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Research Article

Productivity of Onions Using Subsurface Drip Irrigation versus Furrow Irrigation Systems with an Internet Based Irrigation Scheduling Program

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Selection of the proper irrigation method will be advantageous to manage limited water supplies and increase crop profitability. The overall objective of this study was to evaluate the effect of subsurface drip irrigation (SDI) and furrow irrigation on onion yield and irrigation use efficiency. This study was conducted in two locations, a commercial field and a field located at the Texas A&M AgriLife Research Center in Weslaco, TX. This study was conducted as a split-plot design for both sites with two treatments (SDI and furrow irrigation) and three replications per treatment. The total onion yield obtained with the SDI systems was more than 93% higher than the yield obtained with furrow irrigation systems. The large onion size was 181% higher for the SDI system than the furrow system in both sites. The colossal size yield was also higher. At one site colossal yield was 206% higher than furrow, while at another site furrow yielded no colossal onions and SDI had some production. It was concluded that drip irrigation systems more than double yields and increased onion size while using almost half of the water. This was due to SDI allowing for more frequent and smaller irrigation depths with higher irrigation efficiency than furrow irrigation systems.

1. Introduction

Texas is frequently affected by periods of drought, including the drought that started in 2011 and continued in 2012 and 2013, with 2012 being one of the driest years on record. These drought periods commonly cause water shortages and impose additional restrictions which reduce irrigated acreage, impacting the farming productivity and profitability. Under these circumstances, farmers often seek alternatives to increase their productivity and net return per unit of water applied by converting from furrow to drip irrigation systems and implementing irrigation scheduling strategies. Federal and state governments have implemented several programs that support this irrigation system conversion. However, many producers feel that the costs of employing these water saving technologies far exceed the benefit of increased vegetable yields and water savings. To reduce the economic risk of farming operations it is important to make sound decisions when selecting an irrigation method for a particular crop. Farmers that continue to use traditional furrow irrigation methods may benefit by using deficit irrigation [1] and shorter furrows [2] or may consider using SDI for vegetable crops in water limited regions if the productivity and profitability per unit of water increase with these systems. The SDI system is critical to secure uniform onion germination and to schedule irrigation under different irrigation strategies such as managing the onion crop with soil water stress or replacing onion evapotranspiration [3–5]. SDI may also facilitate the management and regulation of onion water stress deficits in semiarid regions of the world [6–8]. According to Camp [9], yields of horticultural crop irrigated with SDI were equal to or greater than those obtained for other irrigation systems in most cases. For cantaloupes, onions, and carrot grown in Arizona, crop yields were very similar for SDI and furrow irrigation systems [10]. Slightly higher yields have been observed for crops such as sweet corn and tomatoes which produced 12 and 20% greater yields when using SDI instead of furrow systems [11–13]. Cabbage and zucchini grown in Arizona had approximately 350% and 35% higher yields for SDI than furrow systems [14]. Alfalfa and cotton have also shown large gains with the adoption of SDI compared to furrow or flood irrigation [15]. The production of onions with the use of subsurface drip irrigation (SDI) may help increase yields and allow producers to sell their produce in early spring markets, justifying the use of SDI systems.

In Texas, where deficit irrigation is widely practiced and where many irrigated areas obtain their water supply from aquifers, it has been observed that SDI systems have been increasingly adopted especially for irrigating cotton. Presently, there are more than 170,972 acres of SDI and 81,569 of surface drip irrigation [16–18]. Similar trends have been observed in other regions of the world where water is very limited, indicating that drip systems are preferred over surface irrigation systems for selected crops such as cotton [19].

In Colorado, Halvorson et al. [20] obtained higher fresh onion yields, irrigation water use efficiency, and economic returns with SDI compared to furrow irrigation systems. Their study demonstrated that drip irrigation used at least 57% less water than the furrow system and its yields were 15% higher. However, SDI does not always result in higher yields and less water used than furrow systems; for example, in a New Mexico study, onion yields and irrigation use efficiencies between SDI and furrow irrigation were very similar [1]. In Al-Jalmal's study, furrow systems were irrigated using the concept of deficit irrigation in which high irrigation efficiencies were attained. In contrast, the surface drip irrigation system required leaching of salts to maintain low salt levels in the root zone which resulted in an excess of water applied and high deep percolation water losses. The contradictory results obtained in different locations point to the necessity to evaluate the adaptability of SDI in South Texas considering its weather conditions, rainfall patterns, water quality, and whether it is economically justifiable to make investments to adopt these systems. The overall objective of this study was to evaluate the effect of irrigation methods (SDI and furrow irrigation) on onion yield and water use.

