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Response of selected soil physical and hydrological properties to soil applied and incorporated wood biomass in almond orchards

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We, the undersigned, certify that the publishable manuscript of Cameron Adam Tokoro Zuber meets the required standards of scholarship of the university and the student's graduate degree program for the awarding of the master's degree.

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Dedicated to my son
and, as always, for Melissa.

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ABSTRACT

Response of selected soil physical and hydrological properties to soil applied and incorporated wood biomass in almond orchards

Plant biomass amendments affect soil hydrological properties. The objective of this study was to evaluate the effects when wood biomass from a previous orchard is applied and incorporated into the soil prior to planting the next orchard with the practice of whole orchard recycling (WOR). Select soil properties of bulk density (ρ_b), porosity (ϕ), saturated hydraulic conductivity (K_{sat}), matric flux potential (Ψ), and water retention curves were measured for non-amended soil (Control) and WOR treatments. Results show significantly different values ($p < 0.05$) at depth with wood biomass present (15 cm) for ϕ, K_{sat}, and Ψ. For the same depth, differences in van Genutchen (1980) model parameters resulted in different water retention curves. I conclude WOR has effects on soil properties where wood biomass is incorporated. Based on the properties affected (e.g., K_{sat}), WOR may also influence soil moisture content deeper in the soil (i.e., below the depth where wood biomass is incorporated) given the interaction of surface soil properties to irrigated water's timing and amount.

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1. Introduction

Healthy soils and proper water use in perennial crops is important in regions like California with long-term intensive agricultural production and high water demands. Specialty perennial crops, like almonds [*Prunus dulcis* (Mill.) D. A. Webb], have a high level of susceptibility to a changing climate due to the frequency of extreme weather events and constrained water resources (Kerr et al., 2018). This is concerning given almonds are an important agricultural commodity in California as it provides a large economic output, estimated to be $21.5 billion (Sumner et al., 2014), and cover approximately 0.65 million ha of California's land area (USDA, 2021).

California specialty crops have additional challenges from increased water demand due to higher summer evapotranspiration (ET; Parker et al., 2022) and variable water availability from volatility and shifts between dry and wet precipitation periods (Swain et al., 2018). Agriculture needs to navigate these potential changes to historical and expected water resources while also mitigating soil degradation (Lal, 2015) and reducing greenhouse gas emissions.

The promotion of climate smart and soil health practices has resulted in the adoption of various agricultural practices including whole orchard recycling (WOR) which spreads and incorporates wood biomass from the previous orchard into the soil prior to planting the new orchard or crop. Historically, this wood biomass was burned onsite or used in co-generation energy plants contributing to global greenhouse gas emissions. Whole orchard recycling provides an alternative to these disposal practices and is recognized as improving soil health and carbon sequestration (USDA, 2017a; USDA, 2017b; Wolff and Guo, 2020), but little has been done to determine how much affect this practice has on the soil and related hydrological properties which could impact water use.

For other practices that applied plant biomass to agricultural fields, studies have limited soil physiological, biological, and hydrological assessments to surface or shallow soil depth despite indications of deeper affects (Kader et al., 2017; Mulumba and Lal, 2008). Soil properties affect water balances, movement, and storage which in-turn can affect crop production and health. While soil properties for a given soil texture are well documented, a better understanding of how land-use and new agricultural practices affects these properties is needed for improved water use and sustaining agricultural systems in California. For perennial crops, this understanding needs to include greater depths to account for the larger rootzone of these crops.

I hypothesize WOR affects soil hydrological properties by changing the soil structure or specific characteristics in the soil (e.g., pore size and distribution). While soil texture remains static, structure can be altered by root growth and dieback, compaction, or wetting and drying cycles. This along with practices becoming popular in California agriculture, such as cover cropping, WOR, organic amendments, or no till, may affect soil structure over time. Along with its temporal changes, variables that affect structure may have different affects across different soil texture sometime resulting in opposite affects to certain properties like hydraulic conductivity (Araya and Ghezzehei, 2019).

As hydraulic conductivity depends on pore characteristics (Han et al., 2022; Nielsen et al., 2018), many hydrological estimates rely on parameters determined by soil texture and structure for calculations. However, if a new practice significantly changes soil property, then these parameters need to be quantified or reasonably assumed for existing estimates to make accurate calculation for this practice. This study examines the affects WOR has on commonly used soil physical and hydrology properties with the intent to compare this to a conventionally managed almond orchard with non-amended soil. The potential implication for water use, movement, and content will be discussed with regards to the larger Californian agricultural landscape across different types of land-use and new agricultural practices being developed and implemented.

