Comparing Water Use Efficiency in South Texas Furrow and Drip Irrigated Watermelon

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Abstract. Crop production in the Lower Rio Grande Valley (LRGV) of South Texas is at continual risk due to drought conditions. Irrigation sources stem from the Rio Grande, and when water resources are limiting, water conserving methods are needed. The purpose of this project was to evaluate drip irrigation with plastic mulch as a water conservation strategy to drip without plastic and furrow irrigated watermelon. Crop water requirements were estimated using a weather station, Penman-Montieith evapotranspiration (ET) equation, and FAO crop coefficients. Drip irrigation was employed by a water balance approach, replacing ET water loss within the drip irrigated plots versus irrigating to soil saturation point in furrow irrigated plots. Harvested watermelon were measured for total soluble solids (TSS), size and weight to determine yield and quality. In the drip with plastic treated plots, the highest average yield and best overall irrigation use efficiency compared to the other systems was observed.

Introduction

The LRGV of South Texas faces ongoing drought conditions and water supply shortages which negatively impact the regional water users. Most of the water resources stem from the Amistad-Falcon reservoir system which is operated by Mexico and the United States by the International Boundry & Water Commission. Currently Mexico is failing to meet treaty commitments which oblige it to contribute a certain volume of water inflow from the Rio Conchos into the Rio Grande which upstreams into reservoirs such as the Asmistad-Falcon (RGRWA, 2014). As the LRGV remains to deal with such impact of current water deficits, irrigation districts have already announced to agricultural producers that water distributions may become postponed or suspended. When the LRGV districts are no longer able to pump water, metropolises will be affected as well.

LRGV crop production is at continual risk due to drought conditions. As water resources are limiting in the LRGV, the need to change to a more water conserving method to irrigate crops. Growers often apply an excess amount of water using traditional furrow (flood) irrigation. Majority of farmers in the LRGV use furrow irrigation because of how irrigation is distributed; water is pumped through gravity-flow canals and underground pipelines (Fipps & Pope, 1998) distributing a large amount of water in a short period of time. The water must be ordered, so short frequent irrigations would be costly. One of the limiting factors in using the drip system is that a cistern or small reservoir is needed where land is taken out of production to store water in order to irrigate frequently. Growers are hesitant to change because water is cheap in South Texas. However, research suggests that using a water-balance approach for irrigation scheduling may improve yield and quality as well as decrease the amount of water applied by only ordering need specific irrigation.

Objectives

The purpose of this project is to develop an irrigation strategy to manage limiting water resources by using a water-balance approach. Drip irrigation was evaluated as a water conservation strategy to conventional furrow irrigation for watermelon. The waterbalance approach was also tested with furrow irrigation, since it is the conventional method in South Texas. Water use efficiency (WUE) and Irrigation Use Efficiency (IUE) was also determined for treatments.

Determining Irrigation Scheduling

In order to estimate the crop water requirements for watermelon, a weather station, the Penman Montieth evapotranspiration (ET) equation, and FAO coefficients were used to determine waterbalance calculations.

Water balance

Influenced by South Texas' high temperatures, the primary source of water, rainfall supply, is insufficient and consequently the region's drought conditions become poorer. Irrigation is fundamentally the alteration of the environment's water balance. Water is added to satisfy the needs of crop growth. Rainfall, evaporation, surface water, and water stored in soil all make up and modify the waterbalance. A water balance is the relationship between the amount of water stored and water lost (Teare & Peet, 1982). According to (Teare & Peet, 1982), the irrigation scheduling program using meteorological data to compute water use and maintain a water balance is conveyed as

$$D_{pi} = D_{pi}\text{-}1 + K_{ci} \text{ x } E_{tpi} + E_{tri} - (R_i - Ro_i) + W_{di} \qquad [1]$$

Where D_{pi} is depletion on day I, K_{ci} represents crop coefficient (role of crop stage), E_{tpi} is the reference evapotranspiration,E_{tri} is the added soil evaporation after irrigation or rain, R_i is the the sum of effective rainfall and net irrigation on day i, Ro_i is the surface runoff, W_{di} is the drainage underneath root zone or groundwater ascending flow (Teare & Peet, 1982).