2. Material and Methods

This study was conducted during the 2012-2013 fall-spring onion growing seasons in a commercial field located in Los Ebanos close to Rio Grande City, TX (longitude 26°15′9.62″N, latitude 98°33′W), and during 2013-2014 at the Texas A&M AgriLife Research Center located in Weslaco, TX (longitude 26″9′N, latitude 97″57′W). The soil at the commercial field was a Reynosa silty clay loam (35% clay, 45% silt, and 20% sand: fine-silty, mixed, active, hyperthermic Torrifluventic Haplustepts) and the soil at the research site was a Hidalgo sandy clay loam (22% clay, 18% silt, and 60% sand: fine-loamy, mixed, hyperthermic Typic Calciustolls). This region has a semiarid climate and the average annual rainfall is 558 mm of which only about 226 mm is received during the onion growing season, of which more than 60% is received during the first three months when the onion crop germinates and grows very slowly. Onions (*Allium cepa*; hybrid sweet sunrise, a short day, yellow hybrid sweet onion) were planted on November 8, 2012, at the commercial field and October 24, 2013 (Table 1), at the Weslaco research center. The onions were direct seeded 0.1 m apart in a bare soil with a Matermacc Planter in 1.02 m (40 in.) raised beds in four rows with 0.1 m distance between onion rows.

Plot length was 97.5 m, and there were four beds per plot for a total area per plot of 397 m^2 at the Weslaco site. Two rows were left unplanted between each plot as a buffer. Standard commercial practices for spring onion production were followed [21]. At the commercial field cv. Cougar (a short day, yellow hybrid sweet onion) was planted on November 8, 2012, on 1.02 m (40 in.) raised beds with the same planting configuration as the experimental station but with longer rows (178 m), resulting in a plot area of 726 m^2. Two unplanted rows were used as buffer between replicated plots.

Fertilizer was applied through the drip system in four or five split applications each year (Table 1) at rates of 200 kg ha^{-1} N, 120 kg ha^{-1} P, and 65 kg ha^{-1} K at the commercial field and of 60 kg ha^{-1} N, 60 kg ha^{-1} P, and 20 kg ha^{-1} K at the Weslaco research station. The fertilizer was injected with the subsurface drip irrigation system and buried into the soil with the furrow irrigation system. Preplant fertilizer was buried into the soil at the commercial field. The drip and furrow irrigation systems received the same amount of fertilizer at each site.

This study was conducted as a split-plot design for both sites with two treatments (SDI and furrow irrigation) and three replications per treatment. The Rio Grande River was the source of irrigation water and had an average electrical conductivity of 0.13 S m^{-1} and was filtered using sand media filters at both locations for the SDI systems. There is no risk of salinization considering that the soils are well drained and there is enough leaching in the fall season due to heavy rains produced during the hurricane season. The drip tubes at the commercial field had nominal discharge ratings of 1.02 L h^{-1} per emitter and 30 cm emitter spacing (T-Systems International, Inc., San Diego, CA) and 0.93 L h^{-1} per emitter with 30 cm emitter spacing at the Weslaco site (Netafim USA, Fresno, Cal.). One drip-line was buried at approximately 0.05 m depth and placed beneath each planted row.

Irrigation at the commercial field site was done by a cooperating commercial grower and was based on empirical methods such as the feel and appearance method when soil moisture reached 25% depletion within the top foot depth. A water balance approach was used for irrigation scheduling at the Weslaco site (http://southtexasweather.tamu.edu/). Withdrawals included calculating crop evapotranspiration (ETc) based on Pennman-Monteith reference evapotranspiration and the crop coefficient curves for each irrigation treatment [22]. The water balance started by determining the percent

Table 1: Production operations and crop growth parameters for the two seasons this study was conducted.

