Agronomy

SUGARCANE YIELD MODELS FOR PRODUCTION SIMULATION*

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ABSTRACT

Presented in this paper are sugarcane yield models for a 10,000-hectare zone in the Victorias Mill District developed primarily for application to computer simulation. The yield models were formulated by multiple regression using the criterion of least squares. Separate models for tonnage and rendement were developed for the periods January to June and July to December. Model verification yielded a close agreement between the estimated and actual tonnage but there were slight discrepancies between estimated and actual rendement.

Conclusions derived from this work are as follows:
1) Influence of some climatic factors on the growth and yield of sugar-cane is manifested more by the sequences of their occurrence than by the absolute values.
2) The models for estimating sugarcane yields developed using multiple regression with the criterion of least squares were adequate for simulation application.
3) There is an increasing time trend in tonnage production and a decreasing trend in rendement for the area studied.
4) Preliminary simulation studies indicate that an optimum cropping cycle may be obtained by stopping or slowing down operations in the area during the months of August and September.

INTRODUCTION

Sugarcane productivity and cropping cycle in the Philippines are, to a great extent, determined by the climatic variables obtaining in the area. Generally, the harvesting and planting season covers a period of 6 to 8 months and this occurs during the drier part of the year. In the Victorias Mill District, however, harvesting lasts for approximately 10½ months and, in some cases, continues throughout the year with only a 4- to 6-week slow-down period to allow for repairs and maintenance of factory and farm equipment. Normally, the shut-down or slow-down of operations is done during the November-December period. The production and economic implications of this shut-down period (or the resulting cropping cycles) are not well established.

Several investigators have applied computer simulation analysis to the study of the complex interplay of factors in agricultural production systems. Results of such analyses would be useful in the search for an optimum cropping cycle. Simulation analysis requires the development of representative stochastic models embodying the cause and effect relationships of the various production

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factors. This paper presents sugarcane yield models for a 10 000 hectare zone in the Victorias Mill District, developed primarily for application to computer simulation. Also presented are preliminary indications of alternative cropping cycles for this area based on simulation trials using the models.

The 10 000 hectare area studied is referred to in this paper as Victorias upland. It comprises one of the three zones of the 34 000 hectare cropped area of the district. The zone is characterised by level to slightly undulating topography and has no distinct dry and wet season. Its maximum rainfall occurs during the months July to December and annual precipitation is about 2 500 mm.

YIELD MODEL DEVELOPMENT

Since the amount of sugar produced per unit area is obtained as the product of the amount of cane harvested per hectare (tonnage) and the sucrose extracted (rendement), separate models were developed for each of these yield components. Moreover, because of the significant differences in average weather conditions during the periods January to June and July to December, it was decided to construct yield models for each of these two periods. Therefore, two tonnage models and two rendement models were developed for the particular area. The tonnage models were on a monthly basis and the rendement models on a weekly basis.

Data Used

The set of data used for the tonnage models is a record of monthly tonnage for the period 1951 to 1969 for the particular area studied. While weekly data on rendement were available for the same period, only the data for the period 1960 to 1969 were used for the rendement models. It was considered necessary to drop earlier data because of the significant changes that had taken place both in the varieties planted in the district and in the extraction efficiency of the factory.

Weather records available include daily rainfall, sunlight hours, and maximum and minimum temperatures for the years 1949 to 1970.

Model Formulation

Growing Period

A 12-month period from planting to harvesting was assumed. In Victorias, actual harvesting age varies from about 11 to 13 months although some cane fields are harvested at the age of 9 or 10 months, while others are allowed to grow up to 14 to 15 months.

Because of the importance of the amount of precipitation before land preparation, an 8 week period before planting and the 12 month (52 weeks) planting to harvesting period were considered in developing the tonnage model. The 52 week period was divided into thirteen 4 week crop ages and the 8 week period before planting was divided into two 4 week periods.

