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Evaluation of citrus grove floor management strategies for water use efficiency and conservation

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ABSTRACT

Perennial crops require water year-round, straining water resources, particularly in arid and semi-arid regions throught the world. Of those regions, the Lower Rio Grande Valley of Texas, USA, depends on flood irrigation to meet water demands of crops. Approximately 60–70% of citrus producers use flood irrigation to irrigate their groves, which is less efficient than other irrigation methods such as micro-jet or drip irrigation. Flood irrigation is to reduce cost, equipment, and energy required, and no land needs to be taken out of production to be used for holding ponds. Therefore, conservation practices that are adapted for flood irrigation are necessary in these areas where infrastructure is less conducive to other practices. Water use efficiency and potential water savings in different grove-floor management strategies, citrus tree growth, soil moisture, and irrigation volume were measured over the course of 3 years (from establishment to first harvest) in four different grove floor management strategies. These strategies, flat-bed no plastic mesh groundcover (traditional), flat-bed with plastic mesh groundcover, raised bed no groundcover, and raised bed with groundcover showed varying impacts on young citrus tree growth, soil moisture, and water savings over this study period. By the end of the study, 2.2% water savings (44,403 L over 4 years) were found in the flat bed with groundcover treatment compared to traditional grove floor management. This treatment also resulted in higher water use efficiency and greater initial growth of young citrus. Overall, the use of ground cover showed much potential for conserving water compared to traditional, uncovered flat bed management methods. These grove floor management practices can improve tree growth and establishment in young citrus trees in addition to improving water use efficiency. However, it is yet to see how these benefits will translate to more mature trees.

1. Introduction

Drought and water scarcity in arid, semi-arid, and subtropical regions is of great concern as climate change intensifies weather extremes (Wheaton and Kulshreshtha, 2017). As agricultural regions are being urbanized and water is prioritized in municipal areas, less is being allocated for agricultural consumption. Problems such as increased municipal use and demand, frequent droughts, and neighboring states and countries sharing water supplies have stretched water resources beyond their limits. In the United States of America (US), the Lower Rio Grande Valley (LRGV) located in southern Texas, borders Mexico, and is characterized by a semi-arid, subtropical climate. It also has one of the fastest growing population regions in the country, and one of the most unique water delivery systems (Knight, 2009). However, water restrictions and drought have left regional water authorities struggling to meet the current agricultural and municipal needs.

The primary source of water for the LRGV is the Rio Grande (Rio Bravo in Mexico) that borders the US and Mexico. Water is diverted from the river by both countries and is governed by an agreement contract which dictates diversion allowances (Stubbs et al., 2003). Irrigation districts in the LRGV operate pumping stations that provide water to cities and agricultural producers, which creates friction as priorities for water shift to municipal areas in times of drought. A canal system operated by 27 water districts delivers water from the Rio Grande to the municipalities and agricultural producers through 5,618 km of canals, pipelines, and resacas (Knight, 2009). Furthermore, these districts

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require "push water" to move water from pumping stations located along the river to different end user locations that radiate north, east, and west throughout the LRGV. This results in areas further away from the pumping stations requiring larger allocations of "push water" and in turn increases the likelihood of these regions to not receive water during times of drought (Rio Grande Regional Water Planning Group, 2015).

Taking into account the infrastructure of the region is important when developing more efficient strategies. The canals in the LRGV that deliver water are more suited for flood irrigation practices because growers can directly divert water with a smaller amount of energy than drip and microjet systems require (Knight, 2009). Therefore, flood irrigation practices prevail in south Texas even though newer, more efficient irrigation technologies are available (Young et al., 2011). This negatively impacts water conservation due to the large amount of water applied to a grove or field and the resulting evaporation, runoff, or leaching that occurs. Producers must provide enough water to maintain yields and growth, while facing the reality of less water availability (García-Sánchez et al., 2007; Hondebrink et al., 2017; Kusakabe et al., 2016; Nelson et al., 2013).

Water management and conservation through various conservation practices is a priority for the Texas state and regional water plans (Rio Grande Regional Water Planning Group, 2015; www.twdb.texas.gov). Recent research has shown that narrow border flood (NBF), drip irrigation (DI), and microsprinkler (MS) water conservation methods could potentially save between 32.3 to 60.4 million cubic meters (26,200 to 49,000 acre-feet) of water in the Texas citrus industry each year (Nelson and Young, 2011; TexasAWE.org). While these findings have encouraged some adoption of water conservation methods, many citrus producers face other challenges that require more intensive grove floor management. Weeds, vines, clayey soils with poor drainage, soil moisture variation, and water-borne diseases like *Phytopthora spp*. are common problems for citrus producers (Abouziena et al., 2008; Enciso et al., 2005; Graham and Timmer, 2003; Wiedenfeld et al., 1999). However, many of these issues can be addressed through proper grove floor management practices. Grove floor management is becoming more whole-systems centric to incorporate not only pest and disease, weed management, and water conservation strategies but also provide sustainable solutions that improve tree growth, health, and production. In previous research studies conducted by Simpson et al. (2019, 2020), grove floor management strategies that incorporated raised beds and black plastic mesh groundcovers had significant impacts on citrus tree growth, production, and root distribution. However, these studies did not include analysis of water savings or water use efficiency due to field site limitations. Therefore, the study of these promising new grove floor management strategies as they pertain to water conservation are important for future adoption.

