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Water storage in the soil profile under subsurface drip irrigation: Evaluating two installation depths of emitters and two water qualities

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ABSTRACT

Knowledge about soil moisture is essential to maximize irrigation efficiency because it allows the application of water in the proper quantity and at the proper time, thus improving water management. The objective of this study was to evaluate water storage in the soil profile when using a subsurface drip irrigation system at two emitter installation depths (0.20 or 0.40 m) and two water qualities (treated sewage effluent (TSE) and freshwater) in two crop cycles of sugarcane (*Saccharum officinarum* L.) in Campinas—SP (Brazil). The experiment was conducted in the experimental area of FEAGRI-UNICAMP, Campinas—SP, Brazil, adopting a randomized block design (RBD) in a factorial 2 × 2 + 1 with 3 replications. The factors studied included the installation of dripper tube at two depths (0.2 and 0.4 m) and two qualities of water (TSE and freshwater) plus a non-irrigation control. The TDR (time domain reflectometry) technique was used to evaluate the moisture in the soil profile by installing five probes with rods at 0.2 m up to 1.0 m depth. Replacement of the calibration equation provided by the TDR reduced the water depth between the first ratoon and the sugarcane plant and reduced the excess humidity from 0.029 and 0.045 cm^3 to 0.002 and 0.007 cm^3 when the drippers were installed at 0.2 m depth (T2 and T4). The installation of a 0.2 m drip tube proved to be an ideal solution for both environmental management and water use efficiency when using treated sewage effluent. No effect on the water distribution in the soil was observed when comparing the water qualities. For management of subsurface drip irrigation by the water balance in the soil, different layers in the soil profile should be considered to calculate the water depth, using the depth of the drip tube installation as a reference.

1. Introduction

Good agricultural performance may be limited by the chemical and physical quality of the soil, water availability, steep topography and adverse climate phenomena, among other factors. These characteristics affect the crop yield, requiring human interference to obtain sufficient productivity to pay the investment costs and generate a positive income. Thus, the use of adequate irrigation should be practiced to meet agricultural demand if we consider that irrigated areas account for 40% of the total food production in only 20% of the world's agricultural areas (Turral et al., 2011).

In Brazil, the total water consumption by the agricultural sector in the 1980s was 29.5% of the total usage (Barth, 1987), a figure that has risen in recent decades, corresponding currently to 72% of the total consumed by society (ANA, 2012). Furthermore, projections by Alexandratos and Bruinsma (2012) indicate a 60% increase in irrigated areas by 2050, so there is a need to develop techniques that minimize the environmental impact caused by this expansion.

Population growth, changes in consumption habits and increased demand for water in the various sectors of society have increased the consumption and use of water resources. A growing increase in the use of water resources has been observed and consequently an increase in the generated volume of sewage. Thus, we can note the importance of the development and improvement of technologies that can contribute to meeting the water demands of the various sectors of society in addition to ensuring food production and bioenergy. Therefore, the use of treated sewage effluent (TSE) for irrigation may be an interesting alternative for the water and nutrient supply of plants (compensating the use of mineral fertilizers), allowing the use of better quality water for human con-

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sumption and reducing contamination of water bodies by domestic wastewater. It is noteworthy that the application of TSE for nutritional input and water demand can be an option for the replacement of freshwater in many cultures, especially in extensive crops such as sugarcane, due to its high capacity for the production of ethanol and sugar extraction and due to the growing national and international demand for ethanol (Leal et al., 2009).

The application of TSE can affect water availability depending on its sodicity and salinity. Many studies have reported the effects of these two attributes on the variations of physical and hydraulic properties of the soil, such as the implications on the porosity, permeability, infiltration capacity and water retention (Balks et al., 1998; Bond, 1998; Abedi-Koupai et al., 2006; Gonçalves et al., 2010; Souza et al., 2010; Morugán-Coronado et al., 2011; Tzanakakis et al., 2011; Mojid and Wyseure, 2013). The lack of studies in tropical and subtropical climate conditions, with different characteristics from the arid and temperate zones, justifies the development of studies for this purpose, as the results will provide the basis for the establishment of technical and scientific criteria aimed at adapting land use to irrigation practices with TSE and considering environmental sustainability.

Among irrigation systems, drip irrigation, especially subsurface drip irrigation (SDI), has more favorable characteristics for the application of TSE than other methods (Puig-Bargués et al., 2010) because this method has shown a high efficiency of application (Gil et al., 2008) and less contact of the operators with the TSE, reducing the risk of operator contamination and the effect of drift and wetness on the irrigated crop and minimizing the risks to human health and environmental pollution (Resende et al., 2004; Cararo and Botrel, 2007; Lamm and Camp, 2007).

