MODELLING THE WATER CONTENT OF THE SUGARCANE STALK

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Abstract

In most countries where sugarcane is grown, the industry uses cane yield and sucrose content expressed on a fresh weight basis. It is therefore important to be able to estimate the stalk water content.

This study models the amount of water stored in the millable stalk as a function of the dry weight of the stalk structures and of the stored sucrose. The correlation was highly significant (r^2=0.98, n=30). Structural material was equated to the difference between the stalk total dry weight and sucrose. Knowing the effect of the water deficit on the water content of the cane, the deficits were compared with the residuals in the above regression and it was shown that the use of the soil water deficit did not improve the relationship found.

To explain this, the results were used from studies of biomass and soil water deficit during periods of soil drying and re-wetting. They showed that the relative variations of structural material and sucrose already took account of the soil water deficit and that these variables are therefore sufficient to explain the quantity of water stored in the stalk.

Thus the sucrose content of cane and the yield can be estimated directly as a function of the cane dry weight and sucrose produced.

Keywords: sugarcane, stalk water content, millable stalk components, crop growth model, soil water deficit.

Introduction

In most cane-growing countries, the sugar industry calculates the cane yield and sucrose content in terms of fresh weight. If these variables are to be estimated, the water content must be correctly simulated.

Studies on the variability of sugarcane water content as a function of environmental conditions (Yates, 1996) and of drying-off (Robertson and Donaldson, 1998; Robertson *et al*, 1999) show that apparent ripening is very often due both to an increase in the stalk sucrose content and to drying out, i.e. a decline in water content.

This variability in water content reinforces the importance of knowing how to conveniently estimate it. A recent review of the models used (O'Leary, 2000) shows that most of them give a poor simulation of stalk water content. Only APSIM (Keating *et al*, 1999; O'Leary, 2000) estimates the amount of water by linking it to stalk structural material and age in a fairly mechanistic way. Thus for each gram of stalk structure produced a certain weight of water is accumulated. The latter is not constant but varies according to age expressed in thermal time. Moreover the accumulation of sucrose causes a reduction in the water pool at a rate of 1g water per g of sucrose. Hence age and sucrose content influence water content independently.

Given good water supply, this water content can even be simulated directly as a function of cumulative temperature (Martiné *et al*., 1999). However studies of ripening show clearly that progressive desiccation can be influenced by minor or major water stress. The soil water content and its relationship with crop transpiration should be incorporated into the model (O'Leary, 2000).

Studies carried out in La Réunion, over a wide range of climates and cane crops, enable the variability and trends in this water content to be analysed, and provide solutions for modelling them. The estimations of cane yield and sucrose content result from this process.

Materials and methods

Experiments

Calibration - At three sites, six crops (the treatments) were studied under contrasting soil and weather conditions and using different management systems. Treatments 5 and 6 represented a study of the effect of water stress followed by soil rewetting. Treatment 5 was not irrigated from 17 Oct 97 until 25 Dec 97, after which it was irrigated normally. Treatment 6 was irrigated optimally during the whole period of study. These crops were grown during different periods than the others.

The six experiments were located in La Réunion between 21.3º and 21.9º S latitude and at 55.5ºE longitude. The crops were ratoons of the variety R570 grown 1.5 m apart with drip irrigation on the irrigated plots. Fertilisation, which was optimal, consisted of 150-200 kg/ha N, 70 kg/ha P_2O_5 and 150-200 kg/ha K_2O.

At each experiment plant and soil moisture measurements were made and weather data collected.

Validation - In order to validate the relation found, the cane harvested at several dates on subplots of 13 production plots (51 sample dates) was used. These plots were cropped under contrasting soil and weather conditions using different management systems, and were totally independent of the six crops described above. The crops used for calibration and validation as well as their soil and weather conditions, are described in Table 1.

Plant measurements

Because of a lack of plant material for sampling, a non-destructive method was used to measure changes in biomass. Devel-

Table 1. Characteristics of the experimental sites and the observations.

