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Sugar cane crop coefficient by the soil water balance method

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Current assay, conducted on the experimental farm of the Goiás Federal Institute, campus at Urutaí GO Brazil, determines the crop coefficient (*Kc*) for sugar cane in the Brazilian savannah at several phases of development. *Kc* was determined by the soil water balance method in a 3.0 m^3 suspended drainage lysimeter, measuring 1.0 m in width and height and 3.0 m in length. Reference evapotranspiration (ET_0) was determined by Penman-Piche's equation with data on air evaporating capacity with Piche's evaporimeter. Crop evapotranspiration (ETc) was performed by the amount of water available at the bottom of the lysimeter. Irrigation occurred when water capacity on the soil reached -100 KPa, by employing drip subsurface irrigation system. Coefficients of sugar cane crop at different phases were 0.31 (initial), 1.15 (crop development), 1.25 (mid-season) and 0.90 (late season). Crop coefficient values were similar to the suggested by FAO-33.

Key words: *Saccharum officinarum* L., drainage lysimeter, drip subsurface irrigation, evapotranspiration of crops.

INTRODUCTION

Sugar cane is a highly relevant crop in agribusiness worldwide due to the production of most biofuel and high capacity for production expansion, especially in tropical and subtropical regions. Very important sugar cane planting areas occur in the Brazilian savannah, occupying approximately 2,550,000 ha, producing 28.6% of all the sugar and alcohol in Brazil (CONAB, 2014). The savannah of the central-western region of Brazil is characterized by severe water deficits, with yearly rainfall ranging between 800 and 2000 mm, in a seasonal

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Abbreviations: D, Drainage (mm); **DAP,** Days after planting; **ET,** Evapotranspiration (mm); **ET_0,** Reference evaporation-transpiration (mm); **ET_c,** Crop evapotranspiration (mm); **I,** Irrigation (mm); ***Kc*,** Crop coefficient; **R,** Rainfall (mm); **Tmax,** Maximum temperature (°C); **Tmin,** Minimum temperature (°C); **UR,** Relative air humidity (%).

climate alternating the rainy and dry periods which, according to the region, may vary from 4 to 7 months (Assad, 1994). Irrigation in such cases is fundamentally and economically feasible, especially when efficient management is employed. According to Doorenbos and Kassam (1979), adequate moisture during the entire growing period is important for maximum yields. In fact, vegetal growth is proportional to transpired water.

Kashyap and Panda (2001) report that precise estimates for the crop's water demand is an important aspect for planning. Water amount varies according to specific crops and even between their different periods of development. Crops' water needs are normally expressed by evapotranspiration rate (ET), in d^{-1}. The empirically determined crop coefficients (*Kc*) may be employed to relate reference evapotranspiration (ET_0) to maximum evapotranspiration of the crop (ETc), when water supply fulfills the water needs of each crop.

In order for the irrigation management to be efficient, irrigation water foregrounded on crop coefficients which meet the true water requirements of crop conditions is used (Gomes et al., 2010).

Although, Doorenbos and Pruitt (1977) recommend coefficient rates for several crops at different development phases, it is highly important to calibrate crop coefficient for each region since rates may be strongly affected by climate conditions. The lysimeter method to obtain actual evapotranspiration was used with high precision in many researches (Xu and Chen, 2005; Allen et al., 2011; Valipour et al., 2013; Valipour, 2015). The crop coefficients of sugar cane from lysimeter have not been determined for conditions of the Brazilian savannah.

Considering the importance of adequate supply of water for sugarcane cultivation and the adequate management of water resources for agricultural production, the present study aims to determines crop coefficient for sugar cane in the Brazilian savannah during the crop's several development phases, by the soil water balance method, with a drainage lysimeter. This effort aims at contribution to the sugarcane production in the region and further management of irrigation works.

MATERIALS AND METHODS

The present work was performed on the experimental area of the Instituto Federal Goiano, campus at Urutaí GO Brazil, latitude 17°46'78"S and longitude 48°20'75"W, mean altitude 740 m. According to Köppen classification, the region's climate is Aw (tropical), with rainfall between October and May, and a dry season between June and September. The experiment was developed between August 2012 and September 2013.

