.org/10.3390/w11051007.

[6] Koumanov, Kouman & Hopmans, Jan & Schwankl, L.J. Soil water dynamics in the root zone of a micro-sprinkler irrigated almond tree. Acta Horticulturae(2004). 664. 369-375. 10.17660/ActaHortic.2004.664.46.

[7] Simunek et al., 2008. J. Šimůnek, M.Th van Genuchten, M. Šejna. The HYDRUS-1D Software Package for Simulating the One-dimensional Movement of Water, Heat, and Multiple Solutes in Variably-saturated Media**.** Dep. of Environmental Sciences, Univ. of California, Riverside (2008). Version 4.0. HYDRUS Software Ser. 3.

[8] Baram, S., et al. "Estimating Nitrate Leaching to Groundwater from Orchards: Comparing Crop Nitrogen Excess, Deep Vadose Zone Data-Driven Estimates, and Hydrus Modeling." *Vadose Zone Journal*, vol. 15, no. 11, 2016, pp. 1–13., https://doi.org/10.2136/vzj2016.07.0061.

[9] Van Genuchten, M.T. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Soc. Am. J.* **1980**, *44*, 892–898.

[10] Li, Yong, et al. “Evaluation of Water Movement and Water Losses in a Direct-Seeded-Rice Field Experiment Using HYDRUS-1D.” *Agricultural Water Management*, vol. 142, 2014, pp. 38–46., https://doi.org/10.1016/j.agwat.2014.04.021.

[11] Maldera, Francesco, et al. “Row Orientation and Canopy Position Affect Bud Differentiation, Leaf Area Index and Some Agronomical Traits of a Super High-Density Almond Orchard.” *Agronomy*, vol. 11, no. 2, 2021, p. 251., https://doi.org/10.3390/agronomy11020251.

[12] Waller, Peter, and Muluneh Yitayew. *Irrigation and Drainage Engineering*. Springer International Publishing, 2016.