SUGARCANE LEAF AREA INDEX MODELING UNDER DIFFERENT SOIL WATER CONDITIONS

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ABSTRACT: The knowledge of the Leaf Area Index (LAI) variation during the whole crop cycle is essential to the modeling of the plant growth and development and, consequently, of the crop yield. Sugarcane LAI evolution models were developed for different crop cycles, by adjusting observed LAI values and growing degree-days summation data on a power-exponential function. The resultant equations simulate adequately the LAI behavior during the entire crop cycle. The effect of different water stress levels was calculated in different growth periods, upon the LAI growth The LAI growth deficit was correlated with the ratio between actual evapotranspiration and maximum evapotranspiration, and a constant named k_{LAI} was obtained in each situation. It was noticed that the k_{LAI} must be estimated not just for different growth periods, but also for different water stress levels in each growth period.

Key Words: Leaf Area Index, sugarcane, growing degree-days, water stress, modeling

MODELAGEM DO ÍNDICE DE ÁREA FOLIAR EM CANA-DE-AÇÚCAR SOB DIFERENTES CONDIÇÕES HÍDRICAS DO SOLO

RESUMO: O conhecimento da variação do Índice de Área Foliar (IAF) durante todo o ciclo da cultura é essencial para que se possa modelar o crescimento e o desenvolvimento das plantas e, em consequência, a produtividade da cultura. Desenvolveu-se neste trabalho modelos de estimativa de IAF da cultura da cana-de-açúcar para os diferentes ciclos de cultivo, a partir do ajuste de valores medidos de IAF e dados de somatório de graus-dia corrigido pelo comprimento do dia a uma função do tipo exponencial-potencial. As equações obtidas modelam adequadamente a variação do IAF durante todo o ciclo. Foi também calculado o efeito de diferentes níveis de déficit hídrico e em diferentes estádios fenológicos, sobre o crescimento do IAF. Correlacionou-se o déficit de crescimento de IAF com a relação entre a evapotranspiração real e evapotranspiração máxima da cultura e obteve-se, em cada situação, uma constante chamada aqui de k_{IAF}. Em face dos resultados conclui-se que k_{IAF} deve ser estimado não só para diferentes estádios fenológicos mas também para diferentes níveis de déficit hídrico em cada estádio.

Descritores: Índice de Área Foliar, cana-de-açúcar, graus-dia, estresse hídrico, modelagem

INTRODUCTION

The sugarcane crop has grown in importance due to its use as raw material for alcohol and sugar production.

The crop yield is determined by the interaction between plants and environment and it is directly related to the solar radiation intercepted by the leaves and transformed into chemical energy during the photosynthesis. Therefore the knowledge of the Leaf Area Index (LAI) variation along the crop cycle is of paramount importance in the development of crop growth and yield models.

The LAI is an important adjustment factor in most sugarcane growth and yield models known (Doorembos & Kassan, 1979; Machado, 1981; Pereira & Machado, 1986; Barbieri, 1993). However, the LAI models used in those crop models seem to be defective because they do not represent adequately all phenological stages.

Hence it is reasonable that a better adjustment of LAI evolution along the crop cycle, with and without water stress, be done. This paper presents LAI mathematical models developed with data collected by Leme *et al.* (1984) in irrigated and non-irrigated sugarcane fields.

MATERIAL AND METHODS

The LAI and meteorological data were collected at the PLANALSUCAR-Estação Central Sul, Araras, São Paulo, Brazil. The experimental fields were located at an elevation of 617 m, latitude 22° 18' S, and longitude 42° 23' W.

LAI data were measured in the plant (first) crop and in two following ratoon crops, during four years in irrigated and non-irrigated plots of sugarcane cultivar CB 47-355.

The growing degree-day values were calculated by using the following equations (Villa Nova *et al.*, 1972):

a) When Tm > Tb

$$GDD = \left(\frac{TM + Tm}{2}\right) - Tb \qquad (1)$$

b) When Tm ≤ Tb

$$GDD = \frac{(TM - Tb)^2}{2(TM - Tm)} \qquad (2)$$

in which: GDD = growing degree-days
TM = maximum daily air temperature
Tm = minimum daily air temperature
Tb = basal temperature

As basal temperature a value of 18°C was used (Bachi & Souza,1978). An upper temperature hazard threshold was not considered to calculate GDD because during the four years of experimentation only on four days the maximum temperature reached the hazard threshold which is 35°C according to Fauconier & Bassereau (1975).