Sugar cane crop coefficient was determined by the soil water balance method. The amount of water in the soil was calculated with a suspended drainage lysimeter which stored percolated water. The 3.0 m^3 volume lysimeter was made of steel and wood, with a thickness of 0.03 m, and measuring 1.0 × 3.0 m (height × width). Its inside was coated by a corrosion-resistant plastic sheet. Drainage occurred through an orifice at the bottom which directed the flow of water to a 15 L-collector.

The lysimeter was filled first by a 0.05 m layer of thick sand and a 0.03 layer of size 2 pebbles to facilitate water drain. A plastic 16-mesh sheet was then placed to avoid the entrance of soil in the drainage area. Figure 1 shows the development of sugar cane plants in the drainage lysimeter throughout the crop cycle.

Soil was initially limed and fertilized with 0.1 kg urea, 0.0105 kg simple superphosphate and 0.029 kg potassium chlorate when the sugar cane was planted, following recommendations by Raij et al. (1997). Urea was applied in two phases, or rather, 50% on planting and 50% after 190 days after planting.

Crop implantation in the lysimeter occurred in double rows, with 16 shoots per square meter, distributing 1.5 kg/m^2 of shoots. Irrigation consisted of the subsurface drip method. The drip tube was placed 0.25 m deep under the soil surface and between the plantation furrows in a double row. Nominal discharge was 1.6 L h^{-1} and a 0.20 m distance was kept between the pipes.

Irrigation occurred when water potential in the soil was -100 KPa. Irrigation water was determined by the relationship of the water volume applied by the area of the lysimeter. A 0.1 L precision hydrometer was installed within the irrigation line to monitor exactly the volume of water applied. Amount of drained water was determined by the relationship between the water volume collected by the receiver and the area of the lysimeter.

Equipments for monitoring local climate were installed on the experimental area, following FAO, whilst meteorological parameters were registered daily at 9 am. Rainfall was measured by a Ville-de-Paris pluviometer placed 1.5 m above the ground, with a measuring cylinder for reading in millimeters. Temperature and relative air moisture were registered by digital maximum-minimum thermo-hygrometer installed within a meteorological cabinet on the experimental area, 1.0 above ground level, and in a North-South position.

Piche evaporation method (Stanhill, 1962) was placed in the meteorological cabinet to determine the evaporating capacity of the air, whereas the mathematical model proposed by Penman-Piche (Papaioannou et al., 1996) was employed to calculate evapotranspiration (Equation 1). According Pereira et al. (2002), these equations are utilized to dispense tem measures of wind speed and saturation deficit. Fernandes et al. (2011) reported being satisfied to estimate the reference evaporation measured by the Piche evaporimeter in conditions of climate type Aw, hot humid tropical.

$$ET_0 = \frac{0.28Pi}{(1-W)} \quad (1)$$

where ET_0 = reference evapotranspiration in mm; *Pi* = evaporation measured by Piche evaporation meter in mm d^{-1}.

W is a function of the humid bulb, defined by Makkink (1957), according to Equations 2 and 3. The graph of the psychometric diagram was used to determine the temperature of the humid bulb.

$$W = 0.407 + 0.0145\,TU, \quad for\ 0°C \le TU \le 16°C \quad (2)$$

$$W = 0.483 + 0.0100\,TU, \quad for\ 16.1°C \le TU \le 32°C \quad (3)$$

where *W* = function of the humid bulb (a-dimensional); *TU* = temperature of humid bulb, °C.

Crop evapotranspiration was determined by the water balance in the lysimeter, following Equation 4. Since water balance was determined between two successive irrigation occurrences,

Figure 1. Suspended drainage lysimeter with sugar cane crops at different development phases.

moisture variation in the soil is negligible. In fact, prior to irrigation, water content in the soil was in a critical tension for irrigation (-50 KPa) and *ET* is the data average in time intervals between irrigations (Aboukhaled et al., 1982).

$$ET = R + I - D \quad (4)$$

where *ET* = evapotranspiration of sugar cane, mm; *R* = rainfall, mm; *I* = irrigation, mm; *D* = drainage, mm.

