Irrigating Onions with Subsurface Drip Irrigation under Different Stress Levels

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Abstract

Irrigation technologies that conserve water are necessary to assure the economic and environmental sustainability of commercial agriculture. This study was conducted in the lower Rio Grande Valley in Texas to evaluate yield and quality of subsurface drip irrigated onions using different scheduling strategies and water stress levels. One strategy consisted on initiating irrigation when the reading of a watermark sensor reached 20 kPa (optimum), 30 kPa and 50kPa. The second strategy was to replace 100%, 75%, and 50% of crop evapotranspiration (ETc) weekly. Even though yields were very similar for the 100% and 75% ET treatments, about 85 mm of water could be conserved by slightly stressing the crop. The soil moisture based method permitted better control of the irrigation because onion yields for the 20 and 30 kPa soil moisture treatments were very similar to the 100% ET based treatment, and 104 and 132 mm of water could be conserved with these treatments without sacrificing yields. This suggests that crop coefficients may over estimated ET requirements. Onions in the large size class were increased for the 20 kPa, 30 kPa, and 100% ET treatments. There was no effect of irrigation scheduling treatment or irrigation level on the small, medium and colossal size classes. There was no difference between the irrigation scheduling treatments on pungency levels. Although soluble solids concentrations were different between treatments, there was not a clear trend that indicated higher soluble solids for any irrigation method

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treatment or water level. Productivity based on the amount of water applied ranged from 10.7 to 12.9 kg/m^3, and highest water use efficiencies were observed for the soil moisture based methods and for the 50% ET method. The 50% ET method also resulted in the lower onion yields.

Introduction

Significant water savings can be achieved for a variety of crops by deliberately stressing the crop to a certain profitable level. This management technique is generally known as deficit irrigation. To manage plant water stress it is necessary to carefully schedule irrigation which consists of determining the amount and timing of irrigation applications (Martin et al., 1990). There are two main methods to schedule irrigation: 1) by replacing crop evapotranspiration (ETc) fractions according to a soil water balance, or 2) by triggering irrigation according to water content status of the soil, storage capacity, rooting depth and allowable depletion (Hanson et al., 2000). The first method requires the use of a weather station and a computer program to follow the soil water balance and the second method consists of monitoring soil water status either by direct sampling or using soil moisture sensors. One of the difficulties of irrigation scheduling using ETc is that local crop coefficients are needed, and these vary according to crop varieties, plant densities, row configurations and planting dates (Enciso et al., 2007). Another problem is that soil variability may influence water retention and consequently the allowable depletion to trigger irrigation. Soil water status can be monitored and measured directly with sensors such as watermark sensors, tensiometers, and capacitance probes (Enciso, 2006). The choice of sensor will depend on soil water range to be measured, cost effectiveness, easiness to maintain, and the sensor's performance reliability. According to Muñoz-Carpena et al., (2005) granular matrix (GM) sensors and dielectric sensors like time domain reflectometry (TDR) require less field maintenance than tensiometers and have a greater potential for commercial adoption. The use of soil moisture data from GM sensors as a decision making tool for irrigation is convenient and inexpensive. However, the sensor reading is highly dependent on type of soil, climate, plant root zone depth, soil salinity, and soil temperature. Sensor calibration, installation and placement must also be taken into consideration.

Irrigation scheduling with watermark sensors using different ranges of water potentials have been studied for onions by Shock et al. 2000. They studied the yield response to five soil water potentials (-10, -20, -30, -50 and -70 KPa) when the sensors were installed at 200 mm soil depth. Onion profits and yields were highest with higher water application levels. Bekele and Tilahun (2007) found no differences between irrigation replacing of 25%, 50%, 75% ET, and optimal irrigation defined as 100% ET when stresses were applied in the first and last part of the onion growing season. They also reported that if the deficits persist during all the onion growing season or during the second and third of four growing stages, the yields were significantly different between the stress and optimal treatments. The water-saving strategy of reducing irrigation rates at predetermined developmental stages where deficits would not severely impact productivity is called regulated deficit irrigation (RDI) (Kirda, 2002). The net effect is an increase in crop water use efficiency especially when the impact on yield is not significant. Considering farmer's preference to use pan evaporation, Kumar et. al., (2007) studied the influence of four ratios (0.6, 0.8, 1.0 and 1.2) between irrigation water and cumulative evaporation on onion yield. The best yields were observed for the 1.0 and 1.2 ratios but the highest irrigation water use efficiency at the 0.8 ratio and declined at higher irrigation levels. Although the possibility of achieving optimum yields under RDI practices has been demonstrated for many crops (Bekele and Tilahun, 2007; Kirda, 2002; Thompson et al., 2007), the potential water savings from scheduling RDI using ET-based data versus soil moisture monitoring has not been evaluated.