The GDD values for each day were standardized by the ratio between day length in hours (N) and 12 hours.

$$GDD_{st} = GDD \cdot N/12 \qquad (3)$$

The LAI data measured in the irrigated fields for each crop (plant, first and second ratoon) were adjusted to a power-exponential function:

$$Y = a \cdot x^b \cdot e^{cx} \qquad (4)$$

being: Y = LAI at a given time
x = ΣGDD_{st} until that given time
a, b and c = adjustment parameters

To estimate the effects of water stress on LAI variation until maximum LAI, a modification of the Stewart *et al.* (1977) method was elaborated:

$$(1 - \text{LAI growth deficit}) = k_{LAIi}\,(1\text{-Eta/Etm}) \qquad (5)$$

$$\text{LAI growth deficit} = \frac{LAIws_t - LAIws_{t-1}}{LAIo_t - LAIws_{t-1}} \qquad (6)$$

with,
k_{LAIi} = LAI coefficient in the stage i
Eta = actual evapotranspiration
Etm = maximum evapotranspiration
$LAIws_t$ = LAI with water stress at time t
$LAIws_{t-1}$ = LAI with water stress at time t-1
$LAIo_t$ = potential LAI at time t (LAI that would be achieved with a growth rate of a crop without water stress)

k_{LAI} values were calculated for intervals (t) of 200 GDD.

RESULTS AND DISCUSSION

The following LAI estimate equations, for crops without water stress (under irrigation), were obtained by regressions in which LAI and ΣGDD_{st} were correlated:

a) Plant (first) crop (eq. 7):

$$LAI = e^{-13{,}521} * (\Sigma GDD_{st})^{2{,}784} * e^{-0{,}004023 * \Sigma GDDst}$$

$r^2 = 0{,}58$

b) First ratoon crop (eq. 8):

$$LAI = e^{-17{,}707} * (\Sigma GDD_{st})^{3{,}373} * e^{-0{,}004265 * \Sigma GDDst}$$

$r^2 = 0{,}88$

c) Second ratoon crop (eq. 9):

$$LAI = e^{-20{,}207} * (\Sigma GDD_{st})^{3{,}832} * e^{-0{,}004936 * \Sigma GDDst}$$

$r^2 = 0{,}80$

The shape of the resulting curves (figures 1, 2 and 3) and the statistic tests show that the equations fit the points satisfactorily.

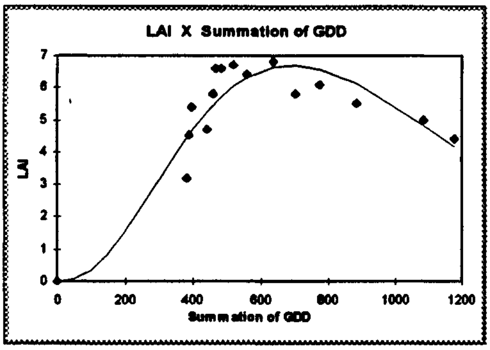

Figure 1 - LAI values - Plant crop.

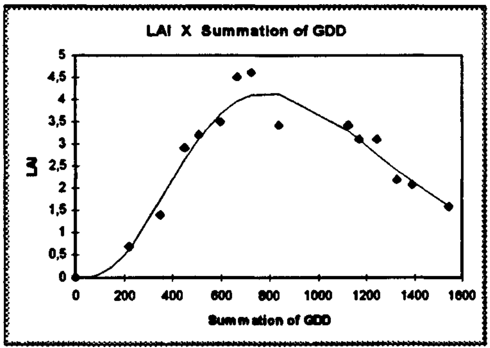

Figure 2 - LAI values - 1st ratoon crop.

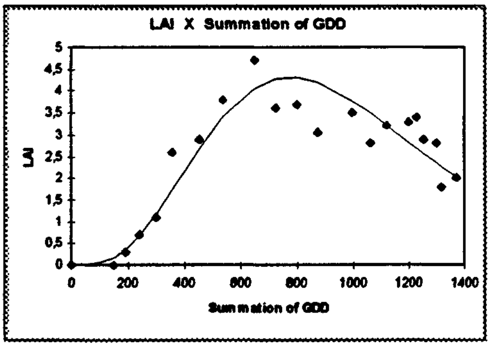

Figure 3 - LAI values - 2nd ratoon crop.

The LAI variation curves for all the crops (plant, first and second ratoon) have a similar shape, showing a initial phase of slow growth, followed by a fast growth phase, another slow growth or stabilization phase, and finally a phase of decrease in LAI (figure 4).