FAO Penman Montieth ET equation

The FAO Penman Montieth ET equation is known as (Allen, Pereira, Raes, & Smith, 2004):

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad [2]$$

Where FAO coefficients, ET_o represents reference evapotranspiration [mm day $^{-1}$], R_n is net radiation at the crop surface [MJ $m^{-2}day^{-1}$], G is soil heat flux density [MJ m^{-2} day^{-1}], T is mean daily air temperature at 2 m height [°C], u_2 is wind speed at 2 m height [m s^{-1}], e_s is saturation vapour pressure [kPa], e_a is actual vapour pressure [kPa], $e_s - e_a$ represents saturation vapour pressure deficit [kPa], Δ is slope vapour pressure curve [kPa $°C^{-1}$], and ϒ denotes psychrometric constant [kPa $°C^{-1}$]. Evapotranspiration of different crops at different periods of the year and in different regions can be compared with the Penman Monteith equation.

Soil Water Content & Water Storage Capacity

Other values needed to determine when and amount to irrigate are the field's capacity, plant available water, and the permanent wilting point (Enciso, Porter, & Evett, 2012). The following values were obtained to determine the soil's field capacity and available water content from the USDA-NRCS National Engineering Handbook Irrigation Guide (Table 1). Water storage capacity of soil values are shown in (Table 2). It is important to note that root depths can be affected by soil and other conditions (Enciso, Porter, & Evett, 2012).

Table 1. Soil water parameters for Hidalgo Sandy Clay Loam

Soil Texture	Field Capacity (in/ft)	Field Capacity	Plant Available Water (in/ft)	Available Water Content	Permanent Wilting Point (in/ft)	Wilting Point
Sandy Clay Loam	4	0.33	1.8	0.15	2.4	0.20

Table 2. Allowable soil water depletions (MAD, %) and root depths (m) for watermelon

Crop	Allowable depletion (%)	Root depth (m)
Watermelons	40-45	79.25 - 91.44

Determining Water Use Efficiency and Irrigation Use Efficiency

Water Use Efficiency (WUE) is the proficiency with which water is able to produce yield. WUE is yield divided by irrigation applied + rainfall, WUE = (kg/ha·mm) (Sadras & Angus, 2006). Irrigation Use Efficiency (IUE) is the yield divided by the irrigation applied, IUE = (kg/irrigation applied). WUE and IUE are crucial in determining how well an irrigation treatment would be able to sustain a crop when water availability is limited.

Materials and Methods

This study was conducted during the spring watermelon growing season of 2014 at the Texas A&M AgriLife Research Center located in Weslaco, Texas (longitude 26" 9' N, latitude 97" 57' W). The soil at the research site was Hidalgo sandy clay loam (fine-loamy, mixed, hyperthermic Typic Calciustolls). This region has a semiarid climate and the average annual rainfall is 56 cm. Watermelon seedless variety SS 7191 (Abbott and Cobb®) was seeded in a greenhouse on February 10, 2014, then transplanted to field on March 17, 2014. Watermelon was planted in a 3:1 ratio (the 1 being the pollinizer) with the pollinator POL-4370 from the same company spaced 0.9 m apart in 2 m wide raised beds.

This study was conducted as a split-plot design with three treatments: Furrow, Drip with Plastic mulch (Drip-Plastic), and drip on bare ground (Drip-Bare). There were four replications per treatment. The Rio Grande was the source of irrigation water, which was filtered at both locations for the drip irrigation systems. The drip tubes with different emitter spacing had nominal discharge ratings of 0.245 GPH per emitter with 30 cm emitter spacing for the Weslaco site (Netafim USA, Fresno, Cal.).

Irrigation scheduling was targeting using a balance sheet approach at the Weslaco site. Withdrawals includes calculated crop evapotranspiration (ETc) based on Pennman–Monteith reference evapotranspiration and the crop coefficient curves for each irrigation treatment, adjusted by a stress coefficient based on the depletion level and daily ETc rate (Allen et al., 1998). Plots were irrigated approximately twice per week depending on rainfall inputs. An automatic weather station (model ET106, Campbell Scientific, Logan, UT) at the site was used to measure rainfall (TE525 tipping bucket rain gauge), maximum and minimum temperature and relative humidity (CS500 temperature and relative humidity sensor), total solar radiation (LI200X pyranometer), and average wind speed (034A wind set) which was recorded hourly using a CR10X data logger. In field soil moisture sensors (Watermark Soil Moisture Sensors, Irrometer, Co., Riverside, CA) were placed at 15 cm below the soil surface to monitor irrigation near root zone. One water mark sensor was installed per treatment in each of the replications. In field soil moisture sensors, Watermark® Soil Sensors and Decagon® 5TE and 5TM sensors, were installed. Dataloggers and handheld meters were used to obtain soil moisture readings from sensors. Watermark® Sensors were placed at 15 cm below soil surface to monitor irrigation near root zone. Decagon sensors were installed at 15, 30, and 46 cm below soil surface. Sensors were not used as an irrigation scheduling technique; they were used as a reference tool to see if patterns between sensors and water balance could be seen.