The objective of this study was to evaluate the water-saving potential of ET-based versus soil moisture monitoring approaches of managing RDI in onion production.

Material and Methods

This study was conducted during the fall-spring onion growing seasons (2005-2006 and 2006-2007) in a commercial-type field in Weslaco, S. Texas (longitude 26" 9' N, latitude 97" 57' W; Hidalgo sandy clay loam soil). This region has a semiarid climate and the average annual rainfall is 558 mm. The onion variety, 'Cougar' (hybrid, yellow short day sweet onion) was direct-seeded on 11 Nov 2005, and on 30 Oct 2006 (Table 1) on 1.02 m (40 inch) wide raised beds in double rows and onion plants were spaced along each row at 254 mm (10 inches) apart. Standard commercial practices for spring onion production were followed (Danielo and Anciso, 2004). Treatments consisted of two irrigation scheduling approaches (ET-based or direct soil moisture monitoring based) and three irrigation levels within each approach. The ET-based irrigation levels were (100% ET or optimum, 75% and 50% ET) whereas the soil moisture monitoring irrigation levels were 20 kPa (or optimum), 30 kPa and 50 kPa. These treatments were randomly assigned to three-row plots replicated tree times. Data were collected only from the center experimental row. The treatments were set up to replace ET fractions (100, 75 and 50%) or by initiating irrigation based on the pre-determined soil water status (20, 30 or 50 kPa). All treatments were irrigated with a subsurface drip irrigation system with the drip tape (model Typhoon 875-10 mil-F; 0.908 L/h flow rate; Netafim) installed at 150 mm below the soil surface and emitters spaced every 300 mm. The irrigation water source was the Rio Grande river, which was filtered with a sand media filter.

Granular matrix sensors (Watermark soil moisture sensor, Irrometer, Co., Riverside, CA) were installed at 300 mm below the soil surface to monitor soil moisture changes. One watermark sensor was installed per treatment. For the ET-based treatments, irrigations were applied approximately twice per week depending on rainfall inputs and the ETc fraction treatments; for the soil moisture monitoring treatments, irrigation was triggered whenever the soil moisture readings reached the set points (20, 30 or 50 kPa) for each treatment. The amount of water applied to each plot was recorded with totalizing water meters connected to the irrigation system with one flow meter installed plot. Crop water use was estimated as ETc using weather data and the Penman-Monteith method (Walter et al., 2000) with FAO crop coefficients for seed onions (0.7 for initial, 1.05 for mid, and 0.8 for end season) as suggested by Allen et al. (1998). The lengths of the four growth stages were 20 d for initial, 35 d for development, 80 d for mid and 23 d for the end stage in 2006 and 21 d in 2007. These durations were adjusted based on visible developmental changes. Onion were harvested on 19 Apr 2006 and on 4 Apr 2007 and classified by size as small (<50 mm diameter), medium (50 - 75 mm), large (75 - 100 mm), or colossal (>100 mm). The weight for each size class was recorded and total yields computed. Onion bulb quality parameters included pungency which was measured as the pyruvic acid concentration, and soluble solids concentration (brix) were determined using the method of Randle and Bussard (1993). Data were analyzed with a general linear model (GLM) procedure of SAS (Cary, NC). Least square differences test (P = 0.05) was used to for mean comparisons within each season.

Results and Discussion

Total rainfall amounts for the two growing seasons were 81 mm and 133 mm in 2006 and 2007 respectively. In both years, more than 70% of the total rainfall was received within the first 12 weeks of the study, between October and March. Hence, it was difficult to sustain the desired dry soil conditions in 50 kPa and 50% ET treatments (Fig 1). Despite these inputs, the top soil tended to dry out faster than the lower soil profile thanks to high air temperatures and vapor pressure deficits, thus requiring additional small irrigation inputs to ensure adequate stand establishment. Cumulative crop evapotranspiration amounts for 2006 and 2007 were 470 mm and 340 mm respectively. Less rainfall received and higher crop water demand during 2006, resulted in bigger irrigation amounts applied than in 2007.

The amount of water applied in each scheduling approach was significantly different in each of the study years (P = 0.05). In 2006, the total irrigation amounts were 430 mm, 350 mm and 270 mm for the 100%, 75% and 50% ET treatments respectively. Over 80% of these amounts were applied late in the crop during the bulb development and maturing stages of growth (Feb-May). Compared to the 100% ET treatment, 80 mm of water was saved by scheduling irrigation at 75%ET. Similarly, the water savings from the 50% ET approach was 160 mm compared to the 100% ET. In 2007, the corresponding water savings were 40 mm for the 75% ET, and 80 mm for the 50% ET treatments.

