

Carbon storage in sugarcane fields of Brazilian South-Central region

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Abstract

The questions on the change in carbon storage caused by land use change led to the search for a methodology to estimate carbon storage in sugarcane fields, covering crop features of Brazilian farming system. Data from 22 years of systematic surveys on sugarcane stabilized crops in Brazilian South-Central, made by CTC - Center for Sugarcane Technology -, were used to characterize the sugarcane production cycle pattern, taking into account ratoon number, harvest cycles and planting seasons of sugarcane fields in South-Central Brazil. DSSAT/CANEGRO model was parameterized for the farming conditions of South-Central Brazil, was used to simulate the dynamic crop carbon accumulation and well compared with observed data from one sugar mill based on the State of Sao Paulo. Such simulations resulted average carbon stocks for the crop aerial part of 8.8 t ha⁻¹carbon.

Introduction

The increasing worldwide interest in the use of sugarcane ethanol as biofuel led to intense discussions on environmental sustainability. One of them involving the question of greenhouse gases emissions, considered those derived from the energy use for production of machinery, equipment and buildings required to process plant biomass; from the energy needed to produce and transport the inputs to the agricultural production and industrial conversion of sugar cane to ethanol; and from the energy needed to both processes (Macedo 2008). Besides, the GHG emissions not related to energy (soil emissions from fertilizers, for instance) were also considered.

Even though this issue has been considered elucidated by the scientific community, some others have not yet been fully clarified, especially the change in carbon stocks (soil and biomass) caused by changing land use, due to the expansion of sugarcane cultivation.

The significant expansion of sugarcane in South-Central Brazil in recent years highlights the need to define a calculation methodology to measure the impact of carbon storage change, comprising the features of crop growth process. Sugarcane crop is semi-perennial crop, with high biomass production and fast vegetative growth, what may lead to mistakes in carbon stocks estimates when compared with other crops such as soybean, maize and pastures.

This paper focused to assess the above ground carbon stock in sugarcane cultivation in the conditions of South-Central Brazil, through a method based on a large database collected in South-Central and crop and modeling techniques.

Material and Methods

Characterizing an average sugarcane plantation of Brazilian South-Central region

The study was based on a database collected and organized by CTC - Center of Sugarcane Technology, containing the area yield, cycles, varieties, and ratoon number yield, started in 86/87 season, comprising a total of 23 crop seasons (years). This database is used by the CTC benchmarking program, which includes, among other:

1) Varietal census: Started in 1986 with area and ratoon stage information by variety. It reached 6.2 million hectares registered in 319 sugar mills, being 280 in the South-Central region;

2) Mutual control: started in 1991, the program provides monthly reports on agricultural and industrial efficiencies rates, allowing the comparison of performance among the participating units. In the 2009/2010 season, 170 producing units from South-Central were involved in the program. From this database, data from the ratoon stage were used to establish the average profile and planting and harvesting season of the crop, which combined gave rise to an array indicating the temporal variation of crop development staged throughout the calendar. It considers the ratoon season and their relative frequency of occurrence; this has been used to determine the weight of biomass with the simulation provided by DSSAT/CANEGRO model. This was done for all situations likely to occur, following the Mutual Control array.

DSSAT/CANEGRO model for crop growth simulation

The cumulative biomass quantification throughout the crop cycle was made by the DSSAT/CANEGRO model using the parameterization developed by Marin et al. (2011) for the

South-Central Brazil. This parameterization was tested against experimental data collected over five seasons (2001/2002 to 2006/2007) to assess the time course of accumulation of green mass of shoots over the cycle, performed in a plant associated with the CTC (Usina Iracema, Iracemópolis, latitude 22.59 S, longitude: 47.53 W). Kolmogorov-Smirnov test was used to verify if probability distributions model differ from the green mass measurements in the field; the coefficient of determination (r^2) of the estimated values was established.

Simulations were made for sugarcane planted on March 1st, representing the most frequent time for planting in this plant over the five crops analyzed. Were also simulated ratoon dates in May, July and October, seeking to represent respectively the ratoon cycle early, mid and late stages.

