MODELING YIELD AND WEATHER FOR SUGARCANE PRODUCTION SIMULATION

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ABSTRACT

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by

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The primary objective of this project was to develop sugarcane yield and weather models for simulation application. In addition, preliminary indications of alternative cropping cycles for the Victorias milling district were to be obtained by simulation, using the models developed.

The yield models were formulated by multiple regression using the least-squares criterion. Separate models for tonnage and rendement were developed for the periods January to June and July to December. In the models, the climatic influence tends to be manifested in sequences of occurrence rather than the absolute value of the weather factors. The various area models indicate different controlling weather factors on growth and yield.

Model verification using 1970 production data yielded a close agreement between the estimated and actual tonnage. However, there were slight discrepancies between the estimated and actual rendement. Possibly, this can be attributed to the effect of residual fertilizer from previous crops.

Models for generating weather variables were

developed for the two areas of the district. Determination of rainfall occurrence in the first area is by a Monte Carlo technique using second-order Markov probabilities. The amount of rainfall was determined from a probability density function derived for the area. Sunlight and maximum and minimum temperatures were generated from regression equations in lagged values of the variables. The choice of the regression equation to use on a given day depends on the first order rain-no rain state in the area. For the second area, rainfall occurrence was also determined by the Monte Carlo technique. Here, the probability of rain depends only on the rain-no rain state in the first area, for the same day. The models for sunlight and temperatures consist of regression equations with lagged values of the variables. The choice of the equation to use depends on the first order rain-no rain state in this area and the present rain-no rain state in the first area.

Two simulations were made to obtain preliminary indications of alternative cropping cycles. One simulation used the historical weather records and another used stochastically generated weather factors. This also provided a test of the performance of the stochastic weather generator in production simulation applications. Means and standard deviations of yields and revenues for each month and pair of months were calculated. Five annual sets of monthly prices were used in calculating revenue. The calculated mean yields and revenues with the two simulations were in close agreement with each other.

There are strong indications, based on yield and revenue, that the November-December period is not the best time to cease operations in the district.

Conclusions derived from these results included:

1. The tonnage and rendement models developed are adequate for production simulation applications.
2. The weather simulator is adequate for production simulation applications.
3. There is an annual time trend of increasing tonnage and decreasing rendement in the three areas of the district.

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MODELING YIELD AND WEATHER FOR SUGARCANE PRODUCTION SIMULATION

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1. INTRODUCTION

Successful sugarcane production requires an understanding of the influence of and the interaction among the various factors affecting the growth and yield of the crop. Of primary importance among these factors are the soil productive capacity, climatic condition, sugarcane variety, cultural practice, labor supply, field machinery and transport equipment availability. Of particular interest in this study is the selection of an appropriate cropping cycle for a given region or farm district. The selection of an appropriate harvesting season or cropping cycle is dependent upon the interactive influences of the various production factors.

In the Philippines, the harvesting season for sugarcane varies among milling districts. Some areas harvest only for about six months each year, while others harvest for as long as ten and one-half months.

Basically, climatic conditions determine the length of the harvesting and planting season. In most areas, the crop is harvested only during the drier part of the year, a period of about five to seven months, depending upon the particular geographic location. Harvesting only in the drier period normally provides for relatively higher cane quality. It also facilitates field operations during the harvesting and planting. However, such short milling periods result in heavy seasonal labor and equipment demands both in the production and processing sectors. Thus, the longer milling season has positive social implications in terms of continuous employment opportunities.

The Victorias milling district, which is the largest sugar producing district in the Philippines, harvests cane approximately ten and one-half months each year. Normally, milling in the district ceases in early or mid November and starts again in late December. This shutdown period of about six weeks is used for repairs and retooling of factory and farm equipment for the next milling season. The production and economic implications of this November-December period (or of the resultant cropping cycle) are not well established. Recommendations as to the best cropping cycle for the district have been made. Some were purely intuitive while others were based on conventional analyses given the existing data (VMC, 1967; VMC, 1968).

Several researchers have applied computer simulation analysis as a tool in the study of the complex interplay of the various factors in agricultural production systems (Holtman, et al., 1970; Stapleton, 1967; Sowell, et al., 1967; Morey, et al., 1969). Results of such analyses would be useful in the search for an optimum cropping cycle in the Victorias milling district. The simulation analysis requires the development of representative stochastic models embodying the cause-and-effect relationships of the various production factors. It is the primary objective of this project to develop sugarcane yield and weather models for the Victorias milling district. Such models will provide a fundamental step towards future simulation applications and also other immediate benefits. Cane yield models, for instance, are useful in developing operational projections for production, processing and marketing. Moreover, an understanding of the influence of various factors on cane growth and yield will be valuable in assessing current cultural practices in the district. A secondary objective of this project is to obtain preliminary indications of alternative cropping cycles for the district.

1.1 Description of the Victorias Area

The Victorias milling district covers a total area of about 40,000 hectares (1 hectare = 2.47 acres). It is situated on the northern part of Negros Island, Philippines. The area is bounded by the Visayan Sea on the east and by volcanic chains on the southwest and is characterized by an irregular coastline. The relief is level to undulating to rolling. Of the total district area, about 30,000 hectares are currently planted in sugarcane. The remainder consists of second growth forest, coconut plantations and other crops such as rice, fruit trees, etc. The district is divided into three areas as follows:

(1) Victorias lowland with 1,500 hectares under cane,

(2) Victorias upland with 9,500 hectares of sugarcane, and (3) Manapla-Cadiz, with a cropped area of 19,000 hectares. The Victorias upland and Manapla-Cadiz areas respectively have approximately 1,000 and 5,000 hectares more that could be put to sugarcane cultivation. However, these additional areas and even recent plantings are, in most cases, of marginal productivity.

There are about 900 individual planters or growers in the district with farm units ranging in size from about 10 to as much as 1,000 hectares. The average farm size in the district is about 40 hectares. Sugarcane produced by the planters is processed into either brown or refined sugar by the Victorias Milling Company, which is located in the district.

1.2 Soils of the District

Soils of the Victorias milling district are generally grouped into lowland and upland soils based on the relief of the area. Lowland soils in the district are formed from recent alluvial deposits and have generally level relief with poor to adequate natural drainage. The lowland soils are considered the most productive in the district. These soils are located mainly in the Victorias lowland section.

Upland soils in the district are developed either from the weathered products of igneous rocks, from older alluvial deposits or from the weathered products of coralline limestone. They have generally sloping to rolling relief with excessive surface and poor to fair internal drainage, resulting in varying degrees of soil erosion. The majority of the upland soils have about the same productivity ratings (Locsin and Tabayoyong, 1953). The moisture equivalent of the soils in the district varies from about 20% to as much as 30%. Available moisture is estimated to range from 5 to 15 per cent.

1.3 Climate of the District

Under the climatic classification in the Philippines, which is based on the distribution and amount of annual precipitation, the climate of the Victorias milling district is characterized as having no dry season and no pronounced maximum rain period. The average annual precipitation in the district is 101 inches. The monthly and daily means and standard deviations of rainfall and also the daily means and standard deviations of maximum temperature, minimum temperature and sunlight for the Victorias and Manapla stations are tabulated in Appendix A. These values are based on 20-year weather records from both stations.

Generally, February, March and April are drier months. These are also the months of higher daily sunlight. The period from July to December is normally the wettest part of the year. Likewise, this period has lower sunlight. Minimum temperature is lowest during the months of December, January and early February. Maximum temperature is highest during the months of April and May. Under the climatic conditions in the district, sugarcane has been grown without irrigation.

1.4 The Sugarcane Plant

Sugarcane (*Saccharum officinarum*, Linn.) belongs to the vast family of grasses. Being a tropical plant, sugarcane thrives in hot, sunny areas. The cane plant is composed of four principal parts, the leaves, the stalk, the roots and the flower or arrow. The leaves contain the green chlorophyll which makes possible the synthesis of sugar from water and carbon dioxide, which is absorbed from the air through the stomatal openings in the leaves.

The cane stalk is the above-ground portion of the plant supporting the leaves and the flower. The small portion of it underground is known as the stubble or root stalk. The stalk, which is composed of a number of sections or internodes, is almost cylindrical in cross-section and consists of three recognizable substances, the hard rind, a softer internal flesh and fibers. The softer tissues of the stalk surrounding the vascular bundles are made up largely of the cells which store the sweet sugary juices of the plant. Generally, a 12-month crop will have cane stalks varying in length from five to as much as 12 feet. Each cane stalk weighs from one-half to one and one-half kilograms when harvested.

The root system of a sugarcane plant, as in many other crops, anchors the plant in the soil. More importantly, it serves as a supplier of and vehicle for the plant nutrients and water absorbed from the soil. Depending on the soil horizon, cane roots may extend to a depth of more than six feet. Normally, however, the root mass concentration is within the first two feet of soil. The depth to which the majority of the roots extend determines, to a great extent, the drought-resistance of the crop.

Commercial sugarcane planting uses either the top portion of the harvested stalks or the stalks of young (about 7 to 10 months) cane grown in nurseries. These planting materials are cut to a length of 12 to 18 inches and covered in furrows of well-tilled fields. Depending on the climatic conditions and cultural practices of the area, the growing period varies from 10 to 36 months. In the Philippines, the average growing season is 12 months.

When the cane is harvested, a regrowth will occur from the stubble left in the soil. This crop is called a ratoon crop. Several ratoon crops are being grown in some areas before a new crop is planted, at which time the field is tilled accordingly. In the Philippines, only one ratoon is normally grown. While a ratoon crop involves less production cost, since land preparation and planting are not required, ratoon yields are generally lower.

1.5 Influence of Climatic Factors

Several workers have investigated the influence of various climatic conditions on sugarcane growth. The work of Burr and associates (1957) is of particular interest. Sugarcane was grown for several years in culture solutions under controlled conditions of temperature and light. Briefly, some of their findings were:

1. Below 70°F, root temperatures become strongly limiting to growth. At 50°F, there is no growth. An 80°F root temperature is optimum for both growth and nutrient uptake.
2. Cutting full Hawaiian sunlight one-half reduces growth one-half.
3. Using sugarcane grown under identical day conditions but different night temperatures--one cooled to 57°F and the other warmed to 73°F--it was found after 20 weeks that the cool night group had a weight of approximately half that of the warm night group. A similar reduction was observed for the weight of the leaves and overnight translocation of sucrose from the leaves to the stalk.

A close relationship of stalk length and diameter to temperature in Hawaii was earlier shown by Stender (1924). His measurements showed that winter growth of the primary stalks was reduced to one-third the summer growth. Moreover, greenhouse studies in Hawaii showed that irrespective of air temperature, root temperatures of 62°F and below restrict nitrogen uptake, water consumption, translocation and growth (Anon., 1957). It was further reported that at root temperatures of 74°F and above, light becomes the dominant factor affecting growth.

Das (1935) in studying the effect of climate in Hawaii, planted two cane varieties in pots containing the same soil. One group of pots (including both varieties) was grown at a location 40 feet above sea level with an annual rainfall of 30 inches. Another group was grown three miles away, but at 650 feet above sea level where the annual rainfall was 200 inches. The climate in the former is characterized by bright sunny weather. The latter area received a quantity of sunlight (hours) less than 50% of the former. Maximum temperatures are about 4°F higher in the former location and minimum temperatures are about equal. The result of the experiment was striking in that both varieties produced nearly three times as much cane in the former area than in the latter. The result of Borden's (1936) more elaborate studies gave further evidence of the dominant influence of climatic factors upon cane yield. Clements (1964) also reported a positive response of sugarcane to increasing maximum and minimum temperatures as well as sunlight.

Moisture shortages can exert a dominant influence on stalk elongation. Clements and Kubota (1942) for instance, reported a correlation coefficient of 0.756 between the moisture content of the elongating cane and meristem and the rate of stalk elongation. Sun and Chow (1949) found a high positive correlation between rate of stalk elongation and rainfall in Taiwan.

While it is generally agreed that extended periods of drought often depress growth, such periods may also have beneficial effects: the forced development of a deeper root system, the prevention of undesirable flowering and an increase of carbohydrate accumulation during the ripening stage (Clements, 1964). Moreover, excessive rainfall is not only ineffective but may cause reduced growth rates, particularly where drainage is impeded. A desired environment provides a balance between transpiration and water absorption that is conducive to highest growth during the vegetative stage and to ripening during the maturity stage.

Like growth, maturity of sugarcane is also influenced significantly by climatic factors. Humbert (1968) pointed out the dramatic effect of minimum temperatures on the maturity of field cane at Los Mochis, Mexico. It was noted that lower minimum temperatures about a month before harvest are favorable for ripening and hence contribute to higher juice quality. Johnson (1966), reported that sucrose percentages in cane are closely related to the diurnal range one month before harvesting.

In studying the relationship of low atmospheric temperatures with juice quality, Panje, et al. (1968) found that temperatures in the range of 2 to 12°C caused a depression in juice quality. The cane was able to recover under normal growing temperatures, however. The work of Singh and Lal (1935), confirmed by the work of Hartt (1940), indicated that the optimum temperature for the synthesis of sucrose by excised blades of sugarcane is approximately 30°C.

Although sufficient moisture is required during the vegetative stage, moisture has a depressing influence on cane juice quality during the ripening stage. Escober (1961) related Victorias district yields to certain weather factors. There existed an inverse relation between juice quality and rainfall excesses over a calculated effective rainfall, preceding and during the harvesting months. In Hawaii, irrigation is terminated as cane approaches maturity in order to reduce the rate of vegetative growth, dehydrate the cane and force the conversion of reducing sugars to recoverable sucrose (Humbert, 1968).

The influence of climatic factors on cane production is best summarized by Mangelsdorf (1950) in characterizing an ideal climate for the production of sugarcane:

1. A long, warm summer growing season with adequate rainfall.
2. A fairly dry, sunny and cool, but frost free, ripening and harvesting season.
3. Freedom from typhoons and hurricanes.

2. YIELD MODEL DEVELOPMENT

The amount of sugar obtained per unit area is the product of the quantity of cane produced and the quality of the juice extracted from it. The quantity of cane harvested is commonly referred to as cane tonnage and expressed as tons cane per unit area. The juice quality is commonly referred to as rendement and expressed as weight of sugar obtained per ton cane processed. In the Philippines, rendement is expressed in piculs (1 picul = 63.25 kilograms) per ton cane. These expressions of cane yield and rendement are used throughout the report.

Because of the observed differences in the pedologic, physiographic and biotic complexes in each of the three areas of the district, it was advantageous to develop distinct yield models for each section. Likewise, 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.

2.1 Available Data

2.1.1 Monthly Tonnage and Rendement

One of the two sets of yield data available is a record of monthly tonnage, rendement and hectarage harvested in each of the three areas for the period 1951 to 1970. The data for the year 1970 were reserved for model verification and were not utilized in the modeling process. The data were gathered by personnel of the Victorias Milling Company. During the harvesting season, field inspectors visit each farm every month to determine the actual area harvested. Using a record of the amount of cane that came from a given farm, the tonnage for the farm was calculated. Juice samples were obtained in the factory from each shipment of cane coming from a farm. They were used to determine the rendement of the cane milled. At the end of each milling month, average tonnage and rendement were computed for each area and reported with the total hectarage harvested. The percentages of ratoon crop were also reported at the end of each crop year.

When a crop was damaged by a typhoon, the reported tonnage did not include the tonnage lost. The tonnage data for the months affected by typhoons were adjusted, based upon the estimated losses due to typhoons (VMC, 1968). Appendix B gives the adjustments made for the tonnage affected by typhoons.

Because of the regular shutdown period, the months of October, November and December have less tonnage data available than the rest of the months. In the 19-crop year sequence (1951 to 1969), there were two missing values for October, ten for November and four for

December. Moreover, some of the data reported for the months of November and December did not cover the entire month.

2.1.2 Weekly Rendement and Production

Weekly average rendement and the amount of cane milled for the entire district were recorded by the factory. Typhoon loss adjustments were also made on these rendement data; these adjustments are given in Appendix C. Data are missing for those periods corresponding to the periods without monthly tonnage.

Because of the significant changes that took place in both the varieties planted in the district and the factory extraction efficiency, it was decided to utilize only the weekly rendement data for the period 1960 to 1969. The data for the year 1970 were saved for model verification. The weekly rendement for each of the three areas were obtained by multiplying the district rendement data by a factor based on monthly yield data in the three areas. The formula for calculating the factor is given in Appendix C.

2.1.3 Weather Data

Available weather records include daily rainfall, sunlight hours, and maximum and minimum temperatures for the Victorias and Manapla weather stations for the years 1949 to 1970.

2.2 Model Formulation

2.2.1 Growing Period

A 12-month period from planting to harvesting was assumed. Actual harvesting age in the district varies from about 11 to 13 months. In extreme cases, some cane fields are harvested at the age of nine or 10 months while others are allowed to grow up to 14 or 15 months before they are harvested.

A period of several weeks before planting is required for field preparation. During this period, the amount of precipitation is of utmost importance. Excessive rainfall delays land preparation and may result in the deterioration of the planting materials. If the field is too dry, adequate tillage is hardly possible. This may result in poor germination and growth. It is, therefore, necessary to consider soil moisture conditions before planting.