In 2006, the total irrigation amounts were 330 mm, 300 mm and 190 mm for the 20 kPa, 30 kPa and 50 kPa treatments respectively. Over 80% of these amounts were applied during the bulb development and maturing stages of growth (Feb-May). Compared to the well-watered 20 kPa treatment, 30 mm and 140 mm of water were saved by scheduling irrigation at 30 kPa and 50 kPa respectively. In 2007, the savings were 50 mm for the 20 kPa and 90 mm for the 50 kPa treatments.

Yield and irrigation water use.

There was no interaction between treatment and year, therefore onion yields from the two years of the experiment were combined (Table 3). There was no significant difference in total yield between the 20 kPa, 30 kPa, 100% ET and 75% ET treatments. Lower yields were observed for the 50 kPa and 50% ET treatments. Even though more irrigation water was applied with the 100% ET treatment (434 mm) than with the 75% ET treatment (349 mm), there were no significant differences in yield between these treatments, indicating that 85 mm of water can be conserved by slightly stressing the crop (Table 3). When scheduling irrigating with soil water sensors about 28 mm can be conserved by slightly increasing the stress from 20 to 30 kPa without sacrificing onions yields. If the soil water deficit is increased further to 50 kPa onion yields are decreased significantly. More water was applied while scheduling irrigation based on ET than when using soil water sensors. The reason that although more water was applied with the ET method and that yields were not different between ET and soil moisture based, could be that the crop coefficients could be overestimating ET, and the soil moisture sensors may be more accurately matching water demand with water supply.

Large and colossal size onions are easy to market according to farmers' perceptions. When onion yields were sorted by size into small, medium, large, and colossal size classes, irrigation method and water level did not significantly affect the small, medium and colossal onion sizes. In the large size class, higher yields were observed for the 20 kPa, 30 kPa and 100% ET treatments, and lower yields were observed for the 50 kPa and 50% ET treatments. This is an indication that larger onion sizes can be produced when more water is applied, and the water stress affects the size of the onions.

Onion bulb pungency (pyruvic acid content), an indicator of the hotness of the onions, ranged from 3.9 to 4.4. There was no distinctive trend due to the treatments applied in this experiment indicating a relationship between pungency level and water stress (Table 4). The soluble solids concentration (brix), an indicator of the sweetness of the onion, in this experiment ranged from 7.1 to 7.8. Higher brix was observed with the 20 kPa treatment, and there was no significant difference between this treatment and the ET based treatments. Although higher brix values were observed with the 20 kPa treatments there is no a clear indication to relate brix to water levels or irrigation scheduling method. There are not any reported values on the literature that indicated a relation between onion quality parameters such as pungency or brix content and water stress.

Highest was use efficiencies were observed for the soil moisture based scheduling method and for the 50% ET method. The lower water use efficiency was observed for the 100% ET treatment. The lower productivity of the 100% ET treatment compared to the 20 and 30 kPa soil moisture based treatments, even though similar yields were obtained, is an indication that water was over-applied by the ET scheduling method.

Onion Yield and Quality

Productivity per unit of water applied

Productivity per unit of water applied estimated as the ratio between onion yield and irrigation plus rainfall received ranged from 10.7 to 12.9 kg/m^3 (Table 2). The highest water use efficiencies were observed for the soil moisture based methods and for the 50% ET method. The 50% ET method also resulted in the lower onion yields. Some other studies have reported water use efficiency for SDI onions from 11.7 to 13.7 kg/m^3 in the Lower Rio Grande Valley of Texas (Enciso et al., 2007). Bekele and Tilahun (2007) obtained water use efficiencies that ranged from 9 to 9.7 kg/m^3 in well water onions that received 100% ET or onions that received 75% of ET only in the initial or final stage of onion growth, but 100% in the rest of the growing season.

Summary and Conclusions

Slightly stressing the crop can be used as a water conservation strategy for onions. About 85 mm of water could be conserved by slightly stressing the crop from 100% to 75% ET without affecting yield or onion quality indicators such as pungency and brix content. The soil moisture based methods at the 20 and 30 kPa permitted a better control of irrigation than the 100% ET based treatments, because 104 and 132 mm more water could be conserved with this method without sacrificing onion yield or quality. This suggest than that onion crop coefficients may over estimated ET requirements.

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Table 1. Agronomic and irrigation data for two irrigation seasons.

Variable	2005-06	2006-07
Planting date	11-Nov-05	30-Oct-06
Last irrigation	17-Apr-06	25-Mar-06
Harvest date	19-Apr 06	04-Apr 07
First fertilizer application	12-Dec-05	04-Dec-06
Amount applied during first application	33 kg/ha N	28 kg/ha N
Second fertilizer application	02-Jan-05	31-Jan-07
Amount applied during second application	33 kg/ha N	117 kg/ha N 26 kg of P_2O_5 34 kg of K_2O
Third fertilizer application	March 13-06	-----------
Amount applied during third application	33 kg/ha N	------------
Length of growing season (days)	158	156
Estimated Onion ETc (mm)		
Irrigation applied after planting to germinate the seed (mm)	100	84
In-season irrigation (mm)	434	260
Growing season precipitation (mm)	81	133

Table 2. Rainfall, irrigated applied and water use efficiencies for two irrigation scheduling methods and 6 irrigation water levels.