In the first crop (plant crop), a higher vegetative vigor was observed. In this crop, LAI reached values between 6 and 7, and before 400 GDD was accumulated the LAI was greater than 4, being the leaves able to intercept at least 95% of the incident solar radiation (Machado *et al.*, 1985). LAI remained greater than 4 for a long time, until a summation of 1200 GDD.

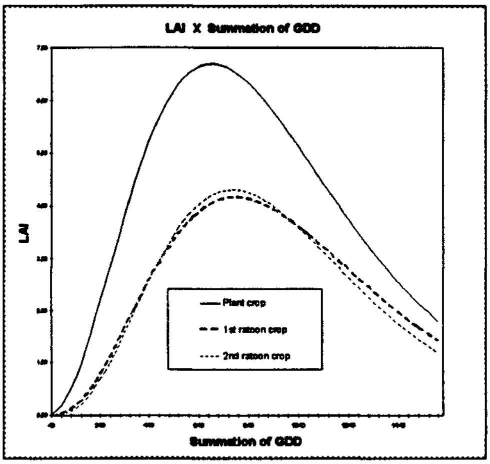

Figure 4 - LAI Values - Crop comparison.

In the following crop (1st ratoon crop), the vegetative vigor had a significant decrease, having no additional decrease in the second ratoon crop. For that reason, as it can be seen in figure 4, the LAI values along the cycle were similar for the first and second ratoon crops. Thus it was possible to adjust a single model for both ratoon crops.

In the ratoon crops the maximum LAI was lower than 4.5 and it remained above 4, for a shorter period (650 to 900 GDD).

LAI values lower than 3.5 at the end of cycle, typical of the ripening stage (Yoon, 1971), were found in the plant crop when the summation of GDD reached 1300 and in the ratoon crops when it reached 1100.

The reduction in LAI values in the ratoon crops may result from the smaller number of tillers per meter in these crops in comparison with the plant crop, besides the worsening of chemical soil characteristics, and the soil compactation caused by the traffic of heavy vehicles during the harvest.

It should be remarked that the growing degree-days used in these models were accumulated from the day of planting in the first crop and from the day of cutting (harvest) in the following crops, and not from the beginning of sprouting. The models represented well the period between planting (or cutting) and sprouts emergence; as it can be seen in the figures, the models resulted in LAI values close to zero until summation of GDD around 80, required for sprouts emergence.

Regarding the effects of water stress on LAI, a constant named k_{LAI} was obtained for each crop in intervals of 200 GDD, because the water stress influence on LAI varies according to the stage in which it occurs.

In the stage between 0 and 200 GDD (stage 0) after planting or cutting, the water stress did not cause significant effect on LAI:

$$LAI_{0\text{-}200} = LAIws_{0\text{-}200}$$

The k_{LAI} for the other stages are the following:

-Plant crop

* Stage 1 (200 - 400 GDD)
1st replicate → $k_{LAI1} = 1.29$
2nd replicate → $k_{LAI1} = 0.95$

* Stage 2 (400 - 600 GDD)
1st replicate → $k_{LAI2} = 0.82$
2nd replicate → $k_{LAI2} = 1.25$

* Stage 3 (600 - 700 GDD)
1st replicate → $k_{LAI3} = 11.44$
2nd replicate → $k_{LAI3} = 13.01$

In this crop, LAI begins to decrease after 700 GDD.

The soil water deficit was always greater in the first replicate.

-First and second ratoon

* Stage 1 (200 - 400 GDD)
1st replicate → $k_{LAI1} = 4.44$

other replicates → k_{LAI} was not feasible to calculate due to absence of soil water deficit during this stage.

* Stage 2 (400 - 600 GDD)
3rd replicate → $k_{LAI2} = 7.36$

other replicates → k_{LAI} was not feasible to calculate due to absence of soil water deficit during this stage.

* Stage 3 (600 - 800 GDD)
1ª replicate → $k_{LAI3} = 4.57$
2ª replicate → $k_{LAI3} = 3.25$

other replicates → k_{LAI} was not feasible to calculate due to absence of soil water deficit during this stage.

The 1st and 2nd replicates refer to the first ratoon crop, while 3rd and 4th replicates refer to the second ratoon crop.

To exemplify the calculation method, the k_{LAI1} calculation of the plant crop first replicate will be showed:

$$1-\left(\frac{2.88_a-0.68_b}{3.74_c-0.68_b}\right)=k_{LAI1}\left(1-\frac{155.89_d}{199.13_e}\right)$$

a = LAIws at 400 GDD; b = LAIws at 200 GDD; c = LAI at 400 GDD, beginning at a value equal to 0.68 (LAIws at 200 GDD) and increasing with the growth rate of a crop without water stress (*); d = accumulated actual evapotranspiration in the stage; e = accumulated maximum evapotranspiration in the stage

(*) By using the LAI forecast equation for the plant crop, it can be found which GDD summation value corresponds to a LAI of 0.68 (135 GDD in this particular case), then 200 GDD should be added to that GDD value in order to calculate the new LAI value ($\sum GDD = 335 \rightarrow LAI = 3.74$).