The amount of water applied to each plot through irrigation was measured with water meters connected to the irrigation system. One flow meter was installed per treatment and replication for the drip irrigation system, and one flow meter was used for all the furrow irrigated plots. Approximately the same amount of water was applied to the different drip irrigation treatments during each irrigation event. Since evapotranspiration cannot be calculated with plastic mulch covering plot topsoil, water soil sensors were used. Drip-Plastic was irrigated when sensors reached the level at which Drip-Bare needed to be irrigated. With Drip-Plastic, time in between irrigations was a lot longer than Drip-Bare because moisture was retained longer. Waterbalance calculations indicated that a total of 39.62 cm of water were evapotranspirated as shown in (Figure 1). In attempt to replace ET, Irrigation applied + Rainfall were approximately 41 cm for Furrow, 28.45 cm for Drip-Plastic, and 25.40 cm for Drip-Bare.

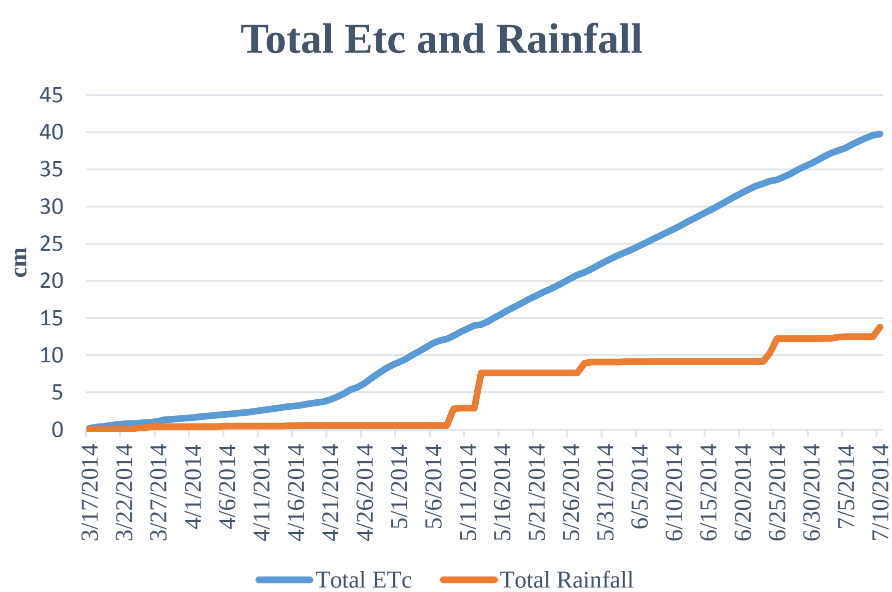


Figure 1. Total Etc and Rainfall

Crop water used was estimated using the crop coefficients for watermelon (0.7 for initial, 1.05 for mid, and 0.8 for end) as suggested by Allen et al., 1998. Curves were adjusted to local conditions regarding the duration of the various growth phases based on previous visual observation of the crop. The lengths for the four growth stages were adjusted according to visual observations. The length of each stage was 20 days for initial, 30 days for development, 100 days for mid and 10 days for the end stage. Watermelons were harvested on June 23 and July 9, 2014. The watermelons were harvested and the number of fruits and weight per fruit were recorded in each plot. After harvesting, the length, diameter, rind thickness and total soluble solids (TSS) (brix %) were measured in each fruit. Data were analyzed with a general linear model (GLM) procedure using SAS (Cary, NC). Duncan's multiple range test (P = 0.05) was used to for mean comparisons.