The highest vegetative growth (boom stage) of cane in the district occurs in the period five to nine months after planting. After the boom stage, the cane starts to ripen if climatic conditions are favorable.

An eight-week period before planting and the 12-month (52 week) 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 eight-week period before planting was divided into two 4-week periods.

The period beginning at the thirty-fourth week after planting and including the harvesting week (19 weeks) was considered for the rendement. This period was divided into six crop ages: four 4-week periods, one 2-week period before harvest and the harvesting week.

2.2.2 Discrete Time Models

Models for simulation applications can be formulated either in the continuous time form (described as differential equations) or the discrete time form (described as difference equation). The factors that determine whether a continuous time model or a discrete time model should be selected are: (1) the level of detail necessary to answer relevant questions, (2) the frequency of events or the flow rate of objects relative to the minimum time interval of interest, and (3) cost of programming and operating the models (Manetsch, 1970). It was decided to develop the models in the discrete time form with one week as the time interval for rendement and a time interval of one month for tonnage.

It was assumed that the following functional relations exist:

$$TC_i = F\left(\left[W_j \right]_{j=1}^{15}, A_i, RC, YR \right)$$

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

$$REND_n = Q(\left[W_k\right]_{k=1}^{6}, TON_n, T_m, YR)$$

where: TC = tonnage per hectare for month i or i+6

i = 1, 2,...6, denoting the harvesting months January to June, i+6 denotes the harvesting months July to December

$\left[W_j\right]_{j=1}^{15}$ = 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

$\left[W_k\right]_{k=1}^{6}$ = 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 = tonnage per hectare during the month m which contains week n

YR = cropping year (1951-1969 for tonnage and 1960-1969 for rendement).

It is necessary to identify an appropriate quantitative expression for each climatic factor. 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 daily diurnal range, (5) sequence of days exceeding two days with minimum temperature less than 22°C, (6) square of the sequences in 5, (7) squared sequence of days exceeding one day with sunlight less than one hour, (8) squared sequence of days exceeding three days with sunlight less than four hours, (9) sequence of days exceeding two days with maximum temperature greater than 33°C, (10) sequence of days exceedings two days with sunlight greater than 10.0 hours, (11) summation of sunlight hours in excess of 10.0 hours, and (12) summation of daily sunlight hours.

For periods prior to harvest, the sequences are computed in the following manner. If the sequence had not ended, say, in week m, it is allowed to continue to week m+1. A non-zero value is then assigned only to the week in which the sequence ended. However, if week m 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 m. The value is then assigned to week m.

The use of sequences instead of absolute values of the climatic factors was based on the result of a preliminary regression analysis of factors affecting yield. A small amount of variety experiment data was used in this analysis. Monthly mean maximum and minimum temperatures did not show any significant influence. There was also no measurable influence on yield if the sequence of days with rainfall less than 0.50 inches was shorter than 25 days. Also, 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 four 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 of 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 in the models for the latter period.

The six crop ages and 12 weather factors considered for rendement yielded a total of 72 weather variables. The amount of cane milled for the week was included to consider the possible effect of the volume of cane milled on the factory extraction efficiency. 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.

2.2.3 Basic Assumptions

Inherent in this modeling process was the assumption that the weather factors observed and recorded in each of the two weather stations sufficiently characterize the weather occurring throughout the respective area served by the station. The assumption was also made that the crop response to weather variation is uniform throughout the given area (i.e., the interactions between weather factors and the various agronomic variables are uniform throughout the particular area).

2.3 Parameter Estimation Procedure

The parameters of both the tonnage and rendement models were estimated by multiple regression utilizing the method of least squares (Kmenta, 1971; Kane, 1968; Draper and Smith, 1966). A general linear hypothesis for k explanatory variables and N observations is:

$$
\begin{array}{l}
Y_1 = b_0 + b_1X_{11} + b_2X_{21} + \ldots + b_iX_{i1} + \ldots + b_kX_{k1} + U_1 \\
\vdots \\
Y_t = b_0 + b_1X_{1t} + b_2X_{2t} + \ldots + b_iX_{it} + \ldots + b_kX_{kt} + U_t \\
\vdots \\
Y_N = b_0 + b_1X_{1N} + b_2X_{2N} + \ldots + b_iX_{iN} + \ldots + b_kX_{kN} + U_N
\end{array}
$$

where:

Y_t = observation t of the dependent variable Y

X_{it} = observation t of the explanatory variable X_i

U_t = stochastic disturbance associated with observation t and constants: $b_0, b_1, b_2 \ldots b_i \ldots b_k$.

The method of least squares consists of determining estimates $(\hat{b}_0, \hat{b}_1, \hat{b}_2 \ldots \hat{b}_i \ldots \hat{b}_k)$ of the constants $b_0, b_1, b_2 \ldots b_i \ldots b_k$, such that the sum of the squared residuals, $\hat{U}_t$ is a minimum, i.e., $\sum_{t=1}^{N} \hat{U}_t$ is a minimum, where:

$$\hat{U}_t = Y_t - (\hat{b}_0 + \hat{b}_1 X_{1t} + \hat{b}_2 X_{2t} + \ldots + \hat{b}_i X_{it} + \ldots + \hat{b}_k X_{kt}).$$

A null hypothesis that the individual b_i's equal zero is established and tested to obtain the regression equation.

An important measure of how much of the variation in the dependent variable may be accounted for by the group of explanatory variables is the coefficient of multiple determination (R^2). R^2 is the proportion of the sum of the squared deviation from the mean of the dependent variable accounted for by the explanatory variables (Kane, 1968). The square root of R^2 is the so-called coefficient of multiple correlation.

2.3.1 Stepwise Addition of Variables

In this work, the method of least squares with stepwise addition of variables (Rafter and Ruble, 1969; Draper and Smith, 1966) was first used because of the large number of variables involved and the possibility of singularity problems. High requirements of computer time and memory provide additional motivation to begin with stepwise addition. The steps involved in the method of least squares with stepwise addition of variables are summarized below.

1. A regression equation involving only the dependent variable and its mean is formed.
2. From among the explanatory variables not presently in the least squares equation, a candidate for inclusion in the equation is selected. The candidate is that variable X_i which will yield a maximum increase in R^2.
3. An F_{bi} statistic is calculated for the variable and a significance probability* for this variable is determined.
4. If the significance probability is less than a preset value, the variable is added to the least squares equation. Then the procedure reverts to step 2 and the process is repeated.
5. When the significance probability is greater than the preset value, the candidate is not entered into the equation and the procedure is terminated.

There is the inherent danger that a group of variables which individually account for little of the variation in the dependent variable, but as a group explain much of this variation, may never be entered into the equation (Rafter and Ruble, 1969). Therefore, a relatively high preset significance probability level of 0.05 was used.

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*Significance probability is the maximum probability of rejecting the hypothesis: $b_i = 0$, when $b_i = 0$ (i.e., the probability of committing a type I error).

2.3.2 Stepwise Deletion of Variables

A set of explanatory variables $\left[E\right]$ was established utilizing 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 $\left[W_j\right]_{j=1}^{15}$ for tonnage and from $\left[W_k\right]_{k=1}^{6}$ for rendement. For instance, one explanatory variable in the tonnage model was total rainfall during the period beginning the twenty-first week and ending the twenty-fourth week (a 4-week period), R_5. The rainfall in the preceding 4-week period was added to R_5 forming one new explanatory variable. Similarly, the rainfall in the following 4-week period was added to R_5 yielding another explanatory variable. Multiple regression utilizing the method of least squares with stepwise deletion of variables was then applied to $\left[E\right]$. The procedure of stepwise deletion is composed of the following steps:

1. A least squares equation is formed utilizing the elements of $\left[E\right]$.
2. The explanatory variable (having a significance probability greater than a preset level) which when deleted produces a minimum reduction in R^2 is removed from $\left[E\right]$.
3. A new least squares equation utilizing the remaining elements of $\left[E\right]$ is formed. Then the process returns to step 2.

Since the selection of a candidate variable for deletion is closely tied to the stopping criterion, the preset significance probability was set at 0.005. The resulting regression models were then scrutinized. Particular attention was given to the sign and magnitude of the coefficient of each explanatory variable, their standard errors of estimate as well as the magnitude of the coefficient of determination (R^2) and the overall standard error of estimate for the model.

Three additional variables were also deleted from the models. Each of them had a marginal significance probability (close to 0.005). Furthermore, the sign of their coefficients was inconsistent with results of previous investigations. Least squares models were then estimated utilizing the remaining explanatory variables.

2.4 Estimated Tonnage Models

The estimated models obtained for tonnage for each of the three areas are given below.

January-June Harvesting:

$$TC1_i = \underset{(7.27634)}{56.419307} - \underset{(0.09759)}{0.539063}\ VLR1 - \underset{(0.08198)}{0.688571}\ VLR2$$

$$+ \underset{(0.02191)}{0.142532}\ VLHU + \underset{(0.22355)}{1.376277}\ YR$$

$$R^2 = 0.690 \quad R = 0.830 \quad S.E. = 9.37046$$

$$\underset{}{TC2_i} = \underset{(1.31407)}{52.233198} - \underset{(0.02301)}{0.110380\ VUSLS} - \underset{(0.08854)}{0.506847\ VUTN1}$$

$$+ \underset{(0.10947)}{1.499525\ YR}$$

$R^2 = 0.690$ R = 0.830 S.E. = 5.68666

$$TC3_i = \underset{(9.40218)}{39.849315} - \underset{(0.06648)}{0.349193\ MR1} - \underset{(0.00922)}{0.040779\ DRM}$$

$$+ \underset{(0.05687)}{0.213806\ MR2} + \underset{(0.02234)}{0.083472\ MHU1} + \underset{(0.01502)}{0.068853\ MHU2}$$

$$+ \underset{(0.01075)}{0.041533\ SSM} + \underset{(0.11319)}{0.777629\ YR}$$

$R^2 = 0.621$ R = 0.788 S.E. = 5.60270

July-December Harvesting:

$$TC1_{i+6} = \underset{(10.5712)}{73.649783} + \underset{(0.00871)}{0.054936\ VLDR1} - \underset{(0.01266)}{0.069704\ VLDR2}$$

$$+ \underset{(0.09344)}{0.527413\ ATON1}$$

$R^2 = 0.545$ R = 0.738 S.E. = 9.57022

$$TC2_{i+6} = \underset{(7.01971)}{41.287846} - \underset{(0.06328)}{0.283702\ VURN1} + \underset{(0.07271)}{0.307148\ VURN2}$$

$$+ \underset{(0.07527}{0.289710\ VURN3} + \underset{(0.01206)}{0.056751\ VUHU} - \underset{(0.00723)}{0.005019\ VUDR}$$

$$+ \underset{(0.06786)}{1.111755\ ATON2}$$

$R^2 = 0.808$ R = 0.899 S.E. = 5.69818

$$TC3_{i+6} = \underset{(3.30415)}{49.838779} - \underset{(0.04702)}{0.221258\ MR3} + \underset{(0.08822)}{0.360850\ MR4}$$

$$- \underset{(0.02201)}{0.064704\ MSLS1} - \underset{(0.06796)}{0.269533\ MSLS2} + \underset{(0.09545)}{1.147577\ ATON2}$$

$R^2 = 0.768$ R = 0.876 S.E. = 6.76793

where:

- i = 1, 2, ... 6, denotes the harvesting months January to June respectively.
- TC1, TC2, TC3 = tons cane per hectare for the Victorias lowland, Victorias upland and Manapla-Cadiz areas respectively.
- VLR1 = total rainfall in Victorias for the period beginning the 5th week and including the 28th week after planting.
- VLR2 = total rainfall in Victorias during the 8-week period prior to planting.
- VLHU = total heat units accumulated in Victorias for the period beginning the 29th week and including the 40th week after planting.
- VUSLS = sum of squared sequences of days exceeding one day with sunlight less than one hour in Victorias for the period beginning the 21st week and including the 36th week after planting.
- VUTN1 = sum of sequences of days exceeding two days with minimum temperature less than 22°C for Victorias for the period beginning the 13th week and including the 40th week after planting.
- MR1 = total rainfall in Manapla for the period beginning 8 weeks before planting and including the end of the planting month.
- MR2 = total rainfall in Manapla for the period beginning the 41st week after planting and including the end of the harvesting month.
- MHU1 = total heat units accumulated in Manapla for the period beginning the 17th week and including the 28th week after planting.
- MHU2 = total heat units accumulated in Manapla for the period beginning the 41st week and including the end of the harvesting month.
- DRM = sum of daily diurnal ranges in Manapla for the period beginning the 41st week after planting and including the end of the harvesting month.

SSM = sum of squared sequences of days with sunlight less than four hours in Manapla for the period beginning the 41st week after planting and including the end of the harvesting month.

VLDR1 = sum of daily diurnal ranges in Victorias for the period beginning the 17th week and including the 28th week after planting.

VLDR2 = sum of daily diurnal ranges in Victorias for the period beginning the 41st week after planting and including the end of the harvesting month.

VURN1 = total rainfall in Victorias for the period beginning the 5th week and including the 16th week after planting.

VURN2 = total rainfall in Victorias for the period beginning the 29th week and including the 40th week after planting.

VURN3 = total rainfall in Victorias for the period beginning the 41st week after planting and including the harvesting month.

VUHU = total heat units accumulated in Victorias for the period beginning the 5th week and including the 16th week after planting.

VUDR = sum of daily diurnal range in Victorias for the period beginning the 17th week and including the 28th week after planting.

MR3 = total rainfall in Manapla for the period beginning the 1st week and including the 20th week after planting.

MR4 = total rainfall in Manapla for the period beginning the 29th week and including the 40th week after planting.

MSLS1 = sum of squared sequence of days exceeding one day with sunlight less than one hour in Manapla for the period beginning the 13th week and including the 28th week after planting.

MSLS2 = sum of squared sequence of days exceeding one day with sunlight less than one hour in Manapla for the period beginning the 29th week and including the 44th week after planting.

YR = harvesting year with 1951 taken as 1, 1952, 2, etc.

ATON1,ATON2,ATON3 = average tonnage from January to June (minus their lowest average tonnage: 54.663, 44.973 and 44.950 respectively) for Victorias lowland, Victorias upland and Manapla areas respectively.

R^2, R, S.E. = respectively the multiple coefficient of determination, multiple coefficient of correlation and standard error of estimate for the model. The numbers in parentheses are the standard errors of estimate of the corresponding coefficients.

The negative relation of tonnage with rainfall in the Victorias lowland model is due primarily to the poor internal and surface drainage conditions in the area. As emphasized by Humbert (1968), excessive rainfall is not only ineffective but may cause reduced rates of growth, particularly where drainage is impeded. It is also possible that the phenomenon of limited uptake of potassium due to poor soil aeration, as shown by Lawton (1946) for corn plants, is occurring in this poorly drained area, particularly under excessive rainfall conditions. For the Manapla and Victorias upland areas, the negative relation of tonnage with rainfall, before planting, and during the earlier growth stage of the crop may be attributed to the resulting poor land preparation, erosion of soil and erosion of applied fertilizer. Young sugarcane plants provide very little protection against erosion.

During the period of boom to ripening stage, tonnage had a positive relation with rainfall for the Manapla and Victorias upland areas. The effects of moisture in prolonging growth of sugarcane, i.e., preventing or delaying ripening, is well recognized (Clements, et al., 1948; Humbert, 1968; Willey, 1955). Moreover, the relatively shallow soils, particularly in the Manapla area, require more frequent rainfall. This is particularly important at the full grown stage when the transpiration requirement is high.

The positive relation of tonnage with decreasing sunlight during this stage of cane growth may be due to an effect similar to that of rainfall. Limited relative humidity records indicate that a long sequence of days with relatively lower sunlight is characterized by higher air humidity. Higher temperature levels as well as heavy dews, with more frequent very light showers are also typical. Humbert (1968) notes that light showers and heavy dews stimulate cane growth, since the cane plant is able to absorb moisture through its leaves and sheaths. The higher air humidity also reduces transpiration losses from the plant. Furthermore, it is possible that such a sunlight level is not sufficient to induce ripening, but is sufficient to allow further vegetative growth.

The positive relation of tonnage with heat units is in agreement with the findings of Burr and associates

(1957), Stender (1924) and others cited earlier. The negative relation with low minimum temperatures, expressed in terms of sequences during the growth stage, in the Victorias upland area also agrees with these findings. Moreover, the negative relation with very low sunlight occurring on successive days agrees with the result obtained by Das (1935). Martin and Eckart (1933) 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.

Diurnal ranges occurring in the last 8 to 12 weeks prior to the end of the harvesting month have a negative relationship to tonnage. High diurnal ranges during the few weeks prior to harvest stimulate the synthesis of sucrose (Garza, 1968). Thus, further vegetative growth is inhibited.

In general, there is an increasing yield-time trend for all three areas in the district. However, the annual rate of yield increase for the Manapla area is much lower than those of the Victorias areas. This is primarily due to the continuous addition of marginal productivity hectarages in the Manapla area. Agronomic and cultural improvement effects are attenuated due to the inclusion of these poorer fields. In the Victorias, however, the annual tonnage increase with technological changes is higher, since significant additions of production areas has not occurred.

