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SUGARCANE PRODUCTIVITY ESTIMATION USING AGROMETEOROLOGY

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Abstract: *This study aimed to obtain predictions of sugarcane productivity, at different planting times, in São Roque do Canaã, Espírito Santo state, Brazil. The simulations were performed using the AquaCrop software, using local climate (maximum and minimum daily air temperature, precipitation, wind speed and air relative humidity), soil, crop and irrigation data. We performed simulations for planting in the months of March, April, May, October and November and obtained productivity data (t ha^{-1}), net irrigation requirement (mm) and water use efficiency (kg m^{-3}). April showed the best planting time, requiring a lower irrigation depth (895.6 mm), reaching satisfactory productivity (89.5 t ha^{-1}), as well as having the highest water use efficiency (2.6 kg m^{-3}). Thus, we conclude that the Aquacrop software can be used as a tool for decision making regarding the best planting season for sugarcane.*

Keywords: Irrigation, *Saccharum officinarum*, yield, planting time.

INTRODUCTION

São Roque do Canaã is a regional and national highlight in the production of cachaça, and in 2011 there were 21 distilleries in the city, performing the work of production and bottling of cachaça. These factories constitute important generators of employment and income for the municipality.

Therefore, the production of sugarcane is highlighted in the municipal scenario, being the second crop with the largest planting area, with 750 ha (Proater, 2011). In this context, factors such as edaphoclimatic monitoring aimed at improving the management of sugarcane, as well as the choice of its best cultivars, significantly interfere in production.

The availability of water in the soil interferes with plant production and, in places that do not have irrigation systems, this water availability is governed by the distribution of rainfall and water storage in the soil, factors conditioned by retention capacity and drainage (Maule et al. al, 2001). The water requirements for sugar cane range from 1,500 to 2,500 millimeters per cycle, which should be evenly distributed during the period of vegetative development, according to data from the United Nations Food and Agriculture Organization (FAO). However, recent studies have shown that the amount of water required for the crop to reach its maximum potential is around 1,200 to 1,300 millimeters (Marin, 2005 and Vieira et al., 2014).

The climatic classification of Köppen in the municipality of São Roque do Canaã is Aw, with rains distributed unevenly, raining much more in the summer than in the winter, being 1,155 mm annual precipitation in the historical average. In the last three years, this average has not been reached.

Thus, this study aimed to estimate sugarcane yield using the Aquacrop model; predict possible adverse climatic conditions detrimental to the crop, based on historical meteorological data; and determine the best planting times and the most appropriate cultural treatments for sugarcane.

MATERIAL AND METHODS

Foi utilizado o modelo agrometeorológico AquaCrop versão 6.0 (Figura 1), ferramenta importante por incorporar os conhecimentos atuais das respostas fisiológicas das culturas, fazendo uma previsão de suas biomassa e produtividade, em resposta à água disponível no solo. O modelo abrange uma ampla variedade de culturas herbáceas, incluindo forrageiras, hortaliças de folhas, grãos, frutas, raízes e tubérculos. Além disso, estabelece o equilíbrio entre precisão, simplicidade, robustez e facilidade de uso, sendo destinado a usuários práticos, tais como extensionistas, gestores de recursos hídricos, economistas e especialistas em políticas públicas que utilizem modelos simples para planejamento e análise de cenários (HSIAO et al.,2009 in LIMA et al., 2013).

We used the Agro-meteorological model AquaCrop version 6.0 (Figure 1), an important tool to incorporate the current knowledge of the physiological responses of the crops, making a prediction of their biomass and productivity, in response to the water available in the soil. The model covers a wide variety of herbaceous crops, including forage crops, leafy vegetables, grains, fruits, roots and tubers. In addition, it strikes a balance between accuracy, simplicity, robustness and ease of use, and is intended for practical users such as extensionists, water managers, economists and public policy experts who use simple models for scenario planning and analysis (Hsiao et al., 2009 and Lima et al., 2013).

