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Soil moisture tension effect on sugar cane growth and yield

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ABSTRACT

An experimental plot was established in Campeche, México, to assess the effect of moisture tension on sugarcane growth and yield. Irrigation and water efficiencies were calculated as well as the cane and sucrose virtual water contents. Three levels of soil moisture tensions (−15 kPa in T1, −45 kPa in T2, −75 kPa in T3) were used to begin irrigation in treatments compared with a control without irrigation (T4), in an experimental randomized block design. Height and stem diameter were significantly higher ($p \leq 0.05$) in T1, treatment where also significantly higher cane and sucrose yields were observed (134.7 and 19.9 t ha^{-1}, respectively). No significant differences in industrially relevant variables for the quality of sugar cane juice were found, although in T3 the highest Brix degrees and sucrose content in juice were obtained. Also in this treatment the highest irrigation water use efficiency (*IWUE*) was found, with an average increase in cane weight of 405 kg mm^{-1}. Overall, the *IWUE* and the total water use efficiencies were directly and inversely proportional to the soil moisture tension, respectively. Irrigation water applied varied from 14.0 to 19.56% of the total water depth received by the crop for treatments T3 and T2, respectively, and contributed to a gain in cane and sucrose yields of 179–252%, and from 181 to 242%, for T3 and T1 treatments, respectively. For total cane and sucrose virtual water values, a direct relationship with the soil moisture tension was found. The highest value in cane blue virtual water was found in T2 (0.0274 m^3 kg^{-1}) and the lower in T3 (0.0247 m^3 kg^{-1}). In contrast, higher values of cane green virtual water were found at higher soil moisture tensions (Control treatment, 0.271 m^3 kg^{-1}). Since the final sucrose yield was strongly linked to the cane yield, a very similar behavior as for cane blue and green virtual water values was observed for sucrose blue and green water contents.

1. Introduction

Sugar cane is one of the main crops established in Mexico. The cultivated area in the country was of 828,600 ha in 2014, with a mean crop yield of 74.4 t ha^{-1} (SIAP, 2015), lower than that obtained in the main producing countries, due to several factors, such as: absence of effective schemes for irrigation water management, low efficiency of fertilizer use, and few initiatives to plant or create new varieties. Since the distribution of rainfall throughout the year in Mexico is very irregular, the application of irrigation water to the sugar cane is a factor that greatly determines the final crop yield.

The steady increase in demand for water to meet the needs of a growing population, requires an increasingly efficient water use in agriculture, because the demand for water has increased in the urban and industrial sectors (Inman-Bamber and Smith, 2005). One aspect that has gained attention recently to quantify the efficiency in water use is to assess the present and future value of virtual water content (which is, according to Hanasaki et al., 2010: "the volume of water consumption required to produce commodities traded to an importing or exporting nation") in many different sectors of human activity (Deng et al., 2015), and also for different crops (Aldaya et al., 2010; Abu-Sharar et al., 2012; Vanham, 2013). In crops, the virtual water content (*VW*) is defined as the amount of water used to produce a unit of biomass or yield (Fader et al., 2010; Sun et al., 2013),

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and one of its uses, which has become important in recent years, is to use its value to quantify the implicit transfer of water between the countries through the international trade in agricultural products (Fader et al., 2010; Deng et al., 2015). Sun et al. (2013) indicated that very few studies distinguish between green and blue water in *VW*, and clearly show the difference: green water is the “rainwater consumed during the crop production process”, and blue water is defined as “surface or ground water consumed in crop production” (Hoekstra and Chapagain, 2007). Deng et al. (2015) pointed out that the agricultural sector has the lowest water use efficiency. So, the search for alternatives to increase water use efficiency and reduce the *VW* used in agricultural crops is of increasing importance.

An alternative to improve the management of agricultural water is to measure soil moisture tension using tensiometers, and use their value as an indicator of the most appropriate moment for crops irrigation (Richards, 1960; Gaudin et al., 1998; Rapanoelina et al., 1999). This methodology has the advantage that meteorological data is not necessary, information on the water consumption by crops is not required, a detailed monitoring of the soil moisture content is not necessary, and the reading of tensiometers is very easy. Moisture tension is one of the main components of total water potential in the soil, and therefore is involved in defining the hydraulic gradient within the soil profile. The latter, combined with the soil hydraulic conductivity, allows calculating the magnitude of soil-water flow to the roots through Darcy-Buckingham’s law (Rapanoelina et al., 1999; Gaudin and Rapanoelina, 2003).