The objectives of this research were to determine if different grove floor management strategies could be used to improve water savings in young citrus establishment. Water use efficiency (WUE) and water conservation in different grove floor management strategies were explored. A local citrus producer aided in this study to evaluate these factors along with tree growth, soil moisture, and first year's yield in a young citrus planting. The evaluated four grove floor management strategies were studied for 3 years from planting. This study provides potential methods to prevent excessive water loss from soils and maintain available water in the root zone for plant establishment. This could also reduce the frequency of irrigation events, the amount of water needed for irrigation and, could conserve more water and increase WUE during young tree establishment, benefiting producers both financially and environmentally.

2. Materials and methods

2.1. Experiment site and setup

The experimental site was located in McAllen, Texas, US on a 6 ha (15 acre) plot of land owned by Southmost Farms (26°08′08.9"N, 98°15′50.7"W). The soils in this location were predominantly Matamoros silty clays with >50% clay particles. Four grove floor management treatments: flat beds with no groundcover (traditional; FNC), flat beds with black plastic mesh groundcover (FC), raised beds with no groundcover (RNC), and raised beds with groundcover (RC), were divided by soil berms to distinguish between treatments and allocate water according to the needs of each treatment. Treatments were constructed on 1.61 ha, 1.62 ha, 1.36 ha and 1.47 ha plots of land, respectively.

The site was prepared in late 2015 to early 2016, by laser leveling flat beds or raising the beds depending on treatment. In the raised beds, a specially adapted bedding apparatus was used to raise the soil surface to between 45 and 53 cm (18-21 inches) as reported by Simpson et al. (2019). Briefly, beds were prepared at a slight angle and 1.5 m wide at the top and 2.2 m wide at the bottom and spacing of rows and trees was approximately 7.5 × 4.5 m. The groundcover consisted of a black plastic mesh laid on the raised or leveled bed and the sides were anchored and buried to prevent movement. Valencia orange trees (*Citrus sinensis* cv. Valencia) microbudded onto Sour Orange rootstocks (*Citrus aurantium* L.) were planted in April 2016 in each respective treatment. Each treatment consisted of 11 rows and treatments were laid out in a block design (Fig. 1). Four rows in each treatment were chosen and 10 trees per row (40 trees per treatment) were selected and marked for measurements. The producer maintained tree fertilization and pest management programs throughout the study, and each treatment was treated equally with the exception of irrigation volumes.

2.2. Irrigation and soil moisture measurements

Due to drought and heat conditions the year of planting, trees were initially irrigated frequently to prevent loss. Poly-tubing was used to direct irrigation water to each row and treatment at rates specified by the producer according to experience and moisture sensors. The soil berms (ca. 1.5 m away on each side of tree planting row) created a 'basin' within each treatment and prevented significant water movement to other treatments. The producer recorded the amount of irrigation applied (in acre-inches) then the information was relayed to the researchers and converted to SI units. Soil moisture sensors and dataloggers (Watermark soil moisture sensors, Irrometer Company Inc., Riverside, CA) were installed according to manufacturer's instructions at two locations within each treatment and at two depths per location (15 and 45 cm). Soil moisture measurements (soil water potential, kPa) were programmed to record every two hours each day throughout the study and then averaged. Data from the sensors was used to determine irrigation needs.

In addition to the soil moisture measurements collected, the amount of water applied to each treatment area throughout the seasons was also recorded. From this, water savings (%) and water use efficiency were calculated using the following calculations:

$$\%\ Water\ savings = \left(\frac{water\ applied\ in\ traditional\ planting\ treatment - water\ applied\ in\ comparison\ treatment}{water\ applied\ in\ traditional\ treatment}\right) * 100 \quad (1)$$

Fig. 1. Site location and experimental setup at Southmost Farms in Mission, TX, USA.

$$\textit{Water use efficiency}\left(\frac{kg}{m3}\right) = \left(\frac{\textit{weight of harvested fruit}}{\textit{water applied}}\right) \quad (2)$$

Water use efficiency (WUE) was calculated to determine how effectively trees were using water in each treatment. After harvest, the weight of harvested fruit for each treatment was divided by the amount of water applied during the season (~1 year).

