Trash management effects on fully irrigated sugarcane yield and soil moisture: evaluating the simulation capacity of the APSIM model to a field experiment[1]

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ABSTRACT: Sugarcane trash management is one of most important issues to Brazilian sugarcane industry. Sugarcane trash can be removed from the field for use in ethanol and energy production, which provides a profit to the industry. Conversely, trash removal can have negative impacts on farming systems, such as decreased soil moisture. Process based crop models can be used to investigate sugarcane cropping system dynamics, however it is important to ensure they are appropriately calibrated to the plant varieties and soils of interest. The Agricultural Production Systems sIMulator (APSIM) is capable of simulating trash effects on sugarcane systems. However, APSIMs suitability to simulating trash management in Brazilian sugarcane systems is yet to be validated with field measurements. This project aims to fill this gap by evaluating the capacity of APSIM to simulate a one year sugarcane field experiment with differing trash management. The field experiment site was located at Piracicaba. Measurements of dry stalk mass, dry total above ground biomass, leaf area index (LAI) and soil moisture for two treatments: *WithTrash*; *WithoutTrash* were taken throughout the first ratoon crop, grown in 2013 and 2014. After model calibration, comparison of the measured and simulated results found that dry stalk mass and total above ground biomass were both well simulated ($R^2 > 0.95$). General trends in the LAI over time were captured by the model but simulation of actual LAI values was poorer than for crop productivity ($R^2 = 0.30$). General trends in soil moisture were well simulated over time. This study is provides evidence that APSIM can be used to simulate Brazilian sugarcane cropping system with differing trash management, which is of importance for the Brazilian sugarcane industry.

KEY WORDS: mulch, crop models, irrigation

Efeito do manejo da palhada na produtividade e umidade do solo de um canavial irrigado: avaliação da capacidade do modelo APSIM em simular um experimento de campo[1]

RESUMO: Manejo da palhada da cana-de-açúcar é uma das questões mais importantes para o setor sucroenergético brasileiro. A palhada pode ser removida do campo para produção de etanol e cogeração de energia, o que proporciona um benefício econômico para a indústria. Por outro lado, a remoção da palha pode resultar em problemas ambientais, tais como a diminuição da umidade do solo. Os modelos de simulação de culturas baseados em processos (sigla em inglês, PCMs) podem ser utilizados para investigar os sistemas agrícolas, no entanto, é importante garantir que sejam devidamente calibrados para as variedades e solos de interesse. O Simulador de Sistemas de Produção Agrícola (sigla em inglês, APSIM) é capaz de simular os efeitos da palha na agricultura. No entanto, a validação do modelo APSIM, utilizando experimento de campo, ainda é uma questão a ser respondida no Brasil. Portanto, este projeto visa preencher esta lacuna através da avaliação capacidade do modelo em simular um canavial de primeira soca, com diferentes manejos da palha. O campo experimental está localizado em

Piracicaba. Os dados medidos foram massa seca de colmos, massa seca total, Índice de área foliar (IAF) e a umidade do solo para dois tratamentos: *ComPalha* e *SemPalha*, primeira soca. Depois da calibração do modelo, comparou-se os resultados medidos aos simulados e os resultados mostraram que a massa seca de colmos e biomassa total foram bem simuladas (R^2>0,95). As tendências gerais do IAF, ao longo do tempo, foram capturados pelo modelo, no entanto, os valores estatísticos foram inferiores quando comparados à produtividade das culturas (R^2=0,30). As variações gerais da umidade do solo também foram bem simuladas. Portanto, este estudo fornece provas de que o APSIM pode ser usado para simular os sistema de cultivo de cana de açúcar brasileiros com diferentes manejos da palha, uma das questões fundamentais para o setor sucroenergético brasileiro.

PALAVRAS-CHAVE: palha, modelos de simulação de culturas, irrigação

INTRODUCTION

Sugarcane (*Saccharum* spp.) is an important agricultural crop in Brazil (MARIN et al., 2011). Sugarcane production has recently increased due to expansion of the area cropped and technification. These new cropping areas are located in the North-Western part of São Paulo State and the Centre-West of Brazil (VIANNA and SENTELHAS, 2014). Both of these areas have a longer annual dry period compared to traditional sugarcane regions such as Ribeirão Preto or Piracicaba in São Paulo State. Therefore, the irrigation in these dry regions becomes essential, especially after planting, in the first months of crop growth, or at harvesting. However, the use of irrigation places pressure on existing water resources, particularly if water resources are limited (INMAN-BAMBER and SMITH, 2005).