An important decision in the use of SDI should concern the depth of the drip tube installation. According to Lamm and Camp (2007), the desirable depth of drip tube installation varies according to the crop, soil type, water source, pests, climate, cultural practices and preferences of the irrigation provider. The rooting characteristics of the crop properties and the redistribution of soil water should be the most important factors in choosing the depth. For these authors, with the application of biological effluents, the depth of the drip tube installation should reduce exposure to pathogens in the soil surface and allow adequate biological deterioration. In Brazil, several studies are being conducted using SDI for the culture of sugarcane (Dalri and Cruz, 2002, 2008; Gava et al., 2011; Barbosa et al., 2012, 2013; Quintana et al., 2012). These studies use an average drip tape installation depth between 0.15 and 0.30 m.

The uniformity of water application by irrigation is critical to the success of irrigated crops, as low uniformity causes a heterogeneous water distribution. This may result in lower utilization of irrigation water by the plants, increasing the potential for contamination due to water loss by evaporation, runoff or deep percolation and causing an uneven productivity below the potential that the irrigation could provide.

The development of the root system is an important tool in understanding the response of plants to water distribution in the soil profile, as irrigated systems and fertigated roots follow a pattern of soil wetting and the application of nutrients (Bassoi et al., 2003; Zotarelli et al., 2009). Thus it is expected that the application depth of the water results in different concentrations of the root system in the soil profile.

The evaluation of the redistribution of water in the soil profile becomes indispensable because the dynamics of water in the soil matrix can provide more or less uniformity of irrigation, affecting water and nutrient availability in addition to enabling the sustainable use of low quality water such as TSE.

Accordingly, this study aimed to evaluate the water storage in the soil profile using a subsurface drip irrigation system at two installation depths (0.20 or 0.40 m) and two water qualities (TSE and freshwater) in two crop cycles of sugarcane (*Saccharum officinarum* L.) in Campinas—SP (Brazil).

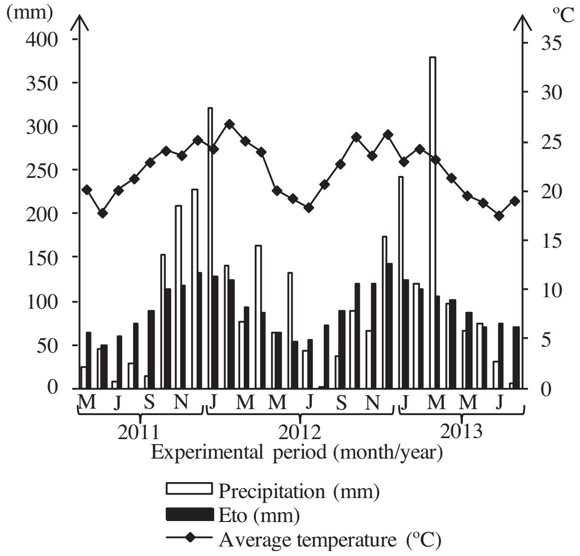

Fig. 1. Precipitation and reference evapotranspiration (ETo), accumulated monthly, and mean air temperature observed in the cycle of plant cane (May 2011 to September 2012) and first ratoon (October 2012 to August 2013) of sugarcane, Campinas—SP.

2. Material and methods

2.1. Description of the study area

The work was conducted in the experimental area of the Faculty of Agricultural Engineering—State University of Campinas (FEAGRI-UNICAMP), Campinas—SP, Brazil, in Oxisol soil (Embrapa, 2013) during the years of 2011 and 2012 (planting the cane) and 2012–2013 (first ratoon). The term “ratoon” refers to growing a culture of sugarcane after the harvest (Carr and Knox, 2011).

The climate, according to the Köppen–Geiger classification (Peel et al., 2007), is a transition between Cwa (subtropical climate of dry winter and hot summer) and Cfa (subtropical climate with hot summers), with an average annual rainfall of approximately 1424.5 mm and an annual average temperature of 22.4 °C (CEPAGRI, 2013). Fig. 1 presents the monthly average precipitation, the reference of evapotranspiration (using the Penman–Monteith FAO method, according to Allen et al., 1998) and the average temperature observed during the experiment.

2.2. Characterization of the soil

Undisturbed soil samples were collected before the implementation of the experiment to determine the physical characteristics of the soil, including of the bulk soil density, porosity (total, macro and micro), texture and water retention curve (Embrapa, 2011). The latter was adjusted according to van Genuchten (1980) (Table 1). To this end, four trenches, 0.8 × 0.8 × 1.0 m in length, width and depth, respectively, were randomly opened, and disturbed and undisturbed samples were collected at mid-depth layers: 0–0.2 m; 0.2–0.4 m; 0.4–0.6 m; 0.6–0.8 m; and 0.8–1.0 m.

2.3. Project and experimental treatments

The experimental design was a randomized block design (RBD), in a 2 × 2 + 1 factorial, with two depths of drip tube installation (0.2 and 0.4 m), two water qualities (freshwater and

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