Climate: (None) Specify climatic data when Running AquaCrop
Growing cycle: Day 1 after sowing: 22 March - Maturity: 24 July
Crop: DEFAULT.CRO a generic crop
Calendar mode
Irrigation: (None) Rainfed cropping
Field: (None) No specific field management
Soil profile: DEFAULT.SOL deep loamy soil profile
Groundwater: (None) no shallow groundwater table
Simulation period: Simulation period: From: 22 March - To: 24 July
Initial conditions: (None) Soil water profile at Field Capacity
Off-season: Simulation period linked to cropping period
Project: (None) No specific project
Field data: (None) No field observations

Figura 1 – Initial interface of AquaCrop 6.0.

The structure of the AquaCrop presents the soil, through its water balance, the plant with its growth, development and production processes, and the atmosphere (rainfall, evaporative demand and carbon dioxide concentration). In addition, some aspects of management are presented, with emphasis on irrigation, soil fertility levels that affect crop development, biomass production in relation to water use, in addition to crop adjustments to water stress, resulting in their final income.

For the evaluation of the AquaCrop model, input variables related to climate, soil and crop information were used. In relation to these, the climate variables required to execute the model are: maximum and minimum daily air temperature, precipitation and reference evapotranspiration (ETo). These local weather data were obtained in a meteorological station installed at IFES - Campus Santa Teresa. These variables were saved in a text file, being retrieved by the model through the user interface. The average annual atmospheric CO_2 concentration of AquaCrop is 369, 47 ppm (716.0 mg m^{-3}) recorded at the Mauna Loa Observatory in Hawaii in the year 2000 (Raes et al., 2009) and adjusted by the model, for the year of simulation.

The characteristics of the soil profile (input file), required by AquaCrop, are: profile thickness, texture, volumetric water content at saturation, field capacity, permanent wilting point and saturated hydraulic conductivity (Ksat). The soil data of cultivated areas of the IFES - Campus Santa Teresa were used to carry out the simulations.

The agronomic performance variables evaluated during the sugarcane cycle were: yield (kg ha^{-1}), cycle length (days), adjusted harvest index (%), soil moisture in several depths (%), net irrigation requirement (mm) and water use efficiency in evapotranspirated water productivity (kg m^{-3}).

AquaCrop is represented by a simple linear function, as presented in Equation 1.

$$Y = B\ IC \tag{1}$$

Where:

Y – crop yield (kg ha^{-1});

B – total biomass (kg ha^{-1});

IC – harvest index (%).

The daily production of biomass (g m^{-2} or t ha^{-1}) above the soil is given by Equation 2.

$$m_i = Ks_b\ WP_i^* \left(\frac{Tr_i}{ETo_i}\right) \tag{2}$$

Where:

Ks_b - adjustment factor for air temperature as a function of day-degrees (depending on the number of degree-days generated in a day, which can vary between 0 and 1)

WP_i^* - daily biomass productivity in relation to the use of water for the crop (kg ha^{-1});

Tr_i - daily crop transpiration on day i calculated by AquaCro p(mm day-1);

ETo_i – daily reference evapotranspiration (mm dia^{-1}).

The total biomass production (t ha^{-1}) above the soil is represented by Equation 3.

$$B = Ks_b \, WP^* \sum \left(\frac{Tr}{ETo} \right) \tag{3}$$

Where:

Ks_b - adjustment factor for air temperature as a function of day-degrees (depending on the number of degree-days generated in a day, which can vary between 0 and 1)

WP^*- standardized biomass productivity in relation to the use of water for the crop (kg ha^{-1});

Tr- total transpiration of the crop on a day calculated by AquaCrop (mm day^{-1});

ETo – reference evapotranspiration in the cycle (mm $cycle^{-1}$).

In the WP * adjustments for atmospheric CO_2 concentration, synthesized products and soil fertility are described by Raes et al. (2009). The model manual presents in detail the equations used in the calculation of WP and IC adjustments, as well as the subroutines for obtaining evapotranspiration through the water balance.

