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Onion yield and quality response to two irrigation scheduling strategies

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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 Rio Grande Valley in Texas to evaluate yield and quality of subsurface drip irrigated onions (*Allium cepa* L.) using different scheduling strategies and water stress levels. One strategy consisted of initiating irrigation when the reading of a granular matrix sensors (Watermark®[1] soil moisture sensor, Irrometer, Co., Riverside, CA) installed at 0.2 m depth reached −20 kPa (optimum), −30 kPa and −50 kPa. The second strategy was to replace 100%, 75%, and 50% of crop evapotranspiration (ETc) weekly. Higher total yields, and jumbo onion size yields were obtained when the soil moisture was kept above −30 kPa. Yields were not affected when water applications were reduced from 100% to 75% ETc and from −20 to −30 kPa. The ETc strategies of 100%, and 75% ETc resulted in similar water usage to the soil moisture monitoring strategies of initiating irrigation at −20 and −30 kPa. Total yields dropped significantly when soil water stress increased below −50 kPa. For the ET based strategy yields also dropped with the 50% ETc treatment. Onion bulb pungency and brix were unaffected by water level.

1. 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 and allowable depletion levels (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 et al., 2006; Thompson et al., 2007). 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 determined the yield response to five soil water potentials (−10, −20, −30, −50 and −70 kPa) when a single sensor was installed at the 200 mm soil depth. Onion profits and yields were highest with higher water application levels. Similar onion results were observed by Kumar et al. (2007) when irrigation was scheduled with pan evaporation. 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; Mpelasoka et al., 2001). Some scientists have found bigger yield differences when the onion crop is stressed at certain growing stages such as the

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study of Martin de Santa Olalla et al. (2004) who showed that inducing water deficits at the bulbification and ripening stages lead to significant differences on yields. Bekele and Tilahun (2007) reported that if the water deficits persist during the whole onion growing season or during the second and third of four growing stages, yields can decrease significantly with the 25%, 50%, and 75% ET replacement compared with the 100% ET replacement. Pelter et al. (2004) found that yields are affected when water stress is imposed at any growth stage, but onion yields are reduced more when stress occurs at the 5-leaf, 7-leaf, and 3- and 7-leaf stages. Onion quality was also reduced 40%, 32%, and 18% when soil-water stressed was imposed at 3- and 7-leaf, 3-leaf and 5-leaf stages respectively. Few studies have attempted to compare the impact of different irrigation scheduling strategies for onion production by size and onion quality. Kruse et al. (1987) evaluated yield and water used while scheduling irrigation with Bellani atmometers and estimated evaporation with meteorological data. Mermoud et al. (2005) compared empirical farmer practices with water balance techniques using different irrigation frequencies. They obtained increased yields and better irrigation efficiency when field water balance irrigation was used in combination with an irrigation frequency of twice per week.

Studies to evaluate and compare different irrigation scheduling strategies are necessary to provide farmers options to manage their irrigation systems according to their preferences and particular situation. The objective of this study was to determine water-saving potential, yield and onion quality parameters (brix and pyruvic acid) responses for ET based and soil moisture based irrigation strategies.

2. Materials and methods

This study was conducted during the fall-spring onion growing seasons (2005–06 and 2006–07) in a commercial-type field in the Lower Rio Grande Valley of Texas (longitude 26″9′N, latitude 97″57′W). The soil at the site was a sandy clay loam (fine-loamy, mixed, hyperthermic Typic Calciustolls). This region has a semiarid climate and the average annual rainfall is 558 mm.