Although the use of tensiometers to plan the implementation of the irrigation water in crops, is a practice that, according to Hodnett et al. (1990) has begun since the late 1940s, and recently is a methodology that has been increasingly used in several crops, experimental works in sugar cane like the one described herein are very scarce. Two of the early works in this field of knowledge, for sugarcane irrigated by furrows, were those of Clements (1950) and Waterhouse and Clements (1954). More recently, Hodnett et al. (1990) conducted one of the first works in which drip irrigation was evaluated. Wiedenfeld (2004) compared the use of tensiometers and a water balance method via estimates of crop evapotranspiration by using crop coefficients and “pan factors”, to plan the implementation of irrigation in the crop. Besides the work of Hodnett et al. (1990) and Wiedenfeld (2004), there has been very few works where tensiometers have been used to define the moment of irrigation in sugarcane; one interesting study (Gaudin et al., 1998; Rapanoelina et al., 1999) has been carried out in the west of Madagascar (Morondava region) with six arrays of tensiometers to map the water potential in row and inter-row of a deep sandy loam soil. In this case, the previous acquisition of the soil hydraulic conductivity enables analysis of potential maps throughout an entire year (Gaudin and Rapanoelina, 2003). Although in their work they defined the soil water potentials to be used as indicators of the beginning of irrigation in sugarcane (from −400 to −600 hPa in a sandy loam soil), the authors did not indicate the yield obtained in the crop, because their objective was to manage irrigation in order to avoid water losses by percolation below the root system of sugarcane, rather than relating tensiometric values with crop yield. Therefore, and considering that the use of tensiometers is becoming more common in many crops for planning the implementation of irrigation (Kang et al., 2004; Orozco-Romero and Pérez-Zamora, 2006; Wang et al., 2007; Rivera-Hernández et al., 2009; Rivera-Hernández et al., 2010; Sudhir-Yadav et al., 2011; Mahajan et al., 2012; Carli et al., 2014; Carrillo-Ávila et al., 2015), the present study aimed to contribute to generate recommendations for irrigating sugarcane, by complementing the results previously obtained in other studies. So, the main objective of this study was to evaluate the effect of the soil water tension as indicator of the

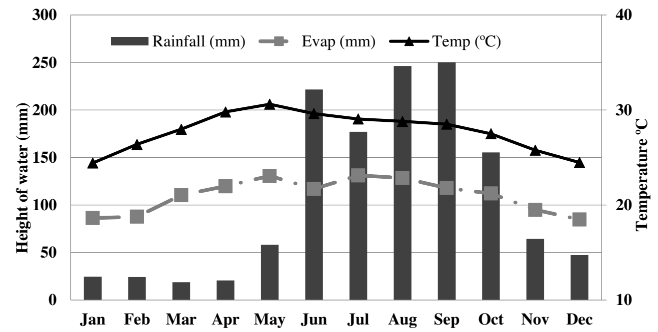

Fig. 1. Annual distribution of rainfall, evaporation and mean temperature in the experimental plot.

beginning of irrigation, on growth and yield, as well as on the water use efficiency and the virtual water values of sugar cane.

2. Materials and methods

2.1. Experimental plot

The experiment was conducted in the experimental field of the Colegio de Postgraduados Campus Campeche, located 65 km from the city of Campeche, with coordinates: 19° 29′ 55′ north latitude and 90° 32′ 45″ west longitude, at 16 m above mean sea level. The predominant climate is AW_0, according to the classification of Köppen, modified by García (1973); warm and sub humid weather with summer precipitations of 1290 mm per year, distributed primarily from June to October, in which about 80% of the rainfall occurs, on average. Mean monthly ambient temperature ranges from 24.4 °C (January) to 30.6 °C (May) and mean monthly evaporation from 84.7 mm (December) to 131.1 mm (July; Fig. 1).

The soil of the experimental field was a vertisol, classified as a clay according to the USDA triangle (76.7% clay, 14% silt, 9.3% sand), with a bulk density of 1.11 g cm^{-3}, and a soil porosity of 0.58, estimated with a soil auger veihmeyer type at the 0–30 cm of soil profile, based in a soil sampling of the entire experimental field. This study was carried out in the Yucatan Peninsula region, which has a limestone karst substrate. Soils in the area have generally high levels of calcium, with different textures ranging from very clayey (vertisol and gleysol) to silty (luvisols) or stony (rendzina). The soil was prepared for planting in April 2005. Sugarcane crop is propagated in a vegetative way by planting pieces of sugar cane stem; the planting of the sugarcane setts was done on June 24, 2005 in furrows 1.4 m apart. The sugar cane variety was Mex 69-290, one of the most used in the southeast region of the country.

2.2. Experimental design

The effect of irrigation on the yield of sugarcane was evaluated based on different values of the soil moisture tension at the beginning of irrigation, similar to the works of Kang et al. (2004), Orozco-Romero and Pérez-Zamora, (2006), Wang et al. (2007), Rivera-Hernández et al. (2009), Rivera-Hernández et al. (2010) and Carrillo-Ávila et al. (2015). A randomized complete block experimental design with four replications was used. The treatments corresponded to different soil moisture tension values at the time of irrigation, testing values of −15, −45 and −75 kPa, during crop growth stage (T1, T2 and T3, respectively). A control treatment without irrigation (T4) was also included. It should be noted that, although the experimental work was conducted in a clay soil, which may eventually be subject to shrinking and swelling, depending on its moisture content (Cornelis et al., 2006; Boivin, 2007; Chertkov, 2007), the moisture tension treatments were defined in a domain