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Water footprint of sugarcane irrigated with treated sewage and freshwater under subsurface drip irrigation, in Southeast Brazil

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ABSTRACT

The application of sewage *via* subsurface drip irrigation is a means of reducing the potential of the water footprint for the production of stems of sugarcane by eliminating the water abstraction for irrigation and reducing the load of pollutants in water bodies. The water footprint is an indicator of the amount of freshwater used to produce a certain quantity of product, which, in the case of this study, is ton of stems. The study was performed in State of São Paulo, Brazil. This study aims to calculate the water footprint from sugarcane that was non-irrigated or irrigated with treated domestic sewage and freshwater by drip irrigation in the presence or absence of nutritional supplementation using fertigation. Application of treated domestic sewage by subsurface drip irrigation reduced the water footprint to component grey, which is related to water pollution. The grey water footprint showed values between 2.4 and 2.7 m^3 Mg^{-1} stems of sugarcane in irrigated treatments, and the non-irrigated with fertilization topdressing showed a value near 7.3 m^3 Mg^{-1} stems. The use of subsurface drip irrigation reduced the water footprint green component, regardless of the quality of the water used for irrigation, with values between 21 and 26 m^3 Mg^{-1} stems for the irrigated treatments, where as the non-irrigated treatment resulted in an average of 52 m^3 Mg^{-1}. Note that the green component contributes the highest fraction of the water footprint in all treatments, with values close to 89% in non-irrigated crops and crops irrigated with freshwater and a value of close to 70% in sugarcane irrigated with treated domestic sewage. The results show a reduction in the water footprint during the production of stems of sugarcane when used for subsurface drip irrigation and treated domestic sewage.

1. Introduction

The irrigated agriculture uses the largest quantity of water, being responsible for roughly 70% of water withdrawals; however, 44% of the agricultural production is obtained in agricultural irrigated areas, which represent only 18% of the cultivated area (FAO, 2014). In this context, it appears necessary to search for techniques that increase the efficiency of water use and encourage reuse, such as the secure use of treated domestic sewage (TDS).

The application of sewage in agricultural crops areas favors both the rural and urban sector because it reduces the withdrawals of freshwater and the fertilizer acquisition production field. Moreover, it provides reduction cost with sewage treatment because significantly mitigates pollution of water bodies brought about by the cities. It is noteworthy that the application of treated sewage can provide increases in the production of bioenergy crops such as sugarcane. This procedure meets the transition ideals in the current models of production for cleaner production systems.

The application of TDS provides water and nutrients for the development of plants and does not inhibit production (Leal et al., 2009; Al-Hamaiedeh and Bino, 2010; Travis et al., 2010), especially in drip irrigation (Oron et al., 1991). Irrigation with TDS provides nutrients to the plants, particularly nitrogen, phosphorus and sulfur (Vazquez-Montiel et al., 1996; Leal et al., 2009).

Subsurface drip irrigation (SDI) presents the advantage of saving water (Lamm et al., 1995) because the water is applied directly in the root zone, reducing the loss of water by direct evaporation from

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the soil and by deep percolation (Ayars et al., 1999; Skaggs et al., 2004), moreover allows the safe application of sewage in the crop irrigation (Camp, 1998). The leaching of nitrate can be minimized due to the possibility of fragmentizing fertilizer doses and high uniformity of application in SDI while improving the application efficiency of fertilizers (Lamm and Trooien, 2003; Gil et al., 2008; Zotarelli et al., 2009).

The cultivation of sugarcane using both SDI (Pires et al., 2014) and treated domestic sewage (Leal et al., 2009) enhances stem productivity with low or no water abstraction of reservoirs; in addition, SDI results in lower nutrient leaching. Thus, application of TDS by SDI shows potential for reduction of sugarcane water footprint by depleting the blue component and mitigates water pollution by nutrient leaching.

The water footprint (WF) concept introduced by Hoekstra (2003) is an indicator of water volume used directly and indirectly for the production of goods and services. Despite the water footprint concept being an established means of determining the water consumption to obtain a certain product, it is not effective in describing the impact of agricultural practices on the availability and water shortage in a particular region (Jeswani and Azapagic, 2011); however, the water footprint proves to be an effective indicator to establish agricultural practices that require less water consumption (Lamastra et al., 2014).

The use of water in production process can be separate in water consumption and water pollution. The water consumption is basically represented by water used by the plants during phenological phases, as characterized by crop evapotranspiration (ETc) (Siebert and Döll, 2010), and is separated in to a green component (C_{green}) and a blue component (C_{blue}). The green component is defined by precipitation that effectively contributes to increased soil moisture (effective precipitation) and, at some point, is consumed by plants. The blue component represents the water captured in reservoirs (surface or subsurface) and used for irrigation of crops (Chapagain and Orr, 2009).