2. Material and Methods

2.1. Site

The site is an almond orchard (N 36.598233°, W 119.514408°, datum WGS84) located at the University of California Kearney Research and Extension Center located in Parlier, CA on Hanford fine sandy loam with an average annual precipitation of 285 mm and air temperature or 17 °C based on California Irrigation Management Information System (CIMIS) station 39 (N 36.597444° W 119.50404°, datum WGS84). The local climate is Mediterranean with precipitation levels below the required ET rates for the almond growing season. Site preparation occurred in 2018 and 2019, and almond trees were planted in 2019. Study sampling and measurements commenced in 2021.

The site was established after termination of a 'Owen T' plum (*Prunus* spp.) orchard on HBOK, Nemaguard, and Krymsk 1 rootstock with row orientation north to south. The site was fumigated by 3.05 m row-strip injection of Tri-Clor (EPA Reg. No. 58266-2-AA-11220; 99.0% Choloropicrin) on May 25th, 2018 at a rate of 0.22 t ha^{-1}. After fumigation the site was covered with a totally impermeable film tarp. Field preparation included using a D10R-3 track-type tractor with a standard ripper to mix the soil to approximately 1.52 m and then disc the soil flat. Even after site preparation, a hard pan exists at an approximate 1.20 m depth across the site based on bore holes dug after preparation.

After fumigation, two soil treatments were established in a split-plot design with non-amended soil (Control) and WOR treatments across three replicates. Wood biomass was applied to the soil surface for WOR treatment plot locations on March 13th to 15th, 2019. Wood biomass was made using a Peterson 1000 horsepower horizontal grinder from the previous orchard's plum trees and additional peach (*Prunus* spp.) trees from another site. These were ground, shredded, and sieved through 51 mm screen in a neighboring field before being spread on the site.

To monitor application amount, applied wood biomass was collected from randomly selected 30 cm by 30 cm square locations within WOR treatment plots. Once final application amount was reached, wood biomass samples were collected using the same method. Four wood biomass samples were collected from each WOR treatment replicate, oven dried, and dry weight measured. The final application rate of wood biomass was 144 t ha^{-1} (dry weight), excluding remaining roots biomass of previous orchard.

On March 19th, 2019, the wood biomass was incorporated into soil using a Northwest Orchard Tiller (Northwest Tillers, II LLC, Yakima, WA). Four randomly selected locations in each WOR treatment replicate were excavated and final depth of wood chips was measured. Average wood biomass incorporation depth was 9.4 cm. After incorporation, approximately 30 cm high berms were created with a Domries three-point disc ridger on March 21st, 2019 in-line with expected location of tree rows. Topsoil with incorporated wood biomass was used for the berm resulting in average incorporation depth on berm of 39.4 cm.

On April 10th, 2019, trees were planted on the berm with 4.8 m tree and 5.9 m row spacings with row orientation west to east. 'Nonpareil' almond trees were planted in the treatment plots' tree rows with alternating 'Sonora' or 'Supareil' tree rows acting as buffers between the 'Nonpareil' rows. Each plot consists of six 'Nonpareil' trees with additional 'Nonpareil' trees between the plots to provide a buffer between treatments. All varieties are on Cornerstone rootstock.

2.2. Climate and irrigation

For 2021, precipitation (mm) and average daily temperature (°C) was measured with a CIMIS station 39 (N 36.597444°, W 119.50404°, datum WGS84) located near the site. Irrigation was applied through pressure compensating micro sprinklers (Jain Irrigation, Inc., Smart Jet PC Blue A (Low) Full Circle, Fresno, CA, USA) installed between each tree and at both ends of the tree row. Regular irrigation began in April 2021 once resident soil moisture from fall and winter precipitation was depleted. Afterwards, the site was irrigated to meet the estimated ET demand of almond trees for the area with periods of deficient irrigation prior to harvest (e.g., in August) following current recommended practices. The site was irrigated primarily once a week until October 2021. Irrigation was monitored using water meters (Assured Automation, Lead Free Brass Water Meter WM-NLC-075, Roselle, NJ, USA) that were calibrated prior to installation at the site. Water meters were installed for tree rows with treatment plots. Water meter readings were recorded to measure the total amount of applied water (mm) for irrigation events.