The study sites were prepared in 1.02 m (40 in.) wide raised beds. Subsurface drip irrigation was installed in the center of each bed using drip tape (Netafim®: model Typhoon 875-10 mil-F; 0.908 L h^{-1} flow rate) installed at 0.15 m below the soil surface and emitters spaced every 0.3 m. The onion variety 'Cougar' (hybrid yellow short day sweet onion) was direct-seeded (Table 1) in double-rows with the distance between onion rows of 0.254 m and seeds were planted 0.1 m apart in the same row. Despite some rainfall received at the beginning of the season, some additional water were applied to the entire study area (100 mm in 2005, 84 mm in 2006) to ensure adequate stand establishment. Fertilizer was applied through the drip system in two or three split applications each year (Table 1) at rates of 100 kg N/ha in 2005–06 and 145 kg N, 26 kg P_2O_5, and 34 kg K_2O per ha in 2006–07. Additional small irrigation amounts were applied to all treatments to fertilize the crops through the irrigation system in December and January. Standard commercial practices for spring onion production were followed (Dainello and Anciso, 2004).

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

Operation	2005–06	2006–07
Planting	11 November 2005	30 October 2006
1st fertilizer application	12 December 2005	4 December 2006
2nd fertilizer application	2 January 2006	31 January 2007
3rd fertilizer application	13 March 2006	–
Last irrigation	17 April 2006	25 March 2007
Harvest	19 April 2006	4 April 2007
Length of growing season (days)	158	156

Table 2
Irrigation applied for two irrigation scheduling methods and three irrigation water levels within each method.

Irrigation method	Irrigation level	Irrigation applied (mm)	
		2006	2007
ET	100%	389	260
	75%	368	220
	50%	286	180
Soil moisture	−20 kPa	348	280
	−30 kPa	321	230
	−50 kPa	211	190

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 (optimum), 75% and 50% ET, and the soil moisture monitoring irrigation levels were −20 kPa (optimum), −30 kPa and −50 kPa. A completely randomized block design was used in plots of four rows wide by 30 m in length, and was replicated three times. Small applications of variable amounts of water were applied per irrigation, to leave some storage space in the soil to hold possible rainfall events. The irrigation water source was the Rio Grande river, which was filtered with a sand media filter.

Granular matrix sensors (GMS; Watermark® soil water sensors, Irrometer Co., Riverside, CA) were installed at 0.2 m below the soil surface to monitor soil moisture changes since onions have shallower root systems and following the recommendations of Shock et al. (2000). One Watermark® sensor was installed in each plot. Irrigations were applied weekly depending on rainfall inputs for the ETc fraction treatments; and for the soil moisture monitoring treatments irrigation was applied weekly whenever the average soil moisture readings of three replications reached the set points (−20, −30 or −50 kPa) for each treatment. Watermark sensors were read daily. The amount of water applied to each plot was recorded with totalizing water meters connected to the irrigation system with one flow meter installed per plot (Table 2). Crop water use was estimated as ETc using weather data and the Penman–Monteith method (ASCE-EWRI Task Committee Report, January, 2005) and using FAO crop coefficients for onions (0.7 for initial, 1.05 for mid, and 0.75 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.

At maturity a section 3 m long was harvested from the middle rows in 2006 and two 3 m long sections were harvested in 2007, and classified by size as small (<50 mm diameter), medium (50–75 mm), jumbo (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 for Windows software (Copywright 2002–03, SAS Institute, Cary, NC). Least square differences test ($P = 0.05$) was used for mean comparisons within each season.

3. Results and discussion

3.1. Onion yield and quality

Onion yields combined over the two years of this study were not significantly different between the −20 kPa, −30 kPa, 100% ETc

Table 3
Effect of three irrigation levels on sweet onion (var. Cougar) yield parameters (t/ha) as classified by size classes during two years of the study (2006–07).