N°	Use	Site	Surf	Rep.	Obs	Irrig	Tm	Rg	AWC	Study period	Altitude
1	C	Colimaçons	4.5	3	4	R	17.9	13.4	159	2/3 -9/99	800
2	C	Colimaçons	4.5	3	8	R/I	17.7	13.3	159	2/95-10/95	800
3	C	Barau	7.5	5	4	R	19.4	16.0	151	22/3 –10/99	550
4	C	Tirano	7.5	10	4	I	20.4	18.0	99	11/3 – 9/99	150
5	C	Tirano	7.5	5	5	R/I	24.4	21.9	99	10/97-2/98	150
6	C	Tirano	7.5	5	5	I	24.4	21.9	99	10/97-2/98	150
V01	V	Colimaçons	4.5	1	4	R	19.0	19.7	-	03-07/98	800
V02	V	LaMare 4	4.5	1	3	R/I	23.3	17.6	-	03-09/98	80
V03	V	LaMare 8	4.5	1	3	R/I	23.3	17.6	-	03-09/98	80
V04	V	LaMare 9	4.5	1	3	R/I	23.3	17.6	-	03-09/98	80
V05	V	LPSE D	4.5	1	4	I	22.6	17.1	-	03-07/98	150
V06	V	LPSE M	4.5	1	4	I	22.0	17.6	-	03-09/98	150
V07	V	LPSE F	4.5	1	4	I	20.3	16.7	-	06-09/98	150
V08	V	StBenoit D1	4.5	1	4	R	23.1	15.3	-	03-07/98	40
V09	V	StBenoit D2	4.5	1	4	R	23.1	15.3	-	03-07/98	40
V10	V	StBenoit F1	4.5	1	5	R	21.4	14.6	-	05-09/98	40
V11	V	StBenoit F2	4.5	1	5	R	21.4	14.6	-	05-09/98	40
V12	V	Mare G17	4.5	1	4	I	24.7	17.8	-	03-06/98	50
V13	V	Mare G18	4.5	1	4	I	24.7	17.8	-	03-06/98	50

Use: Use of the plots for calibration (C) or validation (V). Surf: Surface area (m^2) of the quadrats estimated or subplots harvested. Rep: Number of quadrats or subplots observed at each sampling date. Obs: Number of sampling dates. Irrig: Irrigated (I) or Rainfed (R). Tm: mean daily temperature (°C) during the study period. Rg: average daily total radiation (MJ/m/d) during the study period. AWC: Available water capacity (mm) of the soil. Altitude of the site (m).

opment of biomass and sucrose of plots was studied on the same inner quadrats without harvesting them. At each observation date, all stalk heights were measured up to the top visible dewlap on the same quadrats and a sample of 20-30 stalks was cut from the rows outside the quadrats to estimate the biomass of the latter.

The sample of stalks was separated into four to five subsamples with different mean heights. On each subsample, components of the cane and millable stalks were separated. The heights were measured and the fresh and dry weights recorded. From the subsamples of millable stalks, pulp prepared by means of a Jeffco cutter-grinder was pressed. Sucrose content was determined by the hydraulic press method (Hoarau,1969).

At each date, statistical relationships were then established between the mean height and aerial dry weight per stalk and between the latter and its different components: dry weights of green leaves, dead leaves, cane tops and millable stalks. With the 30 stalks sampling completed on the six crops, the correlation (r^2) between mean height and aerial dry weight per cane stalk ranged from 0.94 to 0.99, with 80% exceeding 0.98.

At each sampling date these relationships were used to determine the dry biomass of each component on each quadrat.

Weather records and soil moisture measurements

Daily weather data were recorded using the Cimel 407 weather station.