Results

The watermelon yields were marginally higher for the drip irrigation than Furrow (Table 3). Numerically, the yield for the Drip-Plastic was slightly higher (70,096 kg/ha) than the Drip-Bare (65,871 kg/ha). Furrow resulted in the lowest yield (64,960 kg/ha). Analysis of variance indicated that the mean yield for treatments were not statistically different (F=0.31, DF=2, P=0.742) (Figure 2).

Table 3. Watermelon yield and average fruit weight

Irrigation Treatment	Yield (kg/ha)	Average fruit weight (kg)
1. Furrow	64960	6.9 a
2. Drip-plastic	70096	7.4 a
3. Drip-bare	65871	8.0 a

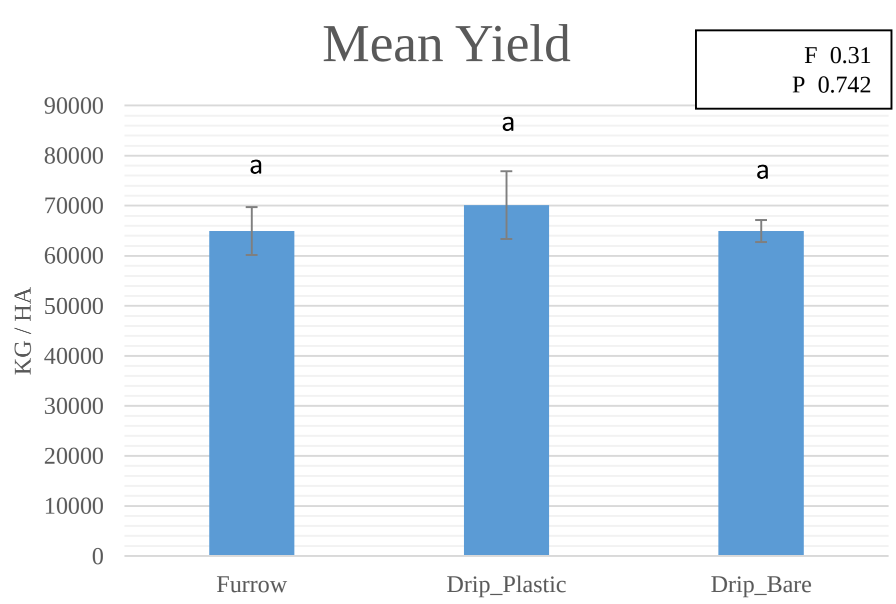


Figure 2. Mean Yield for Irrigation Treatments

Watermelon characteristics for treatments can be seen in (Table 4). Analysis of variance indicated that the TSS were higher for the drip irrigation treatments (Figure 3) compared to the furrow irrigation treatment (F=7.88, DF=2, p=0.001). The length of the watermelons (Figure 4) were faintly higher for the drip irrigation system but were not statistically different (F=1.61, DF=2, p=0.21). The watermelon diameter (Figure 5) for Drip-Plastic was rather higher, but was not statistically different from the other treatments (F=2.43, DF=2, p=0.09). Rind thickness was also evaluated and analysis of variance indicated similar for all irrigation the treatments (F=0.35, DF=2, p=0.71) (Figure 6).

Table 4. Watermelon characteristics for the Furrow, Drip-Plastic and Drip-Bare.

Treatment	TSS (brix %)	Length (cm)	Diameter (cm)	Rind Thickness (cm)
Furrow	11.13	29.22	23.63	1.83
Drip-Plastic	11.91	29.78	24.52	1.83
Drip-Bare	11.86	30.43	24.47	1.76