The crop coefficients (*Kc*) of sugar cane were calculated from ET_0 obtained by the Penman-Piche equation and by ETc rates obtained from the water balance in the lysimeter, according to Equation 5.

$$K_C = \frac{ET_C}{ET_0} \quad (5)$$

Sugar cane plants were harvested on 360 days after planting (DAP) by cutting off the aerial section; only one entire bud per plant remained in the lysimeter. Stem length was measured from the base to the emission of leaf + 1, coupled to weight of plants, to determine the total mass produced in the lysimeter.

RESULTS AND DISCUSSION

Climate variables

Figure 2 shows maximum and minimum temperatures and mean relative air humidity throughout the experiment. Temperature was stable during the whole crop cycle, oscillating between 20 and 30°C during most of the experimental period. Mean relative air humidity from November to March (70 to 220 DAP) was over 60%, precisely the rainfall period in the region. Relative humidity remained between 45 and 60% during the other periods.

Doorenbos and Pruitt (1977) report that climate is one of the most important factors that determine the water requirements of a crop, with the best growth and yield, without restrictions. Figure 3 shows rainfall and

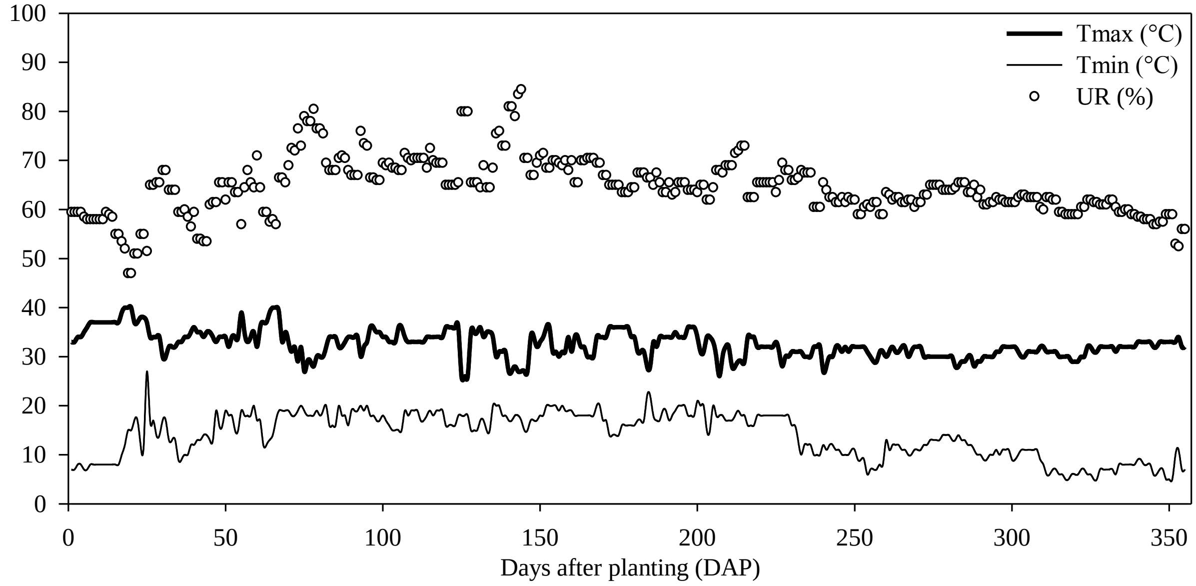

Figure 2. Variation of maximum (Tmax), minimum (Tmin) temperature and mean relative air humidity (UR, %) in the sugar cane crop area during the experiment.