2.3. Plant growth measurements

Tree height, canopy circumference, and trunk diameter were recorded monthly throughout the study. Every fourth tree was marked within each row to ensure growth measurements were collected consistently on the same trees throughout the experiment. A total of 40 trees per treatment (10 trees per row/ 4 rows per treatment and 160 trees total for all 4 treatments) were used for growth measurements. Tree height from the ground to the top of the canopy was measured with a rolled tape measure or incremented measuring pole once they were taller than ~1.5 m. Tree maintenance practices such as pruning, as well as tree size limited tree canopy circumference measurements the first year. After trees had grown enough to develop a canopy structure (one year), tree canopy circumference was measured at the widest point of the canopy. Trunk diameter was measured using digital calipers at 10 cm above the bud union. This location was marked, and measurements were taken consistently at this spot throughout the experiment. To normalize data and account for initial differences in size, tree relative growth rate (RGR, μm m^2 day^{-1}) was calculated from these measurements using the following calculation:

$$RGR = \left(\frac{\ln(t2) - \ln(t1)}{days}\right) * 1000 \quad (3)$$

where: t1 = time 1 t2 = time 2 ln = natural log

This calculation determined the rate of growth of trees within each treatment for height, tree trunk circumference, and canopy circumference parameters, then averages were used to determine the average relative growth rate.

Soil samples were taken for analysis in the last year of the experiment (2019) to evaluate mineral nutrient content and soil carbon. For each treatment, soil samples were taken from the upper 15 cm of soil at three locations along the row, approximately 45–50 cm from the tree trunks. At each location, samples were collected from three holes and mixed for a more representative sample for testing. Soil samples were sent to the Texas A&M University Water and Soil Testing Laboratory (College Station, Texas) for analysis. In addition to the soil samples, root samples were also collected for analysis. A soil corer was used to sample approximately 45 cm from the trunk which corresponded to the dripline of the tree canopy. Root samples were collected at 0–15 cm and then again from 16–45 cm depths. Soil cores were stored in plastic bags and kept in a cooler for transport back to the lab. Root samples were then stored at 4°C until all could be processed. Roots were washed and analyzed using techniques described by Simpson et al. (2020). Briefly, roots were washed using mesh screens, then analyzed using a WinRhizoPro root scanner and software (Regent Instruments Inc., Québec, Canada).

2.4. Yield and fruit quality measurements

In May 2018, estimated yield was measured and calculated to determine fruit distribution amongst treatments. This was performed by counting the number of fruit within a 0.27 m^2 guide on 8 trees within each treatment. These guides were placed randomly within tree canopies, fruit were counted, and recorded. In March 2019, fruit were harvested to determine preliminary average yield. This was considered a preliminary, late-season harvest because the first harvest from young citrus trees does not always determine future yield or fruit quality. However, yield could not be collected from subsequent years because the producer sold the land and access to the trees was not allowed. Trees were harvested by removing fruit and placing them in bins designated for each treatment. Bins were counted, weighed, and the total yield was then estimated. Overall yields within each treatment were determined because individual rows and trees could not be separated for analysis due to technology and harvest crew limitations.

JMP Pro 14.0.0 software (SAS Institute, Cary, NC) was used to determine statistical differences between treatments. Full factorial analysis were conducted when appropriate to determine significance to $P \leq 0.05$ in a completely randomized design. A Tukey's test was used to separate means when significant differences at $P \leq 0.05$ were found between treatments, and these differences were represented by different letters.

3. Results

Trees in all experimental treatments significantly grew over the course of the three-year study (Fig. 2). Tree height was significantly affected by grove floor management practices (p = 0.0003, Fig. 3A).

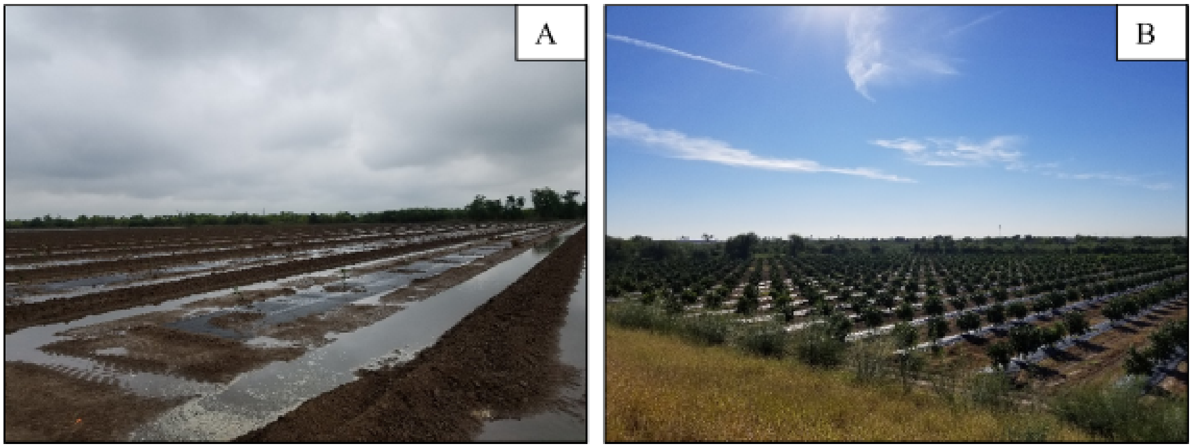

Fig. 2. Experimental site setup, (A) soon after planting (2016) and (B) after three years of growth (2019).