RESULTS AND DISCUSSION

The evaluations were carried out during the period between March 1, 2016 and March 28, 2017. Five planting simulations were carried out in March, April, May, October and November. The AquaCrop model simulated the crop cycle, assuming that it lasted twelve months, which made it possible to obtain two simulations with complete cycle (planting in March and April). The simulation with planting in May considered only eleven months, and the plantation in October and November considered only six and five months of the cycle, respectively.

Transpiration (Tr) and canopy cover (CC) graphs were generated for each planting month, as shown in Figures 2 A, B, C, D and E,

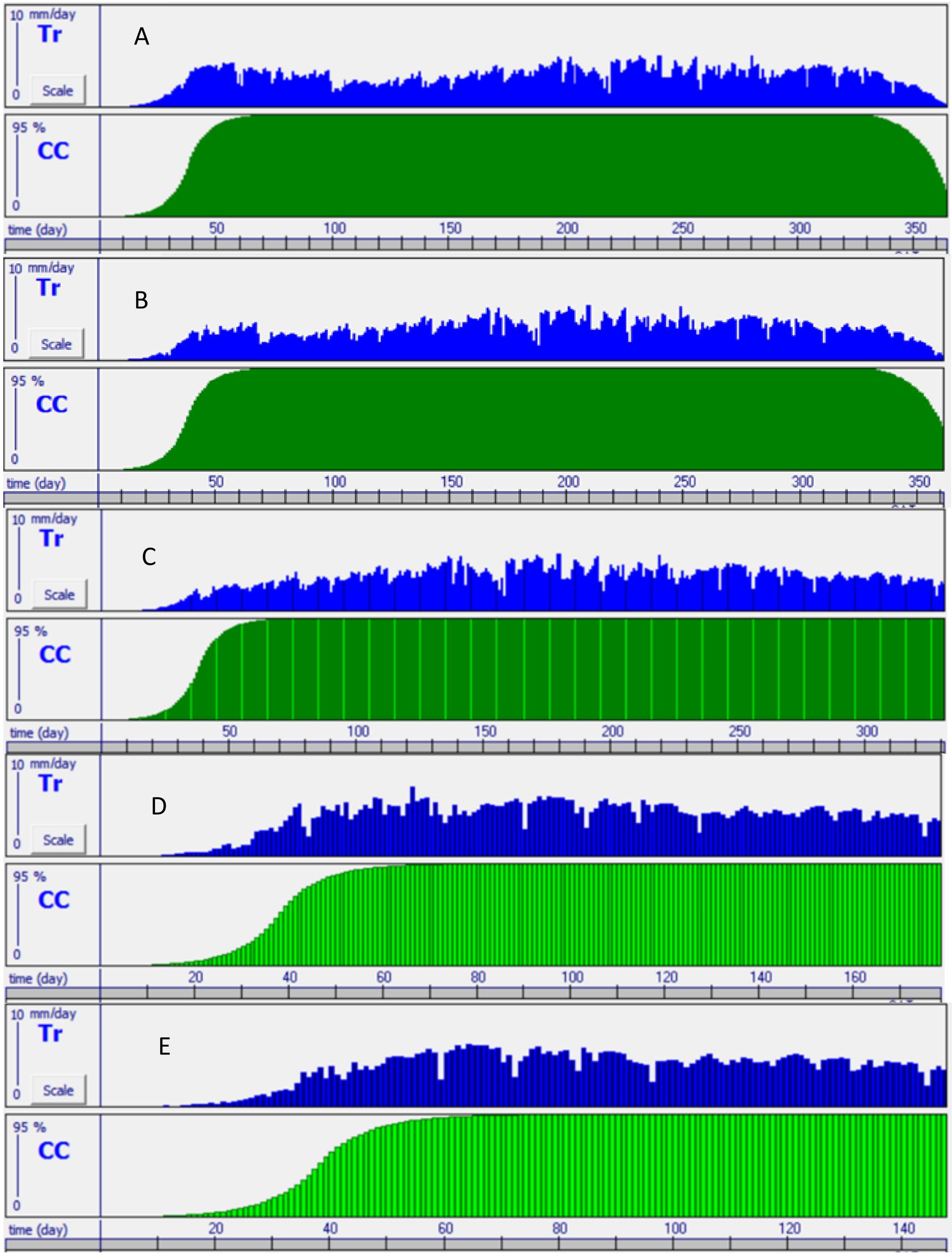

Figure 2 - Crop transpiration (Tr) and canopy coverage (CC) for simulated plantings in the months of March (A), April (B), May (C), October (D) and November (E), respectively.