Irrigation Method	Irrigation Level	Irrigation applied 2006 (mm)	Irrigation applied 2007 (mm)	Average Water Use Efficiency (kg/m^3)
ET	50%	270	180	12.6 ab
	75%	350	220	11.3 bc
	100%	430	260	10.7 c
CB	20cb	330	280	11.6 abc
	30cb	300	230	12.8 ab
	50cb	190	190	12.9 a
P > F				0.0023
LSD				1.5

Means in each column followed by the same letter are not significantly different according to least significant difference (P = 0.05). Where no letters follow means, no significant differences were found.

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Table 3. Effect of two irrigation scheduling methods and 6 irrigation levels on sweet onion (var. Cougar) yield parameters as classified by size classes during two years of the study (2006-2007).

		Size Class				
Irrigation Method	Irrigation Level	Small	Med	Large	Collosal s	Total Yld
		---------------------------- T/ha ---------------------------				
ET	50%	1.2	27.7	7.5 c	0.0	36.4 b
	75%	1.7	27.0	9.9 bc	0.5	39.2 ab
	100%	1.0	25.9	15.3 ab	0.3	42.5 a
Soil moisture	20kPa	0.6	23.5	18.8 a	0.7	43.6 a
	30kPa	0.8	24.6	16.4 a	0.3	42.2 a
	50kPa	1.2	26.5	6.6 c	0.0	34.4 b
P > F		ns	ns	0.0002	ns	0.0018
LSD				5.7		4.8

Means in each column followed by the same letter are not significantly different according to least significant difference (P = 0.05). Where no letters follow means, no significant differences were found.

Table 4. Effect of two irrigation scheduling methods and 6 irrigation levels on sweet onion (var. Cougar) quality parameters during two years of the study.

Irrigation Method	Irrigation Level	Pungency	SSC
ET	50%	4.1	7.2 ab
	75%	3.9	7.3 ab
	100%	4.2	7.2 ab
Soil moisture	20kPa	4.1	7.8 a
	30kPa	4.1	7.1 b
	50kPa	4.4	7.1 b
P > F		ns	0.0438
LSD			0.6

Means in each column followed by the same letter are not significantly different according to least significant difference (P = 0.05). Where no letters follow means, no significant differences were found.

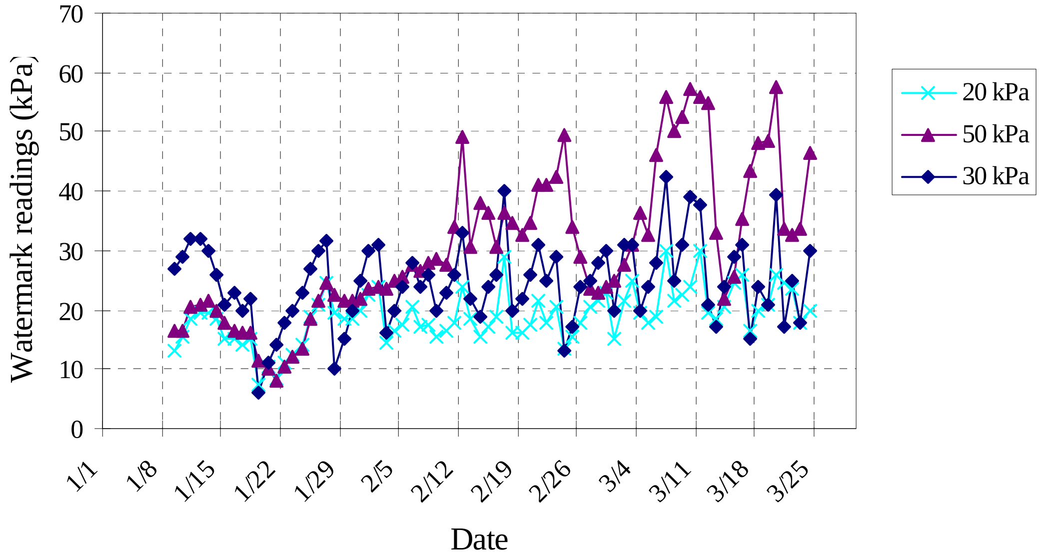

Fig. 1 Average soil moisture readings on the 20, 30 and 50kPa treatments on SDI onions, Weslaco,TX. 2006