2.3. Bulk density and porosity

Bulk density (ρ_b) and total soil porosity (ϕ) could be jointly collected from undisturbed soil cores using the bulk density sampler (AMS, Inc. Bulk Density Soil Sampling Kit 400.84, American Falls, ID, USA). Samples were collected in March 2021 at surface (0-5 cm), 60 cm, and 100 cm soil depths from the WOR and Control plots 1.2 m from the center of the sample tree's trunk. Samples were left in a metal liner (AMS, Inc. Stainless Steel Liner 404.281, American Falls, ID, USA) and covered with plastic caps (AMS, Inc. Plastic End Cap 418.10, American Falls, ID, USA) and processed within the same day of collection. After removing the bottom plastic cap, a filter paper (Cytiva Whatman Grade 595 Filter Paper Circles, Marlborough, MA, USA) was placed at the bottom of the sample and held in place with hose clamp and wire mesh. Following the procedure outlined in Fares et al. (2008), double-distilled water was allowed to soak from bottom and upwards through the sample. Samples were soaked until weight no longer increased. The top plastic cap was kept on the sample to reduce evaporative loss during soaking process.

Weights were measured with a balance (Ohaus Scout SPX422 Portable Precision Balance, Parsippany, NJ, USA) to capture the wet weight of the soil (W_s) without the weight of metal liner, filter paper, metal mesh, and hose clamp. Soil was then removed from the metal liner and placed into drying tin. Soil was oven dried (The Grieve Corporation Laboratory Oven L0-201C, Round Lake, IL, USA) at approximately 96 °C and dry weight was measured (W_d). After, ρ_b and ϕ was calculated using expressions (Grossman and Reinsch, 2002; Flint and Flint, 2002):

$$\rho_b = W_d/V \tag{1}$$

$$\phi = (W_s - W_d)/V \tag{2}$$

where V is the volume (cm^{-3}) of the metal liner used to collect the samples.

2.4. Saturated hydraulic conductivity and soil matric flux potential

Saturated hydraulic conductivity (K_{sat}) and soil matric flux potential (Ψ) was measured using a 2800 and 2800K1 Guelph permeameters (Soilmoisture Equipment Corp., Goleta, CA, USA) on November 11th, 2021 at 15 and 60 cm depths for WOR and Control treatments. Measurements were collected in-line with the tree row and 1.2 m from the center of the sample tree's trunk. Bore holes were excavated and permeameter prepared following instructions from Soilmoisture Equipment Corp. (2012). Using the combined reservoir, the steady-state rate of fall for water in the permeameter's reservoir ($\bar{R}$) was measured for two wellheads in each bore hole with height (H) of 5 and 10 cm.

K_{sat} and Ψ was calculated for each wellhead and then averaged for each measurement location and depth. A soil texture-structure category was assumed to be, "most structured soils from clays through loams; also includes unstructured medium and fine sand," (Soilmoisture Equipment Corp., 2012) for Control and WOR treatments. Category determined microscopic capillary length factor (a^*) of 0.12 cm^{-1} and shape factor (C) calculated as:

$$C = \left(\frac{H/a}{2.074 + 0.093\ H/a}\right)^{0.754} \tag{3}$$

where a is the radius of bore hole (3 cm).

Flow (Q) was then calculated as:

$$Q = \bar{R}x_c \tag{4}$$

where x_c is the combined reservoir constant for the permeameters (35.22 cm^2).

K_{sat} and Ψ was calculated as:

$$K_{sat} = \frac{CQ}{2\pi H^2 + \pi a^2 C + 2\pi(H/a^*)} \tag{5}$$

$$\Psi = \frac{CQ}{(2\pi H^2 + \pi a^2 C)a^* + 2\pi H} \tag{6}$$

2.5. Water retention curves

Soil samples were collected from the surface (0-5 cm), 60 cm, and 100 cm soil depths from the WOR and Control plots using a soil core sampler (AMS, Inc. Soil Core Sampler 404.46, American Falls, ID, USA) with metal liner (AMS, Inc. Stainless Steel Liner 405.21, American Falls, ID, USA). The metal liner used in the soil core sampler was modified to collect a 209.85 cm^{-3} sample. From May to August 2021 samples were collected from four replicates 1.2 m from sample tree's trunk. Two samples were collected during each sampling effort from a WOR and control plot at the same depth and replicate. Samples were covered with plastic caps (AMS, Inc. Plastic End Cap 418.09, American Falls, ID, USA) and processed using a simplified evaporation method (Peters and Durner, 2008; Wind, 1968).

