Simulation of Potential Growth of Sugarcane in the Dry Zone of Sri Lanka

K. Sanmuganathan and G.C.L. Wyseure[1]

Sugarcane Research Institute
Uda Walawe.

ABSTRACT. A crop growth model was developed to simulate the potential growth of sugarcane in the dry zone of Sri Lanka. This growth model was developed using Borland Turbo Pascal compiler version 6.0 on an IBM compatible computer running under MSDOS. The model simulated major physiological processes and phenological development, through mathematical expressions using crop and meteorological parameters. Daily maximum and minimum temperature and day length were used to calculate the dates of emergence, tillering and canopy development, grand period of growth and maturity.

The output of the model was compared with seven years of meteorological and yield data obtained from the Sugarcane Research Institute of Sri Lanka. The results showed a close positive relationship between the simulated and measured dry matter. The simulated results were within a 10% accuracy except in 1981 and 1982.

This model could be used to assess the potential of an area for sugarcane cultivation. It could also be used as a powerful tool by sugarcane agronomists and breeders for interpreting field observations.

INTRODUCTION

Traditional field experimentation evaluating potential production of a sugarcane variety has many limitations. Long growth duration and the high cost of agronomic field trials limit the number of studies involving climatic interactions. Moreover, the resulting information would be site and season specific.

---

[1] University of Newcastle Upon Tyne, United Kingdom.

It is difficult to estimate the potential production of a variety due to the variation in climate. In an optimal environment, growth is determined only by genotype. In nature such conditions are rare. It is difficult to reproduce optimal environments even under greenhouse conditions. In the field, supply of various resources are unbalanced. Under most environments, there is likely to be a specific factor that limits growth. It is further complicated by the variation of environmental factors with time.

De Wit (1982) classified crop production systems into four levels based on growth limiting factors. Production at any of these levels can be considered as members of a broad class of systems in order of decreasing yield. These levels are:

Production level 1

This is the maximum possible production of a crop under unlimited levels of water and nutrients, where growth depends on current weather conditions, particularly radiation and temperature. This is the potential growth rate possible in that radiation and thermal environment and the yield obtained is the potential yield.

Production level 2

In this level the growth is limited by the availability of water.

Production level 3

Growth is restricted by the availability of nitrogen in this level.

Production level 4

In this level, growth is restricted by low phosphorus and other mineral nutrients.

However growth reducing factors such as diseases, insects and pests and weeds can occur at any of these production levels and cause different degrees of growth reductions.

Field situations rarely fit exactly into one of these production levels. However, it is convenient to reduce specific cases to one of the four categories, to focus attention on the dynamics of the main environmental factor and the response of the crop.

The objective of this study was to estimate the potential production of sugarcane grown in the dry zone of Sri Lanka, by a mathematical simulation model. The modeling included major physiological processes and the phenological development such as germination and emergence, tillering and canopy development and grand period of growth and maturity.

MATERIALS AND METHODS

The model

The model presented here was constructed mathematically to obtain a quantitative relationship between the relevant major physiological processes of sugarcane. Crop and meteorological parameters were used to estimate potential production.

The growth model consisted of three sub models (Figure 1), namely radiation interception model by Hay and Walker (1989), photosynthetic model by Marshall and Biscoe (1980) and respiration model by Mc Cree (1974). The phenological development is driven by heat accumulation (thermal time), which begins at planting. The daily heat accumulation is the difference between mean daily air temperature and crop specific base temperature. Heat accumulation is zero for mean temperature less than base temperature.

The phenological development for sugarcane is directly proportional to heat accumulated, which is zero at planting. It reaches the crop specific limit for each phenological stage (Jones *et. al.*, 1989).

Light has both direct and indirect effects on a crop. It affects metabolism directly through photosynthesis, and growth and development indirectly. The photosynthetically active radiation (PAR) roughly corresponds to visible light, and is the most important environmental element for the plant production system. This provides the energy for photosynthesis.

