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Plant response to evapotranspiration and soil water sensor irrigation scheduling methods for papaya production in south Florida

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ABSTRACT

An irrigation study was conducted to determine the effects of implementing different irrigation practices on growth and yields of papaya plants in south Florida. Treatments included using automated switching tensiometers based on soil water status, irrigation based on ET calculated from historic weather data and a set schedule irrigation regime. The study consisted of two trials (2006–2007 and 2008–2009). Water volumes applied, plant height and diameter, leaf gas exchange, leaf petiole nutrient levels, fruit yields and fruit total soluble solids were measured throughout the study. For both trials, significantly more water was applied in the set schedule irrigation treatment than in all other treatments; historic ET and soil water based treatments received only about 31–36% of the water applied in the set schedule irrigation. Trunk diameter and plant height per unit water volume applied values for the set schedule treatment were significantly lower than those from all other treatments during both trials. The set schedule treatment in both trials also had the lowest crop production water use efficiency (CP-WUE); CP-WUE values among all other treatments were generally not significantly different from each other. Soil water and historic ET-based irrigation methods were identified as more sustainable practices compared to set schedule irrigation due to the lower water volumes applied while maintaining plant nutrient content, growth, photosynthetic rates, and fruit yields for this production system.

1. Introduction

Irrigation is a major management component for many agricultural crops, allowing for production in otherwise unproductive or minimally productive locations by reducing potential crop drought stress. Traditionally, irrigation is applied by calendar-based methods formulated primarily on growers' general knowledge of the crop and weather conditions in the area. Advances in irrigation sciences have made new technology available and increasingly accessible to agricultural producers (Wiedenfeld, 2004; Kallestad et al., 2006; Farahani et al., 2007). These technologies include evapotranspiration (ET) based irrigation and soil water sensor based irrigation, sometimes referred to as 'smart technologies' (Vellidis et al., 2008; McCready et al., 2009) that provide irrigation methods based on actual water requirements and crop use taking into account weather factors.

Evapotranspiration technology relies on the understanding of evaporation and transpiration processes that are estimated generally using measured weather parameters and knowledge of the gas exchange characteristics of the plant species to be irrigated. Irrigation is then applied based on estimated water loss. Evapotranspiration technologies vary in the level of sophistication from simple methods of using historical weather data and manually programming irrigation controllers to more complex methods where real-time weather data are received by on-site systems that evaluate this information and determine an ET-based irrigation rate (Kisekka et al., 2010).

A primary limitation to using ET-based systems is the lack of accurate crop coefficients which are necessary to calculate actual ET. However, Yuan et al. (2003) and Goenaga et al. (2004) have implemented ET-based irrigation by substituting traditional cropping coefficients with fractions of pan evaporation. Alternatively, soil water sensor technology relies on the principle of replenishing soil water with irrigation based on a measured value of soil water and a set soil water threshold. However, in some soil types with highly heterogeneous textures and large pore spaces current soil water sensor technology may not be able to representatively depict soil water status. Soil water sensor technology has been evaluated in tomato (Zotarelli et al., 2009), onion (Enciso et al., 2009) and bell pepper (Thompson et al., 2007) crops to name a few. The implementation of ET or soil water based irrigation scheduling techniques requires some training of agricultural producers because manufacturers' instructions for off-the-shelf products do not necessarily include some of the nuances of installing such a system.

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This study evaluated different irrigation technologies, using simple methods that would be easily adoptable by agricultural producers with minimal assistance from an irrigation professional. The implementation of such technologies is very contemporary due to extreme pressures on water supplies, the imminent situation of water shortages being reported worldwide and the need to optimize production practices for economic viability. The specific objectives of this study were to determine the effects of implementing different irrigation practices, i.e., automated switching tensiometers for irrigating based on soil water status, irrigation based on ET calculated from historic weather data and a set schedule irrigation regime, on plant nutrient content, leaf gas exchange, plant growth and fruit production and quality of papaya (*Carica papaya*) in south Florida and to determine if any of these methods conserved water without decreasing plant growth and yields.

2. Materials and methods

2.1. Study site and plant material

This project was conducted in Homestead, FL, at the University of Florida Tropical Research and Education Center (Latitude: 25°30′40.809″N; Longitude: 80°30′3.983″W) which has a subtropical marine climate (Fig. 1). Average annual rainfall at the location is 149 cm based on weather data collected at the Tropical Research and Education Center by the Florida Automated Weather Network (FAWN; http://fawn.ifas.ufl.edu/) from 1998 to 2008 with the majority (70%) of rainfall occurring from late May to early November (Ali et al., 2000). This weather station is approximately 300 m from the study plot. The soil is Krome very gravelly loam, classified as a loamy-skeletal carbonatic hyperthermic lithic Rendoll (Noble et al., 1996) which is a shallow, gravelly, well-drained, human-made mineral soil (Colburn and Goldweber, 1961). Typically, Krome soils are 10–20 cm deep and overlay limestone bedrock (Noble et al., 1996).