Unlike the yield coefficient (ky), k_{LAI} is not constant in a given stage for different soil water deficit conditions. Rawitz (1969) points out that under a low soil water deficit the LAI growth deficit is greater than the evapotranspiration deficit (ETa/Etm), thus greater k_{LAI} values are expected in this condition.

The LAIws values simulated by this model (eq. 10):

$[LAIws_t = LAIo_t - k_{LAIi}(LAIo_t - LAIws_{t-1})(1 - Eta/Etm)]$, with the calculated constants, can be seen in the figures 5 to 10:

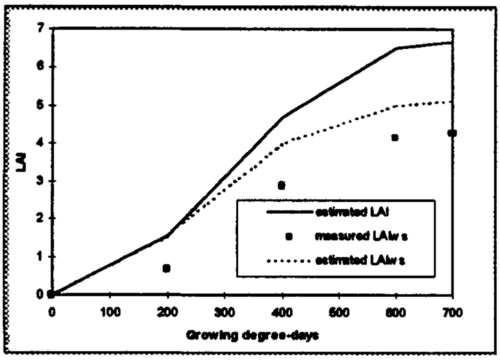

Figure 5 - LAI values - Plant crop under higher soil water deficit condition

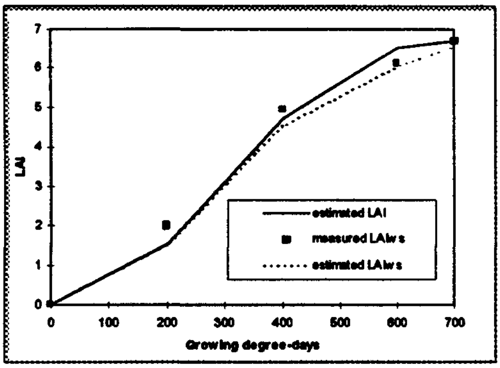

Figure 6 - LAI values - Plant crop under lower soil water deficit condition

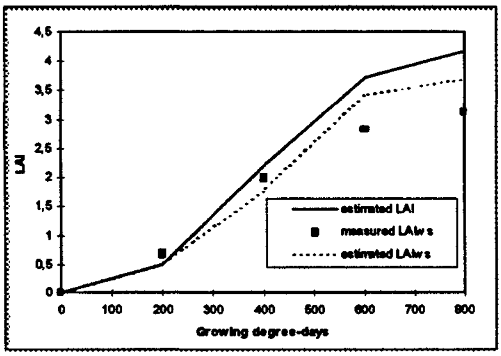

Figure 7 - LAI values - First ratoon crop under higher soil water deficit condition

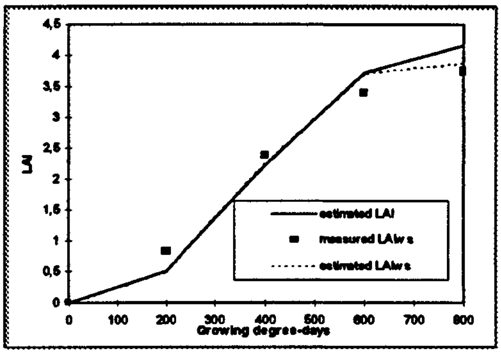

Figure 8 - LAI values - First ratoon crop under lower soil water deficit condition.

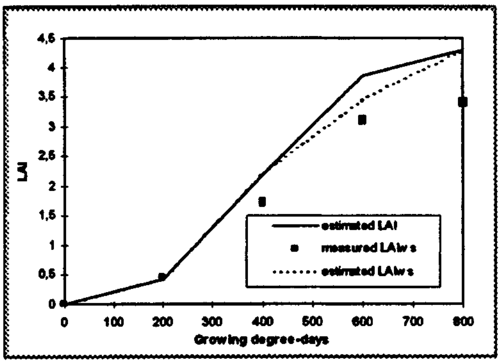

Figure 9 - LAI values - Second ratoon crop under higher soil water deficit condition

