Vegetable Section

Proc. Fla. State Hort. Soc. 129:125–129. 2016.

The Use of Smart Phone Application (SmartIrrigation Vegetable) for Irrigation Scheduling in Tomato (*Solanum Lycopersicon*) Production

Ibukun T. Ayankojo* and Kelly T. Morgan

University of Florida/IFAS, Southwest Florida Research and Education Center (SWFREC), 2685 29 N Road, Immokalee, FL 34142

Additional index words. SmartIrrigation, tomato production, tomato yield, water use efficiency

A study that focused on irrigation scheduling methods and rates for open-field tomato (*Solanum Lycopersicon*) production was conducted at the University of Florida/IFAS Southwest Research and Education Center (SWFREC), Immokalee, FL. The study was carried out during spring and fall seasons of 2015. The main objective was to evaluate use of a smart phone application (SmartIrrigation Vegetable) on tomato productivity and water-use in comparison to University of Florida IFAS (UF/IFAS) irrigation recommendations. Five irrigation rates (66% App, 100% App, 150% App, 66% UF/IFAS and 100% UF/IFAS) were evaluated in a randomized complete-block design with four replicates per treatment. Plant biomass samples were taken at 30, 60, and 90 days after transplanting (DAT) and harvests were conducted at fruit maturity. For both seasons, no significant difference was observed in dry biomass accumulation for 100% App and 100% IFAS at 60 and 90 DAT but a significant increase in dry biomass accumulation was observed for 100% App (266 lb/acre) compare to 100% IFAS (217 lbs.acre^{-1}) at 30 DAT (*P* = 0.002) during spring season. No significant difference was observed in marketable yield among treatments during the spring season as a result of bacterial leaf spot and blossom-end rot. However, a significant increase in average marketable yield (41%) was observed for 100% App compared with 100% IFAS (*P* = 0.03) during the fall season. The low App rate (66% App) was the most water efficient (50 gallons/box of marketable fruit) but yield was lower than 100% App. Water use efficiency (WUE) for 100% App was greater (67 gallons/box) compared with 100% IFAS (111 gallons/box) during the fall season. These results suggest that the SmartIrrigation vegetable (SI) app can be successfully used for irrigation scheduling in tomato production in Florida. Also, SI App can increase WUE by increasing water savings in tomato production and as a result can reduce nutrient leaching and increase yield.

The United States is one of the world's largest tomato (*Solanum lycopersicon* L.) producing countries with more than $2 billion in annual total farm cash receipts and about 403 thousand harvested acres in 2014 (USDA, 2015). Florida is a leading state in the production of fresh market tomatoes and pepper (*Capsicum annum* L.) (Kokalis-Burelle, et al., 2002; Simonne and Ozores-Hampton 2009; Olson et al., 2010; Olson and Santos 2010). Tomato is the leading commodity for Florida vegetable production with 32,000 total harvested acres and total value of about $ 453 million in 2015 (USDA, 2016). Proper irrigation management is an important aspect of vegetable production to meet market quality demands. In vegetable production, an adequate water supply throughout the crop life cycle is an important factor to produce maximum yield and ensure high quality produce. Inadequate water management creates water stress resulting in reduced plant growth and consequently reduced yields. In vegetable production, irrigation can contribute up to 200% yield increase (Doss et al., 1980; Locascio and Myers, 1974).

Maintaining adequate irrigation practices in crop production not only increases yield but also reduces production cost, minimizes nutrient and pesticide leaching into the ground water (Pulupol et al., 1996), and improves tomato fruit nutritional value (Dorais et al., 2008). The supply of potable or non-saline water is limited worldwide so research findings have intensified the necessity for improved water use efficiency (WUE) in agricultural production (Zegbe-Dominguez et al., 2003; Simonne et al., 2010). Considering that tomato has the highest acreage of any vegetable crop in the world (Ho, 1996), increases in WUE in tomato production can make a significant impact in the global agricultural water footprint.