Samples were saturated in the metal liner using degassed double-distilled water following procedures from METER Group AG (2018) and further described in Shokrana and Ghane (2020). Two tensiometer shafts in a sensor unit (METER Group AG HYRPOP 2, Pullman, WA, USA) were inserted into the sample. The sample, metal liner, tensiometer shafts, and sensor unit were then placed on a balance and left to dry at room temperature (20 to 22 °C) via evaporation. While the samples dried pressure head, water potential, and mass were continuously monitored with the HYPROP-FIT program v.4.2.2.0 (METER Group AG, 2021). After air drying, sample was oven dried (Fisher Scientific Isotemp Oven Model 655F, Waltham, MA, USA) at approximately 106 °C to get final W_d of soil. Sample specific information (i.e., metal liner weight, sample volume, and W_d) was entered into HYPROP-FIT. Using curve fitting programs in HYPROP-FIT, water retention curves for samples were fitted to the van Genuchten model (van Genuchten, 1980), expressed as:

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{[1 + (\alpha|h|)^n]^m} \tag{7}$$

where θ is volumetric water content (cm^3 cm^{-3}), θ_r is residual volumetric water content (cm^3 cm^{-3}), θ_s is saturate volumetric water content (cm^3 cm^{-3}), h is the soil matric potential (kPa), α and n are shape fitting parameters (cm^{-1} and dimensionless; respectively), and m an empirical parameter is calculated following the Mualem model (Mualem, 1976) as:

$$m = 1 - \frac{1}{n} \tag{8}$$

2.6. Data analysis

For testing significant difference, a Student's paired *t*-test (JMP Pro v.16.0.0, 2021) was used. Whole orchard recycling and Control values were compared for each depth for the ρ_b, ϕ, K_{sat}, and Ψ soil and hydrological properties. This same test was performed for the θ_r, θ_s, α, and n parameters in the van Genuchten model as fitted by HYPROP-FIT. The mean value of parameters was used to graph water retention curves with Microsoft Excel (v2202 build 16.0.14931.20128). An additional assessment comparing ρ_b at different depths (15, 60, and 100 cm) within the treatments was performed using a Tukey HSD (JMP Pro v.16.0.0, 2021).

3. Results and Discussion

3.1. Climate and irrigation

The total precipitation for 2021 was relatively lower than the annual average precipitation measured near the site (229 and 285 mm; respectively), while the average air temperature was relatively higher (18 and 17 °C; respectively). Much of the precipitation occurred in the beginning (January to April) and end (September to December) of the calendar year; while higher temperatures (i.e., greater than 18 °C) occurred in the middle of the year (April to October) when irrigation was also applied (Figure 1).

Irrigation was applied once a week from April 14th to September 30th, 2021. Irrigation amount ranged from 9.3 to 63.2 mm with an average of 38.6 mm applied once a week. Single irrigation events occurred on March 12th and October 21st. The March irrigation event was minimal (less than two mm water applied) to flush irrigation lines of debris. Tubing and emitters were also checked for damage and repaired. October irrigation event (21.7 mm water applied) was final irrigation to provide water until trees reached dormancy (e.g., substantial portion of leaves terminated and stop transpiring).