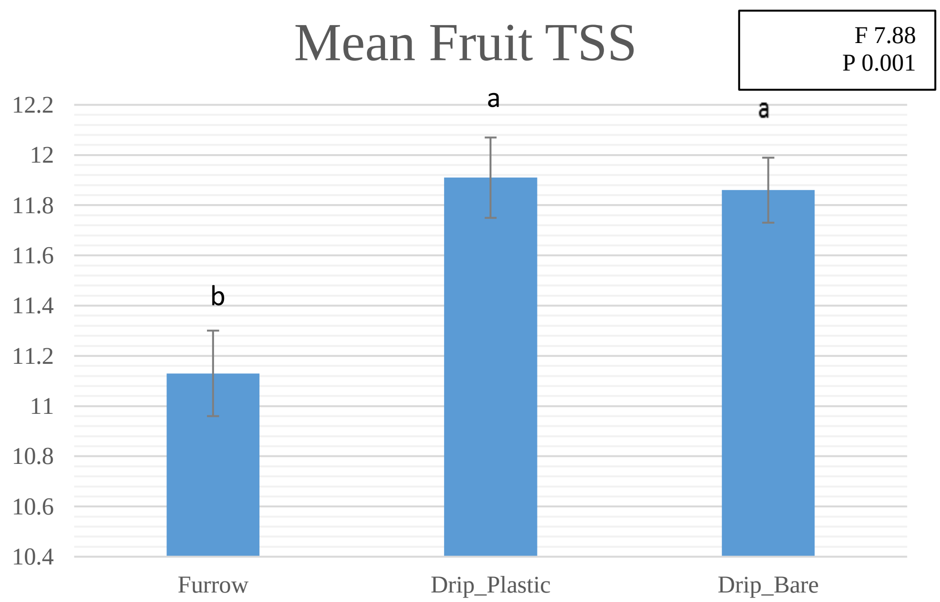


Figure 3. Mean Fruit Total Soluble Solids (Brix%) for irrigation treatments

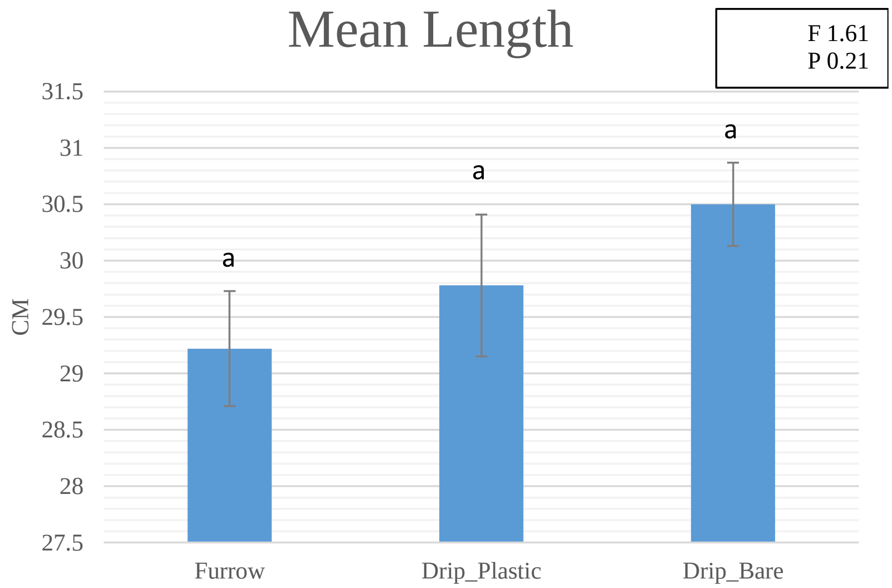


Figure 4. Mean Fruit Length

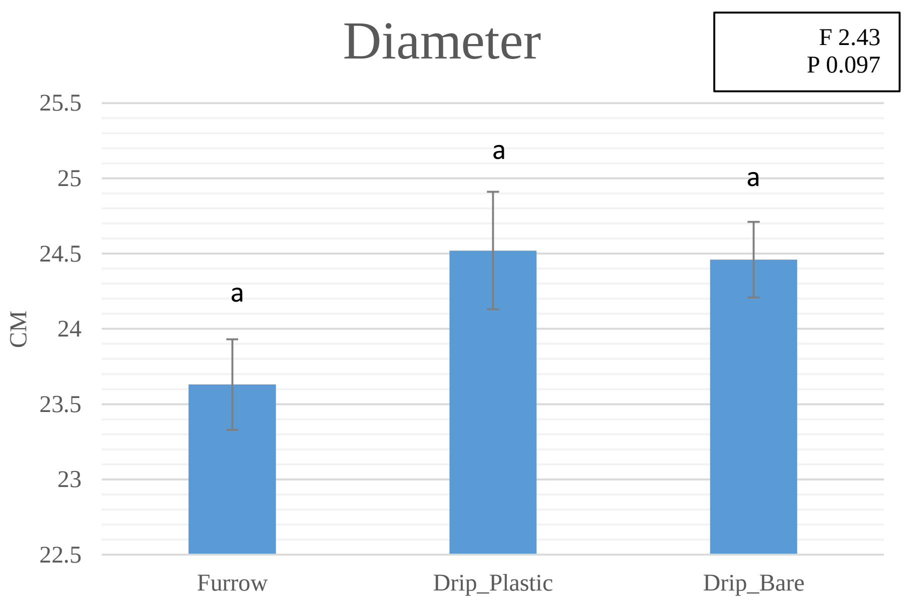


Figure 5. Mean Fruit Diameter

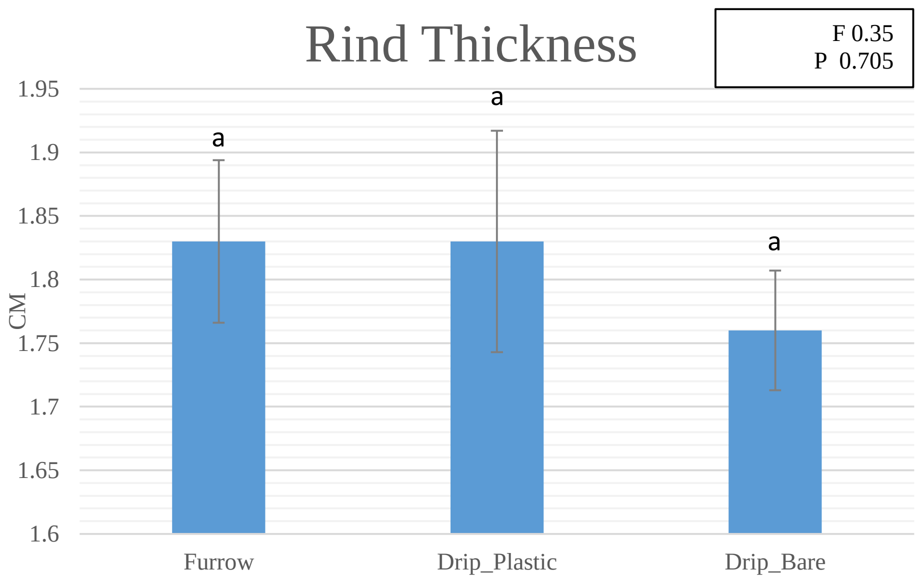


Figure 6. Rind Thickness for each Treatment

Approximately the same number of irrigation events were applied with both drip and furrow irrigation systems (Table 5). The drip irrigation systems applied less than half of the water (Figure 7) than that of the furrow irrigation system and almost double the irrigation efficiency of the furrow. It is important to notice that the length of the furrow rows in this experiment were short rows (roughly 100 m). In normal field conditions with longer furrows, it is impossible to apply small irrigation depths such as the ones applied with this experiment. Generally, commercial farms apply 10 cm or more per irrigation. Less number of irrigations applied could positively impact watermelon yields. Table 5 shows the number of irrigations, irrigation applied watermelon ET and irrigation use efficiency for Furrow, Drip-Plastic and Drip-Bare during the 2014 spring growing season.

Table 5. Calculation of ET, Water Use Efficiency (WUE) and Irrigation Use Efficiency (IUE)

System	Irrigation (cm)	Rainfall (cm)	Irrigations	ET (cm)	WUE (kg/cm)	IUE (kg/cm)
Furrow	27.43	13.71	11	39.62	1579	2368
Drip-Plastic	11.68	13.71	12	39.62	2469	4774
Drip-Bare	14.73	13.71	13	39.62	2284	4410