There are many irrigation scheduling methods for tomato production. One of the most recent scheduling methods is the use of the SmartIrrigation (SI) applications. Presently, many SI applications have been published and used in crops such as citrus (*Citrus sinensis* L.), cotton (*Gossypium* spp. L.), turf, strawberry (*Fragaria spp*) and recently avocado (*Persea Americana* Mill.) (Migliaccio et al., 2014). The smartphone irrigation app has been proven efficient not only in reducing crop irrigation volume but also significant increases in yields of cotton (Vellidis et al., 2014).

Published SI Apps are smart phone enabled irrigation decision support systems that provide users with irrigation schedules based on real-time, location specific weather data (Migliaccio et al., 2014). Smart phone apps for irrigation scheduling have the ability to reduce user calculation error or misplaced irrigation records and timing. They provide the opportunity to enter the necessary information anytime and anywhere with cellular network accessibility. In this publication, the SI Vegetable App was evaluated, using the FAO Penman-Monteith procedure for ETo calculation. Therefore, this project is designed with the main objective of evaluating a smart phone application (SmartIrrigation Vegetable

*Corresponding author: iayankojo@ufl.edu

Application) for irrigation scheduling in open-field fresh market tomato production.

Materials and Methods

The study was conducted during the Spring 2015 (February to May) and Fall 2015 (September to December) seasons at the University of Florida, Institute of Food and Agricultural Sciences (UF/IFAS) Southwest Research and Education Center (SWFREC), Immokalee, FL. The soil at the experimental site is a Spodosol classified as an Immokalee fine sand soil series with nearly flat slope (USDA-NRCS, 2013).

Although, precipitation is high throughout the year, irrigation is a necessity due to the very poor water holding capacity at the experimental site. Therefore, different daily irrigation rates based on the SI Vegetable App were evaluated and compared to established irrigation recommendation by UF/IFAS. For both seasons (spring and fall), five irrigation treatments from two scheduling methods (App and IFAS) were evaluated (Table 1) using a randomized complete-block design (RCBD) with four replications per treatment.

For both production seasons (spring and fall), standard bed size (6-ft bed centers) were used. Fertilizer application, at the UF/IFAS recommended rate, was the same for all treatments (Liu et al., 2015) with 50 lb/acre (N and K) applied pre-plant and 150 lb/acre (N and K) as fertigation. Pre-plant dry fertilizer 19–0–19 (N–P–K) was applied as a bottom mix during bed preparation while water soluble fertilizer 20–0–20 (N–P–K) was applied through fertigation. During bed preparation Pic Clor 60 fumigant (Agrian. Fresno, CA. a.i chloropicrin and 1,3-Dichloropropene at 59.6% and 39% respectively) was applied to the beds at the rate of 200 lb/acre and immediately covered with polyethylene mulch. A 0.8 mil white/black polyethylene mulch (Berry Plastics. Washington, GA) was used throughout the experiment. The white side of the polyethylene mulch was facing up in the fall season and black side facing up during the spring season. All the beds had two drip lines (thinwall drip lines, 5 mil streamline Plus 630 series by Netafilm. Fresno, CA) under the polyethylene mulch for irrigation and fertigation. After bed preparation, tomato seedlings (varieties 'Tygress' by Seminis, St. Louis, MO during the spring and 'Charger' by Sakata, Morgan Hill, CA during the fall season) were transplanted at 24 inches plant spacing in a single row 21 days after bed preparation. Seedlings were transplanted on 23 Feb. 2015, and harvested on 30 Apr., and 19 May 2015, during the spring season. During the fall season, seedlings were transplanted on 14 Sept. 12015 and harvested on 9 and 21 Dec. 2015, and 7 Jan. 2016. Total plant population at transplanting was 3810 per acre for each season.