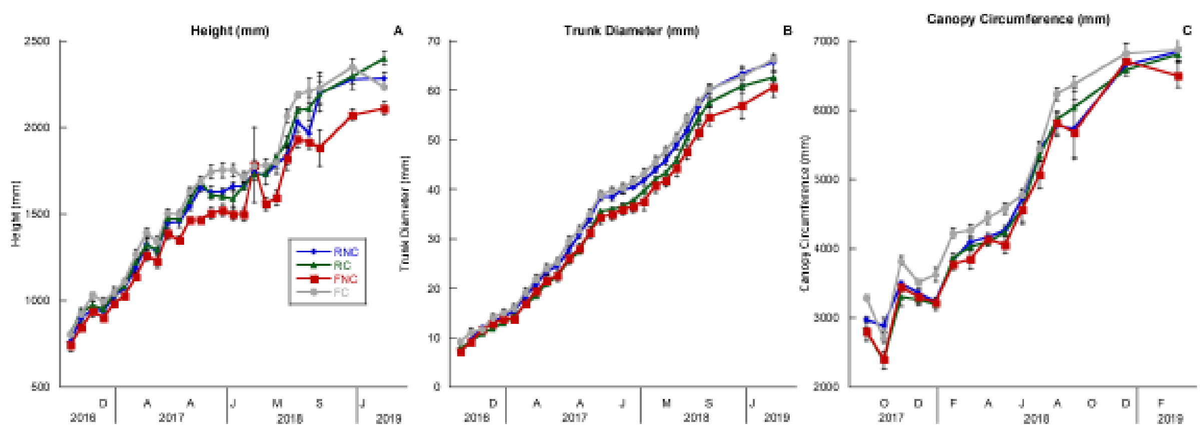

Fig. 3. Vegetative growth parameters recorded for trees during the experimental period. (A) Tree height, (B) tree trunk diameter, and (C) canopy circumference. Raised bed no cover (RNC), Raised bed with cover (RC), Flat bed no cover (FNC), Flat bed with cover (FC). Bars show ±1 standard error of the mean.

Trees grown in FC were tallest at the end of the three-year study, followed by the RC, RNC, and FNC treatments (Fig. 3A). Trunk diameter also followed similar patterns where FC treatments had larger trunk diameters, followed by RNC, RC, and FNC ($p = 0.0001$, Fig. 3B). Canopy circumference only showed significantly larger canopies in FC treatments while all other treatments did not significantly vary ($p = 0.0001$; Fig. 3C). Negative growth measurements indicate times when trees were trimmed.

Throughout the experiment, growth parameters fluctuated in each treatment. However, the differences between treatments were reduced as tree growth progressed and the rate of growth. Initially, the flat bed treatments with covers grew faster which resulted in larger trees more quickly than other treatments. Towards the end of the experiment, other treatments showed increased growth rates and soon had a similar height. Over the entire study period (Aug 2016-2019), tree height relative growth rate showed no statistical differences between

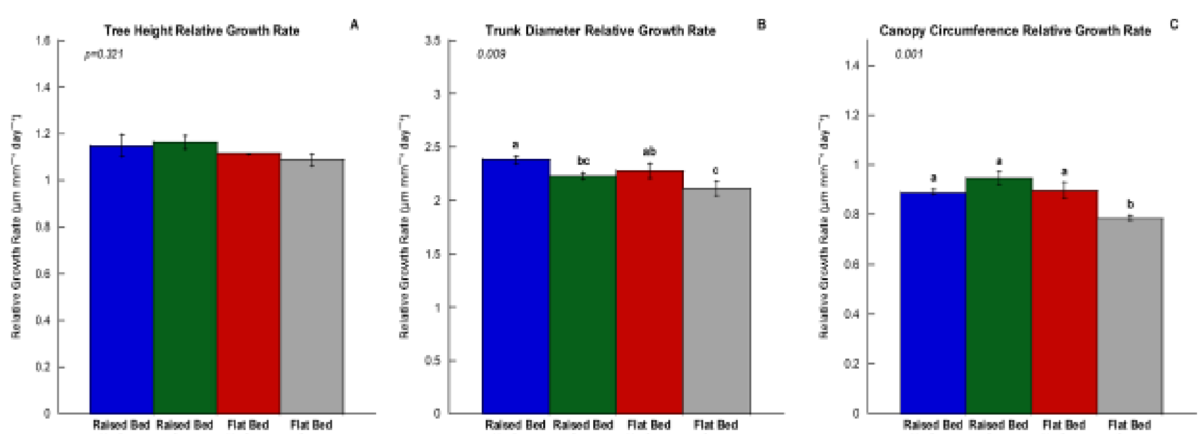

Fig. 4. Average relative growth rate of different tree measurements, (A) Tree height relative growth rate, (B) trunk diameter relative growth rate, (C) canopy circumference relative growth rate. Significant difference between treatments is shown as different lowercase letters. Bars show ±1 standard error of the mean.

treatments (p = 0.321; Fig. 4A). Alternatively, significant differences between treatments were seen for trunk diameter relative growth rate (p = 0.009; Fig. 4B) by 2019 when the study ended. The FC treatment had the smallest trunk diameter relative growth rate and the RNC had the greatest trunk diameter relative growth rate. This pattern was also seen in canopy circumference relative growth rate where trees in the FC treatment had the smallest canopy relative growth rate compared to all other treatments (p = 0.001; Fig. 4C).