2.5 Estimated Rendement Models

January-June Harvesting:

$$\underset{}{REND1_k} = \underset{(0.05752)}{2.625883} - \underset{(0.00014)}{0.000621}\, DR_1 - \underset{(0.00017)}{0.001124}\, HU_2$$

$$- \underset{(0.00011)}{0.000382}\, SUN_1 - \underset{(0.00043)}{0.001582}\, SLS_2$$

$$- \underset{(0.00063)}{0.001853}\, SLS_3 - \underset{(0.01103)}{0.052898}\, YR + \underset{(0.00103)}{0.005397}\, YR^2$$

$$- \underset{(0.00056)}{0.002966}\, TC1_j$$

$R^2 = 0.533$ $\quad$ $R = 0.730$ $\quad$ S.E. = 0.10072

$$REND2_k = \underset{(0.05697)}{2.457020} - \underset{(0.000075)}{0.000451}\, DR_1 - \underset{(0.00012)}{0.001083}\, HU_2$$

$$- \underset{(0.00032)}{0.002379}\, SLS_2 - \underset{(0.00047)}{0.002024}\, SLS_3$$

$$+ \underset{(0.00129)}{0.011206}\, HS_2 + \underset{(0.00183)}{0.007420}\, HS_3 - \underset{(0.00072)}{0.005493}\, TC2_j$$

$R^2 = 0.692$ $\quad$ $R = 0.832$ $\quad$ S.E. = 0.07815

$$REND3_k = \underset{(0.07717)}{2.483599} - \underset{(0.00087)}{0.007146}\, RN_{1m} - 0.004714\, (RN_{2m}+RN_{3m})$$

$$- \underset{(0.00020)}{0.000999}\, HU_{1m} + \underset{(0.00185)}{0.007141}\, (TN_{2m}+TN_{3m})$$

$$+ \underset{(0.00128)}{0.007046}\, TX_{3m} - \underset{(0.00012)}{0.000844}\, (HU_{2m}+HU_{3m})$$

$$- \underset{(0.00275)}{0.020639}\, YR - \underset{(0.00088)}{0.003451}\, TC3_j$$

$R^2 = 0.653$ $\quad$ $R = 0.808$ $\quad$ S.E. = 0.08330

July-December Harvesting:

$$REND1_k = \underset{(0.07914)}{2.254159} - \underset{(0.00066)}{0.004370}\, HU_3 + \underset{(0.00459)}{0.029783}\, TN_1$$

$$- \underset{(0.00009)}{0.000721}\, SUN_1 + \underset{(0.00031)}{0.001573}\, SUN_3 - \underset{(0.00028)}{0.001195}\, S4S_1$$

$$- \underset{(0.00282)}{0.024702}\ YR - \underset{(0.00078)}{0.003653}\ TC1_j$$

$R^2 = 0.612$ $R = 0.783$ $S.E. = 0.10183$

$$REND2_k = \underset{(0.06821)}{2.337035} + \underset{(0.00606)}{0.020440}\ DRY_3 - \underset{(0.00031)}{0.001686}\ HU_1$$

$$+ \underset{(0.00140)}{0.006921}\ TX_1 + \underset{(0.00108)}{0.005143}\ (TX_2+TX_3)$$

$$- \underset{(0.00010)}{0.000541}\ SUN_1 + \underset{(0.00951)}{0.034386}\ HS_3 - \underset{(0.00035)}{0.002946}\ YR^2$$

$$- \underset{(0.00061)}{0.003200}\ TC2_j$$

$R^2 = 0.552$ $R = 0.743$ $S.E. = 0.10070$

$$REND3_k = \underset{(0.06586)}{1.997109} + \underset{(0.00287)}{0.013711}\ DRY_{3m} + \underset{(0.00017)}{0.000979}\ DR_{1m}$$

$$- \underset{(0.00027)}{0.002488}\ HU_{1m} + \underset{(0.00769)}{0.026393}\ TN_{3m}$$

$$+ \underset{(0.00112)}{0.003983}\ TX_{2m} - \underset{(0.00340)}{0.012505}\ HS_{1m} - \underset{(0.00319)}{0.036763}\ YR$$

$$- \underset{(0.00044)}{0.003540}\ TC3_j$$

$R^2 = 0.663$ $R = 0.814$ $S.E. = 0.08424$

where:

$REND1_k$, $REND2_k$, $REND3_k$ = rendement in piculs of sugar per ton cane for week k for Victorias lowland, Victorias upland and Manapla respectively.

DR = sum of daily diurnal ranges.

HU = sum of daily heat units.

RN = sum of daily rainfalls.

DRY = sum of sequences of days exceeding 25 days with rain less than 0.50 inch.

SUN = sum of daily sunlight hours.

TN = sum of sequences of days exceeding two days with minimum temperatures less than 22.0°C.

TX = sum of sequences of days exceeding two days with maximum temperatures greater than 33°C.

SLS = sum of sequences of days exceeding one day with sunlight less than one hour.

S4S = sum of sequences of days exceeding three days with sunlight less than four hours.

HS = sum of sequences of days exceeding two days with sunlight greater than or equal to 10.0 hours.

The subscript 1 on the weather variables denotes the period beginning the 19th week and including the 11th week before harvesting. The subscript 2 denotes the period beginning the 10th week and including the fourth week before harvesting. The subscript 3 denotes the period beginning the third week before harvest and including the harvesting week for Victorias. The subscripts 1m, 2m, 3m indicate the corresponding periods described above, but for the Manapla area.

YR = harvesting year with 1960 taken as 1, 1961, 2, etc.

$TC1_j$, $TC2_j$, $TC3_j$ = tonnage for Victorias lowland, Victorias upland and Manapla areas respectively for month j containing week k.

The relationships of the various weather factors with rendement as manifested by the sign of their coefficients in the estimated models are in agreement with the previously mentioned reports. There is a continuous annual decline in the rendement in all models, except for the Victorias upland model. While these time trends are believed to be representative for the period considered, extensions into the future should be carefully considered. Technological developments will have a significant effect on the time trends. The decline in rendement is possibly due to the increased use of fertilizer, particularly nitrogen. The negative effect of nitrogen fertilizer on rendement of sugarcane is well demonstrated (King, et al., 1965; Humbert, 1968). A similar effect has been noted with sugarbeets (Snyder, 1968).

There is a consistent negative influence of sunlight on rendement during the 34th to 41st week period after planting. This is the latter part of the high vegetative growth period and presumably, sufficient sunlight encourages continuation of vegetative production. High heat units accumulations have a negative influence on the rendement.

There is an indication that during the low rainfall months of January to June, the amount of rainfall variation has significant influence on rendement in Manapla. However, during the high rainfall months of July to December, rainfall variation does not affect rendement. Escober's (1961) analysis has shown that during years of low total rainfall (76 and 66 inches), an increase in rainfall registers a corresponding decrease in rendement. Conversely, during years of higher total rainfall (103 and 88 inches), changes in the amount of precipitation did not affect rendement.

2.6 Tests for Autocorrelation and Heteroskedasticity

In least squares estimation, homoskedasticity and non-autocorrelation are generally assumed. Since these assumptions are of importance in regression problems, they were examined.

2.6.1 Autocorrelation

When successive values of the stochastic disturbance term show some degree of dependence, autocorrelation is indicated. In ordinary least squares estimation, the presence of autocorrelation signals possible inadequacy of the regression model formulation. Generally, autocorrelation does not destroy unbiasedness and consistency of the estimates of the coefficients, but rather of their variances (Kane, 1968). When positive autocorrelation is present, the variances of the coefficients are generally underestimated leading to more frequent rejection of the null hypothesis of b_i equals zero.

A well-known test for the existence of autocorrelation is the Durbin-Watson test (Durbin and Watson, 1951). A test statistic d for the null hypothesis of residual independence is computed. This statistic is also called the Von Neuman ratio. It is the sum of squares of the first differences of the least squares estimated disturbances, divided by the sum of squares of the estimated disturbances, i.e.,

$$d = \frac{\sum_{t=2}^{W} (\hat{U}_t - \hat{U}_{t-1})^2}{\sum_{t=1}^{N} \hat{U}_t^{\,2}}$$

where: d= Durbin-Watson test statistic

$\hat{U}_t$= the least squares estimator of the disturbance for observation t.

If there is no autocorrelation, d is equal to 2. Lower values of d indicate positive correlation, while higher d values indicate negative correlation. Regions of acceptance and rejection of the null hypothesis are tabulated for comparison with the computed d value (Kane, 1968; Durbin and Watson, 1951).

Application of the Durbin-Watson test to the residuals of the models developed indicated a rather high degree of positive autocorrelation, particularly in the rendement models (Table 1). Actually, the d values should still be

Table 1. Durbin-Watson test statistics (d).

Area	January-June		July-December	
	Tonnage	Rendement	Tonnage	Rendement
Victorias Lowland	1.526	0.468	1.553	0.649
Victorias Upland	0.911	0.536	1.191	0.448
Manapla	1.176	0.489	1.210	0.596

slightly lower than those shown in the table, since these were calculated treating the residuals as continuous series. This is not the case as there are separate models for the January to June and July to December periods.

Methods are available to correct for the effect of autocorrelation (Durbin, 1960; Theil and Nagar, 1961). However, because of the discontinuity of the data used for each period, these methods are not appropriate. The autocorrelations should not produce large error accumulations in a simulation, since alternate models are applied every six months. To reduce the possibility of type I error, a minimum significance probability of 0.005 was required. Furthermore, each variable in the model was scrutinized to determine if its effect in the model agrees with known influences or is theoretically possible. This procedure, of course, does not yield strong assurances that none of the b_i's in the regression is equal to zero.

2.6.2 Heteroskedasticity

Heteroskedasticity or non-homogeneity of variance of stochastic disturbances does not result in bias or inconsistency, but rather in inefficient estimates. One commonly used procedure to determine the existence of heteroskedasticity is Bartlett's test (Kane, 1968). The observations of stochastic disturbances are divided into sets of q independent subsamples. An error variance is computed for each. Then the hypothesis that these subsamples have been drawn from a single population is tested. The Bartlett's test statistic is given as the ratio Q/L where:

$$Q = N \operatorname{Log}\left(\sum_{i=1}^{q} \frac{n_i}{N} \cdot S_i^2\right) - \sum_{i=1}^{q} n_i \cdot \operatorname{Log} S_i^2$$

$$L = 1 + \frac{1}{3(q-1)} \left(\sum_{i=1}^{q} \frac{1}{n_i} - \frac{1}{N} \right)$$

for which S_i^2 = error variance for each subsample i

and $N = \sum_{i=1}^{q} n_i.$

Under the assumption that the error term is normally and independently distributed, the ratio Q/L has a chi-square distribution with q-1 degrees of freedom (Anderson and Bancroft, 1952).

To test the yield models for homoskedasticity, the total number of observations was grouped into two subsamples and Bartlett's formula was applied. The Q/L values for the models are given in Table 2.

Table 2. Bartlett's test statistics (Q/L).

Area	January-June		July-December	
	Tonnage	Rendement	Tonnage	Rendement
Victorias Lowland	0.006	0.006	1.687	0.442
Victorias Upland	0.003	1.466	0.027	0.742
Manapla	0.012	4.549	0.006	0.740

All the values are significant at the 0.01 level. Therefore, the hypothesis of homoskedasticity was accepted.

2.7 Model Verification

Verification of the models was attempted using the weather records for the period 1968 to 1970. Monthly tonnage and weekly rendement were estimated. The simulated and actual yields are shown in Figures 1a, 1b, and 1c for the Victorias lowland, Victorias upland and Manapla areas respectively.

The total estimated tonnage was in reasonable agreement with the actual value, with the exception of the tonnage in Victorias lowland in the months of June and July. The January to June models for Victorias lowland and upland slightly overestimated the actual rendement, particularly in the months of April, May and June. However, the July to December model for Victorias upland underestimated the actual values. The Manapla models overestimated the June and July rendement.

There seems to be no unusual weather conditions during the period that could affect the rendement, except for an unusually dry October in 1969. One possible disturbance that could have affected the model performance is the effect of residual fertilizer from the previous crop. The 1969 crop was a comparatively low yield due to a long drought that occurred during the growing period. Particularly affected by this drought is the cane tonnage

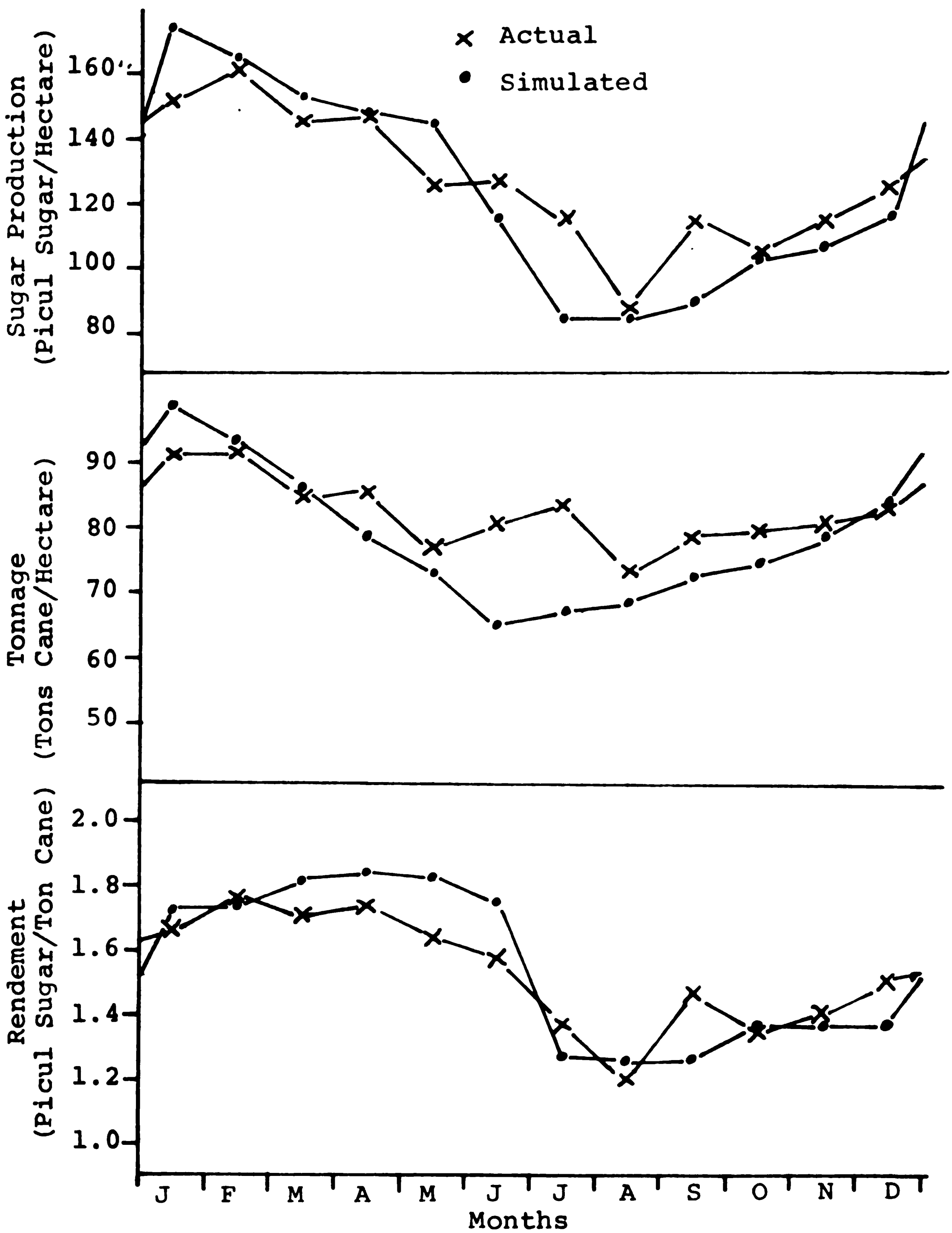

Figure 1a. Actual and simulated values, Victorias lowland (1970)