In the rendement model, the period from the 34th week to harvesting (19 weeks) was considered. This period was divided into six crop ages: four 4 week periods, one 2 week period before harvest and the harvesting week. It was assumed that this is the period where weather factors would influence the juice quality of the cane at harvest.
Discrete Time Models

Models for simulation application can be formulated either in the continuous time form (described as differential equations) or the discrete time form (described as difference equations). The models presented were developed in the discrete time form with one week as the time interval for rendement and one month as a time interval for tonnage. It was assumed that the following functional relationships existed:

\[
TC_i = F([W_j]_{j=1}^{15}, A, RC, YR)
\]

\[
TC_{i+6} = H([W_j]_{j=1}^{15}, A_{i+6}, RC, YR, \sum_{i=1}^{6} TC_i)
\]

\[
REND_n = O([W_k]_{k=1}^{8}, TON_n, T_n, YR)
\]

Where:

\(TC\) = tons cane per hectare for month \(i\) or \(i + 6\)

\(i = 1, 2, \ldots, 6\), denotes the harvesting months January to June, \(i + 6\) denotes the harvesting months July to December

\([W_j]_{j=1}^{15}\) = set of weather factors occurring during the period \(j\)

\(A\) = area in hectares harvested during the month \(i\) or \(i + 6\)

\(RC\) = percentage by area of ratoon crop for the year

\(REND_n\) = rendement for week \(n\)

\([W_k]_{k=1}^{8}\) = set of weather factors occurring during the period \(k\)

\(TON_n\) = total amount of cane milled in the district during the week \(n\)

\(T_m\) = tons cane per hectare during the month \(m\) which contains week \(n\)

\(YR\) = cropping year.

The appropriate quantitative expression for each climatic factor was identified. Twelve weather factors were considered for the tonnage and rendement models. These factors, computed weekly, are: (1) total rainfall, (2) sequence of days exceeding 25 days with rainfall less than 0.50 inches, (3) summation of daily heat units with 24 C as the base temperature, (4) summation of diurnal range, (5) sequence of days exceeding 2 days with minimum temperature less than 22 C, (6) square of the sequences in 5, (7) squared sequence of days exceeding 1 day with sunlight less than 1 hour, (8) squared sequence of days exceeding 3 days with sunlight less than 4 hours, (9) sequence of days exceeding 2 days with maximum temperature greater than 33 C, (10) sequence of days exceeding 2 days with sunlight greater than 10 hours, (11) summation of sunlight hours in excess of 10 hours, and, (12) summation of daily sunlight hours.

For periods before harvest, the sequences were computed in the following manner. If the sequence has not ended, say, in week \(q\), it is allowed to continue to week \(q + 1\). A non-zero value is then assigned only to the week in which
the sequence ended. However, if week q is the end of the harvesting month in the case of tonnage or the harvesting week for rendement, the sequence is terminated at the end of week q. The value is then assigned to week q.

The use of sequences instead of absolute values for the climatic factors was based on the result of preliminary regression analysis of weather factors affecting yield. A small amount of data from variety experiments was used in this analysis. Monthly mean maximum and minimum temperatures did not show any significant influence, and there was no measurable influence on yield if the sequence of days with rainfall less than 0.50 inch was shorter than 25 days. In addition, the length of the growing period (the age of the crop at harvest) did not show a significant influence on the tonnage or rendement.

Only rainfall and sequences of days with rainfall less than 0.50 inch were considered for the two 4 week periods before planting, giving 4 weather variables for this period. With thirteen 4 week crop ages and 12 weather factors, there were a total of 156 weather variables for the period planting to harvesting. Thus, a total of 160 weather variables were considered for the tonnage models.

The area harvested in each month was included to account for possible yield inflation when a smaller area is planted and harvested. This may be caused by a shift from extensive to intensive production. The percentage of ratoon crop in the district was included to account for possible yield deflation due to the inherently lower ratoon yields. Based upon the observed relationship between the tonnage during the periods January to June and July to December, it was decided to include the average tonnage of the former period for the models of the latter period.

The 6 crop ages and 12 weather factors considered for rendement gave a total of 72 weather variables. The amount of cane milled for the week was included to enable the possible effect of the volume of cane milled on the factory extraction efficiency to be considered. Previous experience suggested the inclusion of tonnage per hectare for the area of interest.

The cropping year, denoting a factor for time trend, was included in both the tonnage and rendement models to isolate the influence of technological changes.

Basic Assumptions

Inherent in the modeling process was the assumption that the weather factors observed and recorded in one station sufficiently characterise the weather occurring throughout the area. The assumption was also made that the crop response to weather variation is uniform throughout the area.

