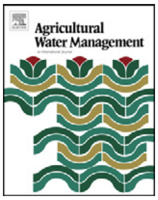
Agricultural Water Management 102 (2011) 1–7

Contents lists available at SciVerse ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat



Components of the water balance in soil with sugarcane crops

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ARTICLE INFO

Article history:
Received 21 April 2011
Accepted 27 September 2011
Available online 22 October 2011

Keywords:
Tensiometry
Nitrogen fertilizer
Saccharum spp.
Evapotranspiration
Hydraulic conductivity

ABSTRACT

The objective of this study was to analyze the components of the water balance in an Ultisol, located in the municipality of Jaboticabal, SP, Brazil (21°20′20″S, 48°18′35″W), that was cultivated with sugarcane. The monitoring was performed during the agricultural cycle of the first ratoon between 11/16/2006 and 7/9/2007. Three treatments were established in four blocks with doses of ammonium sulfate, as follows: *Treatment 1* (T_1), without fertilizer; *Treatment 2* (T_2), 100 kg ha^{-1} of nitrogen (N) and 114 kg ha^{-1} of sulfur (S); and *Treatment 3* (T_3), 150 kg ha^{-1} of N and 172 kg ha^{-1} of S. Rainy precipitation (P) in the area was measured with a rain gauge. The soil water storage (H) and the soil water storage variations (ΔH) were determined by the gravimetric method, and the internal drainage (D)/capillary rise (CR) at a depth of 0.9 m was quantified by the water flux density using the Darcy–Buckingham equation. The actual evapotranspiration (ET_a) was calculated as follows: $ET_a = P - D + CR \pm \Delta H$. During the study period, the amount of rainfall was 1406 mm, 121 mm greater than the historic average for the region (1285 mm), with a notable peak in the month of January of 402 mm (historic average: 251 mm). The internal drainage was 300 mm under T_1, 352 mm under T_2, and 199 mm under T_3, and this was relevant during times with elevated P, when the actual H was greater than the field capacity H. The actual evapotranspiration (T_1: −897.7 mm, T_2: −847.5 mm, and T_3: −970.8 mm) and the water use efficiency (T_1: −131.3 kg mm^{-1}, T_2: −146.6 kg mm^{-1}, and T_3: −127.5 kg mm^{-1}) did not differ among the treatments. The dispersion of D was greater than the other components of the water balance, especially during the period of elevated P, with the errors of this process propagated in the estimation of ET_a. Despite of this propagated standard deviation of ET_a, it accounted less than 15% of the total ET_a, showing that the method may be conveniently used in field studies with sugarcane crops.

1. Introduction

The potential impact of the increasing demand for bioenergy on agricultural water use is large (de Fraiture and Wichelns, 2010). In this context, in Brazil, sugarcane for producing ethanol has increased in cultivated area and productivity, mainly in São Paulo State. This highlights for agronomic research to focus on increasing overall water productivity as suggested by Rijsberman (2006). The study of the soil water balance components provides useful information for managing a crop in both, rainfed and irrigated agriculture, because this reveals the characteristics of the water in the soil–plant–atmosphere system during the crop development.

The water balance in the soil with an agricultural crop is calculated by accounting for the inputs and outputs of water within a given volume of control of the soil during a certain period of time, and it may be described by means of the processes that compose the terms of Eq. (1), as follows:

$$P + I - D + CR - ET_a \pm R \pm \Delta H_z = 0 \tag{1}$$

where P is the rainy precipitation; I is the irrigation; D is the internal drainage; CR is the capillary rise; ET_a is the actual evapotranspiration of the crop; R is the runoff; and ΔH_z is the soil water storage variation until the control depth, Z.

The soil water balance equation is easy to understand but difficult to determine in practice, as it can only be resolved when no more than one term is unknown. The difficulties arise from the complexity of the processes in the soil–plant–atmosphere system and from problems in the precise measurement of the above-mentioned phenomena. These difficulties may generate significant errors that lead to erroneous interpretations of the phenomena, which must therefore be studied in depth.

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doi:10.1016/j.agwat.2011.09.010

The water inputs into the system due to rainfall precipitation or irrigation are relatively easy to determine, and when the area is flat, the runoff may be considered equal to zero. The water content in the soil profile and the variation in storage may also be measured by reliable methods, and it is not very difficult to calculate these values initially. One of the most difficult processes to determine directly is the actual evapotranspiration, for which reason it is calculated from the other terms of the equation or estimated using meteorological data and crop coefficients (da Silva et al., 2007; Allen et al., 2011).

A major potential source error in ET determined by the soil water balance method is uncertainty in the internal drainage and the capillary rise into the zone sampled (Allen et al., 2011). The Darcy–Buckingham equation has frequently been employed to estimate D/CR (Brito et al., 2009) and this equation requires knowledge of the soil hydraulic conductivity as a function of the water content, $K(\theta)$, and also of the soil water total potential. Tensiometers may be used to determine the hydraulic gradient and the water content necessary for the $K(\theta)$ ratio. The spatial variability of the soil attributes, along with the exponential character of the $K(\theta)$ function and the precision of the measurements of the water content and the soil water total potential, may not produce consistent estimates of the drainage, making these factors the main problem when this methodology is used (da Silva et al., 2007; Ghiberto et al., 2009, 2011).