Mechanized harvesting can retain a layer of residue, called trash, on the soil. Alternatively, sugarcane trash can be removed from the field for use in ethanol and energy production, which provides a profit to the industry. It is known that the retention of sugarcane trash in the field can effect crop yield (KINGSTON et al., 2005) and influence different soil processes such as soil moisture content (DENMEAD et al., 1997). However, the effect of trash management in Brazilian sugarcane farming systems is poorly understood. This project aims to fill this gap by investigating trash management through a combined experimental and modeling approach. A strength of using Process-based Crop Models (PCMs) (ROSENZWEIG et al., 2013) is the capacity to simulate a range of different climate, soils and management, which would be difficult to undertake using an experimental approach. When using PCMs, it is important to ensure they are appropriately calibrated to the plant varieties and soils of interest (MARIN et al., 2011).

Among the commonly used PCMs for sugarcane simulation the Agricultural Production Systems sIMulator (APSIM) is the only model capable of simulating trash effects on Brazilian sugarcane growth, soil, water, nutrient, and residue processes (COSTA et al., 2014; MARIN et al., 2014; OLIVEIRA et al., 2015). However, APSIMs suitability to simulating trash management in Brazilian sugarcane systems is yet to be validated with field measurements. This project aims to fill this gap by evaluating the capacity of APSIM to simulate a one year sugarcane field experiment with differing trash management.

MATERIAL AND METHODS

An experiment was carried out in a centre pivot irrigated sugarcane field grown with the cultivar RB867517 (which is the main Brazilian cultivar). The sugarcane crop was planted on 16th October 2012, with single line spacing of 1.4 m between rows, distributing 13-15 shots per linear meter to 0.25 m depth.

This study was carried out during the first ratoon, which started on 16th October 2013, after the plant crop was harvested.

The experimental area is owned by the Department of Biosystems Engineering of College of Agriculture "Luiz de Queiroz", located on Areão Farm, Piracicaba/SP, Brazil, at 540 m of altitude. The climate was characterized as Cwa according to Koeppen and the soil classified as Hapludox (Soil Taxonomy, 2004). The experimental area was divided into two treatments *WithTrash* where sugarcane trash retained and *WithoutTrash* where the trash was totally removed from the paddock by raking (Figure 1).

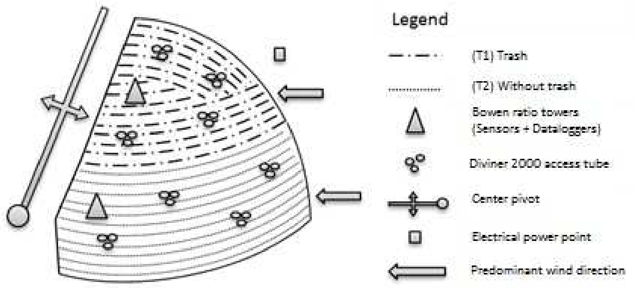

Figure 1. Detail of the experimental area, showing the central pivot, predominant wind direction, and access tubes position for Diviner 2000 probe for each treatment: *WithTrash* and *WithoutTrash*.

During the first ratoon crop, soil water content was measured weekly in the soil profile, using a capacitance probe Diviner 2000®. The installation of probe access tubes were performed after plant crop harvesting, totaling 24 access tubes, 12 for each treatment with 3 replications in each location. The soil moisture probes at the experiment site were all calibrated using one site specific set of calibration variables. Mean soil water content for each 0.10 m layer in the top 0.40 m was compared with the sw (soil water) output parameter of APSIM. Measurement of leaf area index (LAI) and the fresh and dry mass of stalks, cabbage and leaves were conducted monthly. These measurements were compared to lai, biomass and cane_wt APSIM output variables.