As expected, soil moisture fluctuated by season and year. It should be noted that this site experienced three abnormally heavy rain events that caused heavy flooding in 2015, 2017 and 2018. Outside of these events and normal rainfall, irrigation was used to supplement water demands and was applied after producer assessment and to meet plant needs. Moisture in the upper 15 cm of the soil profile fluctuated more dramatically throughout the experiment (Fig. 5A). At 15 cm, soil moisture varied significantly amongst treatments, with the RC treatment having the highest soil water potential values at 15 cm, followed by FNC, RNC, and FC (p = 0.0001). At the 45 cm depth, the RNC had higher soil tension, followed by the RC, FC, and FNC (p = 0.0001; Fig. 5B). This shows that more moisture was retained in the flat bed treatments at 45 cm.

At the end of the experiment, soil nutritional analysis was examined to compare treatments and how they may have influenced soil properties and root development. Overall, there were minor differences in mineral nutrients between treatments that were likely explained by spatial variability rather than treatment effects. However, soil electrical conductivity (EC), sodium (Na), and organic carbon (C) were significantly impacted by the different treatments. The traditional planting methods (FNC) showed higher EC and Na values compared to other treatments (Table 1).

Surprisingly, roots were not significantly affected by grove floor management treatments within the timeframe of this experiment (Table 2). However, a trend of greater root fresh weight was seen in the RNC treatments. Furthermore, the lowest values for root parameters were seen in the FNC (traditional) management treatment.

An average amount of 104 m^3 of water was applied to the FNC treatment, 101 m^3 applied to FC, 120 m^3applied to RC, and 134 m^3applied to RNC treatments (Table 3). Water savings varied throughout the experiment and was highly dependent upon weather and rainfall experienced each year (Tables 3–5). Ultimately, the water use translated to an estimated 2.2% water savings in FC treatments compared to traditional FNC treatments. Furthermore, the increase in water savings from 2016 vs. 2019 illustrated that weather and establishment period influenced water savings. This indicates that an establishment period may be required to realize the full benefits of water savings. Supporting this is the fact that more water was applied in 2016 and 2017, when trees were smaller and younger and required more water. The hottest months, March–August also required greater amounts of irrigation due to high temperatures and high evaporative demands (Table 5).

There were no significant differences between treatments with regards to estimated fruit per tree (Fig. 6). However, FC treatments had higher numbers of observed fruit, followed by the FNC, RNC, and RC. Water use efficiency was greatest in the FC treatment, followed by the FNC, RNC, and RC treatments (Table 6). These trends were consistent when translated to harvested yield (Table 6). No statistical differences were calculated due to harvesting logistics, but, FC treatments yielded approximately 30% more fruit than the traditional FNC treatment.

4. Discussion

Young citrus trees require intensive irrigation and grove management to ensure proper development, survival, and eventual yields. In this study, certain grove floor management strategies have potential to improve water use efficiency as well as growth in young orange trees. However, management techniques that increase soil water infiltration and drainage may take more time to show benefits. Overall plant height was greater in FC in this experiment, which conflicted with results from a similar experiment conducted by Simpson et al. (2019) which found that the greater tree height occurred in trees with RC. Because the comparative study took place over a longer period of time, on grapefruit trees, and in a different location, this could account for many of the differences. However, it should also be stated that the trees planted in the RC and RNC treatments were planted three to four months after the FC and FNC trees due to seedling availability issues. This may have further delayed growth and establishment, putting them behind the other treatments in yield. Furthermore, growth rate could have influenced these findings as growth rate was slower in the FC by the end of the study, most likely due to the slower growth of trees as they reach the reproductive phase (Bond, 2000; Johnson et al., 2011). This theory is further supported by the larger trunk diameter of trees in FC treatments and the decline in expansion rates as the trees grew larger. Alternatively,