Operation	2012-2013 Los Ebanos SDI system	2012-2013 Los Ebanos furrow system	2013-2014 Weslaco SDI system	2013-2014 Weslaco furrow system
Planting	November 8	November 8	October 24	October 24
First in-season irrigation	November 4	November 4	October 28	October 28
Preplant fertilization	October 1	October 1	None	None
1st fertilizer application	November 22	November 22	October 26	October 26
2nd fertilizer application	December 22	December 22	January 17	January 17
3rd fertilizer	January 28	January 2	February 5	January 28
4th fertilizer	February 15	February 15	February 10	February 10
5th fertilizer	March 8	None	February 21	None
Last irrigation	April 5	April 5	April 7	April 7
Harvest	April 22	April 22	April 25	April 25
Rainfall growing season	140	140	294	294
Length of growing season (days)[a]	158	158	156	156

[a]From planting until harvest.

of available water at the beginning of the season and this was considered the initial water content. The irrigation requirement was calculated on a daily basis with the following equation: Dc = SWi − ETc + P + Irr + U − SRO − DP, where Dc is the soil water deficit (net irrigation requirement) in the root zone on the current day, SWi is the soil water content on the previous day, ETc is the crop evapotranspiration rate for the current day, P is the gross precipitation for the current day, Irr is the net irrigation amount infiltrated into the soil for the current day, U is upflux of shallow ground water into the root zone, SRO is surface runoff, and DP is deep percolation or drainage. In this experiment U was assumed to be zero because the water table was significantly deeper than the root system, and SRO was zero. Irrigation was applied whenever Dc was greater than the allowable depletion. The allowable depletion was considered 30% of the available water. Dc was set equal to zero whenever Dc became negative. This occurred if precipitation and/or irrigation exceeded ETc and meant that water added to the root zone already exceeded field capacity within the plant root zone. This excess of water in the root zone was assumed to be lost through DP. The program is able to calculate the irrigation time when the area, the flow rate, and irrigation efficiency are provided. Drip irrigation plots were irrigated approximately twice per week by replacing crop ET minus rainfall. The furrow irrigation treatments were irrigated whenever a soil water depletion of 64 mm was reached in the top 75 cm of soil as calculated by the water balance. An irrigation efficiency of 100% was assumed for both irrigation systems and no leaching requirements were considered in the calculations. Irrigation efficiency was determined by dividing seasonal ETc by the seasonal depth of water applied (I) including rainfall for each irrigation method. 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. Soil moisture sensors (Watermark Soil Moisture Sensors, Irrometer, Co., Riverside, CA) were placed at 30 cm below the soil surface and 5 cm from the drip tape to monitor irrigation. One watermark sensor was installed in one of the replications of the furrow and SDI treatments at the commercial and Weslaco field sites. The strategy for the furrow irrigation system was to advance the water as fast as possible to the lower end of the furrow and to complete irrigation in the estimated time with a given flow rate to apply the estimated irrigation depth. The furrows were blocked at the end and no runoff was produced.

The amount of water applied to each plot through irrigation was recorded with totalizing water meters connected to the irrigation system. One flow meter of 15 mm was installed per replication for the SDI irrigation system, and one flow meter of 200 mm was used for all the furrow irrigated plots in both locations. Approximately the same amount of water was applied to the different SDI replications during each irrigation event at both sites.

Crop single coefficient was estimated using the crop coefficients for seed onions (0.7 for initial, 1.05 for mid, and 0.8 for end) as suggested by Allen et al. [22]. The lengths of the four growth stages were 20 d for initial, 30 d for development, 100 d for mid, and 10 d for the end stage. The lengths for the four growth stages were adjusted according to visual observations. Onions were harvested on April 22, 2013, at the commercial field site and on April 25, 2014, at the Weslaco field site and classified by size as small (<5 cm), medium (5–7.5 cm), large (7.5–10 cm), and colossal (>10 cm) and then weighed. Additionally, the quality parameters, pungency, measured by pyruvic acid concentration, and soluble solids concentration (SSC) were determined using the method of Randle and Bussard [23]. Data were analyzed with a general linear model (GLM) procedure using SAS (Cary, NC). Duncan's multiple

Table 2: Effect of irrigation method on average yield parameters (Mg ha^{-1}) as classified by size classes, onion quality, and gross return at the Los Ebanos and at the Weslaco research station field sites (2012–2014).