Irrigation strategy	Irrigation level	Size class			
		Med	Jumbo	Colossal	Total yld
2005–06					
ET	100%	21.0 a	16.7 ab	0.2	40.0 ab
	75%	14.8 b	12.2 ab	1.6	33.1 abc
	50%	19.2 a	11.0 b	0.0	32.1 bc
Soil moisture	20 kPa	18.7 a	19.5 ab	1.1	40.6 ab
	30 kPa	18.9 a	20.4 a	1.0	41.7 a
	50 kPa	21.4 a	2.1 c	0.0	25.6 c
P > *F*		0.0420	0.0087	ns	0.0490
LSD		3.9	8.8		13.7
2006–07					
ET	100%	28.3	14.7 ab	0.3	43.8 a
	75%	33.0	8.7 bc	0	42.2 ab
	50%	31.8	5.8 c	0	38.5 b
Soil moisture	20 kPa	25.9	18.4 a	0.5	45.1 a
	30 kPa	27.5	14.4 ab	0	42.5 ab
	50 kPa	29.0	8.9 bc	0	38.8 b
P > *F*	0.0033	ns	0.0043	ns	0.0314
LSD			6.5		4.5
Two year study					
ET	100%	25.9	15.3 ab	0.3	42.5 a
	75%	27.0	9.9 bc	0.5	39.2 ab
	50%	27.7	7.5 c	0	36.4 b
Soil moisture	20 kPa	23.5	18.8 a	0.7	43.6 a
	30 kPa	24.6	16.4 a	0.3	42.2 a
	50 kPa	26.5	6.6 c	0	34.4 b
P > *F*		ns	0.0002	ns	0.0092
LSD			5.7		5.9

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 three irrigation levels on sweet onion (var. Cougar) quality parameters for the two years of the study (2006–07).

Soil moisture irrigation strategy	Irrigation level	Quality parameter	
		Pyruvic acid (μmho/cm)	Brix (%)
2005–06			
ET	100%	2.97 b	8.1
	75%	3.13 ab	8.3
	50%	3.03 b	7.7
Soil moisture	20 kPa	3.06 b	9.2
	30 kPa	2.97 b	7.2
	50 kPa	3.43 a	7.6
P > *F*		0.0404	ns
LSD		0.30	
2006–07			
ET	100%	4.8	6.8 bc
	75%	4.4	6.8 c
	50%	4.6	7.0 ab
Soil moisture	20 kPa	4.7	7.1 a
	30 kPa	4.7	7.0 ab
	50 kPa	4.8	6.8 b
P > *F*		ns	0.0115
LSD			0.18
Two year study			
ET	100%	4.2	7.2
	75%	3.9	7.3
	50%	4.1	7.2
Soil moisture	20 kPa	4.1	7.8
	30 kPa	4.1	7.1
	50 kPa	4.4	7.1
P > *F*		ns	ns
LSD			

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.

and 75% ETc treatments (Table 3). Lower yields were observed for the −50 kPa and 50% ETc treatments. In 2006, even though numerically higher yield was observed with the 100% than with the 75% ETc treatments, they were not statistically different. Similar results were observed for these treatments in 2007, probably, because the 100% and 75% Etc treatments kept a water level above −30 kPa for most days of the season (Fig. 1) and crop yields were not affected. However, yields dropped significantly with the 50% Etc treatments in both years. A similar trend was observed with the soil moisture treatment yields in which non-significant differences were observed between the −20 and −30 kPa, but onion yields dropped significantly with the −50 kPa treatments. During the two years of the study there were

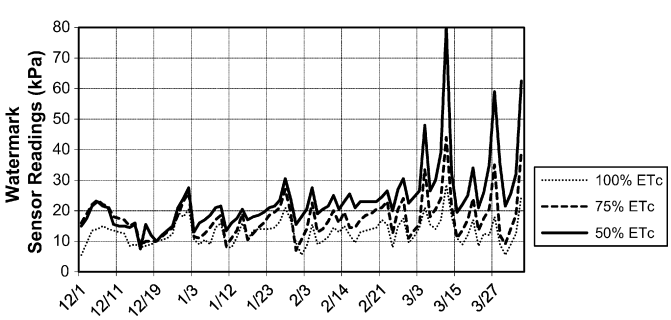

Fig. 1. Average Watermark soil moisture readings for the 100%, 75%, and 50% ETc treatments during 2005–06.

no differences on total yield between the −20 kPa, −30 kPa, 100% ETc and 75% ETc treatments because approximately similar soil moisture conditions were observed. A drop in moisture was observed below these water levels.