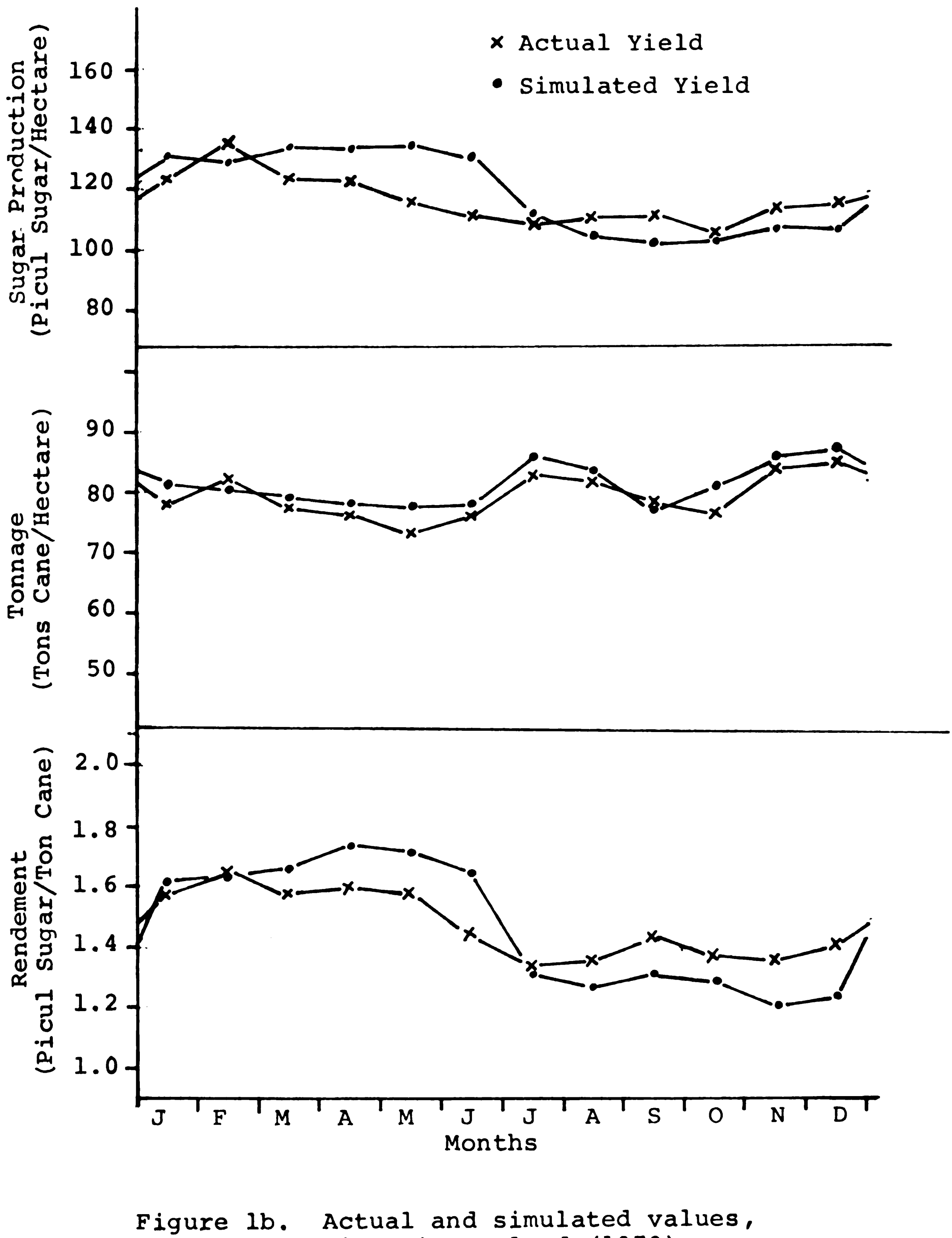

Figure 1b. Actual and simulated values, Victorias upland (1970)

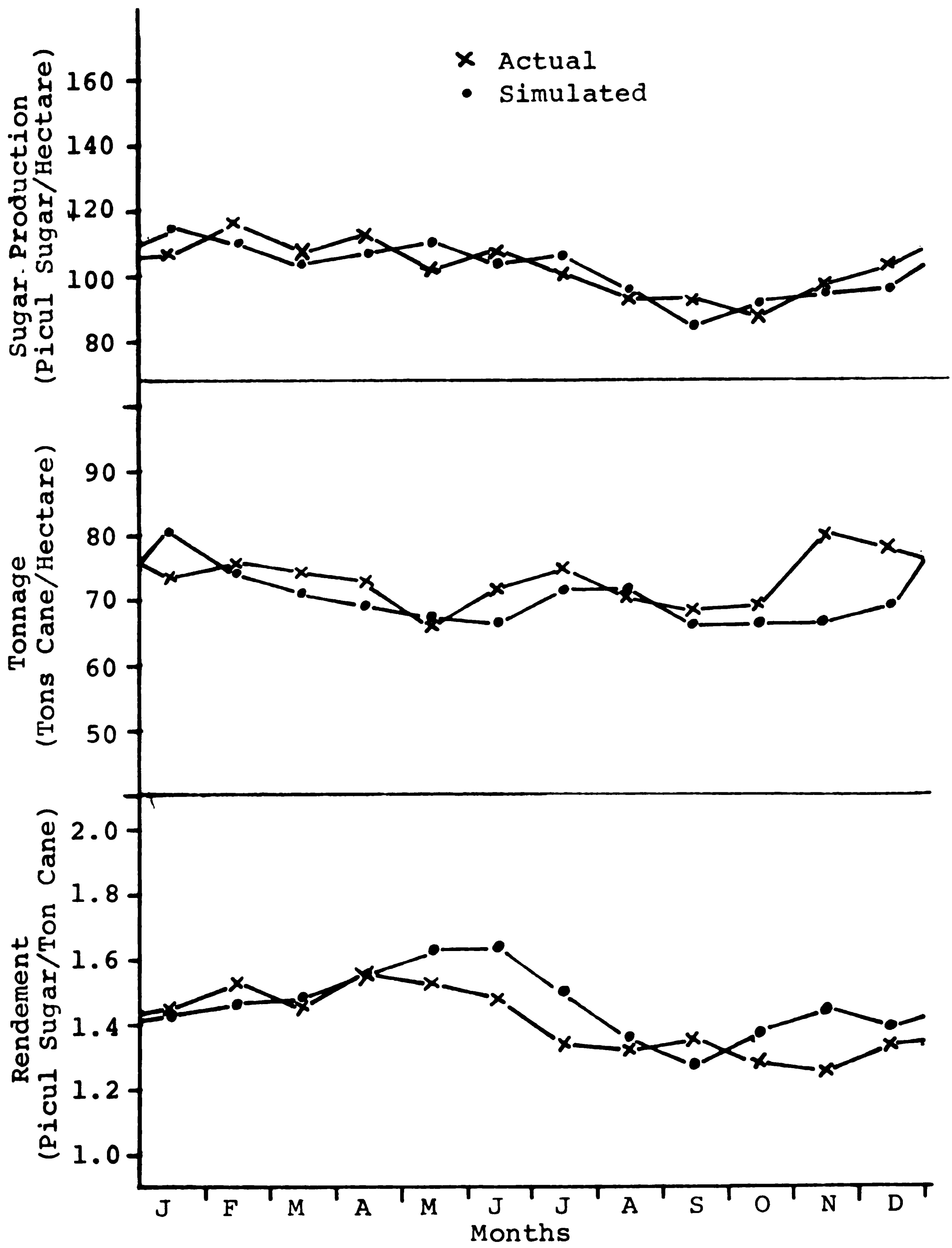

Figure 1c. Actual and simulated values, Manapla (1970)

harvested in the period February to July of 1969. It is highly probable that the poor crop left a significant amount of unused nutrients, particularly nitrogen, in the soil. It is hypothesized that this resulted in the reduction of rendement in spite of favorable weather conditions.

3. WEATHER SIMULATOR

In crop production analyses where the weather factors are normally taken as exogenous system inputs, weather time series can be obtained, either by using historical weather records, or by generating them according to the describing process. The former offers the advantage of providing an exact replication of historical occurrences. It has the serious disadvantage, however, of providing a series of limited length. To obtain a longer time series than available from historical records, a stochastic model was developed for generation of daily weather time series. Actually, models for simulating weather time series were developed for both the Victorias and Manapla areas.

3.1 Victorias Weather Simulator

Preliminary analysis of the 20-year weather time-series (see section 2.1.3) indicated a high degree of cross-correlation and autocorrelation (one day lag) among the weather factors. The following development includes consideration of these relationships. The stochastic weather models follow the format:

1. The generation of quantity of rainfall is dependent upon the occurrence of rainfall on previous days.

2. The sunlight hours probability density function (pdf) parameters are dependent upon sunlight and temperatures (lagged one day) and current and one day lagged rainfall occurrences.
3. The maximum temperatures pdf parameters are dependent upon temperatures (one day lagged), current sunlight and current and one day lagged rainfall occurrences.
4. The minimum temperatures pdf parameters are dependent upon minimum temperature (one day lagged), current sunlight, current maximum temperature and current and one day lagged rainfall occurrences.

Most pdf parameters were dependent upon the previous two days' rainfall occurrences.* There are four possible rain-no rain sequences for these two periods. The superscript j_i is utilized in denoting the rain-no rain states:

$1_i \longrightarrow$ rain on day i and rain on day i-1

$2_i \longrightarrow$ rain on day i and no rain on day i-1

$3_i \longrightarrow$ no rain on day i and rain on day i-1

$4_i \longrightarrow$ no rain on day i and no rain on day i-1

The following pdf's were hypothesized and estimated using the 20-year weather records.

---

*Rainfall was said to occur if recorded rainfall was greater than 0.01 inch.

Rainfall Probability Density Function:

$$
f(r_i^{j_{i-1}}) = \begin{cases}
0, & r_i^{j_{i-1}} < 0 \\
(1-P_i^{j_{i-1}}) \cdot \varsigma(r_i^{j_{i-1}}), & r_i^{j_{i-1}} = 0 \\
0, & 0 \leq r_i^{j_{i-1}} < 0.01 \\
0.7\, A_i \cdot P_i^{j_{i-1}}, & 0.01 \leq r_i^{j_{i-1}} \leq 0.05 \\
0.3\, A_i \cdot P_i^{j_{i-1}}, & 0.05 < r_i^{j_{i-1}} \leq 0.01 \\
P_i^{j_{i-1}} \cdot (1-A_i) \cdot \frac{1}{\mu r_i} \cdot \epsilon^{\frac{-r_i^{j_{i-1}}}{\mu r_i}} & r_i^{j_{i-1}} > 0.10
\end{cases}
$$

where:

$r_i^{j_{i-1}}$ = quantity of rain occurring on day i given rain-no rain state j_{i-1}, $j_{i-1} = 1, 2, 3, 4$

$f(r_i^{j_{i-1}})$ = pdf of $r_i^{j_{i-1}}$

$P_i^{j_{i-1}}$ = probability of rain on day i given rain-no rain state j_{i-1}

$\varsigma(r_i^{j_{i-1}})$ = unit impulse function

A_i = estimate of Prob $(.01 \leq r_i^{j_{i-1}} \leq 0.10)$ given that $r_i^{j_{i-1}} \geq 0.01$

.7 = estimate of Prob $(.01 \leq r_i^{j_{i-1}} \leq 0.05)$ given that $0.01 \leq r_i^{j_{i-1}} \leq 0.10$

$\pi_{.3}$ = estimate of Prob $(0.05 < r_i^{j_{i-1}}) \leq 0.10)$ given that $0.01 \leq r_i^{j_{i-1}} \leq 0.10$

μr_i = mean rainfall given rainfall greater than 0.10 on day i.

Sunlight Probability Density Function:

$$f(S_i^{j_i}) = N\left(\mu s_i^{j_i}\ ,\ (\sigma s_i^{j_i})^2\right)$$

where:

$S_i^{j_i}$ = sunlight hours on day i for rain-no rain state j_i

$f(S_i^{j_i})$ = pdf of $S_i^{j_i}$

$N(\mu,\sigma^2)$ = Normal (Gaussian) probability density function with mean μ and variance σ^2

$$\mu s_i^{j_i} = as_i^{j_i} + bs_i^{j_i} \cdot {}^{j_{i-1}}_{i-1} + cs_i^{j_i} \cdot r_i^{j_{i-1}}$$

$$+ ds_i^{j_i} \cdot X_{i-1}^{j_{i-1}} + es_i^{j_i} \cdot Y_{i-1}^{j_{i-1}}$$

$X_{i-1}^{j_{i-1}}$ = maximum temperature on day i-1

$Y_{i-1}^{j_{i-1}}$ = minimum temperature on day i-1

$as_i^{j_i}$, $bs_i^{j_i}$,

$cs_i^{j_i}$, $ds_i^{j_i}$, = estimated parameters reflecting auto and cross-correlations.

$es_i^{j_i}$

Maximum Temperature Probability Density Function:

$$f(X_i^{j_i}) = N\left(\mu x_i^{j_i}, \quad (\sigma x_i^{j_i})^2\right)$$

where:

$X_i^{j_i}$ = maximum temperature on day i for rain-no rain state j_i

$f(X_i^{j_i})$ = pdf of $X_i^{j_i}$

$$\mu x_i^{j_i} = ax_i^{j_i} + bx_i^{j_i} \cdot X_{i-1}^{j_{i-1}} + cx_i^{j_i} \cdot S_i^{j_i} + dx_i^{j_i} \cdot r_i^{j_{i-1}}$$

$$+ dx_i^{j_i} \cdot r_i^{j_{i-1}} + ex_i^{j_i} \cdot Y_{i-1}^{j_{i-1}}$$

$ax_i^{j_i}$, $bx_i^{j_i}$,

$cx_i^{j_i}$, $dx_i^{j_i}$, = estimated parameters reflecting auto and cross-correlations.

$ex_i^{j_i}$

Minimum Temperature Probability Density Function:

$$f(Y_i^{j_i}) = N\left(\mu y_i^{j_i}, \quad (\sigma y_i^{j_i})^2\right)$$

where:

$Y_i^{j_i}$ = minimum temperature on day i for rain-no rain state j_i

$f(Y_i^{j_i})$ = pdf of $Y_i^{j_i}$

$$\mu y_i^{j_i} = ay_i^{j_i} + by_i^{j_i} \cdot Y_{i-1}^{j_{i-1}} + cy_i^{j_i} \cdot S_i^{j_i} + dy_i^{j_i} \cdot r_i^{j_{i-1}}$$

$$+ ey_i^{j_i} X_i^{j_i}$$

$ay_i^{j_i}$, $by_i^{j_i}$,

$cy_i^{j_i}$, $dy_i^{j_i}$, = estimated parameters reflecting auto and cross-correlations.

$ey_i^{j_i}$

Monthly or bimonthly average estimates of all parameters are given in Appendix C. Sufficient data were not available to estimate daily values of the pdf parameters. The weather data were divided into bimonthly groups and bimonthly parameter averages were estimated by multiple regression utilizing the least squares technique. Because A_i and μr_i were not dependent upon previous rain-no rain states, it was possible to estimate monthly averages of them.

A preliminary weather simulation utilized only the rain-no rain state on the previous day (first-order Markov assumption). The results indicated some inadequacies in capturing the persistency of rain-no rain sequences. Substantial improvement was obtained when a second-order Markov process was assumed. For example, in the two-month period May-June, the probability of rain on day i given rain on day i-1 (first-order Markov process) was estimated to be 0.588. However, in the second-order process, the parameter $P_i^{1_{i-1}}$ (the probability of rain on day i given rain on days i-1 and i-2) was estimated to be 0.652. In this same two-month period, the probability of no rain on day i given no rain on day i-1 was estimated to be 0.552. The estimate of

$P_i^{4\,i-1}$ was 0.600. While second-order estimates yielded substantial improvement, third-order estimates were not considered because of the limited amount of data.

Several alternative stochastic models of rainfall quantity have been proposed (Jones, et al., 1969; Sorensen, 1967). The more common assumption is that rainfall quantity (given rain) is distributed exponentially. A chi-square goodness-of-fit test (Larson, 1968) was applied to see if the rainfall data were distributed exponentially. The results of this test are given in Table 3. Since the test indicates that the hypothesis should be accepted in none of the twelve months, this hypothesis was rejected. The hypothesis that rainfall greater than 0.10 inch is distributed exponentially was accepted in ten of the twelve months. Therefore an exponential distribution was assumed only for rainfall greater than 0.1 inches. The probability of rainfall less than or equal to 0.10 was determined for each month. Histograms suggested that rainfall was distributed uniformly in the ranges (0.01 - 0.05) and (0.05 - 0.10) inch.

3.2 Manapla Weather Simulator

There is a similarity between the weather conditions, particularly rainfall occurrences, in the Victorias and Manapla areas. An attempt was made to maintain spatial correlation between the simulated weather in these two areas. This was done by relating the weather generation

Table 3. Statistics for the chi-square goodness-of-fit test.*

Rainfall		Months					
		January	February	March	April	May	June
Rain	0.01	89.63	114.43	60.99	113.11	86.19	73.36
Rain	0.10	16.06	18.78	11.65	15.44	20.05	15.33
		July	August	September	October	November	December
Rain	0.01	100.05	65.42	59.12	68.36	86.27	99.63
Rain	0.10	12.70	3.79	6.08	5.95	32.29	23.97

* The 99th percentile of the chi-square distribution with nine degrees of freedom is 21.7.

process in Manapla with the rain-no rain states in Victorias. The format of the stochastic weather models for this area is the same as that in the Victorias with the following exceptions:

1. The generation of quantity of rainfall is dependent only upon the current occurrence of rainfall in the Victorias.
2. The generation of sunlight and temperatures depends upon current rainfall occurrence in the Victorias as well as current and one day lagged occurrences in Manapla.

The superscript k_i is utilized in denoting the rain-no rain states given in the second exception:

$1_i \rightarrow$ rain on day i and rain on day i-1 in Manapla and rain in Victorias on day i

$2_i \rightarrow$ rain on day i and no rain on day i-1 in Manapla and rain in Victorias on day i

$3_i \rightarrow$ no rain on day i and rain on day i-1 in Manapla and rain in Victorias on day i

$4_i \rightarrow$ no rain on day i and no rain on day i-1 in Manapla and rain in Victorias on day i

$5_i, 6_i, 7_i, 8_i \rightarrow$ the same as 1_i, 2_i, 3_i, 4_i respectively, but no rain in Victorias.