Spacing (cm)	Size class (Mg ha^{-1}) Small	Medium	Large	Colossal	Total	Pyruvic acid (μmol mL^{-1})	Soluble solid concentration (%)	Gross return \$ ha^{-1}
					Los Ebanos (2012-2013)			
SDI	0.6	14.0	44.1	4.3	62.9	4.3	8.3	25,042
Furrow	0.6	12.1	14.4	1.6	28.7	4.4	8.8	11,372
$P > F$	NS	NS	*	*	*	NS	*	*
					Weslaco research station (2013-2014)			
SDI	3.7	24.4	10.7	0.6	39.3	4.4	6.0	15,994
Furrow	4.1	12.3	3.8	0	20.2	4.3	6.2	7,855
$P > F$	NS	*	*	*	*	NS	NS	*

*Significant at the 0.05 level.

Table 3: Number of irrigations, irrigation applied, onion evapotranspiration, and irrigation use efficiency for SDI and furrow irrigation systems (2012–2014), Weslaco, TX.

Irrigation system	Number of irrigations	Irrigation applied (mm)	Onion ET (cm)	Rainfall (mm)	Irrigation efficiency (%)	Irrigation use efficiency (kg m^{-3})
			Los Ebanos (2012-2013)			
SDI	17	359	442	140	88.5	17.5
Furrow	6	677	442	140	54.1	4.2
			Weslaco research station (2013-2014)			
SDI	14	211	411	294	81.4	25.2
Furrow	5	318	411	294	67.1	6.5

range test ($P = 0.05$) was used for mean comparisons within each study site.

3. Results

3.1. Irrigation Water Use. Total rainfall amounts for the two growing seasons were 140 mm in 2012-2013 and 294 mm in 2013-2014. In the 2012-2013 growing season, more than 65% of the rainfall was received within the first 12 weeks between October and December, and around 72% was received in 2013-2014 in the same period. The rainfall was insufficient to meet the water demands of the crop in both years which were 409 and 411 mm, for 2012-2013 and 2013-2014, respectively (Table 1). The highest water demands occurred between January and April. Less rainfall, received during 2012-2013, required more irrigation to be applied than in the 2013-2014 growing season (Table 1).

The average furrow length for this region is approximately 365 m, but vegetables producers have reduced the furrow length to 200 m to conserve water and improve irrigation efficiencies. The experiment conducted in the commercial field had a furrow length of 178 m and the average irrigation depth applied with furrow systems was 112 mm with a total of six irrigation applications. The average irrigation depth of 112 mm is excessive for shallow root systems and this may explain the low irrigation efficiencies for furrow systems (67.1%). A common problem is the need to decide whether to reduce the number of irrigations or to reduce the irrigated area when water is limited in order to concentrate the available water for vegetable irrigation. Farmers that have a SDI system can apply small and frequent irrigations but they have to pump the water directly from the river, have a reservoir on their farm, or be located near a canal where water can be pumped continuously. At the commercial field that was located close to the Rio Grande River, more frequent irrigations with smaller irrigation depths were possible with the SDI system in which an average irrigation depth of 21.1 mm per irrigation was applied resulting in a high irrigation efficiency of 88.5% (Table 3). The farmer irrigated almost every week from February to harvest time with the SDI system. This resulted in a higher irrigation frequency with the SDI system of 17 applications compared to 6 for the furrow system.

In the Weslaco field site, the furrow length was 100 m long. A total of 14 irrigations were applied with SDI and 5 irrigations with the furrow system at the Weslaco field site (Table 3). With the furrow system, it was difficult to apply small irrigation depths. The average irrigation depth applied with the furrow irrigation systems was 64 mm resulting in lower irrigation efficiency for the furrow system (67.1%) compared to the SDI system (81.4%).