Irrigation was scheduled weekly using UF/IFAS irrigation recommendation and the SI Vegetable App. The volume of irrigation at each rate was applied daily to each treatment for the next seven consecutive days. Irrigation water applied to each treatment was controlled by a flow meter (M 1 1/2" size by Netafilm, Fresno. CA). Water along the drip lines was maintained at constant pressure by pressure regulators (15 PSI by Senninger Irrigation Inc. Orlando, FL). Based on irrigation volume, daily total irrigation time were divided into two to three irrigation events and the time of each event was controlled by hose-end irrigation controller (model IZEHTMR by Rainbird. Azusa, CA). Irrigation time was the same for all treatments, however the desired irrigation volume for each treatment was determined based on different flow rates of the drip lines (Table 1). During fertigation, the required amount of fertilizer was dissolved in 5 gal of water for each treatment and injected into the drip lines using a pressure pump (12 VDC, 1.8 GPM by SHURflo, Cypress CA). A total of 200 lb/acre each of N and K (pre-plant and fertigation) was applied for each season. Fertigation was conducted twice a week and each application was carried out at the last irrigation cycle of the day to ensure that nutrients were maintained within the root zone.

Table 1. Treatment specification for irrigation study in tomato production for the 2015 spring and fall seasons in Immokalee FL.

Treatments[z]	Irrigation schedule method	Drip line[y] (gal/h)
1	100% IFAS rate	0.24
2	66% App rate	0.16
3	100% App rate	0.24
4	150% App rate	0.36
5	66% IFAS rate	0.24

[z]IFAS = Irrigation based on University of Florida Institute of Food and Agricultural Sciences recommendation, App = Irrigation based on SmartIrrigation Vegetable application.
[y]All drip lines used were at 12-inch emitter spacing.

Biomass samples were taken for all treatments consisting of both above ground (leaves, stems and fruits) and below ground (roots) plant parts. Crop biomass samples were collected once every 30 days starting at 30 days after transplanting (DAT) except for fruit sampling that started about 60 DAT. All tissue samples were dried at 149 °F and corresponding dry biomass was recorded as total biomass (lb/acre) per treatment for each season. Harvest was conducted at fruit maturity (66 and 85 DAT during spring season and 86, 96, and 115 DAT during fall) and yields were recorded as total marketable yield (boxes per acre per treatment) for each season. Harvested fruits were graded based on USDA (1997) standards as small, medium, large, and extra-large mature-green and colored fruits. All statistical analysis were using Statistical Analysis Software (SAS Institute Inc., Cary, NC) for the analysis of variance (ANOVA). Duncan's multiple range test was used to identify significant differences among treatments.

Results and Discussions

Biomass Accumulation

No significant differences were observed among treatments for total biomass accumulation during either spring or fall seasons at 60 and 90 DAT (Table 2). However, at 30 DAT in the spring season, 100% IFAS and 150% App were significantly lower (P = 0.002) in total biomass than the lower irrigation rate treatments. Lower biomass suggests that both 100% IFAS and 150% App are likely to provide more water than the young plants required early in the season, and that might lead to the leaching of nutrients below the root zone, resulting in lower biomass production (Pulupol et al., 1996; Dorais et al., 2008)

Marketable Yield

Marketable yield in the spring season was greatly affected by bacteria leaf spot (BLS) and poor fruit quality from blossom-end rot (BER), which is a physiological disorder in plants as a result of low plant calcium level resulting in fruit rot (Saure, 2001). Total marketable yield was lower during the spring season with no significant difference among treatments because the severe BLS greatly reduced productivity (Fig. 1). No effective control was achieved for BLS during the spring season, although a

Table 2. Total biomass accumulation at different days after transplanting (DAT) during the 2015 spring and fall seasons in Immokalee, FL.