At each site, the apparent soil bulk densities and moisture characteristics (moisture content at field capacity and permanent wilting point) were measured for every 20 cm soil layer down to 1 m (crops 1 to 3) and 1.2 m (crops 4 to 6) according to the site and rooting behaviour. These field measurements were made according to the field methods described by IBSNAT (IBSNAT, 1990) Differences between moisture contents at field capacity and permanent wilting point enabled calculation of the available water capacities (AWC).

The volumetric moisture content of each layer was measured using a Time Domain Reflectometry (TDR) probe on the Tirano site and a soil auger (oven-drying for 72 h at 105ºC) at the other sites.

Treatment and analysis of the data

Sucrose and structural material. With the help of the sucrose analyses, the total dry weight of the millable stalk (mstw) was broken down into the dry weight of the structural material (mststw) and sucrose (sucrose). The structural material consisted of all materials other than sucrose. From drying, the weight of stored water (stwat) could be determined.

Moisture stress characteristics. Knowing AWC and the potential evapotranspiration, ETP, a simplified water balance, IRRICANNE (Combres and Jacquemond-Collet, 1990), was calculated for each treatment so as to estimate the maximum (ETM) and real (ETR) evapotranspiration of the crop and soil surface system, together with the available soil water (ASW). Thus, the daily characteristics of water stress ETR/ETM and ASW/AWC (relative soil water content) were averaged between each biomass measurement date. As volumetric water contents were not measured every day, the water contents simulated by the water balance - fitted with the observed measurements - were used to calculate these stress characteristics. On the six crops

used for calibration , mean errors of available soil water (ASW) ranged from 5 to 9 mm for AWC between 99 and 159 mm.

Statistical treatment

The equation parameters, correlations and regressions were calculated using the Splus software. Equation parameters, slope and intercept of regressions are given with their confidence interval.

Results and discussion

The carbon balances of sugarcane growth models (O'Leary, 2000; Keating *et al*, 1999) simulate the dry weight of millable stalk (mstw), the sucrose produced (sucrose) and the dry weight of the stalk structural material (mststw) which can be calculated as the difference of the other two (mstw-sucrose).

To estimate the stored water (stwat) it was assumed that this depends both on the container volume (a positive effect) which can be represented by the dry weight of the structural material, and the quantity of sucrose stored (a negative effect). On all the plots studied, with or without water stress, this hypothesis was tested and a close and very significant relationship was found between the water stored in the stalks and the dry weight of the structural material, and sucrose.

stwat = 5.72±0.5 * mststw - 1.44±0.8 * sucrose (r^2 = 0.98, p=0.0001,n=30) [1]

The closeness of the relationship is shown in Figure 1. Equation 1 may also be written as:

stwat= 5.72* mstw – 7.16*sucrose [2]

However, it is known that the moisture status of the soil (asw/awc) has a considerable effect on that of the stalk (Robertson and Donaldson, 1998; Robertson *et al* 1999). It therefore seemed important to see whether taking soil water content into account could improve the relationship already found. For this the residuals from the regression of model [1] were plotted against the soil water deficit (asw/awc). The correlation was very poor (r^2 = 0.14,p=0.04), although it was statistically significant, and the inclusion of this parameter did not noticeably improve the relationship. Figure 2 shows clearly the weakness of this relationship.

From Figure 3, the results of treatment 5 showed that there was no clear relationship between asw/awc and the change of the stem water content over the four periods. On the other hand, if the accumulation of stalk structural material, sucrose and water weight (Figure 4) are compared, the development of the accumulation of stem water (dstwat) fitted fairly closely to the stalk structural accumulation (dmststw) and asw/awc, but did not fit the sugar accumulation (dsucrose). It appears that soil water deficit had acted indirectly on the water content of the stalks via the intermediary of the biomass, notably the structural one. Using only the amounts of mainly structural material and to a lesser extent sucrose to estimate stalk water is generally sufficient. The variation in these amounts already accounts for the water stress effect.