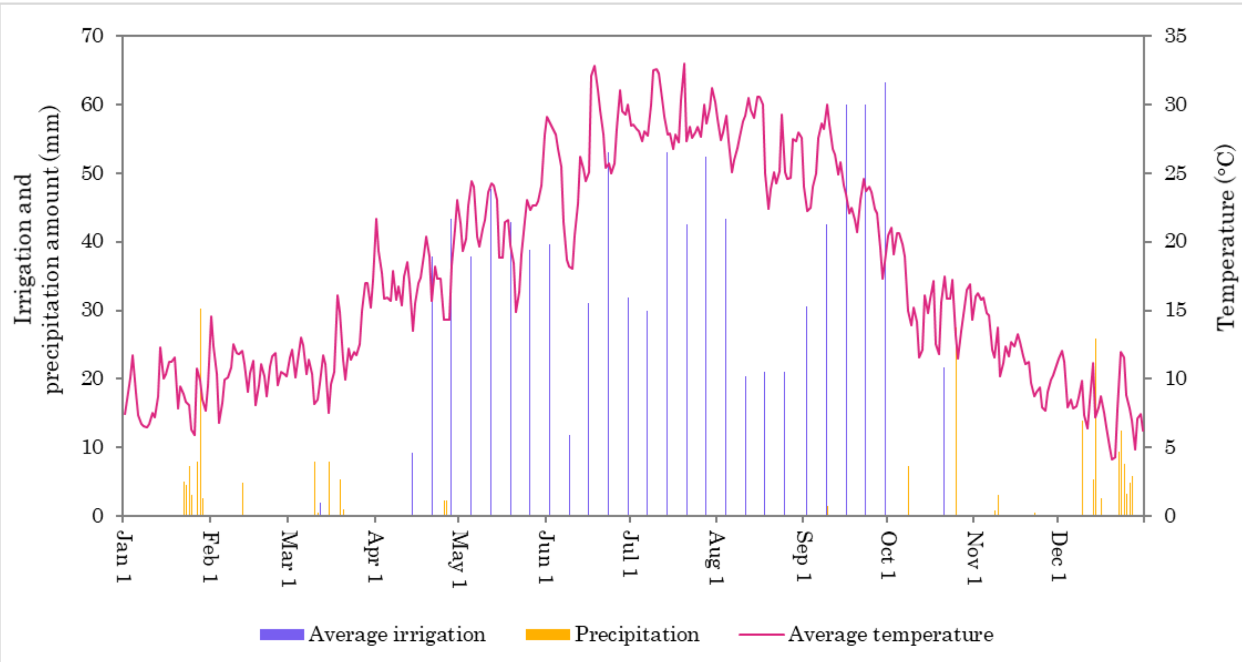

Figure 1. Average applied irrigation (mm, blue bar), daily precipitation (mm, yellow bar), and average daily air temperature (°C, pink line) for site. Irrigation amount measured by water meters installed at site. Precipitation and temperature measured by CIMIS station 39 (N 36.597444°, W 119.50404°, datum WGS84) located near site.

3.2. Bulk density and porosity

The ρ_b ranged from 1.48 to 1.71 g cm^{-3} with no significant differences for WOR and Control treatments at all depths sampled (Table 1). While the WOR ϕ

was significantly lower than the Control at the 15 cm depth (34.1 and 36.7%, respectively), there was no difference in ϕ at the other depths sampled, which ranged from 31.3 to 33.9 % (Table 1).

While ρ_b did not differ between treatments for any depths, an additional assessment comparing ρ_b at different depths within the treatments was performed (Table 2). For the Control, the ρ_b at 15 cm was significantly lower when compared to the ρ_b at 60 cm ($p < 0.05$), while the 100 cm value was not significantly different from either. For WOR, all depths were not significantly different. This supports the idea that soil properties can vary at depth (Domec et al., 2010; Klein et al., 2014) even with the same soil texture. The difference seen between the 15 and 60 cm depths may be due to mechanical practices typical for a conventionally managed orchard like formation of berms, discing surface soil, etc. Whole orchard recycling in sandy loam seems to have less difference across depths or increases variability of ρ_b at the surface.

The decrease in ρ_b at the surface for the Control may explain the significantly higher ϕ, for the Control when compared to the WOR treatment at 15 cm as inverse trends of ρ_b and ϕ concurs with published literature. The difference in 15 cm ϕ may be due to differences in the amount, mean, or distribution size of soil pores. However, the amount of this difference was relatively small (2.6%) and may represent a static difference between treatments or one that will change as the wood biomass decomposes in the soil. These samples were collected in the early portion (i.e., third year) of the production cycle for almonds which can stay in production upwards of twenty years in California. For an almond orchard in the ninth year of production, Janhanzad et al. (2020) attributed increased infiltration in a WOR treatment to increased ϕ as flow pathways increased as large wood biomass decomposed in the soil.

3.3. Saturated hydraulic conductivity and soil matric flux potential

For 15 cm depth, K_{sat} and Ψ was significantly different for WOR when compared to the Control and not significantly different at 60 cm depth (Table 1). The WOR K_{sat} was higher than the Control by approximately 5 cm hr^{-1}. The Ψ for the WOR was also higher by approximately 0.7 cm^2 hr^{-1} compared to the Control.