	Spring season (lb/acre)			Fall season (lb/acre)		
Treatment[z]	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
100% IFAS	217.35 b	1176.51	1676.74	330.15	2748.31	2436.00
66% App	294.68 a	2202.75	2035.53	410.46	2864.31	3283.69
100% App	265.88 a	2052.66	1285.90	383.69	3078.46	3105.23
150% App	173.61 c	1646.40	1962.10	330.15	2498.46	2552.00
66% FAS	256.55 ab	1139.92	3467.06	321.23	3497.85	2944.62
Sig. Level	0.002	ns	ns	ns	ns	ns

[z]IFAS = Irrigation based on University of Florida Institute of Food and Agricultural Sciences recommendation, App = Irrigation based on SmartIrrigation vegetable application.
ns = nonsignificant.

copper-based fungicide/bactericide (Kocide 2000, by Dupont. OK. with a.i. copper hydroxide 53.8%) was applied frequently. The ineffectiveness of the product applied can be related to the possible presence of resistant or tolerant pathogen strains (Marco and Stall, 1983; Ritchie and Dittapongpitch, 1991; and Stall and Thayer, 1962) and favorable weather conditions for disease development (Jones and Jones, 1985). High disease incidence significantly affected crop yield and general growth and development throughout the season. Jones and Jones, (1985) also confirm that a positive yield response is rarely observed in crops affected by copper-tolerant pathogen strains.

Significant differences were observed in yield among treatments during the fall season. The 100% app treatment had significantly higher total marketable yield compared with the other treatments except for 66% App. Total marketable yield from 100% App was 41% higher compared to 100% IFAS rate. The lower marketable yield for higher irrigation rates (100% IFAS and 150% App) is an indication that irrigation schedules from both methods were higher than plant water requirements which might lead to leaching of nutrients below the root zone (Zotarelli et al., 2008). Total marketable yield obtained during this season was similar to reported yield in the literature (Hanson and May, 2004; Zotarelli et al., 2009; Ren et al., 2010; Ozores-Hampton et al., 2015).

Seasonal Irrigation Water Use

Total seasonal water use was lower during fall season compared to spring (Fig. 2) because of lower ET observed (data not provided) during fall season. During spring season, total water applied in irrigation depth ranged from 2.9 to 6.5 inches while total irrigation depth ranged from 2.1 to 4.7 inches during fall season. For all the observed irrigation rates in this study, a similar pattern was observed during both seasons. In both seasons, the total depth of irrigation water applied increased in the order of 66% App < 66% IFAS < 100% App < 100% IFAS < 150% App. For spring and fall seasons respectively, a total of 13% and 17% reduction in total water use were observed for the App-based treatment (100% App) over the corresponding treatment based on the UF/IFAS irrigation scheduling method (100% IFAS). These results suggest that irrigation schedule using real-time and location-specific weather data from SI App could be a more suitable irrigation scheduling method compared to a schedule based on historic weather information (UF/IFAS) in open-field tomato production.

Water and Nitrogen Use Efficiencies

Nitrogen use efficiency (NUE-N) and WUE were based on the amount of nitrogen or water required by plants to produce mea-

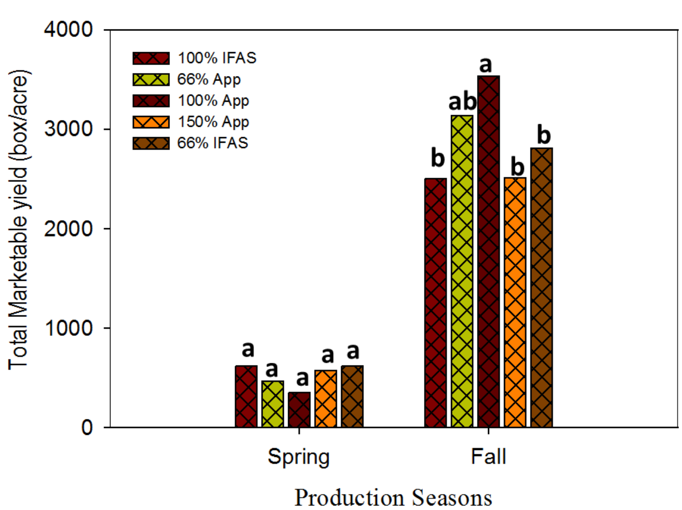

Fig. 1. Effect of irrigation on total marketable yield during the 2015 spring and fall seasons, based on the University of Florida, Institute of Food and Agricultural Sciences recommendation and SmartIrrigation Vegetable application (App) in Immokalee, FL.