The graphs that represented the CC showed no differences in their behavior. At the beginning of development, the relative growth rate is constant and the crop is mainly vegetative, characterizing the exponential phase. After the development of the root system and the expansion of the leaves, the plant increases water and nutrient withdrawal from the soil and develops photosynthesis processes, passing to a linear growth phase, with the greatest increase in biomass accumulation. When reaching the definitive size, the plant enters the senescence phase and shoots maturation, with less interception of light energy, decrease in the accumulation of dry matter and translocation of sugars to the storage organs.

In the simulations of Tr, which covered the entire crop cycle, the planting in April had less transpiration, reducing the need for irrigation during the cycle. The plantings carried out in the months of October and November, even though they did not simulate their complete cycle, had greater sweating for the period in the imposed climatic conditions.

Based on the climatic data used, the model calculated ET_0 values and estimated rainfall and irrigation values for each planting period, as shown in Figure 3. For the full-cycle simulations, in April presented the lower evapotranspiration, the higher volume of rainfall and consequently the lower volume of water used in irrigation, compared to the month of March.

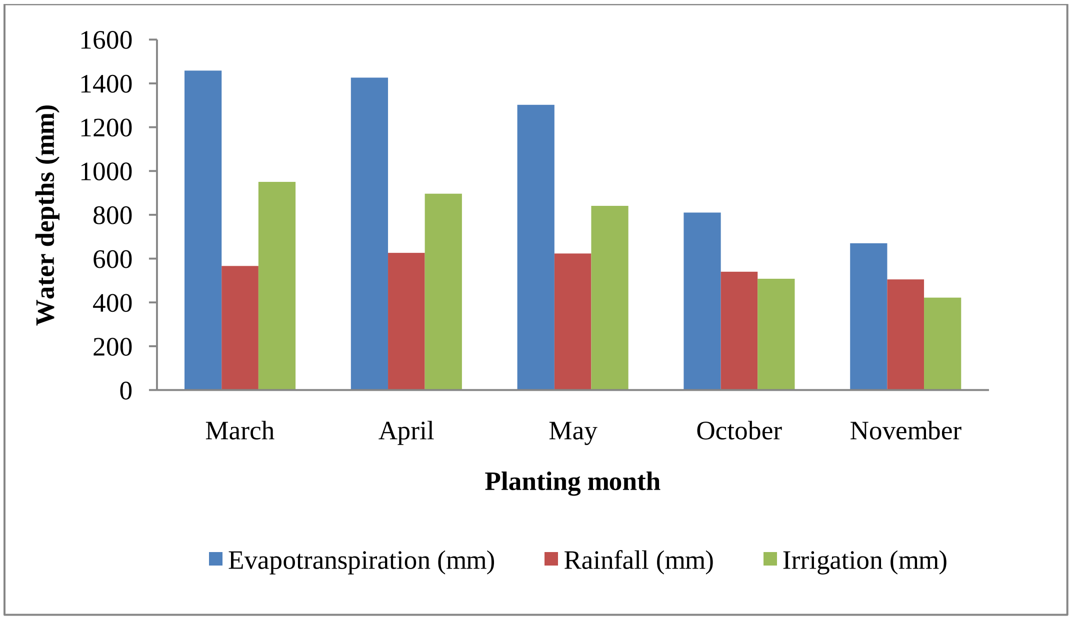

Figure 3. Evapotranspiration, rainfall and irrigation values for the sugarcane cycle according to the planting month.