The higher K_{sat} for WOR may indicate a higher amount of water movement to deeper soil layers past the area where wood biomass is present in the soil (e.g., 39.4 cm depth on berm). The high Ψ for WOR may also indicate this as it is a combination of hydraulic conductivity as well as water potential (Pinheiro et al., 2017; Shaykewich and Stroosnijder, 1977). A high Ψ also implies a water potential gradient that may allow for more available water for plant transpiration at 15 cm depths reducing periods of high-water stress

Table Error! No text of specified style in document.**1.** Soil saturated hydraulic conductivity (cm hr^{-1}) and matric flux potential (cm^2 hr^{-1}) for 15 and 60 cm depths and bulk density (g cm^{-3}) and porosity (%) from 15, 60, and 100 cm depths. Treatments include whole orchard recycling implemented (WOR) and non-amended soils (Control). Symbol (‡) denotes significant different ($p < 0.05$) using Student's paired *t*-test and na denotes depth not assessed.

Sample depth (cm)	Treatment	Bulk density (g cm^{-3})	Porosity (%)	Saturated hydraulic conductivity (cm hr^{-1})	Matric flux potential (cm^2 hr^{-1})
15	Control	1.48	36.7‡	1.32‡	0.18‡
	WOR	1.58	34.1‡	6.38‡	0.89‡
60	Control	1.70	31.4	1.42	0.20
	WOR	1.71	33.5	2.71	0.38
100	Control	1.67	33.9	na	na
	WOR	1.66	31.3	na	na

Table 2. Bulk density (g cm^{-3}) compared across 15, 60, and 100 cm depths for non-amended soils (Control) and whole orchard recycling implemented (WOR) separately. Different letters denote significantly different values ($p < 0.05$) using Tukey HSD within treatments.

Treatment	Sample depth (cm)	Bulk density (g cm^{-3})	
		Measurement	Standard deviation
Control	15	1.48^{A}	0.09
	60	1.70^{B}	0.08
	100	1.67^{AB}	0.17
WOR	15	1.58^{C}	0.13
	60	1.71^{C}	0.22
	100	1.66^{C}	0.13

when irrigation timing and amount may not match overall ET demand for trees.

While the results for ϕ and K_{sat} may contradict, the sampling method for ϕ was selected because it better represents water collecting along the surface of soil particles and in the formation of meniscus between soil particles. As soil samples were soaked from the bottom and water moved up the sample, the ϕ measured may not capture openings in the soil that are too large for the capillary action and tension of water to facilitate water movement up the soil column. Additionally, the soil at the site has a larger fraction of sand (i.e., approximately 63% in the top 30 cm) which is poor for surface and meniscus collection of water when compared to more platy surface of clay soil. Soil sample collection may also result in avoidance of larger wood biomass and roots that could contribute to overall high K_{sat} which these in-situ measurement of K_{sat} potentially capture.

3.4. Water retention curves

The α parameter at the surface (0-5 cm) depth was significantly higher for WOR when compared to the Control ($p < 0.05$) but was not significantly different at other depths. θ_r, θ_s, and n parameters were not significantly different at any depth (Figure 2 and Supplemental 1), except for θ_s at the 60 cm depth ($p < 0.005$). Using mean values of the van Genuchten model parameters, the water retention curves were similar in positioning and shape at 60 cm and 100 cm depths, but different for the surface (0-5 cm) depth (Figure 3).

While the higher α shows that WOR at 15 cm depth start drying at a lower suction the higher range of θ_s may allow for longer period of available water content if irrigation events result in high initial moisture content. α is a scaling parameter in the van Genuchten model and typically assumed to be related to the inverse of the air entry suction for drying, which is the suction where the soil begins to desaturate (Benson et al., 2014; van Genuchten, 1980). As WOR has a higher α at 15 cm depths, this means the soil begins to dry at a lower suction. However, given the higher range of θ_s for WOR (0.213 to 0.475 $cm^3\ cm^{-3}$) compared to the Control (0.085 to 0.166 $cm^3\ cm^{-3}$), WOR has a potential for higher moisture content (Figure 3; left). Additionally, given the same climate, ET rate would be similar and therefore, if irrigated past the θ_s of the Control, the WOR would be at a higher soil moisture content at shallower depths for a relatively longer period potentially resulting in fewer periods of water stress for crops. This affect is further compounded as agricultural crops using micro emitters tend to be irrigated often throughout the growing period. Thus, having the potential for many periods of higher soil moisture content and fewer periods of water stress.