The APSIM model (v7.5) was used to simulate soil, carbon, nitrogen, and water dynamics as well as sugarcane productivity at the experimental site. APSIM was parameterized as follows. Climate data from the nearest meteorological station (University of São Paulo - ESALQ) was used. Bulk density, lower limit, drained upper limit, and saturation were parameterized in the APSIM soil module based on measure data (LACLAU and LACLAU, 2009) Other APSIM soil properties were parameterized based on expert knowledge or calibrated to the site. Management operations including sowing and harvesting date, irrigation, tillage, fertilizer application and rate were specified in the APSIM operations to reflect the actual management operations that occurred on site. The sugarcane crop variety (RB867515) grown at the site, which has been previously parameterized for APSIM by MARIN et al., 2015, was used in APSIM.

For crop parameters, the quality of the simulated predictions were evaluated using: the Slope (s); Intercept (i); Root Mean Square Error (RMSE); R Squared (R2) (WALLACH et al., 2006) and Nash-Sutcliffe efficiency (nse), a normalized statistic that determines the relative magnitude of the residual variance (“noise”) compared to the measured data variance (“information”) (NASH and SUTCLIFFE, 1970). For soil water content, model predictions were compared to measured data over time.

RESULTS AND DISCUSSION

In the field experiment the main difference in sugarcane growth occurred in the first six months of crop growth. Five months after the beginning of the first ratoon crop, the above ground biomass was 15

$t.ha^{-1}$ in the *WithTrash* treatment and 9 $t.ha^{-1}$ in the *WithoutTrash* treatment. In this same period the LAI was 3.9 for the *WithTrash* treatment and 3 for the *WithoutTrash* treatment. It is noteworthy that the LAI has direct influence on physiological crop process (KEATING et al., 1999) and APSIM uses LAI to calculate crop productivity and determine radiation interception. By the end of the crop the dry stalk mass was 20 $t.ha^{-1}$ in the *WithTrash* treatment and 18 $t.ha^{-1}$ in the *WithoutTrash* treatment.

APSIM was capable of simulating both treatments. Dry stalk mass and total above ground biomass were well simulated throughout the growing season (R^2 values of above 0.95; Figure 2). The APSIM model was not able to simulate LAI as well as dry matter (R^2 value of 0.30; Figure 2). While exact LAI values were not able to be well simulated, general trends in the LAI over time were captured by the model (data not shown).

The nse value indicates how well the observed versus simulated data fits the 1:1 line. The best nse value was obtained for dry stalk (0.96) compared to LAI (0.23). This lower nse value for LAI may in part be attributed to over-simulation of leaf area for the beginning of the crop, when total above ground biomass was over-simulated (Figure 2).

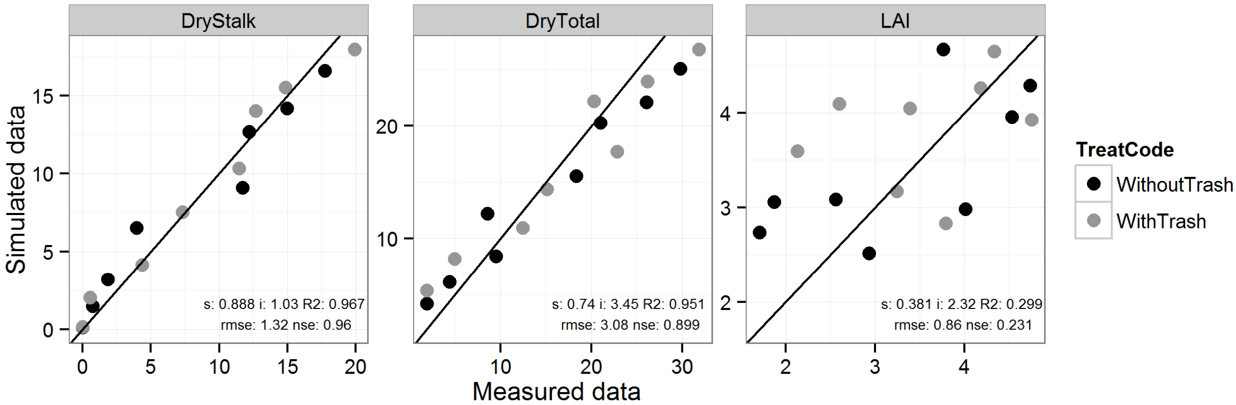

Figure 2. Measured and simulated sugarcane dry stalk mass (DryStalk, $t.ha^{-1}$), total above ground biomass (DryTotal, $t.ha^{-1}$), leaf area index (LAI $mm^2.mm^{-2}$) for two treatments: *WithTrash* and *WithoutTrash*.