The following probability density functions were hypothesized and estimated for the Manapla weather variables:

Rain Probability Density Function:

If rain occurred in Victorias on day i

$$f(r_i) = \begin{cases} 0 & r_i < 0 \\ (1 - P_i) \cdot \varsigma(r_i) & 0 < r_i < 0.01 \\ .55\ B_i \cdot P_i & 0.01 \le r_i \le 0.05 \\ .45\ B_i \cdot P_i & 0.05 < r_i \le 0.10 \\ P_i \cdot (1-B_i) \cdot \frac{1}{\mu i} \epsilon^{\frac{-r_i}{\mu i}} & r_i > 0.10 \end{cases}$$

If no rain occurred in Victorias on day i

$$f(r_i) = \begin{cases} 0 & r_i < 0 \\ (1-Q_i) \cdot \varsigma(r_i) & 0 < r_i < 0.01 \\ Q_i \cdot \frac{1}{wi} \cdot \epsilon^{\frac{-r_i}{wi}} & r_i \ge 0.01 \end{cases}$$

where:

r_i = quantity of rainfall on day i in Manapla

$f(r_i)$ = pdf of r_i

P_i, Q_i, μi, wi = estimated parameters.

Sunlight Probability Density Function:

$$f(S_i^{k_i}) = N\left(\mu s_i^{k_i} \,,\quad (\sigma s_i^{k_i})^2\right)$$

where:

$S_i^{k_i}$ = sunlight hours in Manapla on day i for rain-no rain state k_i, $k_i = 1, 2, \ldots 8$

$f(S_i^{k_i})$ = pdf of $S_i^{k_i}$

$$\mu s_i^{k_i} = as_i^{k_i} + bs_i^{k_i} \cdot S_{i-1}^{k_{i-1}} + cs_i^{k_i} \cdot r_i + ds_i^{k_i} \cdot X_{i-1}^{k_{i-1}} + es_i^{k_i} \cdot Y_{i-1}^{k_{i-1}}$$

$X_{i-1}^{k_{i-1}}, Y_{i-1}^{k_{i-1}}$ = respectively maximum and minimum temperatures in Manapla on day i-1

$as_i^{k_i}$, $bs_i^{k_i}$, $cs_i^{k_i}$, $ds_i^{k_i}$, $es_i^{k_i}$ = estimated parameters reflecting auto and cross correlations.

Maximum Temperature Probability Density Function:

$$f(X_i^{k_i}) = N\left(\mu x_i^{k_i},\ (\sigma x_i^{k_i})^2\right)$$

where:

$X_i^{k_i}$ = maximum temperature in Manapla on day i for rain-no rain state k_i

$f(X_i^{k_i})$ = pdf of $X_i^{k_i}$

$$\mu x_i^{k_i} = ax_i^{k_i} + bx_i^{k_i} \cdot X_{i-1}^{k_{i-1}} + cx_i^{k_i} \cdot S_i^{k_i} + dx_i^{k_i} \cdot r_i + ex_i^{k_i} \cdot Y_{i-1}^{k_{i-1}}$$

$ax_i^{k_i}$, $bx_i^{k_i}$, $cx_i^{k_i}$, $dx_i^{k_i}$, $ex_i^{k_i}$ = estimated parameters reflecting auto and cross-correlations.

Minimum Temperature Probability Density Function:

$$f(Y_i^{k_i}) = N\left(\mu y_i^{k_i}, (\sigma y_i^{k_i})^2\right)$$

where:

$Y_i^{k_i}$ = minimum temperature in Manapla on day i for rain-no rain state k_i

$f(Y_i^{k_i})$ = pdf of $Y_i^{k_i}$

$$\mu y_i^{k_i} = ay_i^{k_i} + by_i^{k_i} \cdot Y_{i-1}^{k_{i-1}} + cy_i^{k_i} \cdot S_i^{k_i} + dy_i^{k_i} \cdot r_i + ey_i^{k_i} X_i^{k_i}$$

$ay_i^{k_i}$, $by_i^{k_i}$, $cy_i^{k_i}$, $dy_i^{k_i}$, $ey_i^{k_i}$ = estimated parameters reflecting auto and cross-correlations.

The formulation of the weather models for Manapla follows the lines similar to the ideas expressed regarding the Victorias weather models. The parameters of the pdf's were estimated by multiple regression using the least squares criterion. P_i, Q_i, B_i, μ_i and ω_i were estimated on a monthly basis. All other parameters were estimated bimonthly.

3.3 Stochastic Weather Simulation

3.3.1 Methodology

Daily values of all weather model pdf parameters were obtained via straight-line interpolation in time on the monthly or bimonthly estimates. Variates of the daily weather variables were generated recursively in the order in which the pdf's were formulated, i.e., rainfall in Victorias on day i is the first, sunlight hours in Victorias, second, ... concluding a one day simulation with the generation of minimum temperature in Manapla on day i. The necessary initial conditions were selected randomly from the historical records.

The necessary random numbers are transforms of uniform (0, 1) random numbers generated via a multiplicative congruential technique (Hillier and Lieberman, 1968). Exponentially distributed random variables ($\mathfrak{z}$) were generated by the inverse transform technique (Naylor, et al., 1968):

$$\mathfrak{z} = -E(\mathfrak{z})\text{Log RN}$$

where:

RN = uniform (0, 1) random number

$E(\mathfrak{z})$ = expected value of $\mathfrak{z}$.

The generation of normally distributed random variates (ν)

with mean μ and standard deviation σ are generated via the application of the central limit theorem (Naylor, et al., 1968):

$$\nu = \mu + \sigma\left(\sum_{i=1}^{12} RN_i - 6\right)$$

where:

RN = uniform (0, 1) random number.

Figures 2 and 3 depict the flow diagrams for generation of respectively, Victorias and Manapla weather.

3.3.2 Simulator Validation

To determine how well the generated weather factors compare with the actual data, a 300-year simulation run was made. The means and standard deviations of monthly and daily rainfall, daily sunlight and maximum and minimum temperatures were calculated. (Figures 4a and 4b give the simulated and actual means of rainfall, sunlight and maximum and minimum temperatures for the Victorias. The means for Manapla are given in Figures 5a and 5b.)

In comparing the simulated means of the four weather factors with the corresponding means based on the actual record, slight descrepancies in the mean are noted. Some months have lower simulated values while others have higher. These discrepancies are not entirely unexpected. The primary reason is the nature of the interpolation method used. Using bimonthly pdf parameters, interpolation between two