Jumbo and colossal size onions have greater market value. When onion yields were sorted by size into small, medium, jumbo, and colossal size classes, irrigation method and water level did not significantly affect the small, medium and colossal onion sizes. In the jumbo size class, higher yields were observed for the −20 kPa, −30 kPa and 100% ETc treatments, and lower yields were observed for the −50 kPa and 50% ETc treatments. This is an indication that larger onion sizes can be produced when more water is applied, and the water stress affected the size of the onion. These results are in agreement with the results reported by Shock et al. (1998, 2000) and Kruse et al. (1987), who obtained higher total marketable, jumbo size and colossal yields with wetter treatments.

Onion bulb pungency (pyruvic acid content), an indicator of the hotness of the onion, ranged from 3.9 to 4.4 μmol/mL juice. There was no distinctive trend due to the treatments applied in this study indicating any relationship between pungency level and water stress when the two years were combined for analysis (Table 4). The soluble solids concentration (brix), which is an indicator of the sweetness of the onion ranged from 7.1% to 7.8%. Although higher brix values were observed with the −20 kPa treatments in 2006–07 there was no clear indication that brix was related to water levels. There are no reported values in the literature that indicate a relationship between onion quality parameters such as pungency or brix content and water stress.

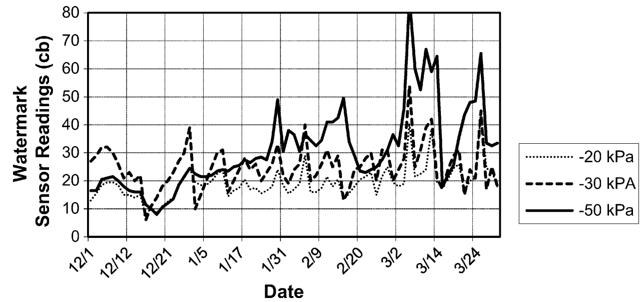

Fig. 2. Average Watermark soil moisture readings for the −20, −30, and −50 kPa treatments during 2005–06.

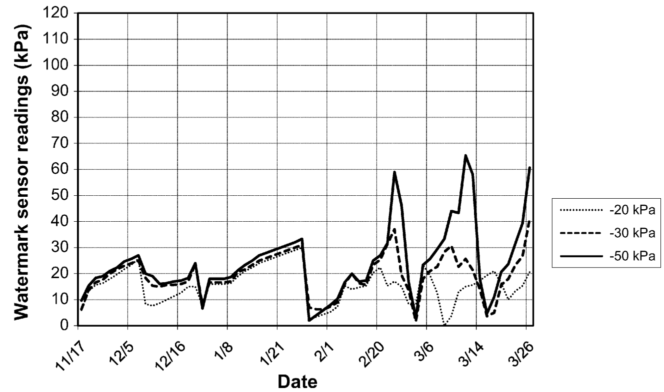

Fig. 4. Average Watermark soil moisture readings for the −20, −30, and −50 kPa treatments during 2006–07.

3.2. Irrigation water use

Total rainfall amounts for the two growing seasons were 65 mm and 132 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 December. Hence, it was difficult to sustain the desired dry soil conditions in −50 kPa and 50% ETc treatments during that period. Cumulative crop evapotranspiration amounts for the 100% ETc treatments during 2006 and 2007 were 389 mm and 320 mm respectively. Less rainfall received and higher crop water demand during 2006, resulted in bigger irrigation amounts applied than in 2007 (Table 2).

