CHARACTERIZING PHYSIOLOGICAL PARAMETERS CONTROLLING GROWTH AND DEVELOPMENT OF BRAZILIAN SUGARCANE

Fábio R. Marin[1]

[1] Eng. Agrônomo, Pesquisador, Laboratório de Modelagem Embrapa Informática Agropecuária, Campinas –SP Fone: (19) 3211-5876; marin@cnptia.embrapa.br,

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ABSTRACT
Several models are available for sugarcane crop and all of them are based on physiological knowledge translated in mathematical equations coordinated in algorithms. For Brazilian sugarcane, however, there are few studies describing the main physiological characteristics to be included in the models. This paper has a major goal to characterize the physiological parameters controlling growth and development of two of the most important Brazilian sugarcane cultivars, and compare them with NCo376, a well-studied South African cultivar. As results, we found maximum leaf size differed little among Brazilian cultivars, being as large as 796 cm^2 for RB72-454 and 733cm^2 for SP83-2847. The mean value for the maximum green leaf number per stalk for the cultivars was approximately 9, and the observed biomass accumulation in the millable stalks closely mirrored the accumulation of above-ground biomass for the two cultivars, starting with 9% at 129 DAP to reach a maximum of around 65% after 330 DAP for RB72-454. Specific root length (m g^{-1}) ranged from 16 m g^{-1} and 22 m g^{-1} on average from 125 DAP onwards.
Key-words: *Saccharum spp.;* base temperature; tillering, partitioning

INTRODUCTION
Sugarcane (Saccharum spp.) is of major social and economic importance in Brazil. It is one of the most important commodities in Brazilian agribusiness, contributing to the energy and food security of the country, as sugar, ethanol and biomass for energy are produced from sugarcane (Goldemberg, 2007).

Crop simulation models may contribute to improved crop monitoring and yield forecasting, while enhancing our understanding of sugarcane growth and yield. Worldwide, there are several models dedicated to sugarcane crop simulation. The efforts to model the sugarcane crop reflect the fact that simulated processes often have to be modified in order to adapt models to specific environments.

All of these crop models are based on physiological knowledge translated in mathematical equations coordinated in algorithms. For Brazilian sugarcane, however, there are few studies describing the main physiological characteristics to be included in the models. This paper has a major goal to characterize the physiological parameters controlling growth and development of two of the most important Brazilian sugarcane cultivars, and compare them with NCo376, a well-studied South African cultivar.

MATERIAL AND METHODS

Data used here were collected in four locations in Brazil (Suguitani, 2005; Laclau and Laclau, 2009; Tasso Jr., 2007; Santos, 2008) (Table 1). All experiments received adequate N, P and K fertilization and regular weed control and were planted using healthy cuttings with 13 to 15 buds m^{-2}. Row spacing varied from 1.4 m to 1.5 m. One of the datasets had two treatments (irrigated and rainfed), and all the remaining data were for rainfed. The irrigated treatment received water by sprinkling and the irrigation schedule was determined by tensiometer monitoring to maintain the soil layers close to field capacity down to a depth of at least 1 m.

Table 1. Sources of experimental data used and main soil and climate characteristics of each site.

Dataset	Site	Planting and Harvest Dates	Cultivars	Crop Cycle[1]	Climate[2]	Treatments
1	Piracicaba/SP, 22º52'S, 47º30'W, 560m asml	10/29/2004 and 9/26/2005	RB72-454 SP83-2847 NCo376	PC	21.6ºC, 1230mm, CWa	1) Irrigated, 2) Rainfed
2	Aparecida do Taboado/MS, 20º05'19"S, 51º17'59"W, 335m asml	7/1/2006 and 9/8/2007	SP83-2847	R1	23,5 ºC, 1560, Aw	3) Rainfed
3	Colina/SP, 20°25'S 48°19'W, 590m asml	2/10/2004 and 6/15/2005	RB72-454 SP83-2847	PC	22.8 ºC, 1363mm, Aw	4) Rainfed
4	Olimpia/SP, 20°26'S, 48°32'W, 500m asml	2/10/2004 and 6/15/2005	RB72-454 SP83-2847	PC	23.3 ºC, 1349mm, Aw	5) Rainfed

[1] PC - Plant cane crop; R - ratoon crop and following number is the ratoon rank.