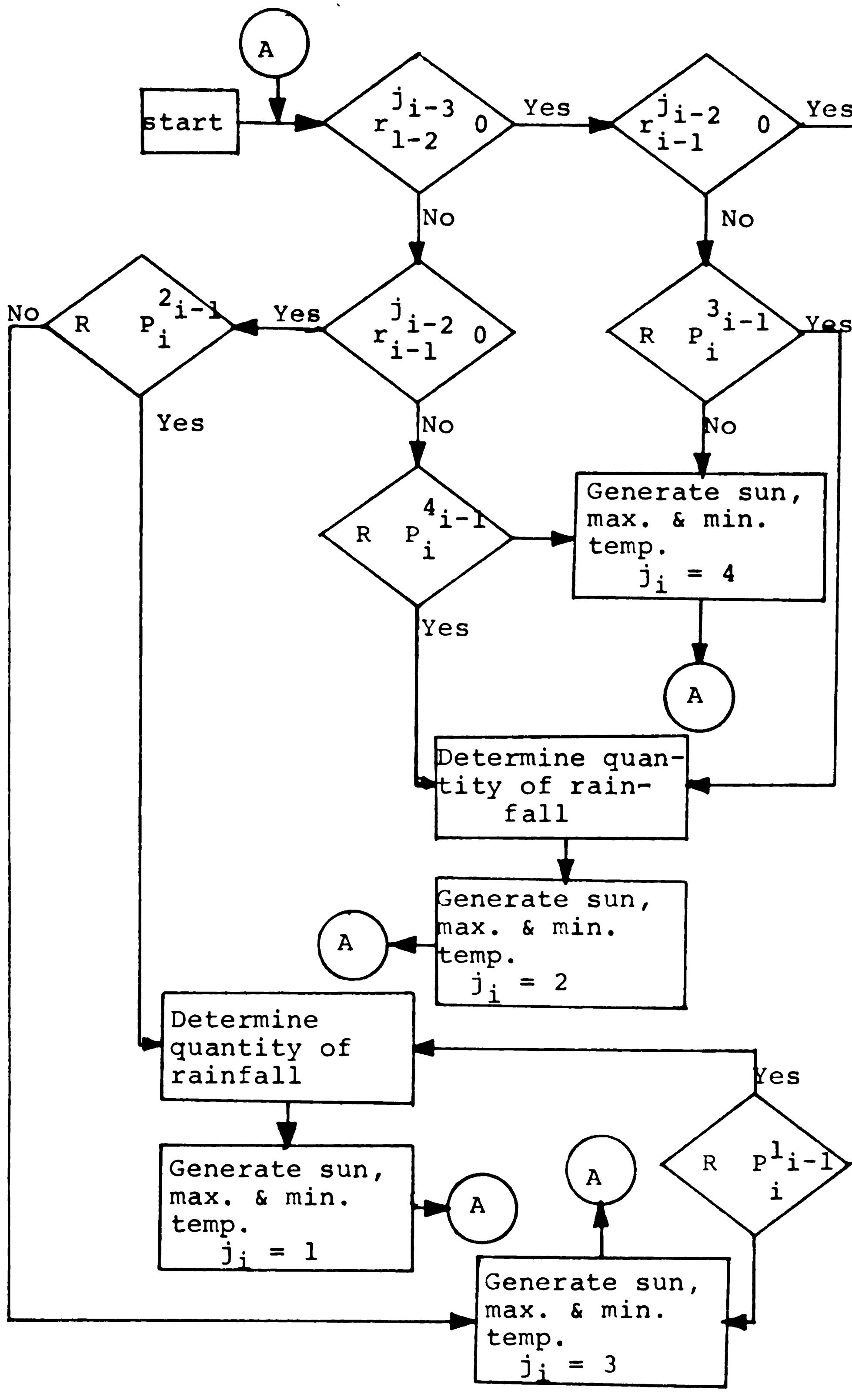

Figure 2. Flow chart for Victorias daily weather simulator

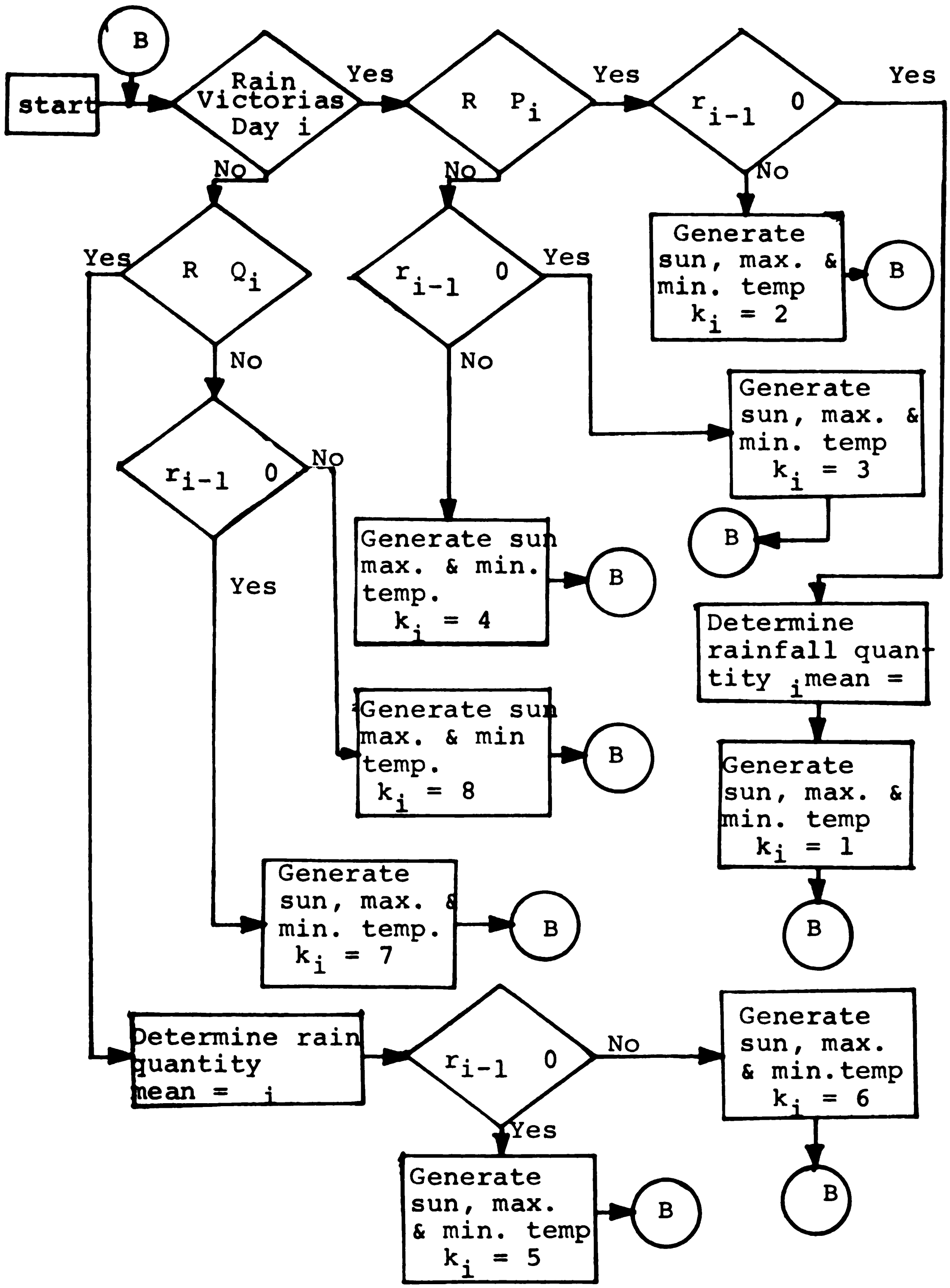

Figure 3. Flow chart for Manapla daily weather simulator

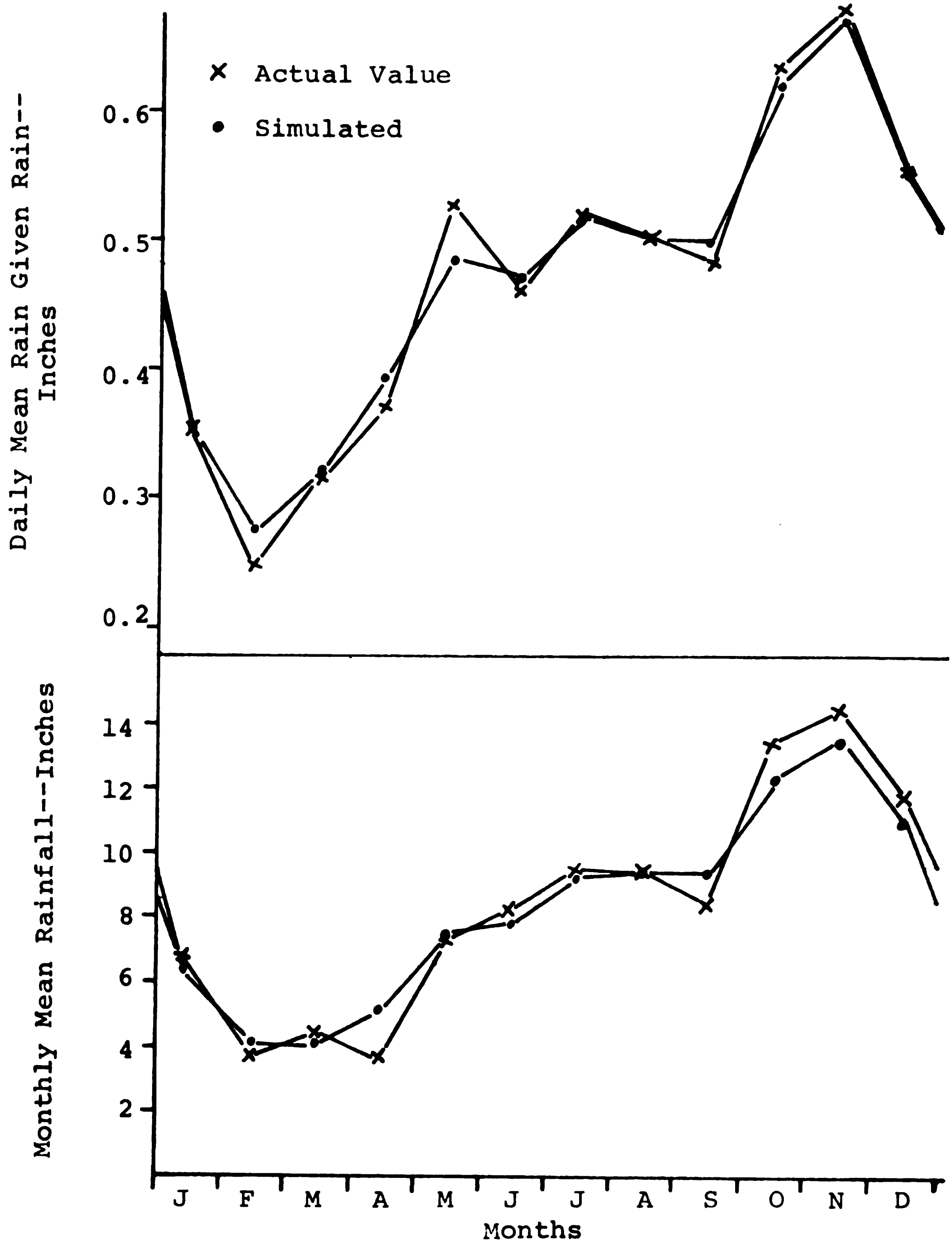

Figure 4a. Actual and simulated values, Victorias

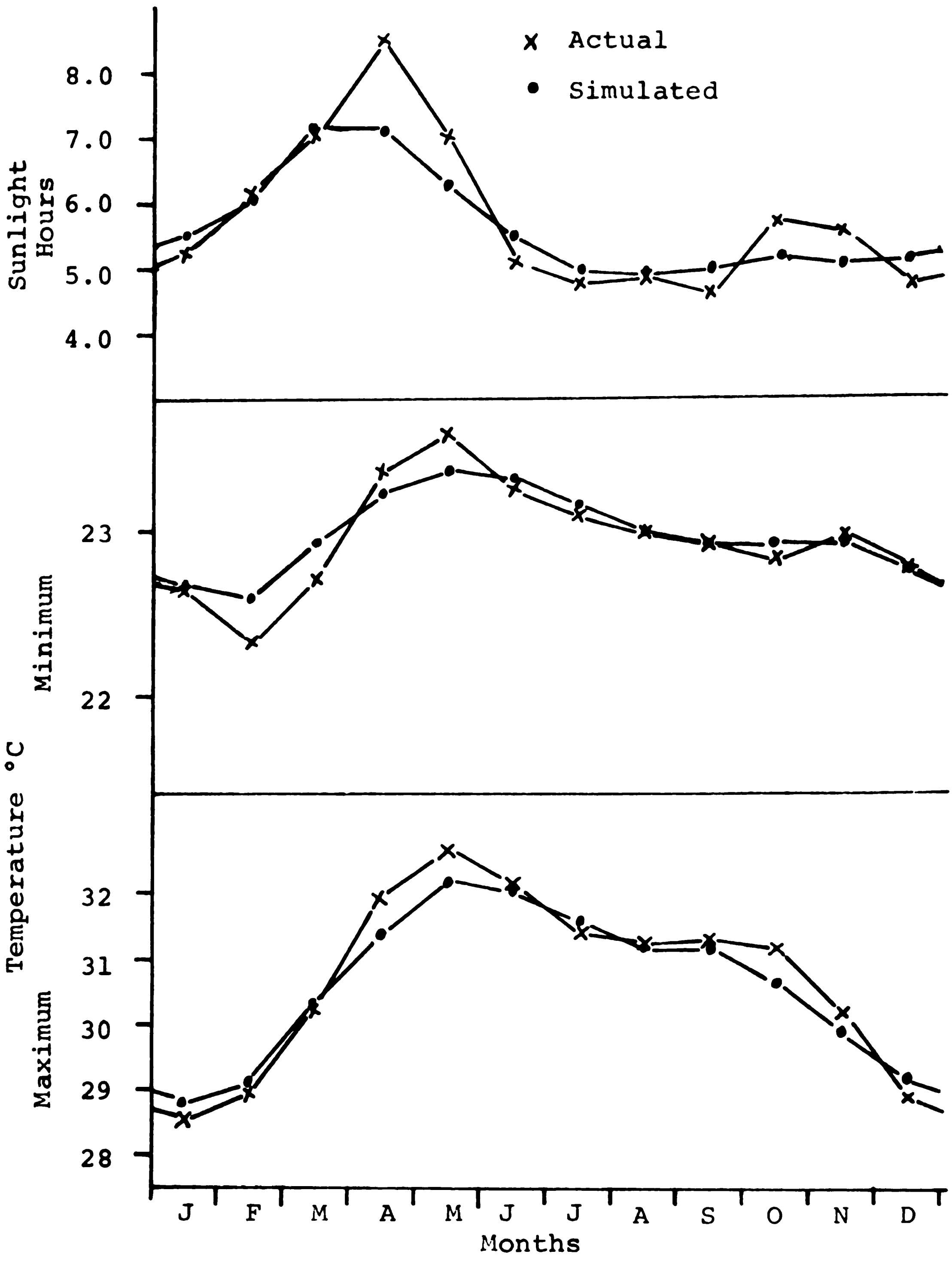

Figure 4b. Actual and simulated values, Victorias

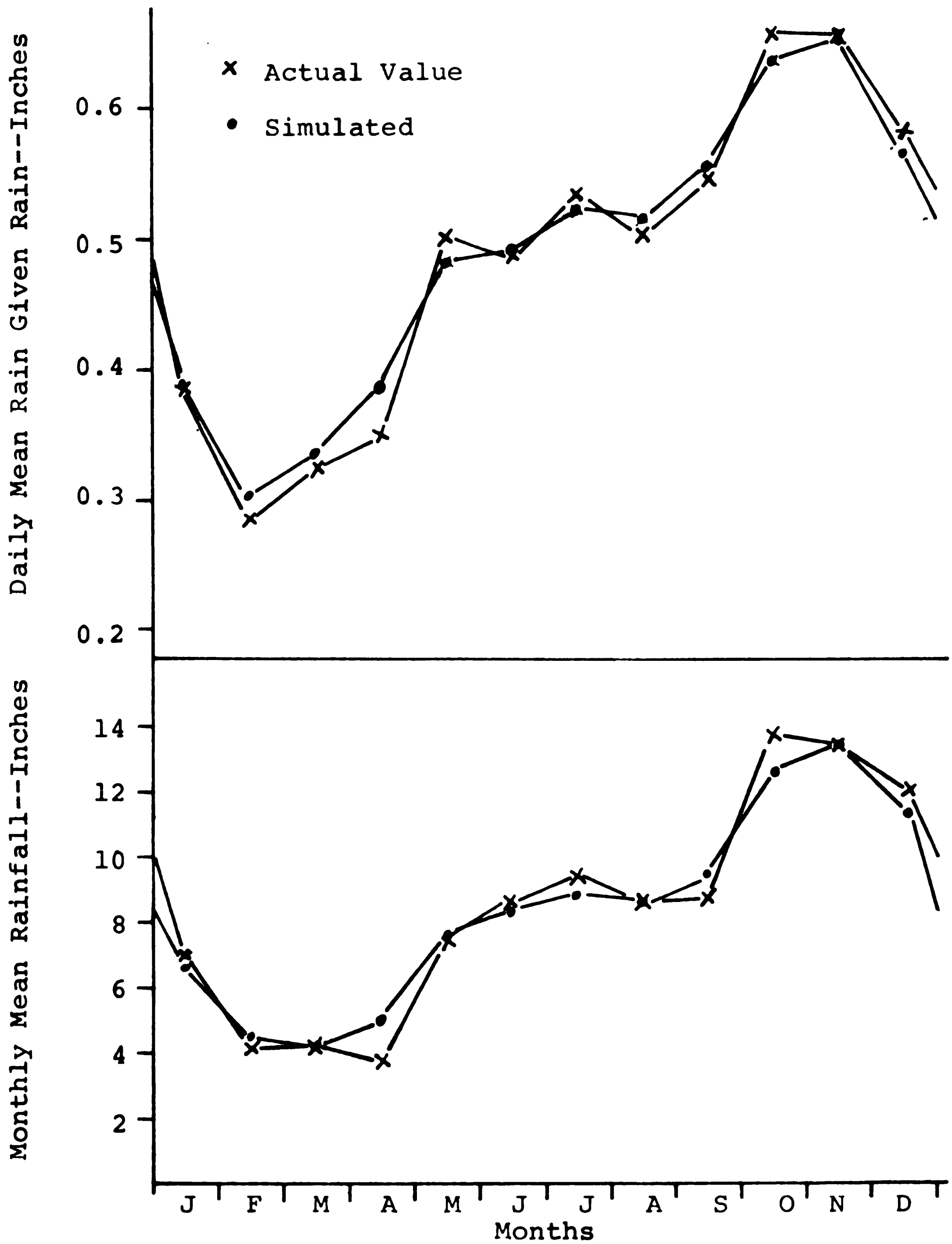

Figure 5a. Actual and simulated values, Manapla

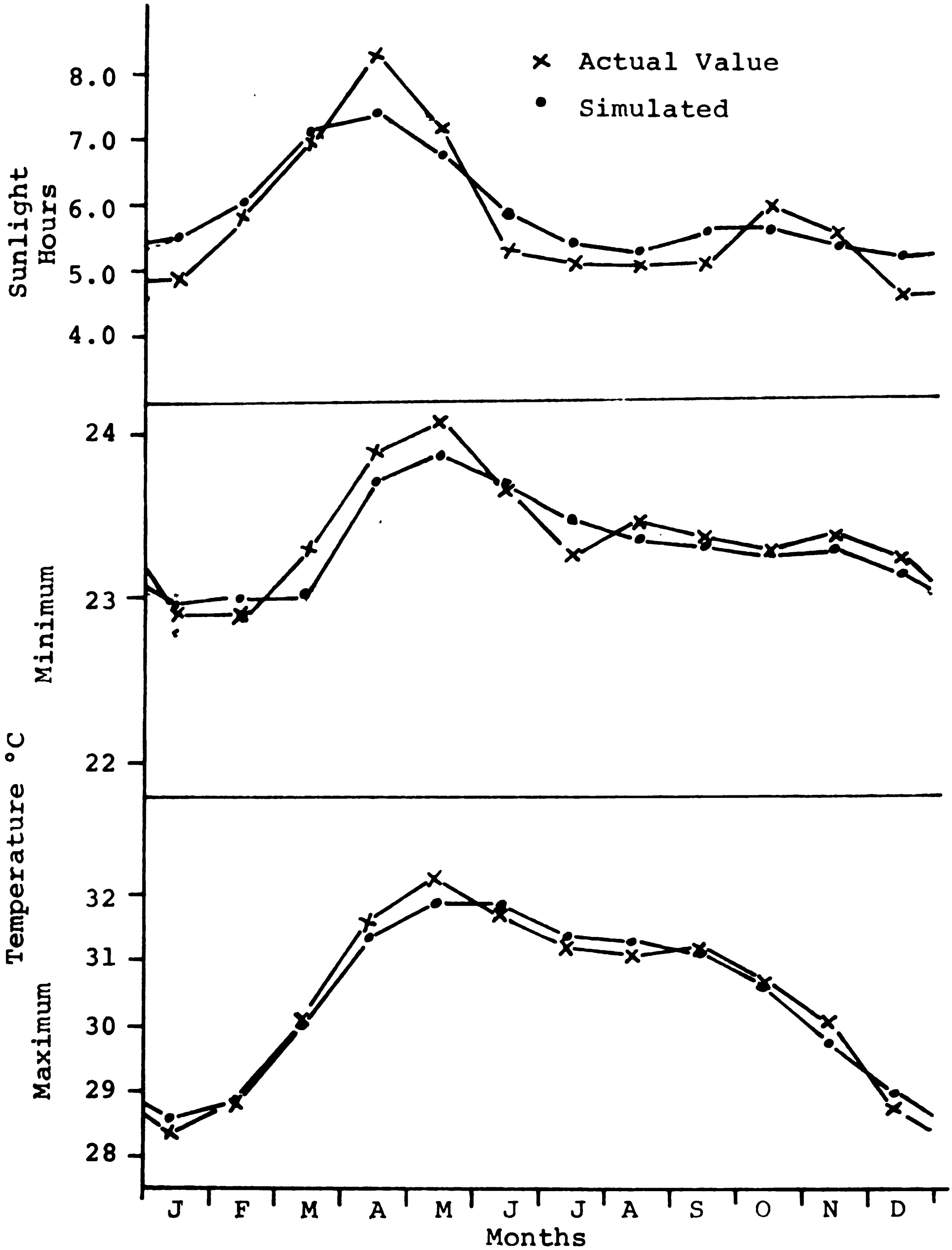

Figure 5b. Actual and simulated values, Manapla

bimonthly values would expectedly yield some errors. High actual values are underestimated and low actual values are overestimated.

In spite of these drawbacks, interpolation was thought necessary since only by doing so could the dynamic behavior of the weather system be adequately simulated. It was considered more important to capture the system dynamics than to zero in on the mean values of the weather factors. To use the weather models for crop production simulation, it is necessary to remedy the discrepancies in the mean values. This was accomplished by adding the differences between the simulated means and the actual means, for the particular month, to the generated daily weather factors. These added differences were subtracted from the lagged values of these factors for the following daily simulation cycle in order to preserve the dynamics of the weather system.

Utilizing this procedure, the 300-year simulation was repeated. Weekly values of each of the 10 weather variables utilized in the yield models were calcuated. Their means, standard deviations and maximum values are given in Table 4. The corresponding values based on the actual weather data are given in Table 5.

Table 4. Simulated weekly weather variables.*

	Rain	Dry	HU	DR	TN	SLS	S4S	TX	HS	SUN
<u>Victorias</u>										
Mean	1.97	0.40	20.10	54.11	.30	0.78	1.57	0.48	0.16	5.85
Std. Dev.	1.67	2.79	7.31	11.06	0.99	3.08	7.47	1.57	0.73	2.01
Max. Value	13.40	53.00	43.74	91.84	29.00	64.00	225.00	22.00	12.00	12.44
<u>Manapla</u>										
Mean	1.97	0.36	21.03	49.70	0.10	0.63	1.08	0.15	0.10	5.88
Std. Dev.	1.59	2.40	6.58	9.45	0.53	2.51	5.09	0.71	0.53	1.86
Max. Value	13.96	55.00	46.31	113.96	15.00	81.00	121.00	12.00	10.00	12.22

Table 5. Actual weekly weather variables.*

	Rain	Dry	HU	DR	TN	SLS	S4S	TX	HS	SUN
<u>Victorias</u>										
Mean	1.97	1.25	19.92	54.02	0.25	1.53	2.25	0.54	0.26	5.87
Std. Dev.	2.19	6.13	7.31	11.57	0.93	5.61	11.53	2.28	1.03	2.18
Max. Value	15.54	75.00	42.00	91.00	9.00	68.00	169.00	27.00	11.00	11.43
<u>Manapla</u>										
Mean	1.96	1.08	21.30	50.21	0.10	1.46	2.686	.40	0.13	5.89
Std. Dev.	2.15	4.74	6.80	10.50	0.55	6.06	14.99	2.06	0.79	2.09
Max. Value	20.43	53.00	45.65	92.68	6.00	100.00	234.00	30.00	11.00	11.39

* As defined in Section 2.5.

4. 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 requirement. In this preliminary simulation study, only yield and sugar price were considered.

4.1 Yield Simulation

Two simulations were made; one used the 20-year weather records and the other used the stochastic weather simulator to obtain the weather variables used in the yield models. Using historical weather records, only 18 production years can be considered. Utilizing the stochastic weather simulator, a 300-production year simulation was made.

The yield models developed for each area were used in the studies. To account for the unexplained variations in each of the tonnage and rendement models, random variation was generated and introduced. The random variation was computed as the product of the standard error of estimate (of the tonnage or rendement model) and a normal variate of mean zero and variance one. New random variations were computed and added to each simulated tonnage and rendement value.

Monthly tonnages and weekly rendements were computed. The weekly rendements were then converted to monthly values and the monthly sugar production was determined. Because the normal shutdown period varies from one to two months, summary statistics were computed monthly and in pairs of months (e.g., June-July, July-August) for each area.

4.2 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 in sugar prices, if it exists. An attempt was made to develop a model embodying price seasonality. However, neither domestic nor export prices exhibited (in a linear or quadratic sense), to an acceptable level of significance (0.005), any price seasonality. Therefore, it was decided for this preliminary analysis to use the monthly domestic and export prices for the five-year period (1965 to 1969), computing the gross revenue for each year. Monthly domestic, export and total revenues were calculated for each area. In calculating domestic and export revenues, it was assumed that 67 per cent of the sugar produced is exported and 33 per cent sold in the domestic market. Means and standard deviations of domestic, export and total gross revenues for each month and pair of months were calculated for the three areas.

4.3 Results and Discussion

4.3.1 Simulated Yields

Monthly mean simulated yields based on the weather records and generated weather values are plotted in Figures 6a, 6b and 6c for Victorias lowland, Victorias upland and Manapla respectively. Figures 7a, 7b and 7c give corresponding values for each pair of months for the three areas.

The monthly yields for the two simulations are in close agreement with each other. There are however, slight differences in the standard deviations obtained from each simulation. The variation among months of the variance of yield was less using stochastically generated weather than with the historical weather records. The standard deviation for tonnage, rendement, and sugar production for the three areas are tabulated in Appendix D.

