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Crop coefficient, water requirements, yield and water use efficiency of sugarcane growth in Brazil

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ABSTRACT

A correct evaluation of water losses as evapotranspiration (ET) by crops is important for allocating irrigation water and improving water use efficiency. Field experiments were conducted throughout 2009/2010 (second ratoon) and 2010/2011 (third ratoon) in a sugarcane field of a commercial distillery located on the coastal area of Paraiba state, Brazil. The main objective of this study was to determine crop coefficient, water requirements and water use efficiency (WUE) of sugarcane grown in a tropical climate. The experimental design was by randomized block design with four irrigation treatments and three replications using two center pivots. Crop evapotranspiration (ET) was determined by field soil water balance and reference evapotranspiration (ET_o) was obtained based on Penman–Monteith method (FAO/56), using data of air temperature, relative humidity, wind speed and solar radiation from Data Collection Platform, located next to the experimental site. The experimental area was cultivated with irrigation applied weekly by a center pivot system in addition to rainfall. The irrigation scheduling was based on four irrigation levels ($T1 = 25\%$, $T2 = 50\%$, $T3 = 75\%$ and $T4 = 100\%$ of ET_o). Results showed that ET and WUE are strongly influenced by soil water availability. When averaged across two years, productivity increased according to increases in water level. Sugarcane ET ranged from 2.7 (rain-fed condition) to 4.2 mm day^{-1} (100% ET_o irrigation treatment)

1. Introduction

In a tropical area with sub humid climate, evapotranspiration ranges over a large interval depending on water amount. Tropical regions have a large variety of climates. In general, semiarid regions during dry season are characterized by high temperatures, high evaporation rates and low precipitation. It is also important to improve the estimates of crop water use in order to improve the irrigation design parameters and scheduling.

Brazil is one of the major sugarcane producing country in the world, with 8.36 million of hectares in planted area which provides 26.6 million of cubic meters in alcohol and 30 million of tons in sugar. However, only few analyses have been carried out in Brazil for studying sugarcane crop. Due to its application in the food industry and in the production of ethanol, a less polluting renewable biofuel (Menossi et al., 2008), sugarcane has great economic value, especially in Brazil (Pinto et al., 2005). In many regions of Brazil sugarcane is grown in rain-fed areas, especially in humid and subhumid regions in the southern parts of the country. However, full or supplementary irrigation is essential for the production of sugarcane in the northeastern region of Brazil, where the climate is predominantly semiarid with air temperature ranging from 20 to 40 °C and mean annual rainfall being about 800 mm (Silva et al., 2006).

Previous studies have shown the impact of extended reduced water availability on sugarcane production because high biomass crop requires large quantities of water for maximum production (Wiedenfeld, 2008). Much has been reported on different aspects of sugarcane growing, including crop coefficients (Watanabe et al., 2004); transpiration (Chabot et al., 2002); leaf and stalk extension, leaf area development; response to water stress (Inman-Bamber and Smith, 2005); yield and juice quality (Choudhary et al., 2004; Wiedenfeld, 2008); water-use efficiency (Inman-Bamber and McGlinchey, 2003) and evapotranspiration (Omary and Izuno, 1995). Even though Brazil is one of the major sugarcane producing countries in the world, studies on water requirements of sugarcane cultivated under tropical conditions in Brazil are scarce.

Reductions in sugarcane yield in rain-fed area are due to the "veranicos" (dry spells of more than 2 weeks during the rainy

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season). The water availability is the major cause of inter-annual yield variation and yield differences of sugarcane grown on different soils in Brazil (Van den Berg et al., 2000). Sugarcane is highly productive in tropical and sub-tropical areas of the world, but the water stress decreases plant productivity (Rodrigues et al., 2009). The crop coefficient plays an essential role in various agricultural practices and it has been widely used to estimate the actual ET in irrigation scheduling (Pereira et al., 1999). Empirical crop coefficients have been criticized as regards their meaning and use, because their values vary according to the conditions of both climate and crop stage under which they were derived. Doorenbos and Pruitt (1977) in FAO-24 and Allen et al. (1998) in FAO-56 suggested crop coefficient values for a large number of crops under different climatic conditions which are commonly used in places where the local data is not available. However, there is a need for local calibration of the crop coefficients under given climatic conditions (Kashyap and Panda, 2001).

This paper addresses possible errors in supplementary irrigation estimates for sugarcane grown in tropical environment, implying an increase in production cost and low crop yield. Our first objective was to determine the evapotranspiration, crop coefficient and water use efficiency of sugarcane grown in a tropical climate, Brazil. Conversely, our second objective was to analyze the relationship between leaf area index/evapotranspiration and sugarcane crop coefficient. This paper also compares rain-fed and irrigated agricultural production in study area.