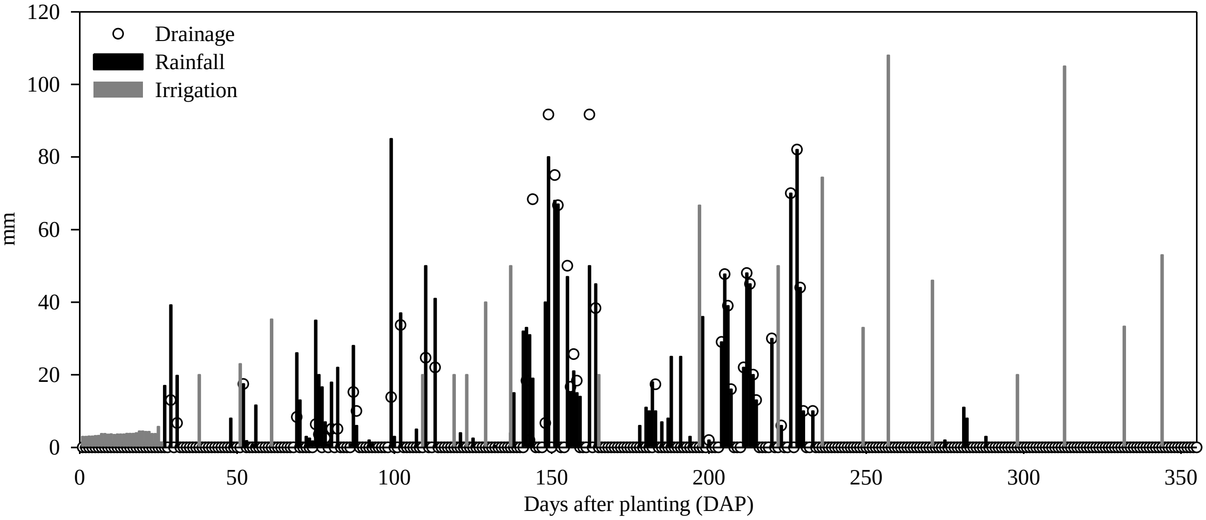

Figure 3. Seasonal period for water supply (rainfall and irrigation) for sugar cane plants and drainage of lysimeter throughout the experiment.

irrigation during the experimental period with sugar cane crop. Water irrigations in small volumes were daily undertaken from planting to 30 DAP to maintain soil moisture and thus favoring budding and the establishment of the crop. Afterwards, irrigations were undertaken according to the crop's needs, based on reference evapotranspiration (ET_0) to raise soil moisture to field conditions and capacity. Rainfall was mostly concentrated between November and March (70 - 220 DAP) when almost 80% of rainfall occurred during the experimental period. Total rainfall during the crop cycle reached 1,860.7 mm, whereas water volume by irrigation totaled 1,033.2 mm.

Drainage of the lysimeter, totaling 1,307.7mm, occurred only during rainfall, whereas the volume of water provided by irrigation was not sufficient for soil saturation.