General trends in soil water content were well simulated over time. The difference between treatments in soil water content was most apparent at the beginning of the crop growing season, when trash residue was present. As the trash decomposed throughout the growing season the treatment difference was less apparent. General trends of wetting and drying between April and June 2014 were captured by APSIM in soil layers to 0.4 m (Figure 3). Soil specific calibration is required to attain accurate measurements of soil water content (LIEB et al., 2003). There may be some small degree of error in the measured soil water content data due to the method used to calibrate the probes: one set of site specific calibration variables were used all 24 soil water content measurement sites.

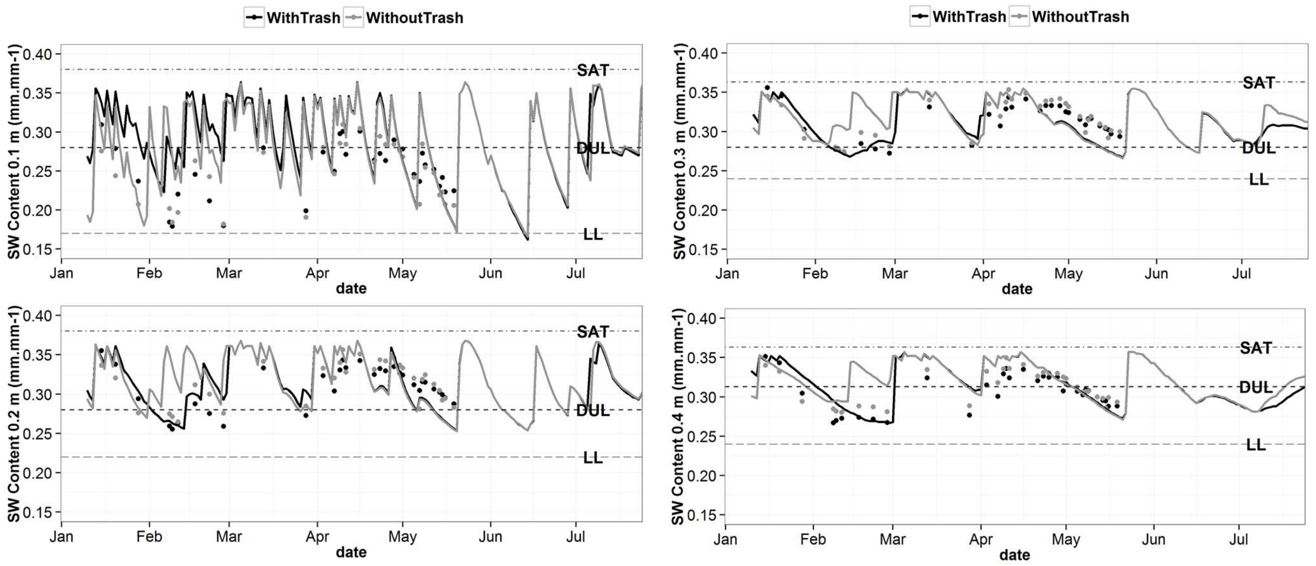

Figure 3. Simulated (line) and measured (points) soil water content (SW Content) ($mm.mm^{-1}$) during de first crop ratoon to 0.4 m depth, divided in four layers at 0.1 m increments. Soil saturation (SAT), drained upper limit (DUL) and lower limit (LL) are displayed on the graph.

CONCLUSIONS

The APSIM model was capable of successfully simulating a Brazilian sugarcane farming system with differing trash management. Dry stalk mass, total above ground biomass, LAI and soil water content were well simulated during the first ratoon for two treatments: *WithTrash* and *WithoutTrash.* A strength of using APSIM to investigate trash management is the capacity to simulate scenarios for different climate, soil, and management combinations. Further research could consider this. This study is of importance for the Brazilian sugarcane industry as it has yet to establish effective trash management for its sugarcane farming systems.

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