The typical soil in area was the Yellow Oxisol, with its hydric parameters estimated by Tomasella et al. (2000) and hydraulic conductivity estimated according to Poulsen et al. (1999). Climatic data were consisted and failures filled using algorithm from the software WGEN (Richardson and Wright, 1984), program available in DSSAT v4.5 (Hoogemboom et al., 2010). Solar radiation data were estimated using the Bristow and Campbell model (1984), method previously calibrated using $A = 0.7812$, $B = 0.00515$, $C = 2.2$ and the model parameters (Conceição & Marin, 2007).

To estimate the above soil biomass stock in each season the year, the model was defined considering the distribution area of crop, age, developmental stage and the green mass accumulation curves obtained by the DSSAT/CANEGRO model. The validated model was used to determine the gain in mass crop for the different months of planting and ratoon considered.

Biomass and Carbon Stocks in Sugarcane

From the average sugarcane profile (distribution of ratoon stages) and period of planting and harvesting, we defined a matrix indicating the time of crop development throughout the season. This matrix was used to ponder the biomass gain estimate obtained with the DSSAT/CANEGRO model. The result of this evaluation for each month of harvest defined the shoots biomass stock, including biomass in sugarcane stems (sucrose and lignocellulosic material) and trash (tops, green and dry leaves).

The carbon content in of each shoot biomass portion (lignocellulose) was calculated with the average values obtained by CTC in the characterization of straw and bagasse (Tufail Neto, 2005), Table 1. The average value of 50% carbon in the sugarcane aerial part composition, also close to value observed in sugars present in the broth, was used.

Table 1 – Average carbon concentration of sugarcane components¹⁾ (%).

	Dry Leaves	Pointer	Bagasse
Carbon	46,2%	43,9%	44,6%

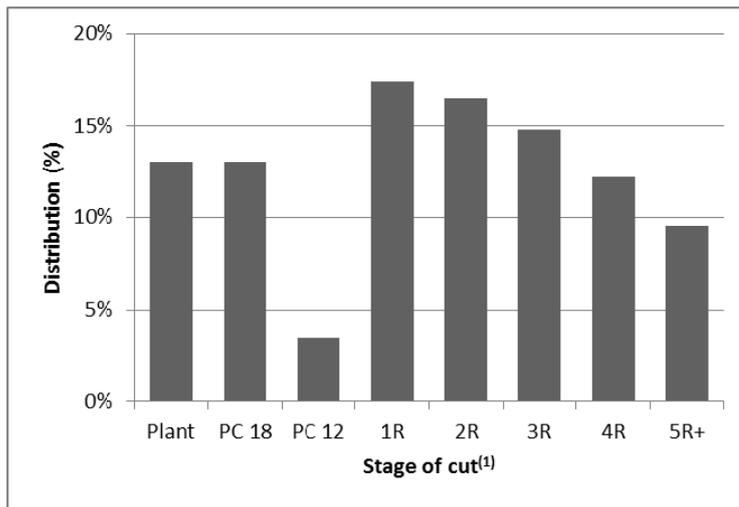
⁽¹⁾Dry mass – ASTM Standards D 3172

Results and Discussion

Sugarcane standard crop characterization of the South-Central

The sugarcane cultivation in Brazilian South-Central region has an established farming system for plant and ratoon cane cycles. The profile of a stabilized crop was

obtained from the average data of 22 crop seasons (Figure 1), indicating a relatively homogeneous distribution for the planting and ratoon systems, ranging between 10% and 17%, except for the first area, regarding sugarcane fields of 12 months sugarcane, with only 3%.



(1)

P

lant is 18 months cane planting, *PC18* is 18 months plant cane, *PC12* is 12 months plant cane and *1R, 2R to 5R* represent the sugar plantations of the first, second to the fifth ratoons.

Figure1. Area distribution of sugarcane field for South-Central Brazil, by ratoon cycle.

In the 12 month system, the cane is planted from May to November, immediately after the last harvest of previous cycle, and harvested again in the next harvest, with approximately 12 months. The planting of 12 months cane has lower yield than the 18 months cane, but the advantage is that the system does not leave areas without harvest during at least one season.