The simulation in May, despite showing only 11 months of the cycle, showed similar behavior to the months of March and April, besides having rainfall volume higher than March, and consequently lower irrigation and evapotranspiration, but the planting in May can be risky, since sugarcane in the tillering phase (40 to 120 days after planting) and initial growth (120 to 270 days after planting), is sensitive to the water deficit coinciding with the period dry in the planting period. Ramesh and Mahadevaswamy (2000) stated that drought during the formation phase will result in lower yields.

For the simulation of planting in October and November, considering only six and five months of the cycle, rainfall volumes close to the value obtained when considering the complete cycle, in the planting situation in March, were worth highlighting. The fact happened because the simulation started in months considered rainy, when in the normal environmental conditions for the region.

The simulated values for fresh and dry mass (Figure 4) in March and April were similar, with an insignificant difference between them. For planting in May, compared to March, the difference reached 4.766 and 1.558 t ha^{-1}, respectively. This is due to the fact that at the beginning of its development the days are short and cold, and the plants received little luminous intensity, reducing its development.

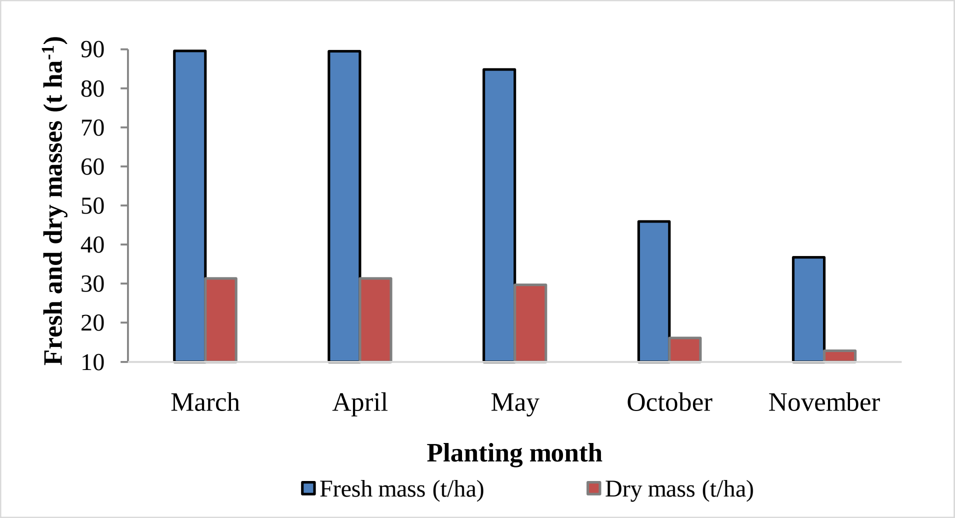

Figure 4 – Production of fresh and dry mass per cycle, according to the planting month.

The sugarcane presents expressive photosynthetic efficiency, mainly in the use and the rescue of CO_2, it is adapted to the high luminous intensities and high temperatures, even with relative water shortage. However, the crop needs large amounts of water to meet its water needs, since only 30% of its total biomass is represented by dry matter, reaching up to 70% water content, depending on the phenological stage (Segato et al., 2006).

Pelo modelo também foi estimada a produtividade/água evapotranspirada (Figura 5), onde o plantio no mês de abril foi o de melhor resultado para esta relação, com 2,6 Kg para cada m³ de água evapotranspirada. O mês de maio, mesmo com valores do ciclo incompleto, obteve resultado semelhante ao mês de março.

The model also estimated the water use efficiency (Figure 5). Planting in April showed the best result for this relation, with 2.6 kg for each m³ of evapotranspirated water. The month of May, was similar to March, even with incomplete cycle values.

