沙漠研究 24-1, 133-136 (2014)
Journal of Arid Land Studies

－ DT11 Refereed Paper －

Irrigation Strategies for Vegetable Crops in Water-Limited Environments

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Abstract: Water used in agriculture is considered a valuable commodity in southern regions of the U.S., such as the Wintergarden of southwest Texas. This region, which is heavily dependent on underground water resources, is being seriously affected by frequent and more severe droughts, limited water resources, and increased regulations restricting water use. Several integrated strategies can be used to increase water savings without reducing marketable yields and product quality. Those include, selecting high-efficiency irrigation systems, applying specific growth-stage crop coefficients and evapotranspiration climatic data for irrigation management, stressing crops to a certain profitable level, selecting cultivars with drought tolerance and growing crops when evapotranspiration demands are low. During the last 8 years, the vegetable physiology program at Texas A&M AgriLife Research at Uvalde has been investigating deficit irrigation (based on % crop evapotranspiration, ET_c) in conjunction with specific crop strategies and irrigation management on root and shoot growth, physiological responses, yield, quality components and phytochemical concentrations of high-value specialty crops. Regulated deficit irrigation strategies (75% ET_c) showed significant water savings with moderate reductions in marketable yields and minimal to no effects in product quality and phytochemical concentrations on short-day onion (*Allium cepa* L.), globe artichoke [*Cynara cardunculus* L. var. *scolymus* (L.) Fiori] and melons (*Cucumis melo* L.).

Key Words: Deficit irrigation, Drought, Evapotranspiration, Irrigation rates, Subsurface drip, Water use efficiency

1. Introduction

In Texas, fresh market and processed vegetables are grown on 73,700 acres with a value of $361 million (NASS, USDA, 2011) and an economic impact in excess of $450 million. The Wintergarden, a semiarid region of southwest Texas, is known for its irrigated agriculture, particularly vegetable crops. The region is located 110 km west of San Antonio and 140 km from the eastern boundary of the Chihuahuan Desert. Hot summers with moderate cool winters and annual rainfall not exceeding 600 mm are typical. Despite the intensive irrigated agriculture, rural communities in these regions are seriously affected by frequent and more severe droughts, limited water resources, and increased regulations restricting water use. Therefore, there is an urgent need for maximizing crop water use efficiency (WUE). In addition, the consumer demand for high-quality, attractive, and nutritious vegetables is rapidly increasing.

In the last few decades, vegetable crop WUE has been improving with the use of efficient irrigation practices such as drip irrigation, plasticulture, and optimum plant density. These system components are now widely used for fresh market vegetable production in open fields worldwide (Caliskan *et al*., 2009; Hanson *et al*., 1997; Lamont, 2005). The improvement in WUE has been linked to reductions in runoff and evapotranspirational losses (Jones, 2004). Deficit irrigation strategies applied through drip systems have been shown to optimize water savings and productivity in several vegetable crops. This practice implies that water is supplied to the crop at levels below crop evapotranspiration (ET_c) deliberately, allowing crops to sustain some degree of water deficit without significant yield reduction but with important savings in irrigation water.

In this paper we highlight the impact of deficit irrigation strategies on growth, physiology, yield, quality and phytochemicals of onion, globe artichoke, and melons.

2. Materials and Methods

Deficit irrigation experiments were established on onion, artichoke and melons at the Texas A&M AgriLife Research Center, Uvalde, TX (Long. 29º1'N, Lat. 99º5'W, elevation 283 m). The soil was silty clay with the following pre-plant characteristics: pH 7.8 to 8.0, EC 0.40 dS m^{-1}, organic matter 2.3 to 2.6%. WUE was calculated as marketable yield divided by total water input (t ha^{-1} mm^{-1}). All data analyses were run in SAS (version 9.2; SAS Institute, Cary, NC, USA) or SPSS (version 14.0; SPSS, Chicago, IL, USA).