Parameter Estimation Procedure

The parameters of both the tonnage and rendement models were estimated by multiple regression utilising the method of least squares. In this work, the method of least squares with stepwise addition of variables was first used because of the large number of variables involved and the possibility of singularity problems. High requirements of computer time and memory provided additional motivation to begin with stepwise addition.

A set of explanatory variables was established utilising all of those variables obtained from stepwise addition and some additional weather variables. The additional weather variables were formed from certain combinations
of variables from \([W_j]^{15}\) for tonnage and from \([W_k]^{k=1}\) for rendement.

Multiple regression utilising the method of least squares with stepwise deletion of variables was then applied to \([E]\).

**ESTIMATED MODELS**

The estimated models obtained for tonnage and rendement are given below.

**Tonneage Models**

**January-June Harvesting:**

\[
TC_i = 52,233 \ 198 - 0,110 \ 380 \ \text{SLS} - 0,506 \ 847 \ \text{TN} \\
+ 1,499 \ 555 \ \text{YR} \\
R^2 = 0.690 \quad R = 0.830 \quad SE = 5,686 \ 66
\]

**July-December Harvesting:**

\[
TC_{i+6} = 41,287 \ 846 - 0,283 \ 702 \ \text{RN1} + 0,307 \ 148 \ \text{RN2} \\
+ 0,289 \ 710 \ \text{RN3} + 0,056 \ 751 \ \text{HU} - 0,005 \ 019 \ \text{DR} \\
+ 1,111 \ 755 \ \text{ATON} \\
R^2 = 0.808 \quad R = 0.899 \quad SE = 5,698 \ 18
\]

\(TC\) = tons (metric) cane per hectare for month \(i\) or \(i + 6\)
\(i = 1, 2, \ldots, 6\) denotes the harvesting months January to June, \(i + 6\) denotes the harvesting months July to December

SLS = sum of squared sequences of days exceeding 1 day with sunlight less than 1 hour for the period beginning the 21st week and including the 36th week after planting

TN = sum of sequences of days exceeding 2 days with minimum temperature less than 22°C for the period beginning the 13th week and including the 40th week after planting

RN1 = total rainfall in inches for the period beginning the 5th week and including the 16th week after planting

RN2 = total rainfall in inches for the period beginning the 29th week and including the 40th week after planting

RN3 = total rainfall for the period beginning the 41st week and including the harvesting month

HU = total heat units accumulated for the period beginning the 5th week and including the 16th week after planting

DR = sum of daily diurnal range for the period beginning the 17th week and including the 28th week after planting

ATON = average tonnage from January to June minus the lowest average tonnage of 44,973

\[
\Sigma_{i=1}^{6} TC_i - 44,973
\]
YR = harvesting year with 1951 taken as 1, 1952, 2, etc.

R², SE = respectively, the multiple coefficient of determination, multiple coefficient of correlation and standard error of estimate for the model. The numbers in parenthesis are the standard errors of estimate of the corresponding coefficients.

The negative relation of tonnage with low temperature expressed in sequences in the first model agrees with the findings of Burr et al., Stender, and Clements. Moreover, the negative relation with very low sunlight occurring on successive days agrees with the result obtained by Das and Borden. Martin and Eckart concluded that since photosynthesis is dependent upon sunlight as a source of energy, the role of light is of major importance in supplying the plant with the food materials necessary for its normal growth.

In the July-December model, the negative relation to tonnage of rainfall 5 weeks after planting may be attributed to the resulting problem of excess moisture erosion of soil and leaching of fertilizer. It must be noted that heavy rainfall occurs in this area during this period and young sugarcane plants provide very little protection against erosion.

**Rendement Models**

**January-June Harvesting:**

\[
\text{REND}_k = 15,540.652 - 0.002853 \text{DR}_1 - 0.006850 \text{HU}_2 \\
(0.36033) (0.00047) (0.00076)
\]

\[- 0.150049 \text{SLS}_3 - 0.012802 \text{SLS}_3 + 0.070878 \text{HS}_2 \\
(0.00202) (0.00297) (0.008159)
\]

\[+ 0.046332 \text{HS}_3 - 0.034743 \text{TC}_1 \\
(0.01157) (0.00455)
\]

\[R^2 = 0.692 \quad R = 0.832 \quad SE = 0.49430
\]