Based on sugar production, it is obvious that the months of June to December comprise the possible region for cessation of harvesting and planting operations. Since

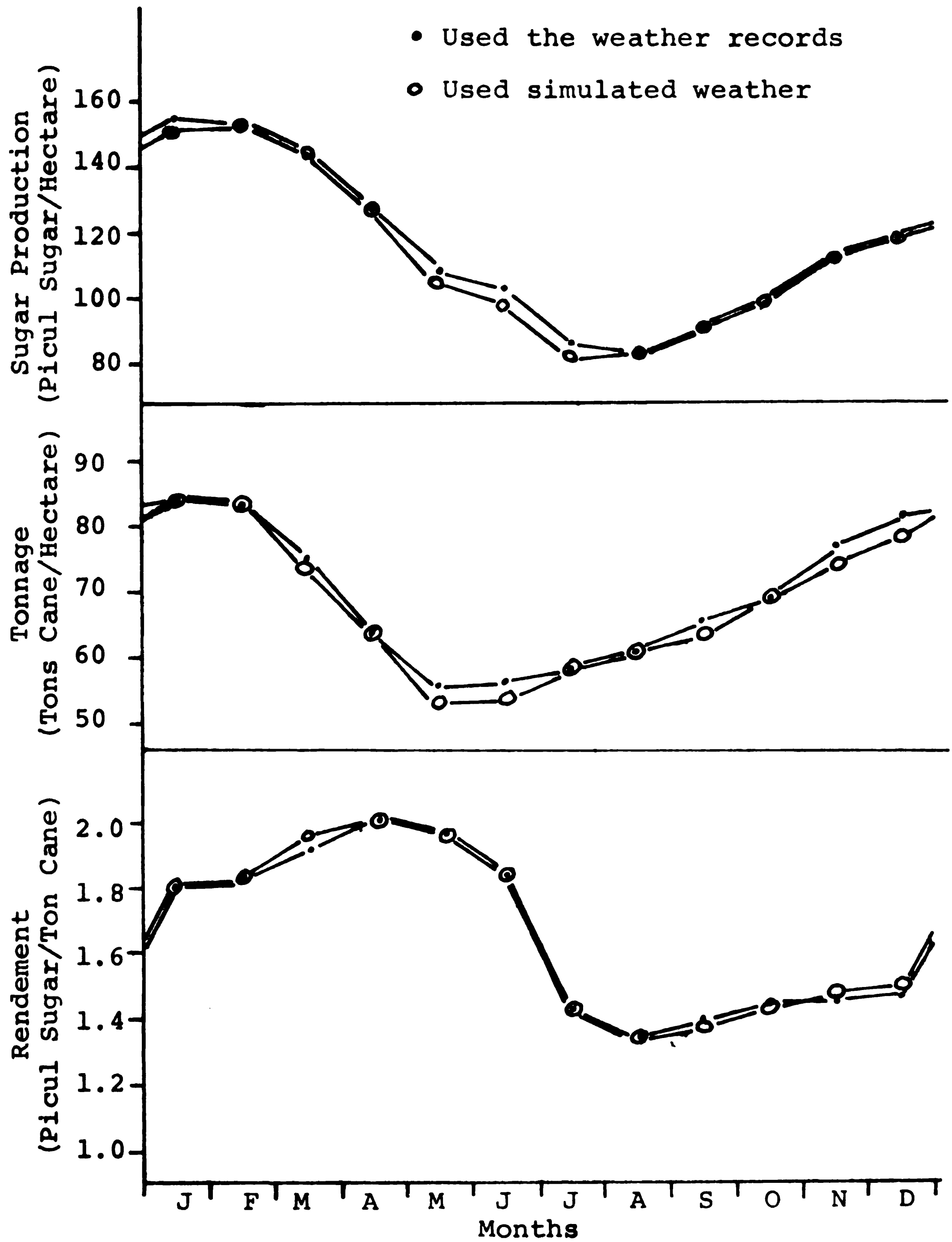

Figure 6a. Monthly mean yield, Victorias lowland

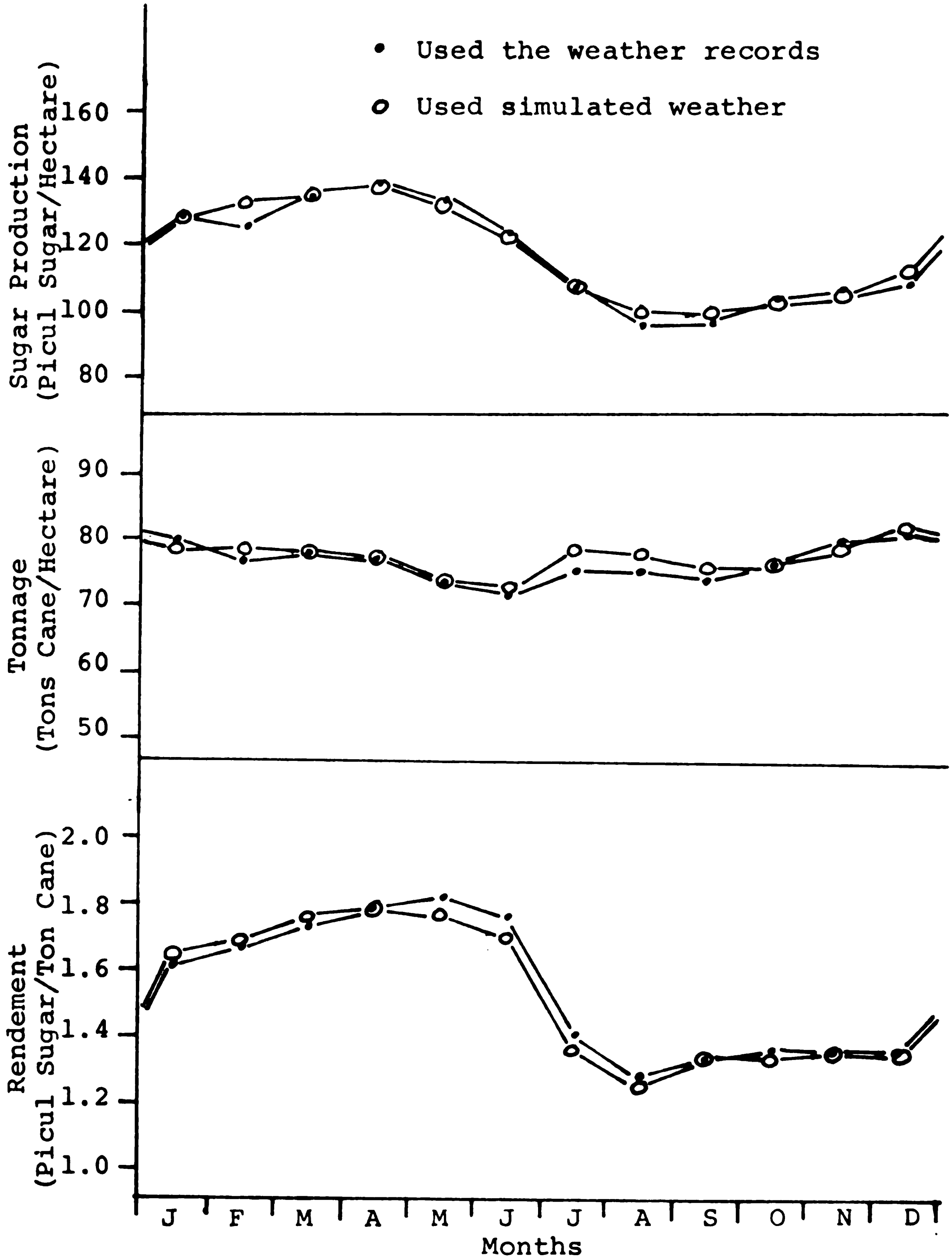

Figure 6b. Monthly mean yield, Victorias upland

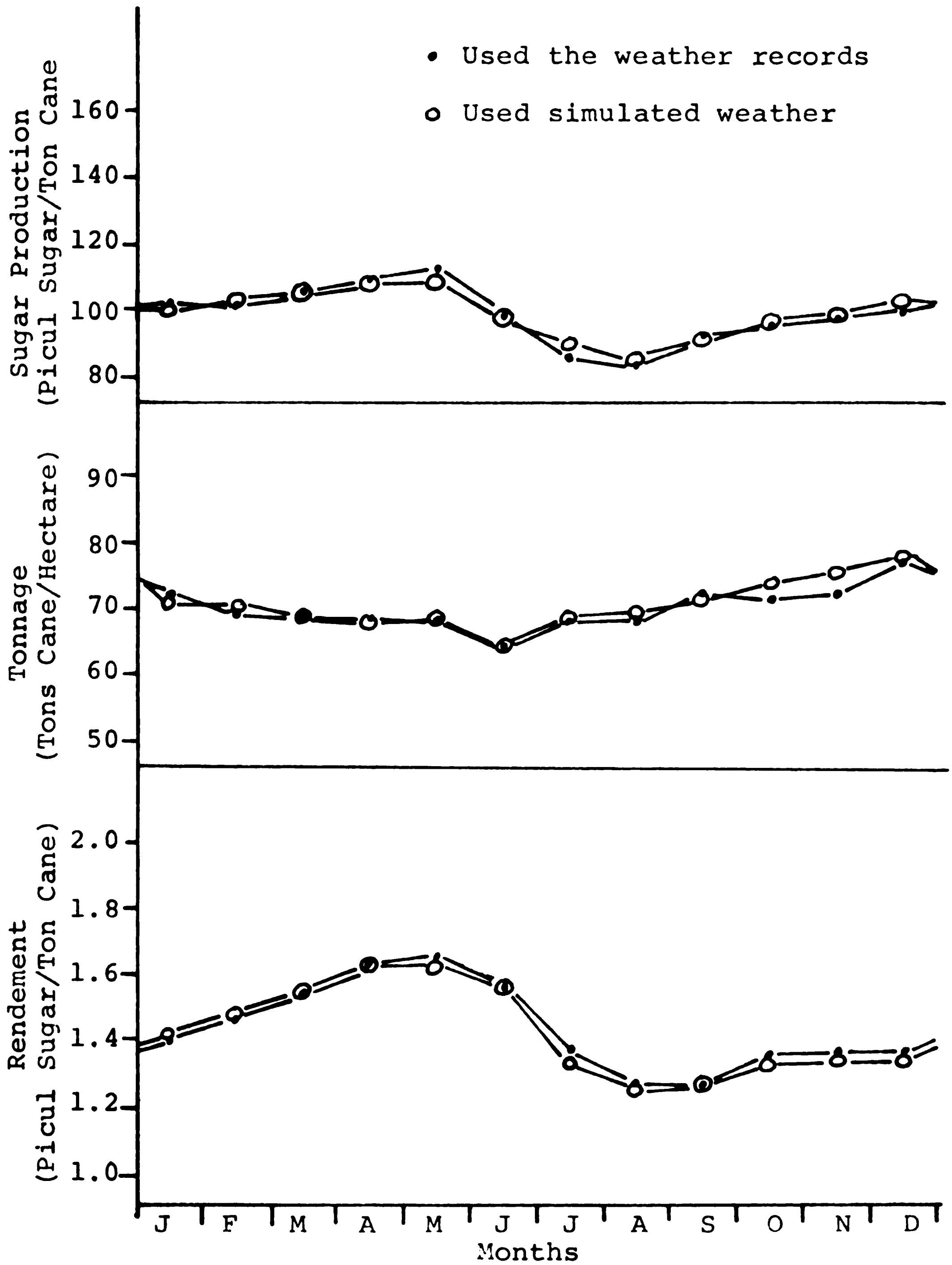

Figure 6c. Monthly mean yield, Manapla

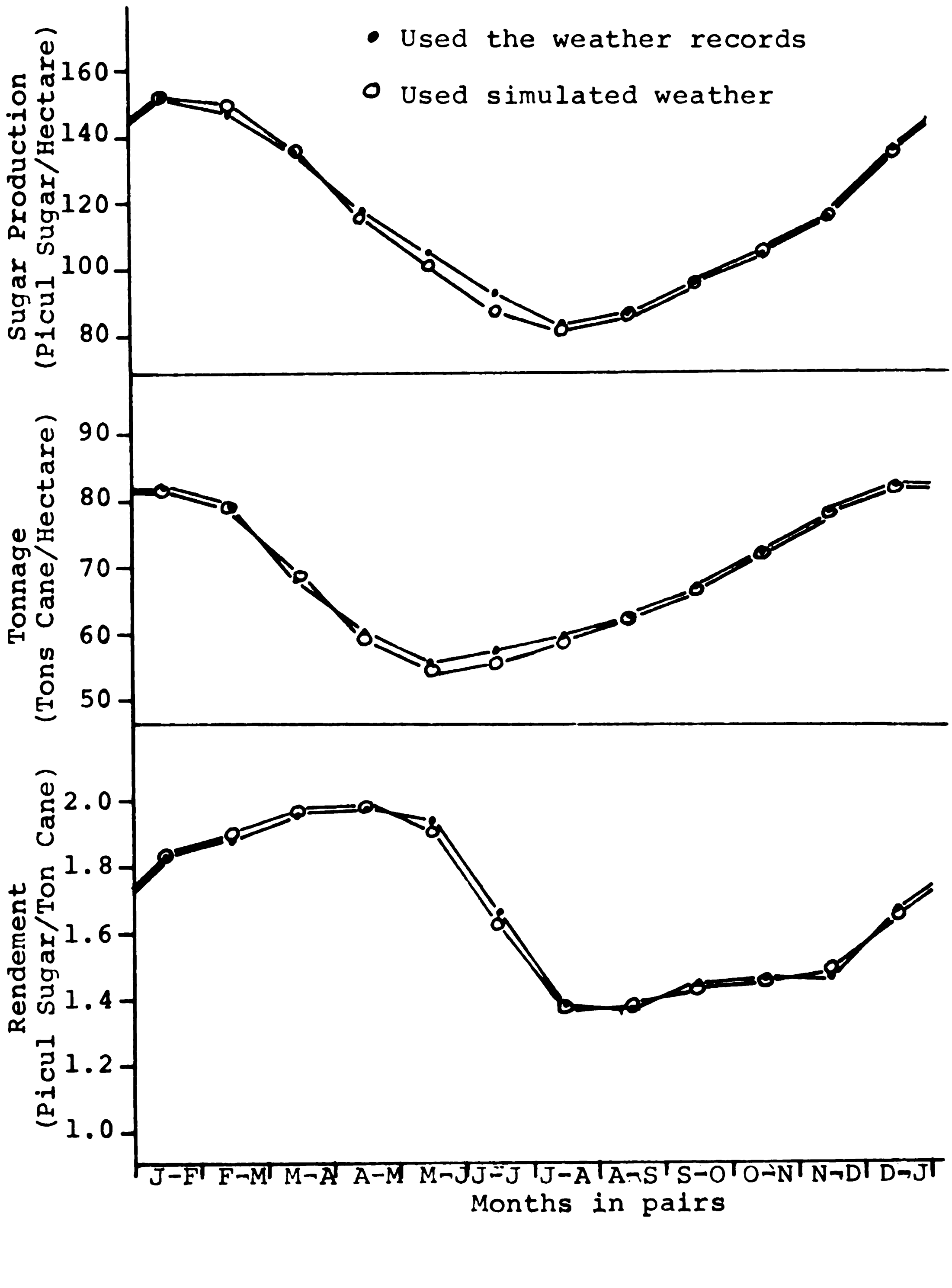

Figure 7a. Mean yield for pairs of months, Victorias lowland

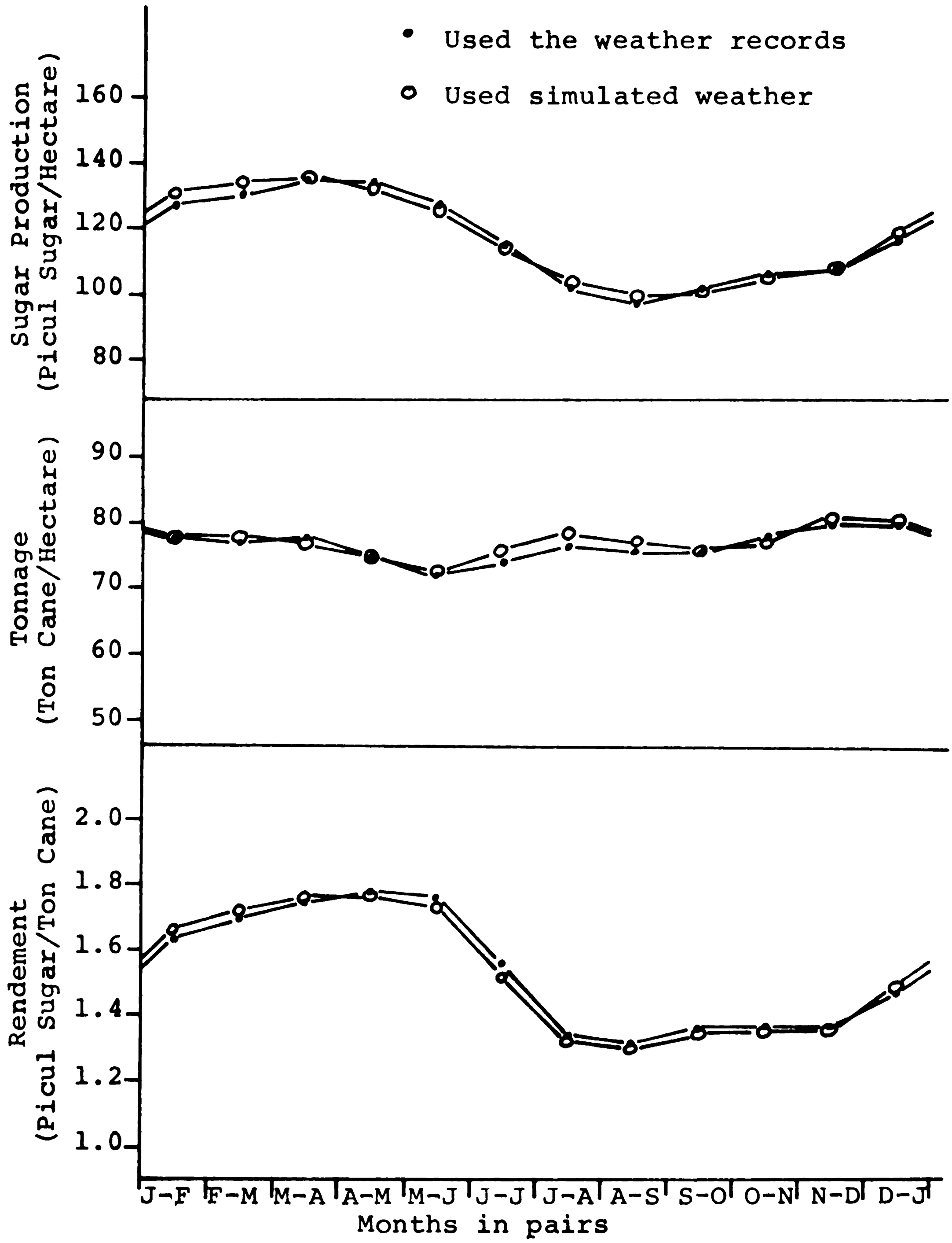

Figure 7b. Mean yield for pairs of months, Victorias upland

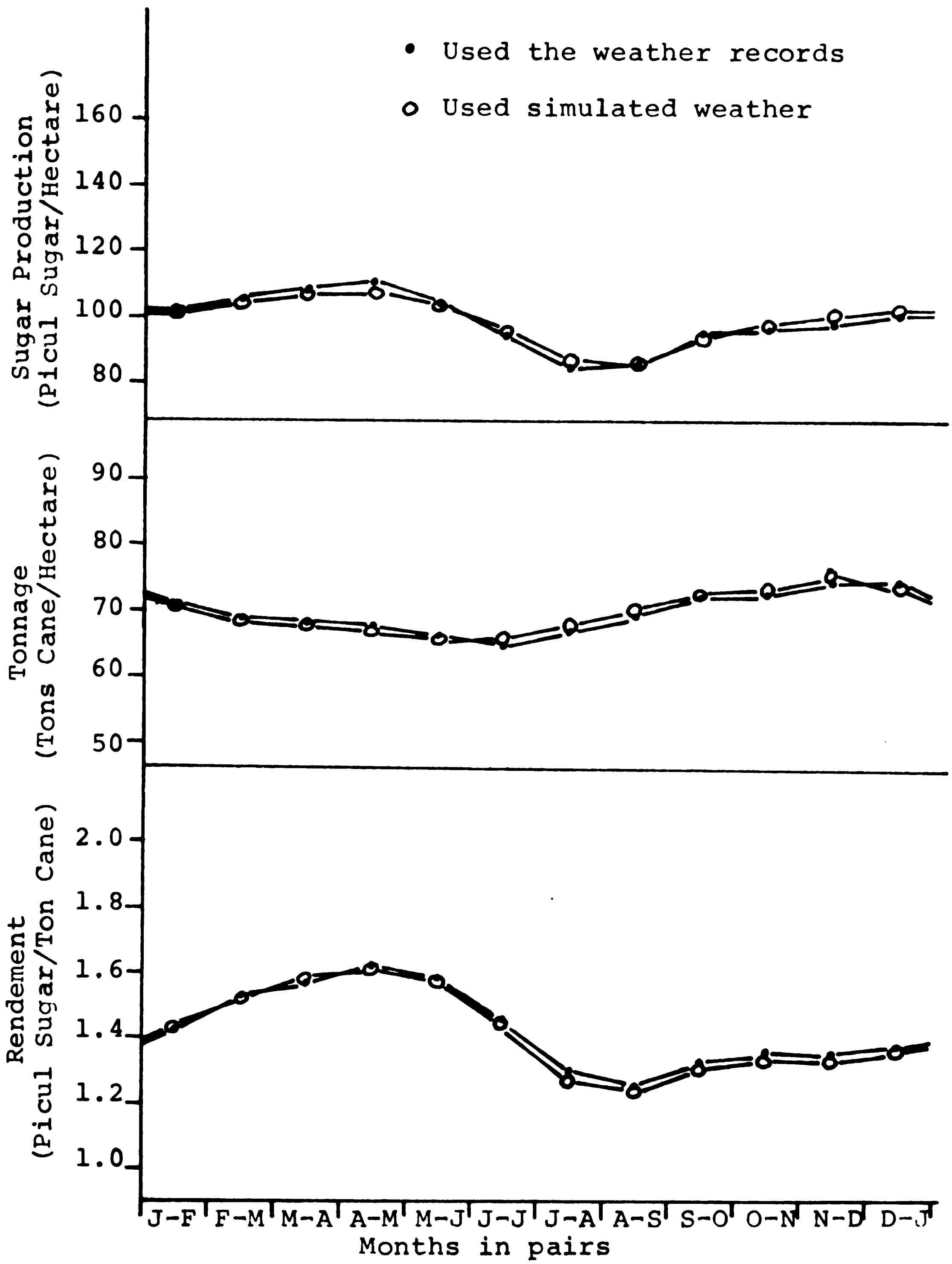

Figure 7c. Mean yield for pairs of months, Manapla

the present shutdown period in the district is during the months of November and December, comparison of yields and revenue will use a base of the values for these months. In the following discussion, if the difference in the means between two periods is significant at the five per cent level, the difference will be referred to simply as significant. If the mean difference is significant at the one per cent level, it will be referred to as highly significant. Determination of the significance between the means assumes that the differences are normally distributed (Spiegel, 1961).

In the Victorias lowland area, lowest sugar production occurs during the July-August period. The mean difference of 35 piculs sugar between this and the November-December period is highly significant (Figure 7a). Even the mean yield differences between the August-September and November-December period are highly significant, as are the differences between September-October or June-July and the November-December periods. The low sugar yield during the June to October period is due primarily to low rendement (Figure 6a).

Sugar yield in the Victorias upland area is lowest during the August-September period (Figure 7b). The mean yield difference of 10.0 piculs 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. As in the lowland area, tonnage is lowest during the May-June period. Although the differences in tonnage for the area are not striking, the drop in rendement during the August to December period (Figure 6b) brought the yield down.