Combining frequency distribution per ratoon stage (Figure 1) with distribution of planting dates (Figure 2), produced the Table 2 that represents the biomass evolution (shown in columns), according to planting or ratoon and relative frequency of each crop system (described in lines).

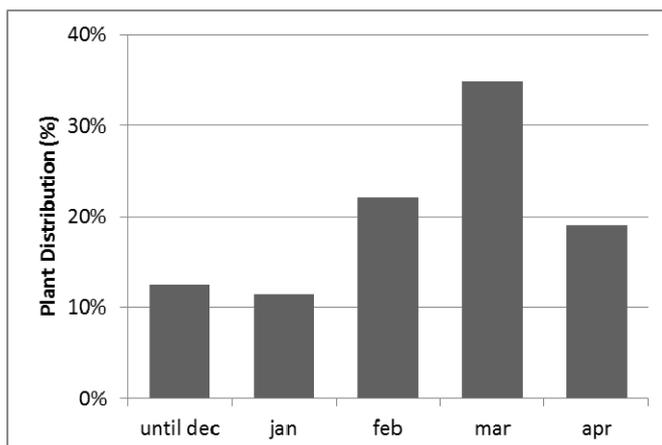


Figure 2. Frequency distribution for planting dates for 18 months cycle sugarcane fields.

Table 2. Age and distribution of crop development stages.

Development Stage	Distrib	Age (months)											
		jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
<i>18 months cane - planting DEC - two crops ago</i>	1,7%	13	14	15	16	1	2	3	4	5	6	7	8
<i>18 months cane - planting JAN - last year</i>	1,4%	12	13	14	15	16	1	2	3	4	5	6	7
<i>18 months cane - planting FEB - last year</i>	2,9%	11	12	13	14	15	16	1	2	3	4	5	6
<i>18 months cane - planting MAR - last year</i>	4,6%	10	11	12	13	14	15	16	1	2	3	4	5
<i>18 months cane - planting APR - last year</i>	2,5%	9	10	11	12	13	14	15	16	1	2	3	4
<i>18 months cane - planting DEC - last year</i>	1,7%	1	2	3	4	5	6	7	8	9	10	11	12
<i>18 months cane - planting JAN</i>	1,4%	-	1	2	3	4	5	6	7	8	9	10	11
<i>18 months cane - planting FEB</i>	2,9%	-	-	1	2	3	4	5	6	7	8	9	10
<i>18 months cane - planting MAR</i>	4,6%	-	-	-	1	2	3	4	5	6	7	8	9
<i>18 months cane - planting APR</i>	2,5%	-	-	-	-	1	2	3	4	5	6	7	8
<i>12 months cane - planting/harvest APR - last year</i>	2,4%	9	10	11	12	1	2	3	4	5	6	7	8
<i>12 months cane - planting/harvest MAY - last year</i>	8,1%	8	9	10	11	12	1	2	3	4	5	6	7
<i>12 months cane - planting/harvest JUN - last year</i>	10,4%	7	8	9	10	9	12	1	2	3	4	5	6
<i>12 months cane - planting/harvest JUL - last year</i>	10,6%	6	7	8	9	10	11	12	1	2	3	4	5
<i>12 months cane - planting/harvest AUG - last year</i>	10,9%	5	6	7	8	9	10	11	12	1	2	3	4
<i>12 months cane - planting/harvest SEP - last year</i>	10,8%	4	5	6	7	8	9	10	11	12	1	2	3
<i>12 months cane - planting/harvest OCT - last year</i>	10,8%	3	4	5	6	7	8	9	10	11	12	1	2
<i>12 months cane - planting/harvest NOV - last year</i>	7,6%	2	3	4	5	6	7	8	9	10	11	12	1
<i>12 months cane - planting/harvest DEC - last year</i>	2,3%	1	2	3	4	5	6	7	8	9	10	11	12
Total	100,0%												

Evaluation and application of the DSSAT / CANEGRO model

Figure 3 shows the green mass gain curves for Piracicaba by comparing average data of the Iracema Mill with the curve obtained by historical DSSAT model for a March planting. The result of Kolmogorov test comparing the DSSAT model with data collected in Iracema

Mill indicates that the two distributions are adhering to the 5% level of significance, with $r^2 = 0.9729$.