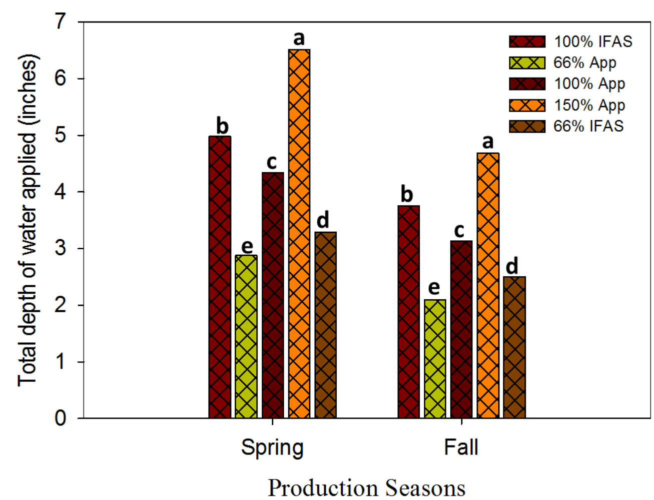

Fig. 2. Total depth of irrigation for the 2015 spring and fall seasons, based on the University of Florida, Institute of Food and Agricultural Sciences recommendation and SmartIrrigation vegetable application (App) in Immokalee, FL.

Table 3. Effect of irrigation rates on water use efficiency (WUE) and nitrogen use efficiency (NUE-N) during the 2015 spring and fall seasons in Immokalee FL.

	Spring season[y]		Fall season[x]	
Treatment[z]	WUE[y] (gal/box)	NUE - N (oz/box)	WUE (gal/box)	NUE - N (oz/box)
100% IFAS	555.37	2.32	111.49 a	0.56 a
66% App	423.61	3.20	50.14 c	0.48 ab
100% App	846.82	2.01	66.80 b	0.40 b
150% App	780.59	2.53	140.41 a	1.60 a
66% IFAS	366.54	2.32	66.22 b	0.53 a
P-value	*0.33*	*0.31*	*0.0003*	*0.03*

[z]IFAS = University of Florida Institute of Food and Agricultural Sciences recommendation and App = SmartIrrigation vegetable.

[y]Data showing mean values of four replicates.

[x]Data showing mean values of three replicates. A box of tomato = 25 lb of fresh marketable yield.

sured marketable fruit yield (Table 3). Although, irrigation rates vary among treatments, no significant differences ($P > 0.05$) were observed among treatments for NUE-N and WUE during spring season because of the severe BLS outbreak. However, there were significant differences ($P = 0.0003$) among irrigation rates during the fall season (Table 3). The 66% SI App treatment resulted in the lowest water use per box of fruit produced (50 gallons/box) but fewer boxes per acre were produced compared to the 100% SI App treatment. Also, significant less water was observed for the 100% App compared to the 100% IFAS at 67 gallons/box and 111 gallons/box, respectively. The WUE observed for 66% App was believed to have been influenced by the abundant and frequent rainfall observed during the fall season that increased soil water content above the desired level. Similarly, significant differences were observed among treatments for NUE-N during fall season (Table 3). The amount of N required by plants for every box (25 lb) of marketable fruits was lowest for the 100% App rate compare to other treatments except 66% App. Lower NUE-N observed for the higher irrigation rates (100% IFAS and 150% App) were attributed to over irrigation. Excessive irrigation can significantly reduce the concentration of soluble nutrients in the soil and thereby reduce plant nutrient uptake and yield (Zotarelli et al., 2008).