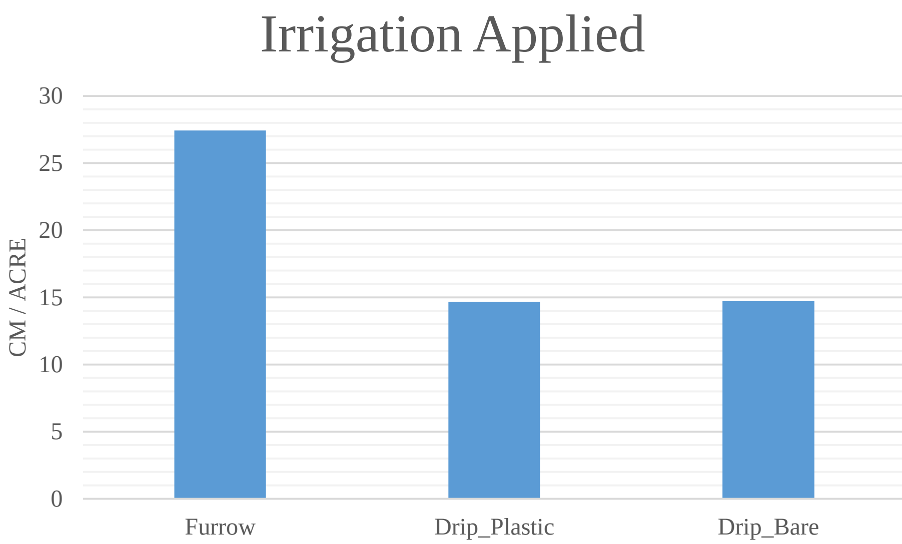
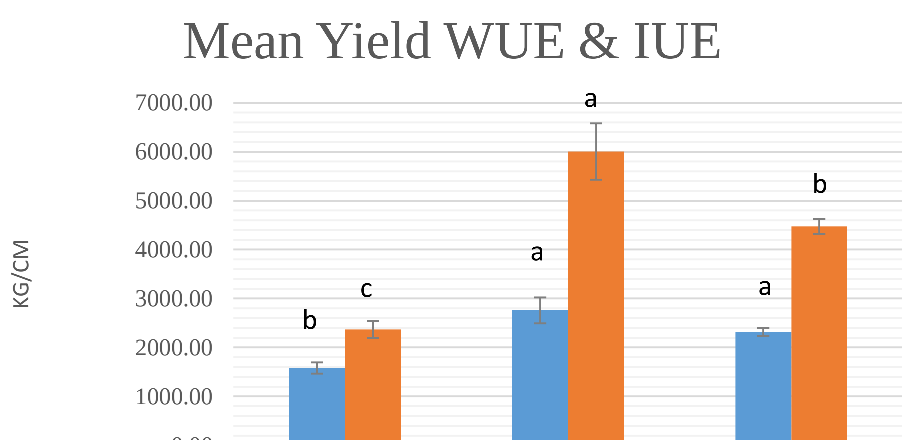


Figure 7. Irrigation Application for Irrigation Treatments



	Furrow	Drip_Plastic	Drip_Bare
WUE (kg/cm irrig)	1579.00	2760.00	2316.00
IUE (kg/cm irrig)	2368.21	6001.00	4471.00

Figure 8. Mean Yield Water Use Efficiency (WUE) & Irrigation Use Efficiency (IUE)

Analysis of variance showed that the total yield WUE of watermelon varied significantly (F= 11.90, DF = 2, p= 0.003). Analysis of variance for total yield IUE varied suggestively (F= 25.90, DF = 2, p= 0.002) (Figure 8).

Conclusions

Furrow and drip irrigated watermelon were compared for crop production WUE and IUE. The overall performance of the three irrigation methods showed little differences in the watermelon yield. Smallest yield occurred for Furrow irrigated plots, with yield about 0.95 times less than drip treatments. Overall total yield WUE for Furrow was 43% less than Drip-Plastic and 32% less thanDrip-Bare; IUE 39% lower than Drip-Plastic and 48% lower than Drip-Bare. Plots with drip irrigation applied 53% less water than furrow irrigated plots. IUE for Drip-Plastic was 1.34 times higher than Furrow; for Drip-Bare ground it was 26% lower than Furrow; WUE was 1.74 times higher for Drip-Plastic and WUE for Drip-Bare was 17% higher than Furrow.

In regards to watermelon quality indicators, percent soluble solids (TSS) measured statistically different for drip and furrow treatments. Sweeter watermelons came from drip treated plots which resulted in TSS 1.07 times higher than furrow treated watermelon. Other quality parameters measured were watermelon length, diameter, and rind thickness; results measured to be statistically similar for all treatments.
The differences in water applied demonstrated that drip irrigation could be used to reduce water usage, water runoff, and deep percolation compared to furrow irrigation. The overall results of this project show that when water availability is limited, drip irrigation will sustain production while upholding that same quality watermelon, to the point of producing higher mean yield per unit of irrigation water applied (IUE). The results also indicate that the water balance approach may be used for furrow irrigation, decreasing the amount of irrigation events.

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