[1] Respectively: mean annual temperature, annual total rainfall, Koeppen Classification

RESULTS AND DISCUSSION

The maximum leaf size differed little among Brazilian cultivars, being as large as 796 cm^2 for RB72-454 and 733cm^2 for SP83-2847 (Table 2). For both cultivars, maximum leaf size (Mxlfarno) was reached around 25th leaf, which is similar to results of Sinclair et al. (2004) for cultivar CP72-2086 in Florida, but substantially different from the values obtained and for cultivars in South Africa and Australia (Cheeroo-Nayamuth et al., 2000, Inman-Bamber, 1994).

The mean value for the maximum green leaf number per stalk for the cultivars was approximately 9 (Table 4). For both cultivars the peak and stable stalk populations were almost the same for both irrigated and rainfed treatments. Both cultivars also showed similar tillering rates, regardless of water treatment and experiment site (Table 4). The tillering pattern is similar to that described by Bezuidenhout et al. (2003), but with a lower tiller density than reported there, at 12 and 14 tiller m^{-2} in the tillering peak, respectively for cultivar RB72-454 and SP83-2847. After the senescence phase, tiller density stabilized at 7 tiller m^{-2} regardless of water source (rain or irrigation) or planting site. Stalk growth began about 500-700 $^oC\ d^{-1}$ after planting, with peak tillering at about 900 $^oC\ d^{-1}$ after planting.

The lower tillering rate and number of final tillers observed in Brazilian compared to South African cultivar (Table 2), seems to be related to quicker initial development and greater leaf area causing higher levels of light interception and early shadowing of the stalk base. This implies that tillering rate is related to canopy light interception (van Dillewijn, 1952; Inman-Bamber, 1994, and Bezuidenhout et al., 2003).

Table 2. Maximum leaf size, number of leaves and green leaves, maximum leaf area index and mean stalk population at peak of tillering and at maturing observed for both cultivars.

Cultivar	Leaf [1] size, cm^2	number of leaves [1]	Max. number green leaves [1]	Pop. at peak tillering, stalk m^{-2}	Pop. at maturing, stalk m^{-2}	Green LAI
SP83-2847	733.9	33.8	8.8	14.1	8.3	4.7
RB72-454	796.0	34.7	9.3	12.7	9.7	5.2

[1] only data from Dataset 1

The leaf appearance algorithm in most of the sugarcane models is based on phyllocron interval concept (Inman-Bamber, 1994), representing the thermal time elapsed between the emergence of subsequent leaves on a tiller (Singels et al, 2008). The plant cycle is divided in two phases (PI1 and PI2), whose transition is controlled by a cultivar specific threshold (Pswitch). The base temperature for leaf development of Brazilian cultivars ranged from 14.4^{o}C to 14.6^{o}C.

The range of PI1 values (104 - 113 ^{o}C days^{-1} leaf^{-1}) was higher for both Brazilian cultivars than cultivar NCo376. However, at 116 – 122 ^{o}C days^{-1} leaf^{-1}, PI2 was smaller than observed for cultivar NCo376. This suggests that use of the two-phyllocron approach does not seem to be as important for Brazilian cultivars as for South Africa, where the results of Inman-Bamber (1994), Bonnett (1998), and Robertson et al. (1998) showed differences between PI1 and PI2 ranging from 14% to 69%. Results from Sinclair et al. (2004) were closer to those observed in this paper, with only 6% difference between PI1 and PI2. Those authors hypothesized that the smaller-than-expected difference in leaf appearance rate between early and late leaves might owe to higher evaporative cooling in fully developed canopies than in younger, more open canopies. This assumption seems to be related to the vegetation-atmosphere decoupling approach (McNaughton and Jarvis, 1983), from which one can derive another assumption, that the two phyllocrons approach would be observed only under highly coupled conditions.