Conclusion

Although no significant differences were observed among treatments in total biomass accumulation, 100% SI App produced significantly higher total marketable yield compared to other treatments and significant water savings compare to 100% IFAS. Yield data suggest irrigation scheduled with 100% SI App was best for tomato fruit production. Irrigation was most likely to be deficient for the 66% App and 66% IFAS treatments and excessive for 100% IFAS and 150% App. Thus, the increase in yield for the 100% App is an indication that irrigation scheduling using the 100% App could be better suited for tomato production in south Florida compared with UF/IFAS recommendations. The fact that app-based schedules were greater in nutrient and water use efficiencies over IFAS was not surprising because irrigation scheduling from the SmartIrrigation Vegetable App is based on real-time location specific weather data therefore, greater scheduling accuracy could be expected.

Literature Cited

Dorais, M., Ehret, D.L., and A.P. Papadopoulos. 2008. Tomato (*Solanum lycopersicum*) health components: from the seed to the consumer. Phytochem. Rev. 7: 231–250.

Doss, B.D., J.L. Turner, and C.E. Evans. 1980. Irrigation methods and in-row chiseling for tomato production. J. Amer. Soc. Hort. Sci. 105:611–614.

Hanson B. and D. May. 2004. Effect of subsurface drip irrigation on processing tomato yield, water table depth, soil salinity, and profitability Agr. Water Mgt. 68(1):1–7. doi.org/10.1016/j.agwat.2004.03.003

Ho, L.C., 1996. Tomato. In: Zemaski, E. and A.A. Schaffer (eds.), Photoassimilate Distribution in Plants and Crops: Source–Sink Relationships. Marcel Dekker, NY, USA, pp. 709–728.

Hochmuth G. and E. Hanlon 2014. A summary of N, P, and K research with tomato in Florida. Soil and Water Dept. Univ. of Fla. Coop. Ext. Serv. EDIS Publication SL355. <http://edis.ifas.ufl.edu/cv236>.

Jones, J.B., and J.P Jones. 1985. The effect of bactericides, tank mixing time and spray schedule on bacterial leaf spot of tomato. Proc. Fla. State Hort. Soc. 98:244–247.

Kokalis-Burelle, N., C. Vavrina, E. Rosskopf, and R. Shelby. 2002. Field evaluation of plant growth-promoting Rhizobacteria amended transplant mixes and soil solarization for tomato and pepper production in Florida. Plant and Soil 238:257–266.

Liu G.D, E.H. Simonne, K.T. Morgan, G.J. Hochmuth, M. Ozores-Hampton, and S. Ageharas. 2015. Fertilization management for vegetable production in Florida. In Vegetable Production Handbook for Florida 2015-2016, P.J. Dittmar, J.H Freeman and G.E Vallad (eds). University of Florida IFAS, Gainesville.

Locascio, S.J. and J.M. Myers. 1974. Tomato response to plug-mix mulch and irrigation method. Proc. Fla. State Hort. Soc.87:126–130.

Marco, G.M., and R.E. Stall. 1983. Control of bacterial spot of pepper initiated by strains of *Xanthomonas campestris* pv. *Vesicatoria* that differ in sensitivity to copper. Plant Dis. 67:779–781.

Migliaccio, K.W., and W. Barclay Shoemaker. 2014. Estimation of urban subtropical bahiagrass (*Paspalum notatum*) evapotranspiration using crop coefficients and the eddy covariance method. Hydrol. Processes, 28:4487–4495.

Olson, S.M., and B. Santos. 2010. Vegetable Production Handbook for Florida. University of Florida IFAS, Gainesville, FL. <http://edis.ifas.ufl.edu/topic_vph>.

Olson, S.M., W.M. Stall, G.E. Vallad, S.E. Webb, S.A. Smith, E. Simonne, E.J. McAvoy, and B.M. Santos. 2010. Tomato Production in Florida. In Vegetable Production Handbook for Florida 2010–2011. S.M. Olson and B. Santos (Eds). University of Florida IFAS, Gainesville.