**July-December Harvesting:**

\[
\text{REND}_k = 14,781.746 + 0.129283 \text{DR}_1 - 0.010664 \text{HU}_1 \\
(0.43143) (0.03833) (0.00196)
\]

\[+ 0.043775 \text{TX}_1 + 0.032529 (\text{TX}_2 + \text{TX}_3) \\
(0.00885) (0.00683)
\]

\[- 0.003422 \text{SUN}_1 + 0.217491 \text{HS}_3 \\
(0.00063) (0.06015)
\]

\[- 0.018633 \text{YR}_2 - 0.020240 \text{TC}_2 \\
(0.00221) (0.00386)
\]

\[R^2 = 0.552 \quad R = 0.743 \quad SE = 0.63693
\]

Where:

REND = average rendement expressed as % sugar produced per ton cane milled for week k

DR = sum of daily diurnal range

HU = sum of daily heat units

SLS = sum of sequence of days exceeding 1 day with sunlight less than 1 hour

HS = sum of sequences of days exceeding 2 days with sunlight greater than or equal to 10 hours
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\[
\begin{align*}
\text{DRY} &= \text{sum of sequences of days exceeding 25 days with rain less than 0.50 inch} \\
\text{TX} &= \text{sum of sequences of days exceeding 2 days with maximum temperature greater than 33 C.} \\
\text{SUN} &= \text{sum of daily sunlight hours} \\
&\text{The subscript 1 on the weather variables denotes the period beginning the 19th week and including the 11th week before harvesting or the period beginning the 34th week and including the 41st week after planting. The subscript 2 denotes the period beginning the 10th week and including the 4th week before harvesting or the period beginning the 42nd week and including the 48th week after planting. The subscript 3 denotes the period beginning the 3rd week before harvest and including the harvesting week or the period beginning the 49th week after planting, and including the harvesting week.} \\
\text{YR} &= \text{harvesting year with 1961 taken as 1, 1962, 2, etc.} \\
\text{TC}_j &= \text{tonnage for month } j \text{ containing week } k. \\
\end{align*}
\]

The relationship of the various weather variables with the rendement as manifested by the sign of their coefficients in the estimated models is in agreement with the previously mentioned reports. There is a decreasing trend in the July-December model. This may be due to the increased use of fertilizer, particularly nitrogen which is always made available by sufficient moisture during this period.

There is a negative influence of sunlight on rendement during the 34th to 41st week (SUN\textsubscript{1}) after planting. This is the latter part of the high vegetative growth period and, presumably, sufficient sunlight still encourages continuation of vegetative production at this stage. High heat unit accumulation had a negative influence on the rendement.

During the wetter, July-December period, long sequences of dry days have a strong positive influence on the rendement. The amount of rainfall, however, does not show any direct influence. Escobar's analysis\textsuperscript{7} has shown that, during the period of high total rainfall, changes in the amount of precipitation do not affect rendement.

**Model Verification**

Verification of the models was attempted using weather records for the period 1968 to 1970. Monthly tonnage and weekly rendement were estimated. The simulated and actual values are shown on Fig. 1.

The total estimated tonnage was in reasonable agreement with the actual value, but the actual rendement was slightly over-estimated particularly in the months of April, May and June and was under-estimated from July to December. This discrepancy may be attributed partly to the residual effect on the soil of the abnormal crop that preceded the 1970 crop used for model verification.

**SIMULATION STUDIES OF ALTERNATIVE CROPPING CYCLES**

There are several important factors that may be included in a simulation analysis of alternative cropping cycles. They include yield, sugar price, market
demand, inventory policy, production lag, labor supply and field operational requirements. In this preliminary simulation study, only yield and sugar price were considered.

Yield Simulation

Two simulations were made: one used the 20 year weather records and the other used a stochastic weather simulator to obtain the weather variables. Using the historical weather records, only 18 production years can be considered, but using the stochastic weather simulator, a 300-production year simulation can be made.

**FIGURE 1.** Actual and simulated values, Victorias upland (1970).
To account for the unexplained variations in the models, a random element was generated and introduced. This random element was computed as the product of the standard error of estimate of the model and a normal variate of mean zero and variance one.

Monthly tonnage and weekly rendement were computed. The weekly rendements were then converted to monthly values and the monthly sugar production was determined. Because the normal shut-down or slow-down period varies from one to about 2 months, summary statistics were computed monthly and in pairs of months (e.g. June-July, July-August, etc.).