4. Conclusion

When discussing soil hydrologic properties and potential implications towards soil, water, and plant interactions, it is important to remember 1) soil hydrologic properties vary with depth (Domec et al., 2010 and Klein et al., 2014) even with non-amended soils and 2) plants do not necessarily extract water homogeneously across the root zone for transpiration (de Jong van Lier et al., 2008 and Pinheiro et al., 2017). This is especially important for California agriculture as there is a predominance of perennial crops with large and deep root systems which are primarily irrigated with micro emitters that limit the locations and amount of water in the soil profile. Soil

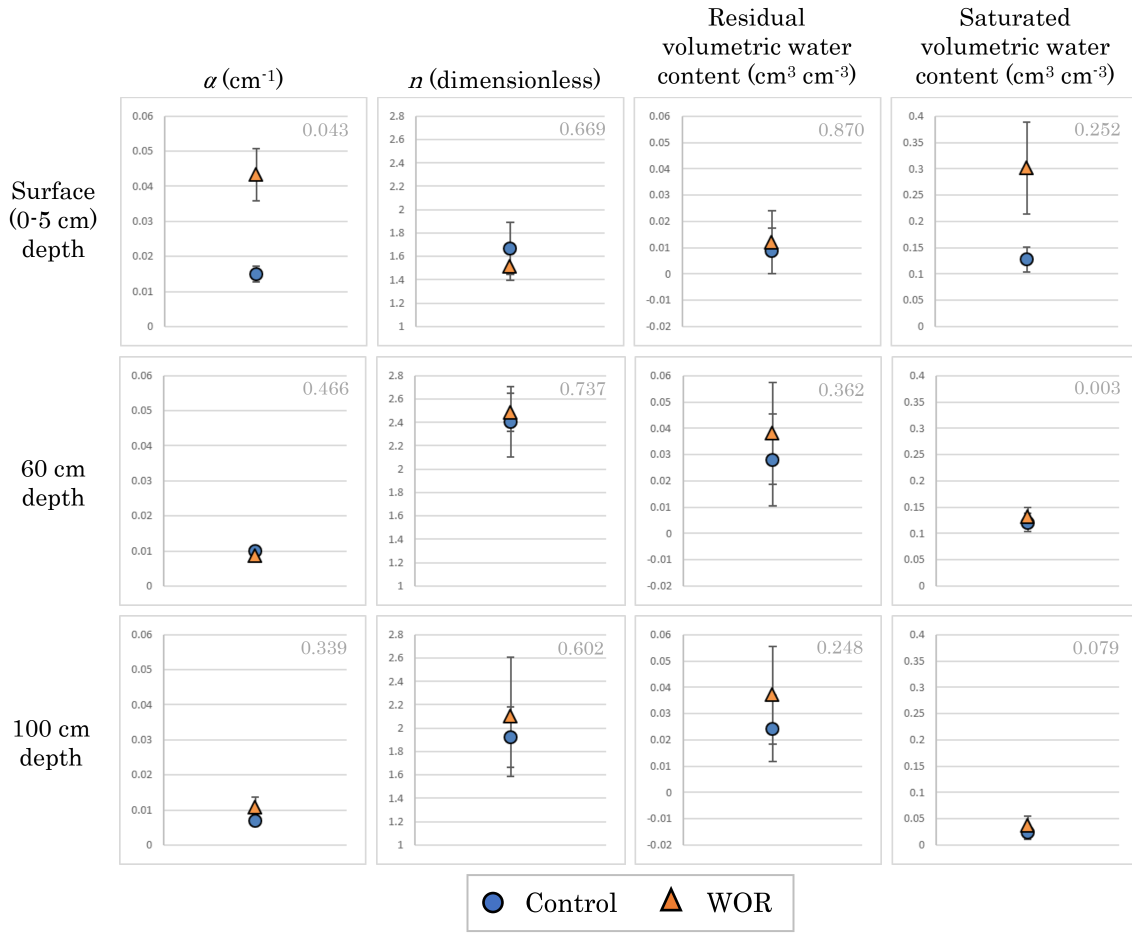

Figure 1. Mean and standard error of van Genuchten model parameters (van Genuchten, 1980) fitted by HYPROP-FIT program v.4.2.2.0 (METER Group AG, 2021) for surface (0-5 cm, top), 60 cm (middle), and 100 cm (bottom) depths. Parameters are α (cm^{-1}; left), n (dimensionless; left-middle), residual volumetric water content (cm^3 cm^{-3}; right-middle), and saturated volumetric water content (cm^3 cm^{-3}; right). Treatments include whole orchard recycling implemented (WOR; orange triangle) and non-amended soils (Control; blue circle). P-values using Student's paired t-test in top-right of each graph. Values in Supplemental 1.