In 2006, over 80% of the irrigation amounts were applied late in the crop during the bulb development and maturing stages of growth (February–May). Compared to the 100% ETc treatment, 21 mm of water was saved by scheduling irrigation at 75% ETc. Similarly, the water savings from the 50% ETc approach was 103 mm compared to the 100% Etc treatment. There were few variations in the soil moisture between the 100% and 75% Etc (Fig. 1) as the soil stayed wet and the soil water mark sensors registered readings mostly below −20 kPa through the growing season. The 100% and 75% ET treatments resulted in similar moisture levels as the −20 kPa soil moisture irrigation treatment during 2006 (Fig. 2), although the soil was kept slightly wetter with the 100% ET treatment.

In 2006, 27 mm of water was saved with the −30 kPa and 137 mm with the −50 kPa irrigation treatments, compared to the −20 kPa treatment. Over 80% of these amounts were applied during the bulb development and maturing stages of growth (February–May).

In 2007, the corresponding water savings were 40 mm for the 75% ETc, and 80 mm for the 50% ETc treatments compared to the 100% ETc treatment. In 2007, 20 mm less water was applied with the 100% ETc than the −20 kPa soil moisture based treatments, indicating that there was not a clear trend that ETc could have been over-predicted during the two year study. In 2007, the 100% ETc treatments had drier soil water conditions (Fig. 3) resulting in similar soil moisture levels to the −30 kPa treatment (Fig. 4). The reason that more water was applied while scheduling irrigation based on ETc than when using soil water sensors in one year, but the opposite during the following year, could be that it was difficult to distinguish the length of each growing stage for the crop coefficient curve and this fact could have affected ETc estimations. Another reason could have been the variability of water application between treatments. In a few occasions, water was delayed for the ET based treatments due to the lack of pressure on the system.

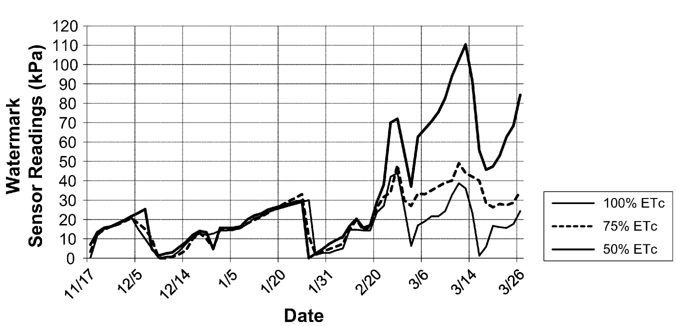

Fig. 3. Average Watermark soil moisture readings for the 100%, 75%, and 50% ETc treatments during 2006–07.

4. Summary and conclusions

Both scheduling strategies, crop ET based on weather data and direct soil moisture monitoring, were found to be appropriate to manage irrigation. During 2006, higher water amounts were applied with the ETc based treatments than the soil moisture treatments, but the opposite situation was observed in 2007. The difference could be attributed to several reasons such as variability in the soil moisture sensors; water applications not being applied exactly when a threshold was reached; the same amount of water was not applied when the threshold was reached; and estimation problems in defining the lengths of the onion growing stages to estimate crop coefficients. Yields were not affected when water applications were reduced from 100% to 75% ETc and from −20 to −30 kPa. There were no differences between the 100% ETc, 75% ETc, −20 kPa and −30 kPa treatments probably because similar water levels were maintained during most of the season in the two years of the study. Total yields and jumbo size onion class were affected by the water applied. Higher yields for jumbo onion sizes were obtained when the soil moisture was kept above −30 kPa for most days of the season when the sensor was installed at 20 cm soil depth.

Onion bulb pungency (pyruvic acid content) and soluble solids concentration (brix) were not affected by water levels or irrigation scheduling strategy.

It is important to address in future studies the inclusion of more sensors at different depths to estimate percolation losses. ETc using basal crop coefficients rather than the single crop coefficient method may be more effective, and a better methodology is needed to differentiate onion growing stages for determining the crop coefficient curve to better estimate onion evapotranspiration.

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