**FIGURE 2.** Monthly mean yield, Victorias upland.
Revenue Simulation

There are available monthly data on domestic and export prices from 1953 to 1969. Of main interest in simulation studies of alternative cropping cycles is the seasonal variation, if any, in sugar prices. An attempt was made to develop a model embodying seasonal price trends. Neither domestic nor export prices exhibited (in a linear or quadratic sense), to an acceptable level of significance (0.005), any seasonal price trends. Therefore, it was decided, for this preliminary analysis, to use the monthly domestic and export prices for the 5 year period (1965 to 1969), computing the gross revenue for each

![Graph showing mean yield for pairs of months, Victorias upland.](image-url)

**FIGURE 3.** Mean yield for pairs of months, Victorias upland.
year. Means and standard deviations of gross revenues for each month and pair of months were calculated.

**Simulation results and discussion**

Monthly mean simulated yields based on the weather records and generated weather values are plotted in Fig. 2 while Fig. 3 gives the corresponding values for each pair of months. The monthly yields for the 2 simulations are in close

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**FIGURE 4.** Simulated revenue for five annual price series (1965-1966), Victorias upland.
agreement with each other but there were slight differences in the standard deviations obtained from each simulation. The variation among months of the variance of yield was smaller using stochastically generated weather than using the historical records.

On a basis of sugar production, it is obvious that the months of June to December comprise the possible period for cessation or slowing down of harvesting and planting operations. Since the present shut-down or slow-down period is during the months of November and December, comparison of yields and revenue will involve the values for these months.

Sugar yield in the particular zone is lowest during the August-September period. The mean yield difference of 0.632 5 ton sugar per hectare between this and the November-December period is significant. The low sugar yield is attributed both to low tonnage and low rendement during this period. Tonnage in the area was lowest during the May-June period and, although the differences in tonnage were not striking, the drop in rendement during the August to December period caused the yield to decrease.

Simulated revenues using generated weather variables and the 5 year price series are shown on Fig. 4. Lowest revenue occurs during the months of August and September. The mean revenues, with the price series used for these periods, are all significantly lower than those of the November-December period.

CONCLUSIONS
Conclusions derived from this work are as follows:
1) Influence of some climatic factors on growth and yield of sugarcane is manifested more by the sequences of occurrence rather than by their absolute values.
2) The models for estimating sugarcane yields developed using multiple regression with the criterion of least squares were adequate for production simulation application.
3) There is an increasing time trend in tonnage production and a decreasing trend in rendement for the area studied.
4) Preliminary simulation studies indicate that optimum cropping cycle may be obtained by stopping or slowing down operations in the area during the months of August and September instead of the November-December period.

REFERENCES
MODELOS DE RENDIMIENTO DE CAÑA DE AZÚCAR PARA SIMULACIÓN DE PRODUCCIÓN

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RESUMEN

Se presentan en esta disertación modelos de rendimiento de caña de azúcar para una zona de 10 000 hectáreas en el Distrito de Victoria Mills desarrollado principalmente para la simulación aplicada de computadora. Los modelos de rendimiento fueron formulados por regresión múltiple usando el criterio de cuadrado menor. Modelos separados para tonelaje y rendimiento fueron desarrollados para los períodos Enero a Junio y Julio a Diciembre. La verificación del modelo produjo un acuerdo cerrado entre el tonelaje estimado y el actual. Sin embargo, hubieron ligeras discrepancias entre los rendimientos estimados y los actuales.

Las conclusiones derivadas de este trabajo son las siguientes:

1) La influencia de algunos factores climáticos sobre el crecimiento y el rendimiento de la caña de azúcar se manifiesta más por las sucesiones de sus sucesos que por sus valores absolutos.
2) Los modelos para estimar los rendimientos de caña desarrollado utilizando regresión múltiple con el criterio de cuadrado menor fueron adecuados para la simulación aplicada.
3) Existe una tendencia de tiempo que aumenta en producción de caña y una tendencia que disminuye en rendimiento para el área estudiada.
4) Estudios preliminares de simulación indicaron que el ciclo óptimo de cosecha se puede obtener parando ó retardando las operaciones en el área durante los meses de Agosto y Septiembre.