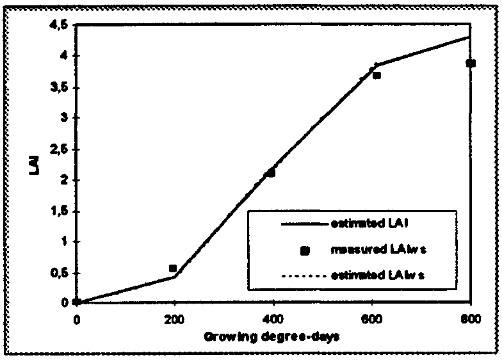

Figure 10 - LAI values - Second ratoon crop under lower soil water deficit condition

To better estimate k_{LAI} and LAIws an experimental design in which different soil water deficits occur in each 200 GDD stage, and with different combinations of soil water deficits between stages is suggested. In this case it would be obtained k_{LAI} values not only for each stage but also for different ranges of soil water deficit in each stage.

CONCLUSIONS

- The power-exponential function $[LAI = a \bullet (\Sigma GDD_{st})^b \bullet e^{c\Sigma GDDst}]$ fits well the LAI evolution curve, showing a initial phase of slow growth, followed by a fast growth phase, another slow growth or stabilization phase, and finally a phase of decrease in LAI

- The LAI (Leaf Area Index without water stress) can be estimated with an easily obtained variable, the summation of GDD standardized by day length.

- The sugarcane plant (first) crop demands a specific LAI estimate equation due to its greater vegetative vigor. The following ratoon crops demand only one estimate equation.

- The soil water deficit effect upon LAI is not linear, that is, this effect is variable according to the soil water deficit level; under a low soil water deficit the LAI growth rate decreases more than the evapotranspiration rate, and under a higher soil water deficit the LAI growth rate decreases less than the evapotranspiration rate.

- Different k_{LAI} are expected not only for different phenological stages, but also for different soil water deficit conditions in a given phenological stage.

- The k_{LAI} calculation method proposed herein seems to be adequate but the experimental design used in this research was incomplete.

REFERENCES

BACCHI, O.O.S.; SOUZA, J.A.G.C. Minimum threshold temperature for sugar cane growth. In: INTERNATIONAL SOCIETY OF SUGAR CANE TECHNOLOGISTS. **Proceedings**, São Paulo, Impress, 1978. v2, p.1733-1741.

BARBIERI, V. Condicionamento climático da produtividade potencial da cana-de-açúcar (*Saccharum* spp): um modelo matemático-fisiológico de estimativa. Piracicaba, 1993, 142p. (Tese) Doutorado - Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo.

DOOREMBOS, J.; KASSAN, A.H. Yield response to water. Rome, FAO, 1979, 193p. (Irrigation and Drainage Paper 33).

FAUCONIER, R.; BASSEREAU, D. La caña de azúcar. Barcelona, Blume, 1975, 433p.

LEME, E.J.A; MANIERO, M.A: GUIDOLIN, J.C. Estimativa da área foliar da cana-de-açúcar e sua relação com a produtividade. **Cadernos PLANALSUCAR**, v.2, p.3-9, mar. 1984.

MACHADO, E.C. Um modelo matemático-fisiológico para simular o acúmulo de matéria-seca na cultura da cana-de-açúcar (*Saccharum* spp). Campinas, 1981, 115p. (Dissertação) Mestrado - Instituto de Biologia, Universidade Estadual de Campinas.

MACHADO, E.C.; PEREIRA, A.R.; CAMARGO, M.B.P.; FAHL, J.I. Relações radiométricas de uma cultura de cana-de-açúcar. **Bragantia**, v.44, n.1, p.229-238, 1985.

PEREIRA, A.R.; MACHADO, E.C. Um simulador dinâmico do crescimento de uma cultura de cana-de-açúcar. **Bragantia**, v.45, n.1, p.107-122, 1986.

RAWITZ, E. The dependence of growth rate and transpiration rate on plant and soil physical parameters under controlled conditions. **Soil Science**, v.110, n.3, p.172-182, 1969.

STEWART, J.I.; CUENCA, R.H.; PRUITT, W.O.; HAGAN, R.M.; TOSSO, J. Determination and utilization of water production functions for principal California crops. **California Contribution of Project Reports**, W-67. University of California, Davis, 1977.

VILLA NOVA, N.A.; PEDRO Jr, M.J.; PEREIRA, A.R.; OMETTO, J.C. Estimativa de Graus-dia, acumulados acima de qualquer temperatura base, em função das temperaturas máxima e mínima. Caderno de Ciências da Terra, Instituto Geográfico-USP, n.30, 1972.

YOON, C.N. Growth studies on sugarcane. **The Malaysian Agricultural Journal**, v.48, n.2, p.47-59, 1971.

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