Using equation 2, the sucrose content (%) and fresh cane yield (t/ha) can be expressed as a function of the ratio sucrose/mstw (ksug) :

Sucrose content = (100*ksug)/(6.72-7.16*ksug) [3]

Yield = mstw*(6.72 - 7.16*ksug)/100 [4]

To validate the relationships 1, 3 and 4 above, the estimates of these equations were compared with 51 observations on 13 plots independent of those used for determination of these relationships. The slope, intercept and r^2 of the regressions were used to quantify their validity. The Student *t* test was applied, and p values refer to the probability that the slope and intercept differ significantly from 1 and 0 respectively. Root mean square error (rmse) was calculated to indicate the accuracy of the relationships and therefore of the predictions.

The following statistical results were found:

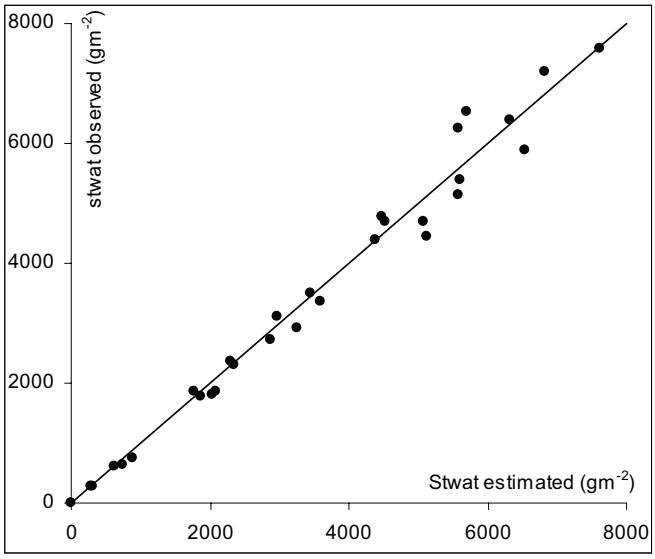

Figure 1. Comparison between the estimated weight of sugarcane stalk water, stwat estimated (5.735*mststw 1.144*sucrose), and stwat observed in g/m².

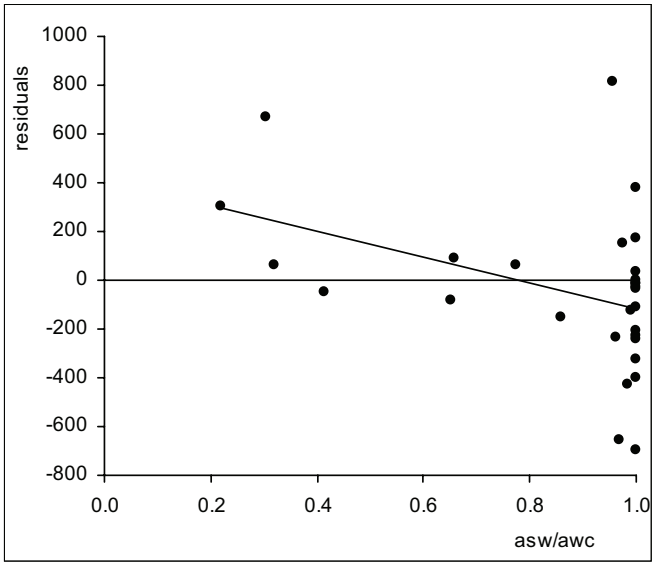

Figure 2. Relationship between soil water deficit (asw/awc) and residuals (stwat observed – stwat simulated) in g/m².