2.1. Deficit irrigation in short-day onion

Onion seeds cultivar (cv) TG 1015 were direct seeded in the field on November 11, 2007 and October 30, 2008 at two planting densities (PD), 397 (standard PD) and 494 (high PD)

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(Received, September 23rd, 2013; Accepted, February 12th, 2014)

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×1000 seeds ha^{-1}. Three irrigation rates, 100, 75 and 50% ET_c, were imposed after plants were fully established. The irrigation scheduling was based on the daily crop ET_c of the well-watered crop, which was calculated as the product of the daily reference evapotranspiration (ET_o) and the related onion crop coefficient (K_c) as described in Piccinni *et al*. (2009). Irrigation water was supplied using a drip tape installed at 15 cm depth in the center of each bed. Harvests were done when more than 80% of the leaves bent over on 27 May 2008 and 18 May 2009. Bulb number, marketable yield (t ha^{-1}) and average bulb size (g bulb^{-1}) were determined. Soluble solids content was measured with a refractometer, and pungency (pyruvic acid) and quercetin content with an HPLC. A total of 10 onion bulbs per replication were used.

2.2. Deficit irrigation in globe artichoke

Two-month-old artichoke seedlings cv. Imperial Star were transplanted in the field on 16 December, 2005 at 6465 plants ha^{-1} and on 24 October, 2007 at 5390 plants ha^{-1}. Three irrigation rates, 100, 75 and 50% ET_c, were imposed using the criteria described above for onion, except that K_c was based on the recommendation by the Food and Agriculture Organization of the United Nations. Net CO_2 assimilation rate (A) and stomatal conductance (g_s) were measured during the vegetative growth with a portable infrared gas analyzer (LI-6400; LI-COR, Lincoln, NE, USA). Immature flower buds were harvested eight times during 13 April and 25 May, 2006 and 12 times during 20 March and 28 April, 2008. Total phenolics content was measured using the Folin-Ciocalteu assay (Singleton and Rossi, 1965) in the edible portion of the buds harvested in 2006.

2.3. Deficit irrigation in melon

Two irrigation rates, 100 and 50% ET_c, and three melon cultivars, Mission (cantaloupe), Da Vinci (Tuscan type) and Super Nectar (honeydew), were arranged in a split plot experimental design with three replications. Irrigation rates were assigned to the main plots and cultivars to the sub plots. Melon seeds were directly planted on raised beds (2.03 m row to row, 0.30 m plant to plant spacing) covered with black plastic mulch on 15 April, 2012. The irrigation was applied with a subsurface drip system based on the daily ET_c which was calculated as a product of ET_o obtained from the lysimeter facility located at the Texas A&M Center and the stage specific K_c. K_c values were used as; K_c ini = 0.5, K_c mid = 0.85 and K_c end = 0.60 (Allen *et al*., 1998). The water requirement was calculated with adjustments for effective rainfall availability (50%) by plastic mulch and reduced evaporation (bare soil K_c = 0.2) (Shinohara *et al*., 2011), effective irrigation wetting bed width (estimated at 70%), and canopy growth. Differential irrigation started after seedlings were fully established. The total rainfall plus irrigation applied for each irrigation rate was 382 and 564 mm for the 50% and 100% ET_c, respectively.

Marketable fruits were harvested at half to full slip stage. In each harvest, fruits were counted and graded according to the U.S. commercial trade standards (9-, 12-, 15-, 18-count per 18 kg carton). Treatments and procedures are described in details in (Sharma *et al*., 2014).

3. Results and Discussion

3.1. Onion

Planting density can increase yield without additional water input, thereby improving WUE (Shock *et al*., 2004; Dellacecca and Lovato, 2000). In this study, increasing planting density by 22% from the local commercial standard increased marketable yield by up to 14% (**Fig. 1**). The limited yield increase relative to planting density was due to 12%-13% reductions in the average bulb size (data not shown), which is a drawback for local growers who receive higher prices for larger bulb sizes.

Another strategy to improve WUE is to implement deficit irrigation. Marketable yield was reduced by 8%-13% at 75% ET_c and by 19%-28% at 50% ET_c compared with 100% ET_c (Fig. 1). However, deficit irrigation had no effect on WUE, while saving up to 181 mm of irrigation water (data not shown). The yield loss was due mainly to reductions in bulb size (data not shown), suggesting that extreme deficit irrigation (50% ET_c) can decrease profitability by reducing both yield and price premiums.

It is well documented that genetics (Kalra *et al*., 1995) and environmental (soil type, climate) conditions play a major role in determining quality and phytochemicals in onion. In this study, neither deficit irrigation rates nor planting density affected bulb quality and nutritional components in both seasons (**Fig. 2**), suggesting that crop management strategies have negligible effects on these parameters.