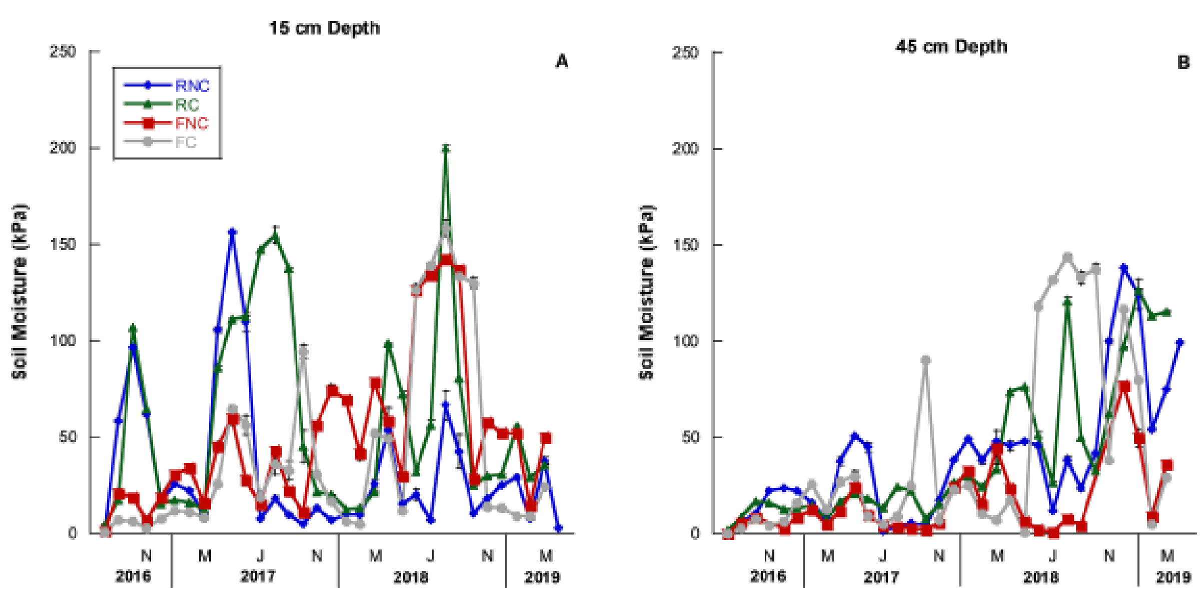

Fig. 5. Soil moisture data for each management treatment. (A) Soil moisture (kPa) at 15 cm and (B) soil moisture (kPa) at 45 cm depths. Bars show ±1 standard error of the mean.

Table 1
Soil nutritional analysis measured at the end of the three-year experiment.

Treatment	pH	Electrical Conductivity (umhos/cm)[a]	NO_3-N (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	S (ppm)[a]	Na (ppm)[a]	Sand (%)	Silt (%)	Clay (%)	Organic Carbon (%)[a]
Flat + Cover	8.3	286.5 ab	9.8	53.5	425.6	11933.1	615.8	47.7 b	282.6 b	17.5	23.0	60.0	0.9 a
Flat No cover	8.4	422.75 a	13.3	56.3	458.3	11534.7	629.4	93.8 b	483.3 a	14.0	25.8	60.3	1.0 a
Raised + Cover	8.4	185.75 b	5.0	48.1	395.0	11780.1	611.8	38.9 b	220.5 b	19.8	24.3	56.0	0.8 b
Raised No Cover	8.4	302 ab	2.6	41.2	403.2	12644.7	608.6	52.5 a	281.2 b	14.3	23.8	62.0	0.95 a
P treatment	0.4	*0.027*	0.47	0.08	0.34	0.492	0.96	*0.0009*	*0.01*	0.33	0.2	0.22	*0.031*

[a] Lowercase letters indicate significant differences between treatments at p ≤ 0.05. Significant p values are italicized.

Table 2
Average root parameters for each management practice located at the experimental site.

Treatment	Depth (cm)	Fresh weight (g)	Area (cm^2)	Width (cm)	Height (cm)	Length (cm)	Surface area (cm^2)	Diameter (mm)
Raised + Cover	0-45	1.01	346.55	16.39	22.17	165.01	61.39	1.13
Raised No Cover	0-45	2.00	381.26	17.15	22.78	149.48	55.35	1.10
Flat + Cover	0-45	0.31	360.56	16.77	22.19	149.53	51.71	1.03
Flat No cover	0-45	0.18	344.05	16.09	21.50	119.63	24.91	0.65
P treatment		0.089	0.389	0.245	0.431	0.719	0.28	0.076

Table 3
Average yearly water (m^3) applied to each plot for each grove floor treatment. Treatments were flat bed no groundcover (FNC, traditional; 1.61 ha), flat bed with groundcover (FC; 1.62 ha), raised bed with groundcover (RC; 1.47 ha), and raised bed no groundcover (RNC; 1.36 ha).

	FNC	FC	RC	RNC
Average	104.35	101.15	120.14	134.08
2016	99.30	103.24	126.56	150.48
2017	106.08	99.30	112.37	127.91
2018	82.27	81.41	96.83	106.70
2019	90.91	89.92	106.45	123.59

Table 4
Difference in water savings (%) for different grove floor treatments from 2016 to 2019 (Equation 1). Treatments were flat bed no groundcover (FNC, traditional), flat bed with groundcover (FC), raised bed with groundcover (RC), and raised bed no groundcover (RNC). Difference from traditional grove floor management treatments is shown in m^3. Negative values indicate less water savings (more water used) in comparison to the traditional planting method while positive values indicate more water savings (less water used) in comparison to the traditional planting method.