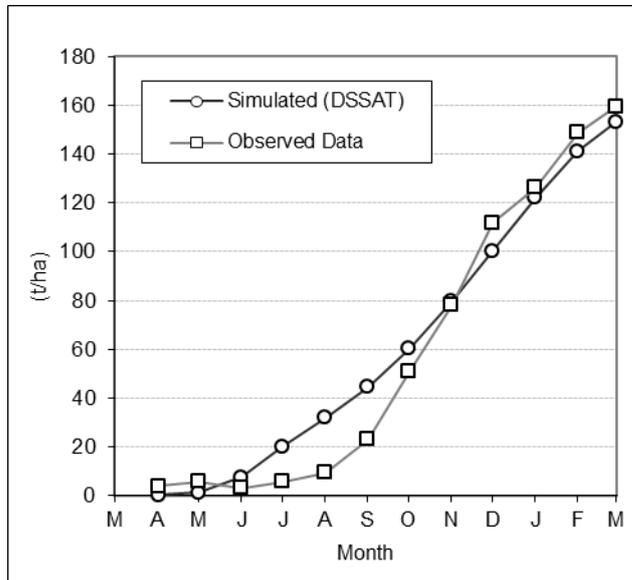


Figure 3 - Monthly variation of above ground fresh mass observed and simulated ($t\ ha^{-1}$).

Biomass and carbon stock in sugarcane production

Weighting the distribution areas by the green mass gain curves generated in the DSSAT model, the dry biomass available in the field throughout the year was estimated (Table 3). The results show that the dry biomass above soil varies during the crop of $28.7\ t\ ha^{-1}$ in May (beginning of the crop) to $9.1\ t\ ha^{-1}$ at the end of harvest season, averaging $17,5\ t\ ha^{-1}$ (equivalent carbon of $8.8\ t\ ha^{-1}$). It must be noted that for any period the average carbon stock was greater than zero since in a farm unit, for each harvest period, there are areas with the crop at different ages and development stages. For comparison the values reported by Amaral 2008 for above soil biomass in grassland indicate $1.3\ t\ ha^{-1}$ in degraded pastures and $6.5\ t\ ha^{-1}$ in well managed pastures. For annual crops, Amaral 2008 reported values of $1.8\ t\ ha^{-1}$ for cotton and soybeans 2.2 to $3.9\ t\ ha^{-1}$ for corn.

Table 3. Time variation of biomass dry mass and field carbon storage.

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	Aver
<i>Aerial part dry biomass (t/ha)</i>	12,4	16,9	21,8	26,3	28,7	25,8	21,4	15,9	11,7	9,8	9,1	10,7	17,5
<i>Carbon storage (t/ha)</i>	6,2	8,4	10,9	13,2	14,3	12,9	10,7	8,0	5,9	4,9	4,5	5,3	8,8

Other studies in the literature adopt a simplified approach (e.g Harris, 2009), which determines the "average" by dividing by 2 the maximum cane biomass point, so disregarding the minimum inventory (which is greater than zero) and arriving to 7 t ha⁻¹ carbon. The methodology proposed here attempts to characterize the development conditions and a representative profile of a mature crop, reaching a more appropriate result for the "average" Brazilian sugarcane field, which represents 25% higher carbon storage than that obtained by Harris (2009).

Conclusions

1. The used methodology, which combines the crop profile, planting and harvest date information with crop modeling techniques is useful to assess sugarcane biomass carbon stock.
2. The sugarcane farming system in South-Central Brazil represents an above-zero carbon stock above the ground throughout the year.
3. The annual average of above soil carbon stock in sugarcane is 8.8 t ha⁻¹, higher than observed in other agricultural systems in the same region, such as degraded and well managed pastures, corn, cotton and soybean.