Given the importance of better understanding the processes involved in the water balance in tropical soils with sugarcane crops, the objectives of this study were the following: (a) to evaluate the processes involved in the water balance equation in a soil with a sugarcane crop; (b) to determine the sugarcane water use efficiency; and (c) to verify the influence of fertilization on the water consumption of the crop.

2. Materials and methods

2.1. Description of the study area

The experiment was conducted in the area of sugarcane production of Usina Santa Adelia, located in the municipality of Jaboticabal, Sao Paulo State (SP), Brazil, at 21°20′20″ south latitude, 48°18′35″ west longitude and at an altitude of 608 m. The area presents a slightly rolling slope, between 2% and 4%, but the plots of the experiment were installed on the summit, where the slope is <2%. The soil with which the evaluations were performed is an Arenic Kandiustults with a silt–clay–sandy texture (Ghiberto et al., 2009). The climate, according to the Köppen classification, is of the Aw type: tropical savanna. The average annual temperature is 22.6 °C, and the average annual rainfall is 1333 mm, which is concentrated between December and March (853 mm). Sentelhas et al. (2009), using the Thornthwaite and Matter (1955) method, determined that the annual potential evapotranspiration is 1115 mm, and the actual evapotranspiration is 987 mm. Between December and March, an excess of water is produced (346 mm), considering the available water holding capacity of 100 mm to a depth of 1.0 m.

2.2. Experimental design

The components of the water balance of the soil under sugarcane cultivation were evaluated during the agricultural cycle of the first ratoon, which was fertilized with ammonium sulfate during the period between 10/23/2006 and 7/9/2007. The sugarcane (SP81-3250 cultivar) was planted between the 4th and the 8th of April 2005, and the plant cane harvested in June 2006. After harvest of the plant cane, three treatments were established, which were randomly distributed into four blocks with one repetition per block. The treatments consisted of the application of nitrogen (N) and sulfur (S), in November of 2006, with the following doses: *Treatment 1* (T_1): control, with no fertilizer; *Treatment 2* (T_2): 100 kg ha^{-1} of N and 114 kg ha^{-1} of S; and *Treatment 3* (T_3): 150 kg ha^{-1} of N and 172 kg ha^{-1} of S. Vinasse was applied for 10 consecutive years before the implantation of sugarcane (de Oliveira, 2011). More details of the experiment can be found in Ghiberto (2009) and Franco et al. (2011).

2.3. Components of the water balance in the soil

The experimental area was managed in a rain-fed system, then, the I component was considered to be equal to zero. The R component was also disregarded in the balance equation considering that the high soil hydraulic conductivity near saturated condition (Ghiberto et al., 2009; Ghiberto, 2009) and the maintenance of high quantity of crop residues (trash) over the soil surface (harvesting without burning the straw) prevents the runoff. The measurements of the other components of Eq. (1) were obtained as described below.

2.3.1. Precipitation (P)

Data on the daily rainy precipitation were obtained from a rain gauge installed at the location of the experiment and were compared with the historical series of precipitation in Jaboticabal, between 1936 and 2004, as obtained from Sigrh (2007).

2.3.2. Soil water storage (H)

The storage of water in the soil (H) was determined by gravimetric analysis for each one of the repetitions approximately every 20 days. Samples of soil drawn from the following layers were obtained using a Dutch auger: 0–0.15, 0.15–0.25, 0.25–0.35, 0.35–0.45, 0.45–0.55, 0.55–0.65, 0.65–0.75, 0.75–0.85, 0.85–0.95, and 0.95–1.05 m. Each sample was placed in an aluminum container and hermetically sealed to avoid water loss. Once in the laboratory, the moist soil was weighed, and mass of the dry soil was determined after drying the moist soil in a stove at 105 °C for 48 h. At the same layers, undisturbed soil samples (5 cm × 5 cm cores) were collected to determine bulk density for each one of the repetitions (Blake and Hartge, 1986). Subsequently, using the gravimetric water content and the bulk density, volumetric water contents (θ) were calculated, along with the H. The variation of the water storage in the soil profile (ΔH) was calculated by the differences of the water contained in the soil on consecutive sampling dates.

2.3.3. Internal drainage (D) and capillary rise (CR)

The water flux density in the soil at a control depth (D or CR) was estimated by the Darcy–Buckingham equation:

$$q_{z=0.9} = -K(\theta)\left[\frac{\Delta(\psi_t)}{L}\right] \qquad (2)$$

where q_z is the soil water flux density (m d^{-1}) at 0.9 m of depth; $K(\theta)$ is the hydraulic conductivity of the soil as a function of the water content θ at 0.9 m of depth (m d^{-1}), and $\Delta\psi_t/L$ is the soil water total potential gradient. The control depth of 0.9 m was selected because the greatest proportion of active roots is found down to this depth (Reichardt and Timm, 2004) and this fact was measured in our experiment in the cane plant cycle by Otto et al. (2009).

For the daily determination of $K(\theta)$ and $\Delta\psi_t/L$, tensiometers were installed at depths of 0.8, 0.9, and 1.0 m in each one of the plots of the different treatments, in similar quota of land, for a total of 36 instruments. The readings of the tensiometers were performed daily (260 days) between 07:00 and 08:00. With the tensiometers installed in the crop rows near of the cane stool, at 0.8 m and 1.0 m in depth, $\Delta\psi_t/L$ was determined. The soil water total potential gradient was calculated as $(\psi_t^{(0.8)} - \psi_t^{(1)})/0.2$, where $\psi_t^{(0.8)}$ and $\psi_t^{(1)}$ are