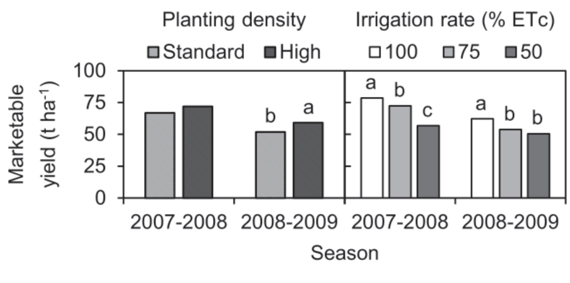

Fig. 1. Marketable yield of onion as affected by planting density and irrigation rate. Means with the same letter are not significantly different (P < 0.05) by the Tukey test.

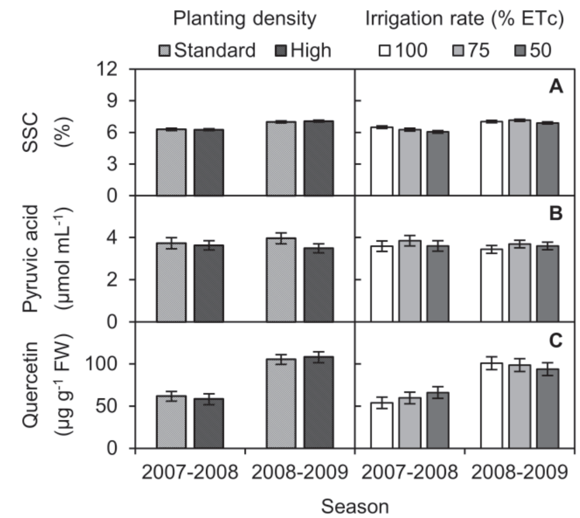

Fig. 2. Nutritional quality components (means ± SE) of onion as affected by planting density and irrigation rate: (A) soluble solids content (SSC), (B) pyruvic acid and (C) quercetin.

3.2. Artichoke

Globe artichoke commercial production in the U.S. is almost exclusively (> 98%) in California. In 2004-2006, the average marketable yield was 11.7-13.6 t ha^{-1} with the gross value of \$9,983-12,340 ha^{-1} (Smith *et al*., 2008). In this study, marketable yield at 100, 75 and 50% ET_c irrigation was 13.2-17.0, 11.6-15.7 and 8.5-11.7 t ha^{-1}, respectively (**Fig. 3A**), suggesting that, even with 75% ETc irrigation, competitively high production of artichoke is feasible in our semi-arid climate. More importantly, in the 2007-2008 season, this moderate deficit irrigation caused only 7% yield loss, while increasing WUE by 15% (Fig. 3**B**) with water savings of 69 mm (data not shown) compared with 100% ET_c irrigation.

Water stress-induced stomatal closure restricts entry of CO_2 and consequently limits A (Lawlor, 2002). This stomatal limitation to photosynthesis was indicated by the reductions in both *A* (**Fig. 4A**) and g_s (Fig. 4**B**) under deficit irrigation, which may have limited the vegetative growth (*e.g.* leaf number and plant size, data not shown) and thus productivity.

Artichoke is known as a rich source of natural antioxidants such as phenolics (Miccadei *et al*., 2008). Deficit irrigation tended to increase total phenolics content in the late harvest (**Fig. 5**), although this improvement in nutritional quality was associated with reductions in head size and overall quality.

3.3. Melon

Across cultivars, deficit irrigation (50% ET_c) resulted in a 31% (54.5 t ha^{-1} at 50% ET_c vs. 78.7 t ha^{-1} at 100% ET_c) reduction in marketable fruit yield (MFY). Deficit irrigation caused 23%, 30%, 33% decrease in MFY in cvs. Mission, Da Vinci and Super Nectar, respectively (**Fig. 6**).

The reduction in fruit size under deficit irrigation resulted

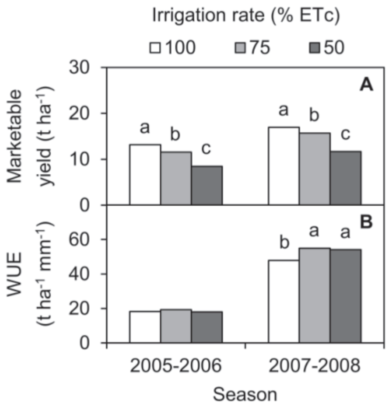

Fig. 3. Marketable yield (A) and water use efficiency (WUE) (B) of artichoke in response to deficit irrigation. Means with the same letter are not significantly different ($P < 0.05$) by the least significant difference.