The study plot consisted of 20 rows of raised beds approximately 1 m in width, 15.2 m in length and 15 cm high; total potential rooting depth was 20–25 cm. Beds were created by scraping the soil to bedrock and depositing soil into rows. Thus, no soil for root development was available between rows, isolating each row from potential between-row interactions. Each row consisted of 7 papaya plants spaced at 2.1 m in-row and 3.7 m between-row corresponding to 1287 plants per ha. The soil in each row was covered with white plastic mulch for weed control. Irrigation was delivered using two Eurodrip lines (one on each side of the plant) under the plastic per row. The drip line had an emitter spacing of 20 cm with a delivery rate of 2.46 L min^{-1} per 30 m.

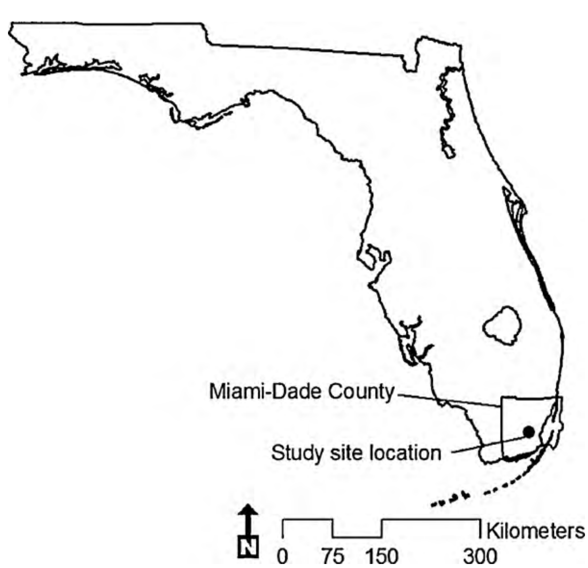

Fig. 1. Plot location for the papaya irrigation study (Tropical Research and Education Center, Homestead, FL) and the state of Florida boundary.

A liquid fertilizer injection system was used to provide a 4–0–8 mixture (4% N [0.49% ammoniacal nitrogen and 3.51% nitrate nitrogen], 0% phosphorus oxide [P_2O_5] and 8% potassium oxide [K_2O] [or 6.64% K]) to the planting. The fertigation system consisted of an additional two drip lines similar to those used for irrigation, with one line on each side of the plant. Micronutrients (i.e., B, Fe, Mg, Mn, Mo, S, Zn) were applied monthly as foliar sprays. Iron chelate (Sequestrene®138 Fe [Becker Underwood, Inc., Ames, Iowa]) was injected monthly through the irrigation system.

The papaya plants used in this study were from the X17-2 × SR transgenic line which produces 66% hermaphroditic and 34% female plants (Davis et al., 2003). This clone was genetically modified to be resistant to Florida strains of papaya ring spot virus (PRSV), a potentially devastating disease in most areas of the world were papaya is grown, including Florida (Conover, 1964; Davis and Ying, 1994; Davis et al., 2003). Transgenic papaya plants were used to remove the risk of PRSV from impacting study results and completion. Papaya plants were grown from seed and transplanted when 15–45 cm in height on 4 May 2006 (trial 1) and 27 March 2008 (trial 2). Seedlings in trial 1 were transplanted from flats (630 mL $slot^{-1}$) after three months into 3.8 L containers (for two months prior to planting in the field), whereas seedlings in trial 2 were grown for three months in flats and then planted directly into the field. Originally 21 plants were placed per row with 3 plants per plant spacing; each spacing refers to a location where 1 plant remained after selection of hermaphroditic plants. The number of plants was later reduced to seven plants per row based on selection of hermaphroditic plants and rouging the female plants from the row. This method was used to maximize the number of hermaphroditic plants in the planting. Only hermaphroditic plants were used to collect plant physiological and yield data. Plants were established in the field for three to five months to ensure that they had acclimated to field weather and soil conditions before treatments were initiated. Commercial papaya cultivars generally have a life span of approximately 24 months in south Florida due to disease pressures and harvesting difficulties of taller plants.

2.2. Experimental design

The study included two different trials. Trial 1 was conducted between May 2006 and August 2007 and trial 2 between March 2008 and August 2009. Both trials used the same treatments and field configuration (Fig. 2). There were five treatments arranged in randomized complete block design. The five treatments were: (1) set schedule irrigation; (2) irrigation based on ET calculated from historic weather data; (3) soil water based irrigation set to irrigate at a soil tension of 10 kPa; (4) soil water based irrigation set to irrigate at a soil tension of 15 kPa; and (5) soil water based irrigation set to irrigate at a soil tension of 25 kPa. The set schedule consisted of irrigating between 1 and 1.5 h per day for 3 days a week to everyday depending on weather and crop conditions. The set schedule was based on irrigation practices observed in the Homestead, FL, area (J.H. Crane, personal communication, 2006). The historic ET irrigation schedule consisted of using historic monthly ET values from an on-site weather station (FAWN data; http://fawn.ifas.ufl.edu/) and estimated crop coefficients (K_c) (J.H. Crane, personal communication, 2005) to determine irrigation rates. Crop coefficients were based on the age of the plants in the field with 1.0 used for plants 0–3 months, 1.2 used for plants 4–6 months and 1.5 used for plants 7 months and older. The actual historic ET was tabulated as the product of the cropping coefficient and the respective monthly