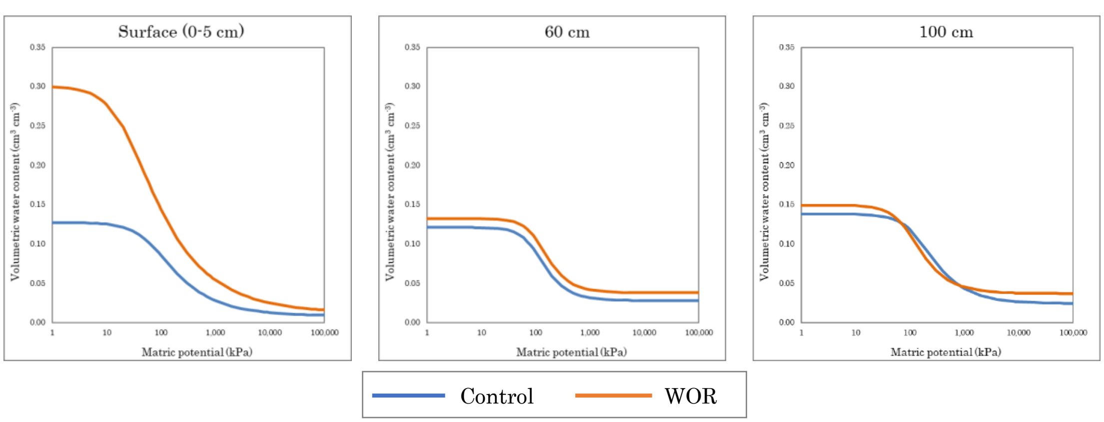

Figure 2. Water retention curves using mean values of parameters in van Genuchten model (van Genuchten, 1980) fitted by HYPROP-FIT program v.4.2.2.0 (METER Group AG, 2021) for surface (0-5 cm, top), 60 cm (middle), and 100 cm (bottom) depths. Treatments include whole orchard recycling implemented (WOR; orange dashed line) and non-amended soils (Control; blue solid line).

hydrologic properties affect the distribute of water vertically and horizontally in the soil column, location and amount of water content, and the period water remains available to plants. As water resources get limited and new practices get adopted across California's agricultural landscape, with its various cropping systems and soil textures, determining if soil hydrologic properties are changing to a degree that would affect water management and crop response is becoming increasingly important. I have shown when compared to non-amended soils, WOR in sandy loam provides longer periods of water availability at the surface and potentially move more water to deeper soil depths. This would benefit large trees in water limited areas and create possibilities for long-term productivity for those agricultural systems.

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Supplemental 1. Mean and standard error of van Genuchten model parameters (van Genuchten, 1980) fitted by HYPROP-FIT program v.4.2.2.0 (METER Group AG, 2021) for surface (0-5 cm), 60 cm, and 100 cm depths. P-values from Student's paired *t*-test. Parameters are α (cm^{-1}), n (dimensionless), residual volumetric water content (cm^3 cm^{-3}), and saturated volumetric water content (cm^3 cm^{-3}). Treatments include whole orchard recycling implemented (WOR) and non-amended soils (Control). Values used in Figures 2 and 3.

Sample depth (cm)	Treatment	α (cm^{-1})			n (dimensionless)			Residual volumetric water content (cm^3 cm^{-3})			Saturated volumetric water content (cm^3 cm^{-3})		
		Mean	Standard error	p-value	Mean	Standard error	p-value	Mean	Standard error	p-value	Mean	Standard error	p-value
Surface (0-5)	Control	0.0149	0.0023	0.0432	1.6707	0.2238	0.6690	0.0087	0.0087	0.8700	0.1273	0.0235	0.2521
	WOR	0.0432	0.0074		1.5110	0.1131		0.0120	0.0120		0.3007	0.0872	
60	Control	0.0101	0.0010	0.4659	2.4063	0.3009	0.7366	0.0280	0.0174	0.3624	0.1210	0.0180	0.0027
	WOR	0.0086	0.0010		2.4840	0.1632		0.0380	0.0193		0.1320	0.0175	
100	Control	0.0069	0.0006	0.3393	1.9210	0.2580	0.6024	0.0243	0.0127	0.2475	0.1380	0.0035	0.0787
	WOR	0.0108	0.0027		2.0970	0.5099		0.0370	0.0185		0.1493	0.0067	