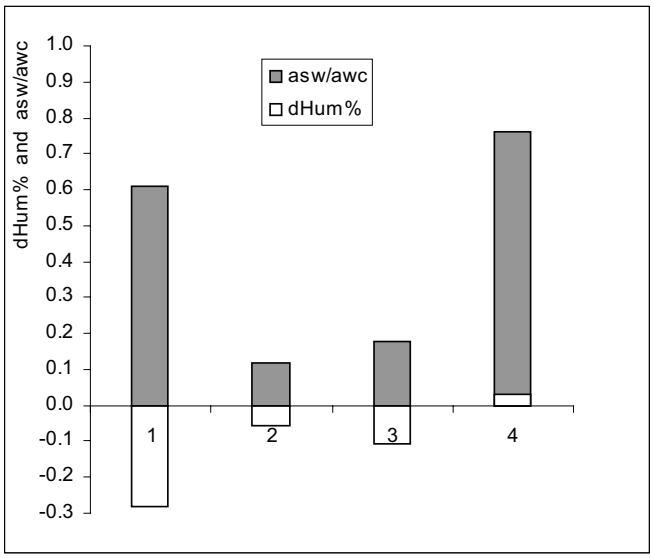

Figure 3. Daily changes of stalk water content dHum% (%/day) and mean relative available soil water content asw/awc (%), on treatment 5, during 4 consecutive periods (1,2,3 drying-off and 4 re-watering of the soil profile).

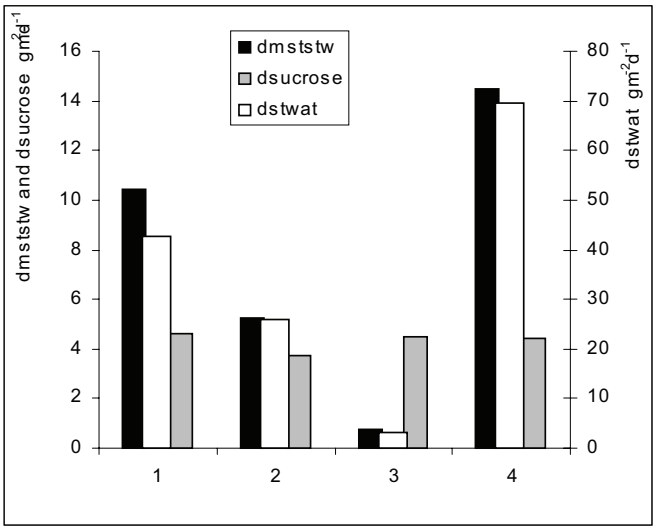

Figure 4. Evolution of accumulations of stalk structures (dmststw), sucrose (dsucrose) and water (dstwat) in g/m²/day on treatment 5 during 4 consecutive periods (1,2,3 drying-off and 4 re-watering of the soil profile).

Equation 1: estimation of the stem weight of water (stwat: g/m^2)

r^2=0.91 with p=0.0001. Rmse=450

Intercept = 337 ±505 with t=1.4 and p=0.19

Slope = 0.96 ± 0.09 with t=0.95 and p=0.35

Equation 3: estimation of the fresh cane sucrose content (%)

r^2=0.97 with p=0.0001. Rmse=0.6

Intercept = -0.49 ±0.6 with t=1.6 and p=0.11

Slope = 1.03 ± 0.05 with t=1.4 and p=0.16

Equation 4: estimation of the fresh cane yield (t/ha)

r^2=0.96 with p=0.0001. Rmse=4.5

Intercept = 3.7 ± 4.7 with t=1.58 and p=0.12

Slope = 0.97 ± 0.06 with t=1.18 and p=0.24

Slopes and intercepts were not significantly different from 1 and 0 respectively. Rmse for simulated stwat were 450 over an observed range of 3100-10000 g/m^2, 0.6 for sugar content % over an observed range of 1.9-14.5% and 4.5 for fresh cane yield over an observed range of 40-140 t/ha. The value of rmse gave a good indication of the accuracy of these relationships.

Conclusion

In order to simulate the yield and quality of sugarcane on a fresh weight basis, stored water must be estimated. The results showed that its determination only requires a knowledge of the dry weight of millable stalks (mstw) and of accumulated sucrose (sucrose). In fact there exists an excellent correlation between stwat and both mstw and sucrose (r^2 = 0.98).

Introducing the available soil water deficit, although this would seem fundamental, appeared to be superfluous and did not significantly improve the relationship. Its effect is already included in the relative variation in structural material and sucrose.

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