	FC	RC	RNC
Average over all years	2.470	-14.800	-29.600
	2.187	-15.256	-30.733
Total for all years	44.400	307.140	617.970
	2.187	-15.256	-30.733
2016	-3.700	-27.140	-50.570
	-3.932	-27.387	-51.531
2017	6.170	-6.170	-22.200
	6.398	-5.972	-20.665
2018	1.230	-14.800	-24.670
	0.969	-17.712	-29.703
2019	1.230	-16.040	32.070
	1.065	-17.051	-35.951

raised bed grown trees had faster growth rates at the end of the study. This may indicate that these trees were allocating more resources to vegetative growth and expansion, while the flat bed treatment was nearing reproductive maturity and allocating more resources to flowering and fruiting. The initial yields seem to support this assumption in that the yields of the flat bed treatments were far greater than those of the raised bed treatments.

Table 5
Quarterly water savings (%) compared to traditional grove floor management. Treatments were flat bed no groundcover (traditional, FNC), flat bed with groundcover (FC), raised bed with groundcover (RC), and raised bed no groundcover (RNC). No water applied is indicated by NWA. Negative values indicate less water savings (more water used) in comparison to the traditional planting method while positive values indicate more water savings (less water used) in comparison to the traditional planting method.

Year	Quarter	Traditional	FC	RC	RNC
2016	Mar-May	-	-17.298	-32.250	-96.520
	June-Aug	-	1.003	-38.843	-71.541
	Sept - Nov	-	1.065	-10.674	6.450
2017	Dec-Feb	NWA	NWA	NWA	NWA
	Mar-May	-	7.133	-2.615	-18.452
	June- Aug	-	6.893	-8.483	-17.403
	Sept - Nov	-	2.994	-3.513	-37.590
2018	Dec-Feb	-	0.500	5.762	-1.531
	Mar-May	-	1.146	-20.654	-40.374
	June- Aug	-	1.146	-29.578	-40.374
	Sept - Nov	NWA	NWA	NWA	NWA
2019	Dec-Feb	-	1.003	-7.446	-24.734
	Mar-May	-	1.065	-20.877	-40.326
	June- Aug	-	1.103	-20.773	-40.348

Environmental factors such as soil moisture have profound effects on tree growth and citrus yields (Aguilar-Fenollosa and Jacas, 2013; Krajewski and Krajewski, 2011; Pedrero et al., 2012). Changing grove floor management strategies has a large effect on moisture retention and infiltration because porosity, bulk density, and other factors are often affected (Bryla et al., 1997; Kadyampakeni et al., 2014; Pedrero et al., 2012). The soil moisture in this study was, in general, lower in the raised bed treatments deeper in the soil profile while the FNC had significantly more moisture in the lower depths. Increased infiltration due to more porous soil could have reduced moisture in raised bed treatments, or this could be due to the distance of lateral water movement through the bed (from initial irrigation application between rows) to reach the sensors (Akbar et al., 2017). In the upper 15 cm of soil, greater differences occurred in the FC treatments, which also retained more moisture at lower depths throughout the year. It is particularly important for greater amounts of water to remain in deeper soil depths due to salts in irrigation water sources (Boman et al., 2005). Evaporation from the soils surface drives water movement upward, which can lead to surface salinity in groves (Grattan, 2002; Levy and Syvertsen, 2004). The water

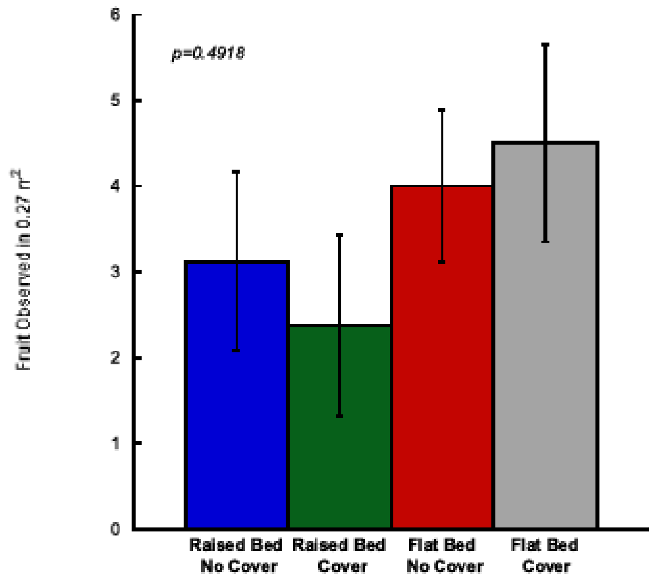

Fig. 6. Fruit estimates conducted early in the 2018 harvest season. Bars show ±1 standard error of the mean.

Table 6
Yield and water use efficiency of young citrus in different grove floor management treatments. Water applied was calculated for only the year prior to harvest (2018).