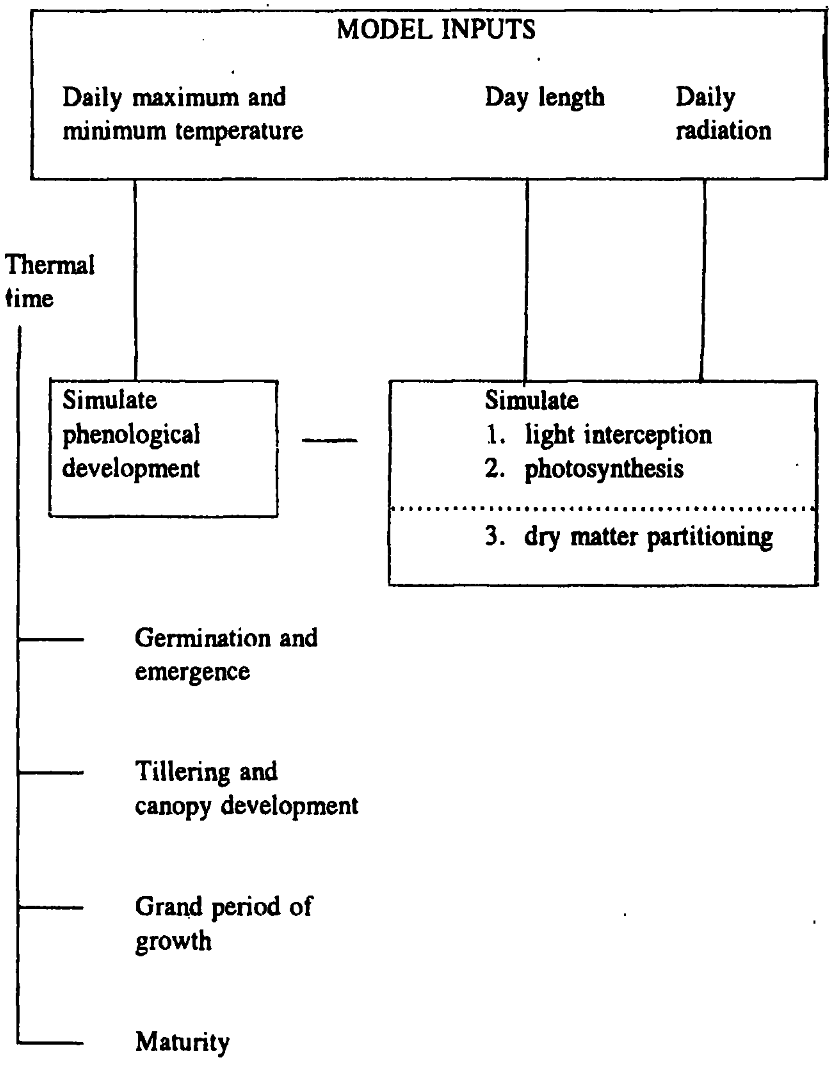

Figure 1. Diagrammatic representation of the computer model

Leaf area development begins from an initially given leaf area index (LAI) after emergence. Thereafter, LAI is calculated by dividing the dry leaf weight by specific leaf weight. The initial LAI is replaced by the calculated LAI when it is greater than the initial. This considers the initial development based on reserves rather than photosynthesis. The specific leaf weight (SLW) is taken as a linear function of plant age (Mc Mennamy, 1980).

$$SLW = 5000 + 40 \times PLANT\ AGE \qquad (1)$$

$$LAI = DRY\ LEAF\ WEIGHT/SLW \qquad (2)$$

where,

SLW = specific leaf weight (weight of unit area of dry leaf)
LAI = leaf area index

The photosynthetic radiation falling on each square meter of the crop canopy (I) is calculated from daily values of PAR (from meteorological data) combined with the daily values of green leaf area index obtained from the leaf area index model:

$$I = PAR \times [1 - \exp(-k \times LAI)] \qquad (3)$$

where,

I = light absorbed
k = light extinction coefficient

Light absorbed is converted to fixed carbon dioxide using the photosynthetic model. The response of leaf photosynthesis to absorbed light under constant carbon dioxide concentration could be described by a curve that relates the rate of gross photosynthesis to the intensity of absorbed light. This type of a photosynthesis-light response curve fitted to a quadratic equation by Marshall and Biscoe (1980) is characterized by three parameters. These are the slope at origin, rate at saturated light intensity and shape factor.

The initial efficiency of absorbed light characterizes the biophysical processes and has a fairly constant value. The maximum rate depends on the plant properties, environmental conditions and reflects biochemical processes and physiological conditions. The shape factor ranges from 0.001 to 0.999. Marshall and Biscoe (1980) after field observations, developed a value of 0.995.

The rate of photosynthesis is expressed per unit of leaf area. Canopy photosynthesis is the sum of the contributions of all leaves, stems and sometimes reproductive organs. However, only photosynthesis of leaves is considered here.

$$(i \times PG^2) - PG\,[X + (s \times It)] + s \times It \times X = 0 \qquad (4)$$

where,

i	= shape factor
X	= initial light efficiency
s	= maximum rate of photosynthesis
It	= absorbed light
PG	= gross photosynthesis

Carbon dioxide fixed is converted to dry matter by a conversion factor of 0.65, and to gross photosynthesis per day by multiplying by day length.

Respiration is simulated by the Mc Cree model (1974). The growth respiration is treated as a function of photosynthesis and 30% of the photosynthate is taken for this process. Maintenance respiration is considered as a function of total plant dry weight and temperature.

The growth and maintenance respiration has the form:

$$TRS = (a \times PG) + (W \times b \times 2)^{0.1T} \qquad (5)$$

where,

TRS	= Total respiration losses
a	= growth respiration coefficient
b	= maintenance respiration coefficient
PG	= gross photosynthesis
W	= plant dry weight
T	= average air temperature

The dry matter accumulated per day is the difference between the gross photosynthesis and the total respiration losses.