The observed accumulation of biomass in the millable stalks closely mirrored the accumulation of above-ground biomass for the two Brazilian cultivars, starting with 9% at 129 DAP to reach a maximum of 61% and 70% after 330 DAP for RB72-454 in irrigated and rainfed treatments, respectively. Cultivar SP83-2847 showed a maximum stalk:above ground biomass ratio of 0.66 for both treatments (Figure 1, Table 3).

The measured root biomass for cultivar RB72-454 shown here (Laclau and Laclau, 2009) corresponds only the first meter of soil depth, so the ratios here presented are somewhat underestimated. The root:shoot ratio decreased from 0.61 kg kg^{-1} at 42 DAP, which is comparable to 0.42 kg kg^{-1} at 50 days age as reported by Smith el al. (2005), to 0.09 kg kg^{-1} at the harvest. The leaf-to-above ground biomass ratio decreased during the crop cycle from 0.26 to 0.10 kg kg^{-1} and 0.18 to 0.09 kg kg^{-1} for irrigated and rainfed RB72-454, respectively, and from 0.21 to 0.11 kg kg^{-1} for both treatments of SP83-2847.

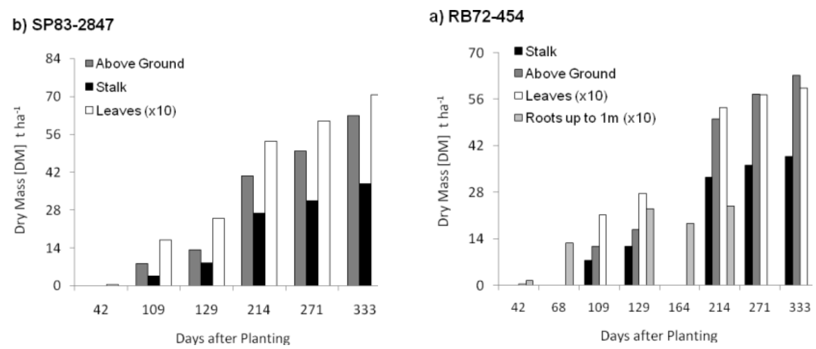

Figure 1. Time series of root, stalk, above ground and green leaves dry mass for three cultivars in Piracicaba, SP.

Table 3. Ratio between root (R) (up to 1m depth), stalk (S) and green leaf (L) dry mass and total dry mass (T) for cultivar RB72-454, and ratio between stalk and green leaves and aerial biomass (A) for cultivar SP83-2847.

Cultivar	Treatment	R/T			S/T			L/T		
		Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
RB72-454	Irrig.	0.35±0.37	0.61	0.09	0.65±0.01	0.66	0.63	0.15±0.07	0.26	0.10
	Rainf.	0.43±0.38	0.70	0.16	0.62±0.03	0.65	0.58	0.14±0.04	0.18	0.09
		S/A			L/A					
		Mean	Max	Min	Mean	Max	Min			
SP83-2847	Irrig.	0.60±0.08	0.66	0.46	0.15±0.04	0.21	0.11			
	Rainf.	0.60±0.09	0.66	0.44	0.15±0.05	0.21	0.11			

Laclau and Laclau (2009) found specific root length (SRL) (m g^{-1}) ranging from 16 to 18 m g^{-1} and 19 to 22 m g^{-1} on average from 125 DAP onwards. Mean SRL down to the depth of 1 m was 17.6 m g^{-1} for rainfed and 19.1 m g^{-1} for irrigated crops. Chopart and Marion (1994) found a large range of SRL's (from 7 m g^{-1} to 91 m g^{-1}) measured at 45 and 113 DAP down to a depth of 1.1m in Ivory Coast. Ball-Coelho et al. (1992) found SRLs near 16.5 m g^{-1} in northeastern Brazil through the plant and first ratoon crop cycles.

CONCLUSIONS

Two Brazilian sugarcane cultivars were initially characterized using experimental data and literature results. This characterization makes it easier to understand how to model sugarcane crop and what would be the limitations of models developed in other regions of world and based in different sugarcane genotypes.

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