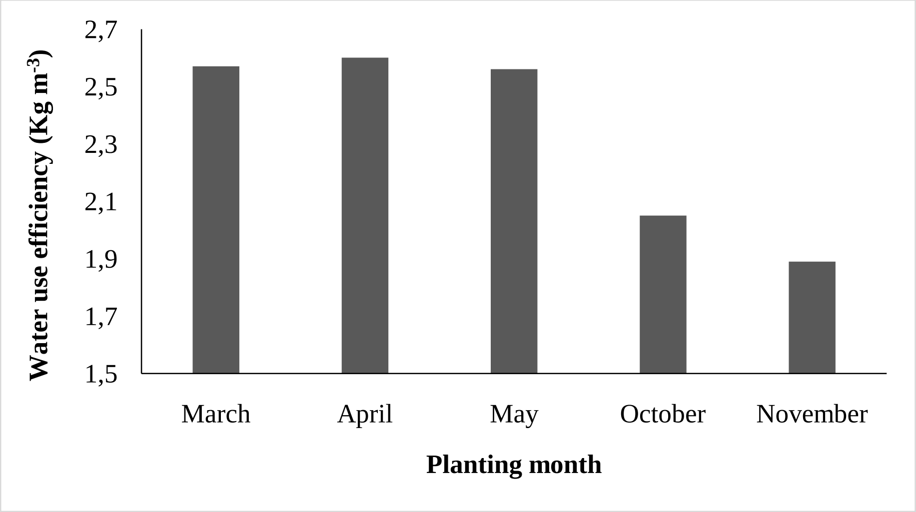

Figure 5 – Water use efficiency for the cycle of each month of planting.

CONCLUSIONS

Planting in April showed the smaller depth of irrigation water need, given by the greater rainfall in the period evaluated. In addition, the simulation of planting in April presented the best water use efficiency. Planting in May can be risky, because the environmental conditions at the beginning of the development of the crop are not favorable.

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REFERENCES

Hsiao, T.C., L.K. Heng, P. Steduto, B. Rojas-Lara, D. Raes, E. Fereres. 2009. AquaCrop - The FAO crop model to simulate yield response to water: III. Parameterization and testing for maize. Agronomy Journal. 101:448-459.

Lima, T.A.D., E.C. oliveira, R.P. Posse, A.A. Pires. 2013. Desempenho do modelo AquaCrop na estimativa da produtividade do feijoeiro (*Phaseolus vulgaris* L.) sob diferentes sistemas de cultivo em Colatina – ES. In: VII Jornada de Iniciação Científica, Desenvolvimento Tecnológico e Inovação do IFES. Serra, ES, Brazil.

Marin, F.R. 2005. Árvore do conhecimento – Cana-de-açúcar. AGITEC – Agência Embrapa de Informação Tecnológica. Also at http://www.agencia.cnptia.embrapa.br/gestor/cana-de-acucar/arvore/CONTAG01_10_711200516716.html

Maule, R.F., J.A. Mazza, G.B. Martha JR. 2001. Produtividade agrícola de cultivares de cana-de-açúcar em diferentes solos e épocas de colheita. Scientia Agricola. 58(2): 295-301.

Marafon, A. C. Análise Quantitativa de Crescimento em Cana-de-açúcar: uma Introdução ao Procedimento Prático. 1 ed. 2012. Embrapa Tabuleiros Costeiros, Aracaju, SE, Brazil.

Pimentel, C. 2004. A relação da planta com a água. Seropédica: Edur, pp. 191.

Proater – Programa de Assistência Técnica e Extensão Rural 2011 – 2013, São Roque do Canaã. INCAPER, 2011.

Raes, D., Steduto, P., Hsiao, T.C., Fereres, E. 2009. AquaCrop - The FAO crop model to simulate yield response to water: II. Main algorithms and software description. Agronomy Journal, 101(3):438-447.

Ramesh, P., M. Mahadevaswamy. 2000. Effect of formative phase drought on diferente classes of shoot, mortality, cane atributes, yield and quality of four sugarcane cultivars. Journal Agronomy & Crop Science. 185:249-258.

Segato, S.V., C.F.M. Mattiuz, A.E. Mozambani. Aspectos fenológicos da cana-de-açúcar. In: Atualização em produção de cana-de-açúcar. Piracicaba, SP, Brazil. 2006. pp. 19-36.

Vieira, G.H.S., E.C. Mantovani, G.C.Sediyama, F.T.Delazari. 2014. Productivity and industrial yield of sugarcane as a function of irrigation depths. 30(1):55-64.