3.2. Onion Yield and Quality. Total onion yields were significantly different for SDI and furrow irrigation in both locations (Table 2). The onion yields were approximately 119% higher for the SDI system than the furrow irrigation systems at the commercial (Table 2) field site. A similar trend was observed at the Weslaco field site where SDI resulted in 95% higher onion yields than the furrow systems (Table 2). The higher onion yields could be produced by the higher frequency of irrigation of the SDI systems. The onion yields obtained by Hatterman-Valenti and Hendrickson [24] for sprinkler irrigated onions ranged between 51.9 and 56.9 Mg ha^{-1}, and the yields obtained by Shock et al. [7] ranged from 43.1 to 49.8 Mg ha^{-1} for SDI irrigated onions. In this study the average onion yields ranged from 20.2 (furrow irrigation) to 62.9 Mg ha^{-1} (SDI). When onion yields were sorted by size, the irrigation system did not have a significant effect on the yields of small and medium classes at the commercial field site, but they had an effect on the yield of medium onions at the Weslaco site. At the Weslaco field site, the average medium onion yield (24.4 Mg ha^{-1}) was higher for the SDI system than the furrow system (12.3 Mg ha^{-1}), and the yield for the average small size onions was statistically similar. Large and colossal onions generally have greater market values than small and medium onions. In both locations the average large and colossal onion yields were higher for the SDI system than the furrow system. These differences were more noticeable at the commercial field site where the average large and colossal onion sizes from the SDI system were 206% and 168% larger than those from the furrow irrigation system. At the Weslaco field site, the average large onions were 182% larger for the SDI system than the furrow system. The average colossal onion yield was 0.6 Mg ha^{-1} for the SDI system and zero for the furrow irrigation system. The higher large and colossal onions of the SDI systems compared to the furrow systems in both locations could be due to the higher irrigation efficiencies and higher irrigation frequencies.

Onion bulb pungency (pyruvic acid content), an indicator of the hotness of the onion, had an average range from 4.3 to 4.4 μmol mL^{-1} juice in both locations. There was no distinctive trend due to the treatments applied in this study indicating that there was no relationship between pungency level and irrigation systems type in both locations (Table 2). The soluble solids concentration (SSC), which is an indicator of the sweetness of the onion, had an average range from 6.0 to 8.8%. Higher brix values were observed with the furrow system at the commercial field site, but no differences were observed at the Weslaco field site.

3.3. Irrigation Use Efficiency. The irrigation use efficiency is calculated by dividing the total onion yield by the irrigation water applied. At the commercial field site for the 2012-2013 season irrigation use efficiency was 17.5 kg m^{-3} for the SDI system and 4.2 kg m^{-3} for the furrow system. At the Weslaco field site, irrigation was scheduled with a water balance method and this may be the reason why higher irrigation efficiencies were observed at the Weslaco field site than at the commercial field site. The irrigation use efficiency was higher for the SDI system with 25.2 kg m^{-3} and only 6.5 kg m^{-3} for the furrow system. In previous studies, Enciso et al. [3, 18] obtained water use efficiencies for drip irrigated onions (defined as the relation between total yield and evapotranspiration, not the gross irrigation depth) that ranged from 11.7 to 13.7 kg m^{-3}. Al-Jamal et al. [1] observed almost similar irrigation use efficiencies in New Mexico for surface drip irrigated onions (4.7 kg m^{-3}) and surface irrigation managed under deficit irrigation where less irrigation was applied (5.9 kg m^{-3}), and they explained the drip irrigation system over applied water for leaching salts out of the root system. The locations of this experiment received rains during September to November that leach the salts and prevent salinization with drip irrigation systems. In another experiment, Ellis et al. [25] obtained that irrigation use efficiencies of 10.4 kg m^{-3} on a plot were small and frequent irrigations were applied with surface irrigation systems in the experimental site which are difficult to attain at large commercial fields.

4. Conclusions

The SDI system allowed more frequent application at smaller irrigation depths than the furrow irrigation system. The irrigation efficiencies were also higher for the SDI system (81–88%) than the furrow system (54–67%). The irrigation use efficiency obtained with the SDI system ranged from 17.5 to 25.2 kg m^{-3} and from 4.2 kg m^{-3} to 6.2 for the furrow system in both locations. It was concluded that drip irrigation systems more than double yields and increased onion size while using at least 44% less water. This was due to SDI system allowing for more frequent application and smaller irrigation depths with higher irrigation efficiency than furrow irrigation systems. Additionally, we can point out that heavy rains during the fall season reduce the potential for salinization.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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