References

- AMARAL, W. A. N.; MARINHO, J.P.; TARASANTCHI, R.; BEBER, A.; GIULIANI E. Environmental sustainability of sugarcane ethanol in Brazil. In: Zuurbier, P.; Van de Vooren J. **Sugarcane ethanol: Contribution to climate change mitigation and the environment**. Wageningen Academic, Wageningen, 2008. p. 121-124.
- BRISTOW, K. L.; CAMPBELL, G. S. On the relationship between incoming solar radiation and daily maximum and minimum temperature. **Agricultural and Forest Meteorology** 31, no. 2, p. 159–166. 1984.
- CTC - CENTRO DE TECNOLOGIA CANAVIEIRA, **Censo Varietal e de Produtividade em 2009**, CTC - Centro de Tecnologia Canavieira, Piracicaba SP, 2010. 20p.
- CONCEIÇÃO, M.A.F.; MARIN, F. R. Avaliação de modelos de estimativa de valores diários da radiação solar global com base na temperatura do ar. **Revista Brasileira de Agrometeorologia**, v. 15, p. 103-108. 2007.
- DOOREMBOS, J.; KASSAM, A.H. **Efectos del agua sobre el rendimiento de los cultivos**. Roma: FAO, 1979. 212p.
- HARRIS, N.; GRIMLAND, S.; BROWN, S. **GHG emission factors for different land-use transitions in selected countries of the world**. Report submitted to US EPA. Technical Report, Winrock International, 2008.
- HOOGENBOOM, G.; JONES J.W.; WINKENS P.; PORTER C.; BOOTE K.; HUNT L.A.; BATCHELOR W.D. AND TSUJI G.Y., **Decision Support System for Agrotechnology Transfer Version 4.0**. University of Hawaii, Honolulu, HI. 2010.
- MACEDO I.C., SEABRA J.E.A., SILVA J.E.A.R. Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: The...., **Biomass and Bioenergy**, doi:10.1016/j.biombioe.2007.12.006, 2008.
- MACHADO, E. C.; PEREIRA, A. R.; FAHL, J. L.; ARRUDA, H. V.; CIONE, J. Índices biométricos de duas variedades de cana-de-açúcar. **Pesq. Agrop. Bras.**, 17: 1321-1329, 1982
- MARIN, F. R.; JONES, J. W.; ROYCE, F.; SUGUITANI, C.; DONZELLI, J.L.; PALLONE FILHO, W. J.; NASSIF, D.S.P. Parameterization and Evaluation of Predictions of DSSAT/CANEGRO for Brazilian Sugarcane. **Agronomy Journal** (Print), v. 103, p. 297-303, 2011.
- PAES, L.A; OLIVEIRA, M.A. Potential Trash Biomass of the Sugarcane Plant in: Hassuani, S., Leal, M.R.L.V. and Macedo, I.C. **Biomass Power Generation: Sugar Cane Bagasse and Trash**, 1st Edition, p. 18-22; PNUD/CTC. 2005.
- POULSEN, T. G., P. MOLDRUP, T. YAMAGUCHI, P. SCHJØNNING, AND J. A. HANSEN. Predicting Soil-Water and Soil-Air Transport Properties and Their Effects on Soil-Vapor Extraction Efficiency. **Ground Water Monitoring & Remediation** 19, no. 3: 61-70. 1999.
- RICHARDSON, C.W.; WRIGHT, D.A. **WGEN: A model for generating daily weather variables**. ARS, 8, 1984. p.83.
- RODRIGUES, DJ. **Fisiologia da cana-de-açúcar**. Botucatu: Universidade Estadual Paulista - UNESP, 1995. 69p.
- TOMASELLA, J.; HODNETT, M. G.; ROSSATO, L. 2000 “Pedotransfer functions for the estimation of soil water retention in Brazilian soils,” **Soil Science Society of America Journal** 64, no. 1. p. 327. 2000.

TUFAILE NETO, M.A. Characterization of Sugar Cane Trash and Bagasse; in: Hassuani, S., Leal, M.R.L.V.; Macedo, I.C., **Biomass Power Generation: Sugar Cane Bagasse and Trash**, 1st Edition; PNUD/CTC, 2005, p. 23-25