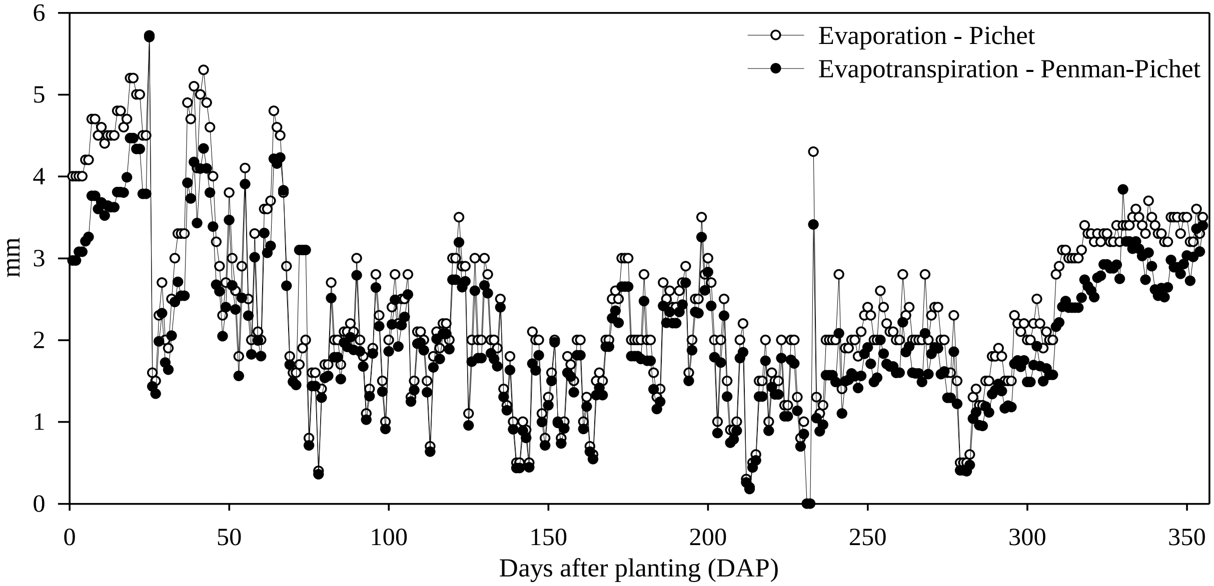

Figure 4. Seasonal evaporation and evapotranspiration period in the area of sugar cane crop during the experiment.

Consequently, total water volume received by the crop was the sum of rainfall and irrigation volumes minus drainage volume, totaling 1,586.2 mm, as Equation 4 shows.

Figure 4 shows daily evaporation determined by Piche evaporation meter and reference evapotranspiration calculated by the Penman-Piche model during the whole experimental period. According to the model, lower relative air humidity rates occurred with great discrepancies between rates for evaporation and reference evapotranspiration, perhaps due to the increase in the evaporating capacity of the air because of a decrease in relative humidity. However, stomata resistance of the crop normally does not follow the demand of air moisture.

Total evaporation registered by Piche evaporation meter reached 857.0 mm, whereas Penman-Piche model revealed total evapotranspiration of 738.3 mm, or a 16.1% difference. The amount of water vapor flow to the atmosphere from humid surfaces coupled to plant transpiration (evapotranspiration) in cultivated areas is highly relevant to determine the water requirements of crops and the soil's water availability (Nascimento et al., 2011).

Crop evapotranspiration and reference evapotranspiration

Figure 5 demonstrates the distinction between crop evapotranspiration (ETc) obtained by water balance in the lysimeter and the reference evapotranspiration (ET_0) accumulated throughout the sugar cane cycle. There were lower ETc rates during the crop's initial phase when compared to ET_0, due to the budding stage and the establishment of sugar cane crop. The second phase shows ET_0 mean daily rate below than ETc, probably due to the addition of leaf transpiration caused by a fast production of photoassimilates during the period.

Farias et al. (2008) evaluated the development of sugar cane under irrigation in the northeastern region of Brazil and reported high growth rates in the leaf area during this phase, with a maximum at 150 DAP. Throughout the phenological stage of maximum sugar cane growth, the daily ET_0 rates averaged 66.7% lower than ETc ones. Transpiration during the maturation phase was less, since ET_0 was closer to ETc, averaging only 28.6% mean daily rate lower.

ETc of sugar cane totaled during the cycle was 1,438.23 mm, whereas ET_0 was a total of 738.32 mm. Mean daily ETc during the sugar cane cycle crop was 4.05 mm, with maximum rate at 5.28 mm in the phenological stage of maximum crop growth (Figure 5).

Crop coefficient for sugar cane

According to Oliveira et al. (2003), crop coefficient is the connection of the effects of the three characteristics distinguishing ETc from ET_0: crop height, surface resistance and reflection coefficient or albedo of the crop-soil surface.

The variation of the crop coefficient (*Kc*) of sugar cane determined by the relationship between ETc and ET_0