The net photosynthesis is partitioned between leaves, stems, roots and sugar. The proportions depend on the phenological development stage of the crop. Sugarcane genotypes vary with respect to their sugar concentration. A genotype with young stalks has a lower sugar concentration. As the crop matures the growth declines due to nitrogen and water stress, and the sugar concentration in the cane increases. This process is simulated by allocating a small quantity of dry matter to sugar at the inception, and increasing it to a maximum at maturity (Bull and Tovey 1974).

The model was developed to run on an IBM compatible computer operating on MSDOS. The program was written using Borland Turbo Pascal version 6.0. It was run on a floppy disk, however, it is advantageous to install the program on a hard disk for analysis of data of a number of years.

Methodology

Daily maximum and minimum temperature and sunshine hours were obtained from the meteorological station of the Sugarcane Research Institute, located in the typical dry zone of Southern Sri Lanka (latitude 6° 21'N, longitude 80° 48'E, altitude 75 m). Crop data required for model building and validation were obtained from the agronomic experiments of the Sugarcane Research Institute. However, other required crop data used were assumed constants or determined through trial and error runs using meteorological data sets.

RESULTS AND DISCUSSION

The comparison between the simulated and measured biomass production is presented in Table 1. The irrigated production was considered to be the water-unlimited production potential. The average simulated potential production (68.89) indicated the potential and the uniformity of the dry zone climate (radiation and temperature) for cultivating sugarcane. It also illustrated the potential of the genotype Co 775 under this environment. In 87-88 and 88-89 the measured production was less than the simulated production. This may be due to the over simplification of the respiration process in the model. The measured production was well below the simulated value in 1981-82, however, simulation improved until 1984-85. Thereafter, measured and simulated production values were close to each other. Improved management of the irrigated crop was probably the reason for narrowing the gap between actual and simulated yields.

Table 1. **Measured and simulated biomass of irrigated sugarcane.**

Year	Measured t/ha	Simulated t/ha	Percentage variation
1981/82	57.26	69.04	+20
1982/83	61.35	75.81	+23
1983/84	63.81	69.24	+08
1984/85	69.54	70.13	+08
1985/86	65.45	66.57	+02
1986/87	63.4	72.96	+15
1987/88	67.49	64.11	-05
1988/89	65.45	62.98	-04
1989/90	64.63	69.14	+07
Mean	64.26	68.89	
SD	3.33	3.79	

The sugarcane growth model was also capable of simulating values for other variables such as stalk weight, root weight, leaf weight, leaf area index and sugar accumulation. However, only simulated biomass was validated. The lack of field data did not permit validation of other variables. This was the main difficulty encountered during the development of this model.

CONCLUSIONS

The model estimates the potential biomass production of sugarcane within a 10% accuracy. However, it was very difficult to determine whether there were unknown constraints present in the irrigated crop. Their removal would have allowed the same genotype to produce more dry matter. It is worth while to investigate the detail of crops giving large yields that were occasionally reported from the fields.

This simulation model could be used:

- as a powerful tool for interpreting field observations for agronomists and sugarcane breeders

- to assess the potential of an area suitable for sugarcane cultivation
- to forecast the yield prior to harvesting the crop
- to train personnel in growth and management of sugarcane

Usefulness of this model could be enhanced by coupling with other sub models including water, nutrient and economics. Although, the initial approach to this model has been primarily agronomic, it is envisaged that the crop growth model will ultimately be incorporated into an overall sugar industry model.

REFERENCES

Bull, T.A. and Tovey, D.A. (1974). Aspects of modelling sugarcane growth by computer simulation. Proc. Int. Soc. Sugar Technol. 15: 1021-1032.

De Wit, C.T. and Panning De Vries, F.W.T. (1982). Simulation of Plant Growth and Crop Production, PUDOC, Wageningen.

Hay, R.M. and Walker, A.J. (1989). An Introduction to the Physiology of Crop Yield. Longman Group U.K., Harlow.

Jones, C.A., Wegner, M.K., Russell, J.S., McLeod, I.M. and Williams, J.R. (1989). AUSCANE-Simulation of Australian Sugarcane with EPIC, CSIRO, Cunningham Laboratory, Brisbane, Australia.

Marshall, B. and Biscoe P.V. (1980). A model for C3 leaves describing the dependence of net photosynthesis on irradiance. I. Derivation, J. of Exp. Bot. 31: 29-39.

Mc Cree, K.J. (1974). Equations for the rate of dark respiration of white clover and grain sorghum, as a function of dry weight, photosynthetic rate, and temperature. Crop Science. 14: 509-1014.

Mc Mennamy, J.A. (1980). Dynamic simulation of irrigated rice crop growth and yield, proceedings of a symposium (1980) on the agrometeorology of the rice crop. The International Rice Research Institute, Los Banos, Laguna, Philippines.