Treatment	Total Yield (kg)	Water applied (m^3)	WUE (kg/m^3)
FNC	2086.5	431.72	4.83
RNC	834.61	553.83	1.51
FC	2921.14	431.72	6.77
RC	417.31	497.09	0.84

quality of the Rio Grande fluctuates throughout the year and salt accumulation can be a major concern for growers (Miyamoto et al., 1995). When electrical conductivity was examined in soils, flat bed treatments showed higher values than the raised bed treatments. But none of these values were enough to negatively affect growth (Maas, 1993; Zekri and Parsons, 1992). The more compact nature of the soil in flat bed treatments may have contributed to the slight accumulation of salts compared to raised bed treatments. Raised beds have better drainage and downward infiltration of water because of mechanically increased porosity (Funt et al., 1997; Zhang et al., 1996, 2018). Furthermore, the RC treatment had slightly less organic C, which could indicate higher temperatures and porosity in this treatment might have increased microbial activity leading to a greater decomposition of C (Butenschoen et al., 2011; Wang et al., 2020).

Adequate irrigation of young citrus trees is essential for establishment and development. In the LRGV, citrus is typically flood irrigated with water from the Rio Grande. However, the Rio Grande fluctuates in quality and droughts limit water availability frequently (Ribera and Mccorkle, 2013). Water conservation efforts have made some headway, but grower infrastructure often limits the use of drip or microjet irrigation methods (Enciso et al., 2005; Knight, 2009; Ribera and McCorkle, 2013). Narrow furrow flood is a modified flood irrigation method that has shown greater water conservation with equal or better yields (Nelson et al., 2013). However, this does not address other factors in grove management. Soil moisture can be retained, weeds can be reduced, and soil temperatures can be increased with the use of groundcovers (Simpson et al., 2019). Yet previous studies were not able to accurately measure actual water savings. Overall, a 2.2% water savings in flat bed and groundcover treatments was achieved. This translates to an average savings of 2468 L of water compared to flat bed with no cover treatments (traditional methods). Over the four year experiment, total savings equaled approximately 44,403 L of water in the FC treatment. The young trees used in this experiment required a large amount of water for establishment due to their small size at planting and the high temperatures experienced that year (Tables 3–5). Unfortunately, the other treatments did not have the same water savings as the FC treatment and water savings fluctuated more each year. This variability could be attributed to root system size, soil characteristics, evapotranspiration, or a number of other factors. However, it would be interesting to see if these findings would change as trees become more mature and root systems develop. Water savings and WUE are reflective of the water applied and how efficiently that water is being used to produce fruit (García-Tejero et al., 2011; Melgar et al., 2008; Romero-Conde et al., 2014; Syvertsen and Garcia-Sanchez, 2014). Water savings and WUE improve when trees produce more fruit per unit of water applied and when less water is lost to evapotranspiration. This could be achieved by reducing the amount of water applied to each treatment and would reduce input costs, optimize yield, reduce soil erosion, and conserve water resources (García-Sánchez et al., 2007; García-Tejero et al., 2011; Panigrahi et al., 2017; Panigrahi and Srivastava, 2017). In this study, WUE was greater in trees grown in the FC treatments (Table 6), this illustrates that groundcovers can improve WUE in young citrus establishment. It should be noted that these results will likely fluctuate in coming years as trees mature and bloom. Furthermore, the first year of yield is not consistent or predictive of future yields. As trees mature, yields become more stable and a greater volume of fruit are produced.

5. Conclusion

In this experiment, certain grove floor management practices, namely flat beds with groundcovers, demonstrated improved water savings, WUE, tree growth, and production in young trees. During the establishment period for young citrus trees, more irrigation is needed, particularly if weather is hot and dry. Plastic mesh groundcovers reduce water loss from evaporation and increase soil moisture by acting as a barrier to evaporation. By retaining moisture in soils, salts are leached more deeply in the soil profile, often beyond the active root region. The FC treatment contained larger trees with greater canopy circumferences and higher preliminary yields, which can largely be attributed to the use of groundcovers. The act of raising planting beds increased water infiltration, creating a more porous soil structure which, in turn, retained less water within the soil profile and could have affected tree growth. However, trees growing in the raised bed treatments were rapidly catching up to other trees in size and canopy circumference by the end of the experiment. In the traditional planting treatments (FNC), trees were visually smaller and soils were more compacted with higher EC than other treatments. Over time it remains to be seen if this results in negative impacts on tree growth and yields.

This study showed potential for improving water savings and WUE in young citrus production. Future studies should include monitoring trees in these treatments for yields, growth, and fruit quality as well as water savings and WUE. Researchers may also want to explore how different soils or irrigation practices are affected by these different management practices.

Credit author statement

CS, MS, and SN conceived the project. CS and MS carried out experiment and performed analyses. CS wrote the original draft manuscript. CS and MS performed the statistical analysis. CS, MS, and SN assisted with study design and experiments. All authors read and contributed to earlier versions and approved the final version.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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