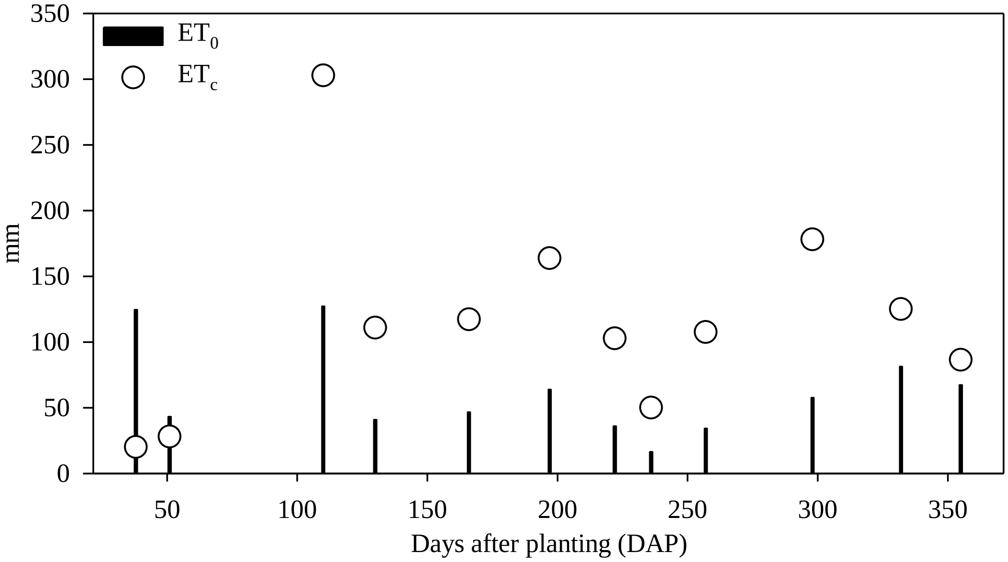

Figure 5. Reference evapotranspiration (ET_0) and crop evapotranspiration (ETc) accumulated throughout the sugar cane cycle.

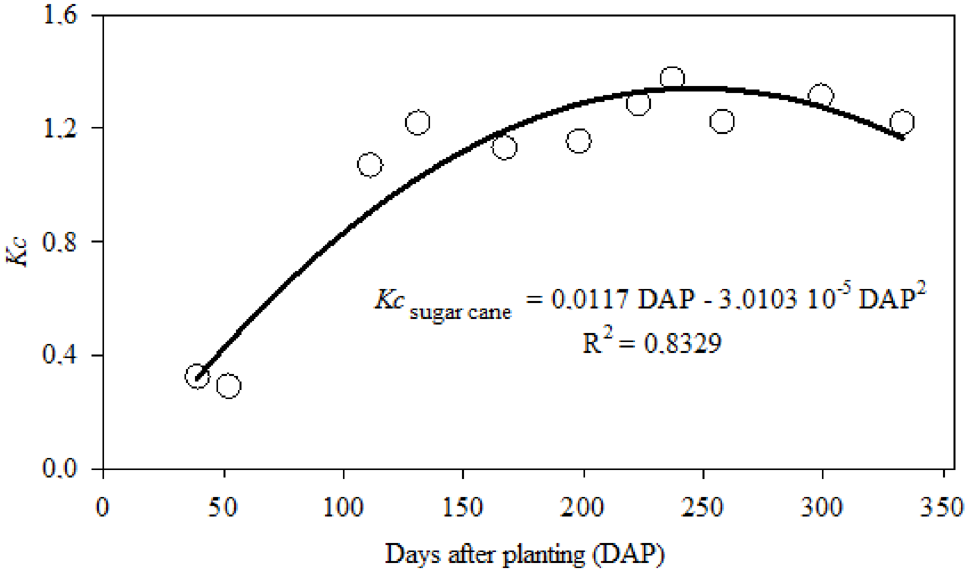

Figure 6. Crop coefficient (*Kc*) during the sugar cane crop cycle.

throughout the crop cycle produced a quadratic model (R^2 = 0.8329) (Figure 6). The coefficient of determination 0.8329 show a good adjustment between rates for *Kc*, enhancing the relevance of the referred to results for sugar cane irrigation management in the savannah region.

Melo et al. (2013) report that variations in *Kc* rates at short time intervals are caused by microclimate variations, differential growth of the plants, measurement mistakes due to hysteresis caused by the addition of water and by the loss of irrigation water by evaporation, expansion and contraction caused by temperature variations during the day, and other factors.

Maximum *Kc* estimated by adjustment model reached 1.29 at 225 DAP. Oliveira et al. (2010) reported the highest production rate of dry matter in the stem of sugar

Table 1. Coefficient of sugar cane crop based on soil water balance with drainage lysimeter and on rates recommended by FAO.