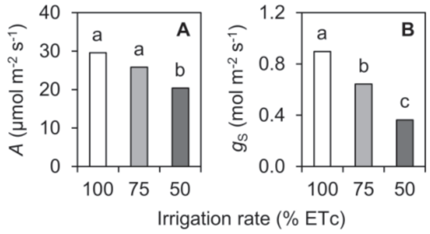

Fig. 4. Gas exchange of artichoke in response to deficit irrigation: (A) net CO_2 assimilation rate (A) and (B) stomatal conductance (g_s). Measurements were made on 10 April, 2008. Means with the same letter are not significantly different ($P < 0.05$) by the least significant difference.

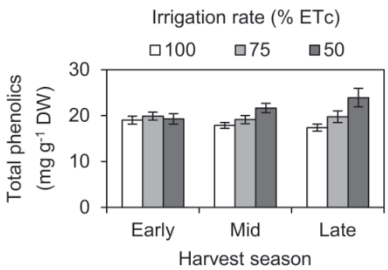

Fig. 5. Total phenolics content (means ± SE) in the edible portion of artichoke buds in response to deficit irrigation. The buds were sampled on 20 April (early), 3 May (mid) and 25 May, 2006 (late).

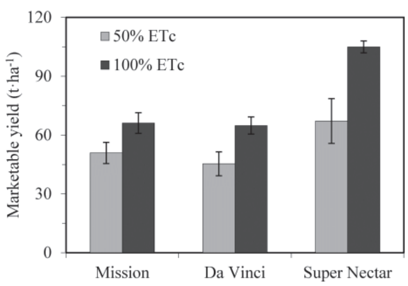

Fig. 6. Marketable fruit yield (t ha^{-1}) (means ± SE) of melons as affected by irrigation rates on three cultivars.

in shifts in fruit size distribution in two of the cultivars (**Fig. 7**). Deficit irrigation caused 48% reduction in the class 9-count,

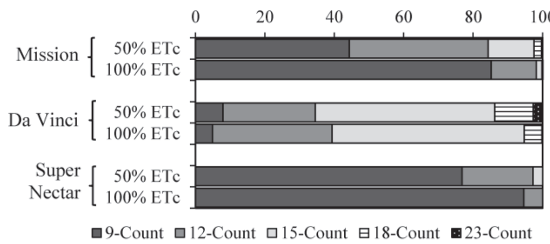

Fig. 7. Fruit size distribution of melons as affected by irrigation rates on three cultivars. Marketable fruits were U.S. commercial standards (9-, 12-, 15-, 18- and 23-count per 18 kg carton).

but a 3- and 8-fold increase in classes 12-count and 15-count size fruit yield respectively in Mission. Similarly, under deficit irrigation, a 19% reduction in percentage of class-9 size fruit yields occurred in Super Nectar (Fig. 7). Yield of melons to water deficit conditions varied among cultivars. The reduction in MFY in Mission was due to a decrease in fruit size, in Da Vinci due to a decreased in fruit number, while in the most sensitive cv. Super Nectar it was due to a reduction in both fruit number as well as fruit size. The differential cultivar responses to deficit irrigation indicate the need for cultivar specific irrigation management in melons. Less reduction in fruit yield can be attributed to the shorter growing season of Mission (Stewart and Musick, 1982). Variable cultivar responses to deficit irrigation have also been reported in watermelons (Leskovar *et al*., 2004).

Deficit irrigation can save 45% of irrigation water (227 mm in 50% ETc as compared to 409 mm in 100% ET_c) in Mission and Da Vinci cultivars with small yield reductions. However, due to higher yield penalties deficit irrigation may not be practical in the cultivar Super Nectar.

4. Conclusion

Drought stress and scarce water resources are the most significant limiting factors affecting agricultural production in the Wintergarden region of Texas. Deficit irrigation management showed significant water savings with moderate reductions in yields and no adverse product quality changes in three specialty vegetable crops. Our future efforts will concentrate on identifying and integrating selective genetic traits with irrigation management aimed to reduce the gap between potential yield and actual yield in drought prone environments.

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