The water pollution, represented by the grey component (C_{grey}), is defined as the volume of water needed to assimilate and dilute the pollutants applied or generated during the production phases, such that its effects are neutralized, thus avoiding impacts to those dependent on the water resources (Hoekstra et al., 2011). In the production of crops, the main polluter used is the nitrate (Herath et al., 2012; Chapagain and Hoekstra, 2011; Rodriguez et al., 2015). Thus, the adoption of more efficient management practices of fertilizers, such as fertigation, contributes to the reduction of the water footprint (Herath et al., 2014). Note that the determination of nitrate should be performed at the local scale due to the great variability of soil and climate of the producing regions (Herath et al., 2013).

The means of assessment of the WF in the production of sugarcane are not specific because they use average values of production, climatic factors, loss of nitrate, and water consumption by irrigation (Mekonnen and Hoekstra, 2011; Gerbens-Leenes and Hoekstra, 2012); thus, the results of these works indicated a greater WF of sugarcane (WF_{cane}) in irrigated crops. However, studies realized in Southeast and Northeastern of Brazil using SDI and considering the same loss of nitrate among crops suggested a lower WF_{cane} over traditional crops without irrigation (Andrade Jr. et al., 2012; Scarpare et al., 2016). The last author highlights that the WF values found in the study place, inserts the Brazilian sugarcane crop as a good water efficient agricultural system compared to other studies worldwide.

This study aims to calculate the water footprint of sugarcane in non-irrigated and irrigated cases using treated domestic sewage and freshwater by subsurface drip irrigation in the presence or absence of nutritional supplementation using fertigation.

2. Material and methods

The experiment was conducted in the experimental field of the Faculty of Agricultural Engineering of the State University of Campinas (FEAGRI/UNICAMP), Brazil (Latitude 22°53′S and Longitude 47°05′W). The study was conducted during the growing cycle of the first ratoon cane, starting in September 2012 after cutting the cane plant. The variety of sugarcane used was RB867515, with the planting performed in May 2011. The soil of the area was classified as Oxisol, and the physical and hydraulic properties are presented in Table 1.

We designed a randomized block with five treatments and four replications for a total of 20 experimental plots. Each plot occupied an area of 91.8 m^2 and consisted of three double rows of 17 m in length, with spacing in a double line (1.4 m × 0.4 m). The following treatments of the sugarcane were applied: (i) non-irrigated control with manual fertilization topdressing (T1NI); (ii) irrigated with TDS, with additional fertigation to sewage (T2SF); (iii) irrigated with TDS, but without nutritional supplementation (T3SNf); (iv) irrigated with freshwater and with complementary fertigation (T4WF); (v) irrigated with freshwater, but without nutritional supplementation (T3WNf).

2.1. Irrigation and fertigation management

Fertilization was performed by applying the fertigation treatments and T1NI at doses of 120, 40 and 80 $kg.ha^{-1}$for N, P_2O_5 and K_2O, respectively. In T1NI, the fertilization was in the topdressing, with a single application between the minor rows (0.4 m); the sources of NPK were urea, MAP and potassium sulfate.

In fertigated treatments with freshwater or TDS, fertilizers were applied as complements of the nutrients supplied by irrigation water. In this context, we performed chemical characterizations of TDS and freshwater (Table 2), collecting samples every two months after filtration of the irrigation system. The samples were conditioned according to the standardized recommendation "*Standard Methods for Examination of Water and Wastewater*" (APHA, 2012). The TDS originating in the FEAGRI was treated in compartmentalized anaerobic reactors and, subsequently, in three wetlands with macrophytes. The freshwater was obtained from a natural reservoir located 100 m from the experimental area.

We used the irrigation system located in the subsurface drip, which was installed at a depth of 0.2 m between the lines of the minor row of crops (0.40 m). The dripper was of the self-compensating type with emitters spaced at 0.65 m and a flow of 1.60 L h^{-1}. Irrigation management was performed with sensors of the soil moisture using the technique of time domain reflectometry (TDR). After determining the moisture level, the irrigation rate was calculated according to Equation (1).

$$V_i = \left[\left(\theta_{fc} - \theta_i\right) \times V_s \times N_l\right] \quad (1)$$

where V_i is the volume of water for irrigation treatment (m^3); θ_i is the initial soil water content measured by TDR in layers at depths of 0.0–0.20, 0.20–0.40 and 0.40–0.60 m (m^3 m^{-3}); θ_{fc} is the soil in field capacity (m^3 m^{-3}); V_s is the volume of soil explored by line (m^3); and N_l is the number of lines per irrigated treatment.

2.2. Water footprint assessment

2.2.1. Soil water balance and evapotranspiration

To calculate the water footprint, we initially held the balance of input - output water in the agro-ecosystem, allowing for the distinction of green and blue components (Siebert and Döll, 2010),