Growth stages	Corresponding period (DAP)	Development phases (days)	*Kc* - FAO	*Kc* obtained
Initial	0-60	60	0.4	0.31
Crop development	61-130	70	1.25	1.15
Mid-season	131-300	170	1.2	1.25
Late season	301-355	55	0.75	0.90
Mean			0.90	0.90
Total		355		

cane plants cultivated under a full irrigation system, between 180 and 240 DAP. They underscored that during this period the crop´s maximum water need occurred for the translocation of the substrate and cell expansion, with maximum effects on the crop´s yield.

The water requirement of sugar cane crop for the region may be obtained during the crop cycle by the following rates of *Kc*: 0-60 DAP (initial) – 0.4; 61-130 DAP (crop development) – 1.25; 131-300 DAP (mid-season) – 1.2; 301-355 (late season) – 0.75.

Rosenfeld and Leme (1984) studied regional periods for sugar cane in the state of São Paulo, Brazil, and concluded that the highest reductions in productivity occurred with water deficiencies during the first eight month of the crop cycle. Based on an analysis of water deficiency at different periods of the crop cycle, Scardua (1985) reported that during the first development period (budding, tillering and establishment), productivity decrease was greater than that during the second period (vegetal production); deficit effect during the third period (maturation) is negligible. According to the same author, water deficit during the first phases may cause a worse root development and low tillering, with low use of water and nutrients available during the latter periods. Doorenbos and Kassam (1979) also reported that the effect of water on crop yield during the maturation period affected productivity only slightly.

The determination of *Kc* rates for different development phases of sugar cane was important for the comparison of results with *Kc* rates proposed by Allen et al. (1998), employing the parameter suggested by FAO (Table 1).

The greatest distance between *Kc* (FAO) rates and *Kc* rates determined with the present work was reported in Phase I, with a 22.5% reduction in current study. Similarity between rates in both studies could be observed in later phases, with an 8% reduction of *Kc* obtained in Phase II and a 4.17% increase in Phase III. A *Kc* increase occurred at the end of the crop cycle (Phase IV) with regard to *Kc*–FAO, with a 20% difference between *Kc* obtained (0.90) with regard to *Kc*–FAO (0.75), *which* is due to the region´s soil and climate specificities. In fact, the physiological conditions of sugar cane, as a C4 crop in a subtropical climate, are greatly affected by the highest mean temperature during the crop cycle.

In spite of the variations in the different phases of crop development, similarity was extant between observed *Kc* rates and the coefficients suggested by FAO-33, since general average was identical (0.90). Although, there is an analogy between average coefficients, the determination of *Kc* for sugar cane crop, adjusted to the soil-climate conditions of the region under analysis, is extremely important for the precise water supplementation in each development phase of the crop. There was not only a decrease in the irrigation regime in Phases I and II without any liabilities for the crop, but an increase in Phase IV provided the best water condition for maximum production of sugar cane biomass.

Mean length of sugar cane stems was 2.20 m, with mean 20 internodes per plant, reaching a mean length of 0.11 m for each internode. Sugar cane yield irrigated by subsurface drip method established in the drainage lysimeter reached 144 Mg ha^{-1}.

Total water volume received by the crop was calculated by the sum of rainfall and irrigation rates minus the drained volume. The efficiency of water use by the sugar cane crop was calculated by dividing total volume of received water (mm) by stem productivity (Mg^{-1} ha^{-1}), with an efficiency of 10.5 mm Mg^{-1} ha^{-1}.

Conclusions

The crop coefficients of sugar cane for edaphoclimatic conditions of the savannah region were similar to the coefficients suggested by FAO-33. The crop coefficients of sugar cane from distinct phases were 0.31 (initial), 1.15 (crop development), 1.25 (mid-season) and 0.90 (late season).

The use of crop coefficients for each region is basic for precise water supplementation in each development phase of the crop. The determined values of Kc can be recommended to be used in future works of hydric supplementation for sugar cane in the Brazilian savannah.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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