Ozores-Hampton, M., F. Di Gioia, S. Sato, E. Simonne, and K. Morgan. 2015. Effects of Nitrogen Rates on Nitrogen, Phosphorous, and Potassium Partitioning, Accumulation, and Use Efficiency in Seepage-irrigated Fresh Market Tomatoes. HortScience 50: 1636–1643.

Pulupol, L.U., M.H. Behboudian and K.J. Fisher. 1996. Growth, yield and postharvest attributes of glasshouse tomatoes produced under water deficit. HortScience 31:926–929.

Ren T., P. Christie, J. Wang, Q. Chen and F. Zhang. 2010. Root zone nitrogen management to maintain high tomato yields and minimum nitrogen losses to the environment. Scienta Hort. 125:25–33.

Ritchie, D.F. and V. Dittapongpitch, 1991. Copper- and streptomycin-resistant strains and host differentiated races of *Xanthomonas campestris* pv. vesicatoria in North Carolina. Plant Dis. 75:733–736.

Saure M.C., 2001. Blossom-end rot of tomato (*Lycopersicon esculentum* Mill.)—A calcium- or stress-related disorder? Sci. Hort. 90: 193-208.

Simonne E, C. Hutchinson. J. DeValerio, R. Hochmuth, D. Treadwell, A. Wright, B. Santos, A. Whidden, G. McAvoy and X. Zhao. 2010. Current knowledge, gaps, and future needs for keeping water and nutrients in the root zone of vegetables grown in Florida. HortTechnology. 20:143–52.

Simonne, E.H. and M. Ozores-Hampton. 2009. Fertilizer and nutrient management for tomato. Proc. Tomato Inst. 41:4.

Stall, R.E. and P.L. Thayer. 1962. Streptomycin resistance of the bacterial spot pathogen and control with streptomycin. Plant Dis. Rep. 46:389–392.

USDA-NRCS, 2013. Official soil series descriptions—Soil survey division. <https://soilseries.sc.egov.usda.gov/>.

USDA, 2016. National Agricultural Statistics Service Florida Office: 2016 Annual statistics Bulletin. <https://www.nass.usda.gov/Statistics_by_State/Florida/Publications/Annual_Statistical_Bulletin/2016/>.

USDA, 2015. 2015 Agricultural Statistics: Statistics of vegetables and melons. <https://www.nass.usda.gov/Publications/Ag_Statistics/2015/Chapter04.pdf>.

Vellidis G., V. Liakos, C. Perry, M. Tucker, G. Collins, J. Snider, J. Andreis, K. Migliaccio, C. Fraisse, K. Morgan, D. Rowland and E. Barnes. 2014. A smartphone App for scheduling irrigation on cotton. In S. Boyd, M. Huffman and B. Robertson (eds.). Proc. 2014 Beltwide Cotton Conf., New Orleans, LA, National Cotton Council, Memphis, TN (paper 15551).

Zegbe-Domınguez, J.A., M.H. Behboudian, A. Lang and B.E. Clothier. 2003. Deficit irrigation and partial root-zone drying maintain fruit dry mass and enhance fruit quality in ‘Petopride’ processing tomato (*Lycopersicon esculentum*. Mill.). HortScience 98:505–510.

Zotarelli L. J.M. Scholberg, M.D. Dukes R. Munoz-Carpena, and J. Icerman 2009. Tomato yield, biomass accumulation, root distribution and irrigation water use efficiency on a sandy soil, as affected by nitrogen rate and irrigation scheduling. Agr. Water Mgt. 96:23–34.

Zotarelli, L., M.D. Dukes, J.M.S. Scholberg, T. Hanselman, K. Femminella and R. Muñoz-Carpena. 2008. Nitrogen and water use efficiency of squash for a plastic mulch bed system on a sandy soil, as affected by nitrogen rate and irrigation method. Sci. Hort. 116:8–16