2. Materials and methods

2.1. Experimental site

Field experiments were carried out from October 2009 to August 2010 (second ratoon) and from September 2010 to July 2011 (third ratoon) in a sugarcane field of commercial distillery located in the coastal area of Paraiba state, Brazil (latitude 6°54′59″S; longitude 35°09′17″ W; altitude 121 m). The study crop was sugarcane (*Saccharum* spp.), cultivar RB 92 579. The mean annual rainfall in study area is about 1500 mm and mean annual air temperature ranges from 23 °C (rainy season) to 27 °C (dry season), while the rainy season generally starts in March and ends in August (Silva, 2004). The local climate is tropical wet with tropical savanna vegetation and the soil type is Lixisols (FAO soil taxonomy) (Silva et al., 2010).

A trench was open in the experimental site for extracting soil samples that were used to determine the textural class, bulk density, porosity, and field capacity and wilting point. The groundwater level at the experimental site dropped down to 3.0 m during the growing season. The experimental area was cultivated with irrigation applied weekly by a center pivot system, in addition to rainfall. Irrigation scheduling was based on four irrigation levels: $T1 = 25\%$, $T2 = 50\%$, $T3 = 75\%$ and $T4 = 100\%$ of ET_o (reference evapotranspiration), which was obtained by the Penman–Monteith approach (Allen et al., 1998).

2.2. Measurements

Daily measurements of air temperature, wind speed, solar radiation and relative humidity for estimating ET_o as well as rainfall were made on a data collection platform (DCP) located near the experimental site. The soil water content was measured every 2–3-days from October 10 to August 25 in both experimental years using a profile probe PR2 sensor and an HH2 data logger (Delta-T Devices LTA). Once a site specific calibration was identified as necessary for the PR2 probe , we used in situ calibrated equations for estimating soil water content. The voltage outputs were converted to θv using the following equation: $\sqrt{\varepsilon} = a_0 + a_{1.}\theta$, where $\sqrt{\varepsilon}$ is the root square of the permittivity, θv is the volumetric water content (cm^3/cm^3) and default a_0 and a_1 parameters are provided by Delta-T Devices, for mineral ($a_0 = 1.6$, $a_1 = 8.4$) and organic ($a_0 = 1.3$, 7.7) soils. However, the calibration coefficients for the experimental site were $a_0 = 1.51$, $a_1 = 8.73$. The soil water content was monitored at 0.10 m intervals down 1.0 m starting at 0.10 m. For representative measurements of soil water content by the profile probe, 9 access tubes were inserted into the ground at the experimental plot for each irrigation treatment and rain-fed conditions, and then the mean soil water content was computed as the arithmetic mean of the water content values observed from access tubes.

Crop parameters were measured during different stages of sugarcane growth. The crop data included the planting date, 10% cover date, full cover date, maturity date, harvest date, and leaf area. One plot of $30\,m^2 \times 30\,m^2$ size was selected in a sugarcane field for obtaining crop parameters and soil water content. The main experimental area was surrounded by other sugarcane fields of 8000 ha. The leaf area was obtained by gravimetric techniques. The gravimetric method correlates the dry weight of leaves and leaf area using predetermined green-leaf-area-to-dry-weight ratios (leaf mass per area, LMA). LMA is determined from a subsample extracted from the global field sample (Jonckheere et al., 2004). The leaf area index was calculated from the measured mean leaf area dividing the plot area.

2.3. Determination of soil water balance

The soil water balance in the root zone over a given time interval was calculated from the mass conservation equation expressed as:

$$\Delta S = R + I + CR - RO - D - ET \qquad (1)$$

where ΔS is the change of water storage in root zone, R is the rainfall, I is the irrigation depth applied, RO is the runoff from the soil surface, CR is the capillary rise, D is the drainage at depth z, below the root zone, and ET is the actual evapotranspiration. All the water balance components are in mm. Surface runoff was neglected, once the experimental site had flat topography. Similarly, CR was assumed to be zero because the water table was more than about 1 m below the bottom of the root zone at the experimental site. The change in soil water storage (ΔS) was determined as:

$$\Delta S = S_t - S_{t-1} \qquad (2)$$

where S_t and S_{t-1} are the changes in soil water storage at times t and $t-1$, respectively. The changes in soil water storage (S_L) were determined by considering the soil layers from the surface ($z = 0$) down to the bottom of the soil depth measurements ($z = 0.6$ m). For subsequent soil layers, soil water content values from the upper and lower borders of each layer were averaged to find the mean water content of the entire layer. Deep drainage (D) in the root zone following a heavy rain or irrigation was calculated as a residual from van Genuchten (1980), following Azevedo et al. (2006).

3. Results and discussion

At various times during the growing season, sugarcane leaf area and calculated leaf area index (LAI) were determined. During the entire growth season, LAI ranged from 1.50 to 5.62 $m^2\,m^{-2}$, following a similar course of crop coefficient (Fig. 1). For some intervals of the curve, due to a number of operational problems related to sampling of leaf area, LAI was not available. During the initial and development stages, in both cycles, LAI increased rapidly reaching a maximum value around the day of year (DOY) 170 and ranged between 5.0 and 5.5 $m^2\,m^{-2}$. There after, LAI decreased slowly