In the Manapla area, the lowest sugar production occurs during the July-August and August-September periods with a difference of 13.02 and 13.0 piculs respectively compared with the November-December yield (Figure 7c). Again, these differences are highly significant. Here the low rendement occurring in August and September is responsible for low sugar yield. Tonnage during this period is relatively high.

4.3.2 Simulated Revenues

Since the simulated sugar yields using actual and generated weather variables are in close agreement with each other, only the gross revenues obtained with the latter are plotted in Figures 8a, 8b and 8c.

Total gross revenue for the Victorias lowland are lowest during the months of July and August (Figure 8a) for all five sugar price series used. The differences in revenue between the July-August and November-December periods for the five sugar price series are all highly significant.

In the Victorias upland area, lowest revenue occurs during the months of August and September (Figure 8b). The differences in mean revenue of these periods as compared

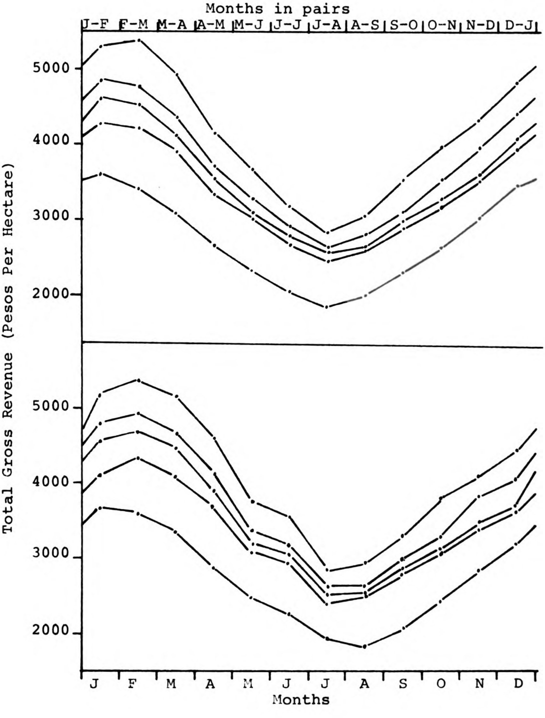

Figure 8a. Simulated revenue for five annual price series (1965-1969), Victorias lowland

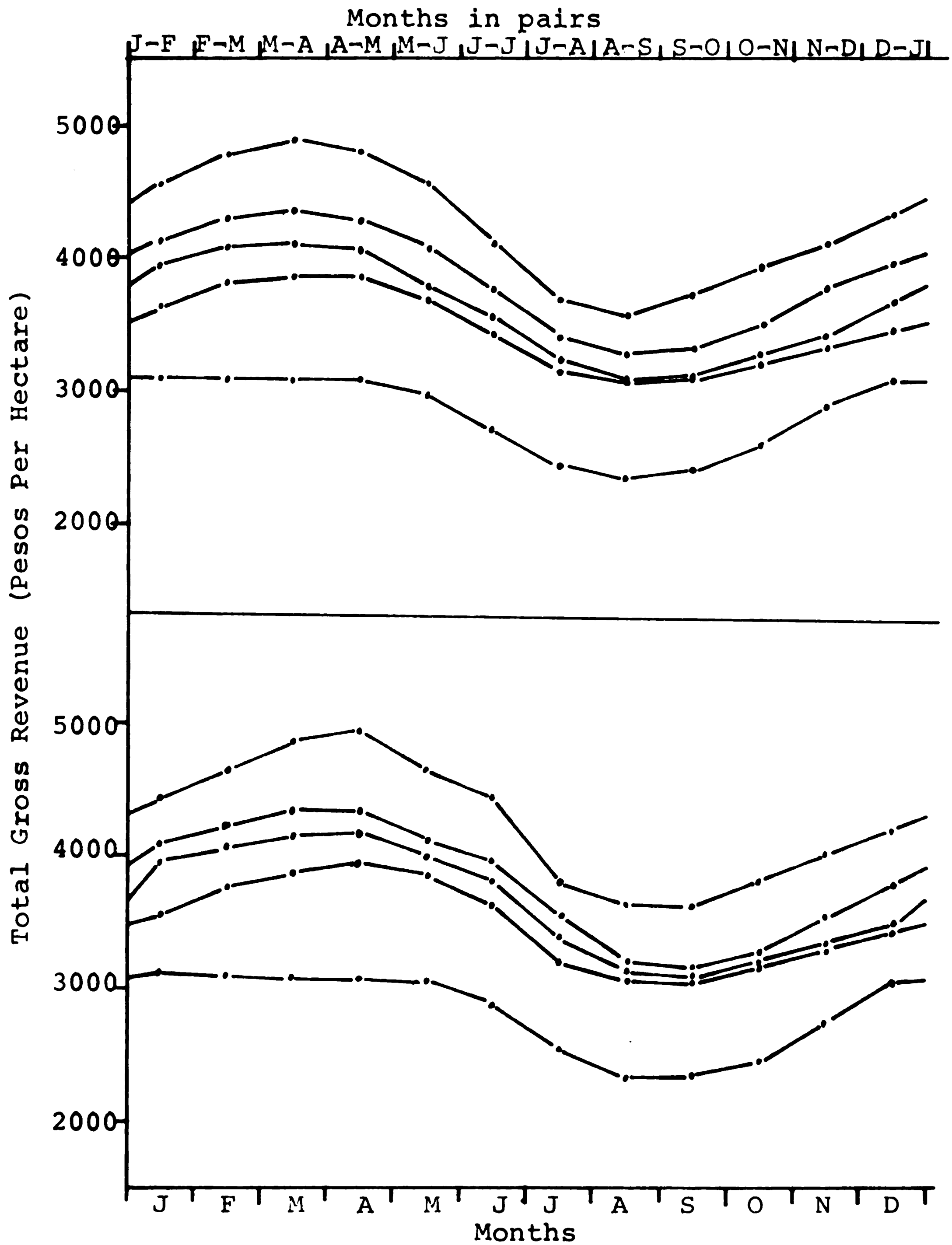

Figure 8b. Simulated revenue for five annual price series (1965-1969), Victorias upland

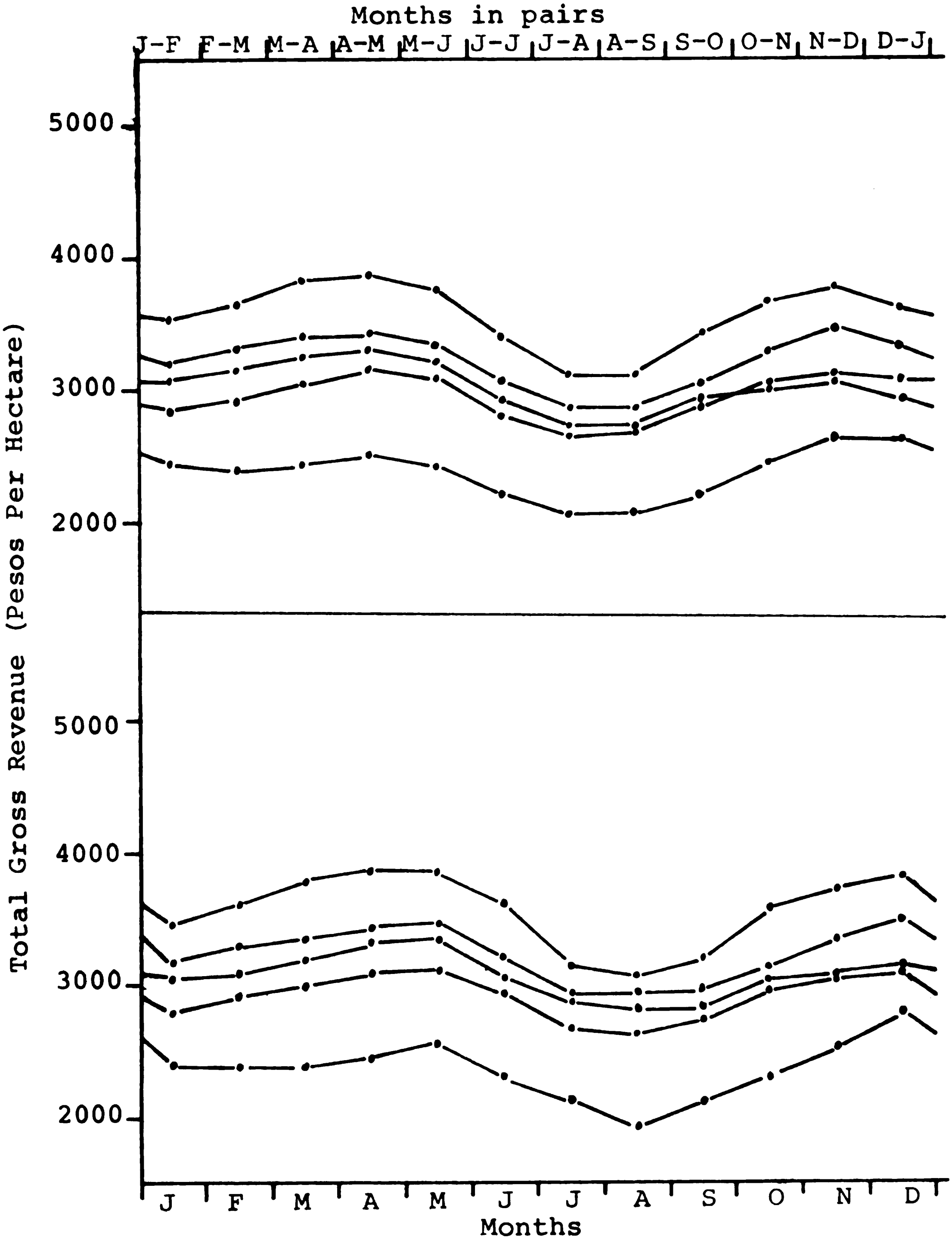

Figure 8c. Simulated revenue for five annual price series (1965-1969), Manapla

with the November-December period are all significant.

The July-August and August-September periods have the lowest revenue in the Manapla area. The difference of the mean of these periods compared with the November-December mean are all highly significant for all five sugar price series. On a monthly basis, the lowest revenue occurs in Manapla during the month of August (Figure 8c).

5. SUMMARY AND CONCLUSIONS

Models for estimating sugarcane yields for the three areas of the Victorias milling district were developed using multiple regression with least-squares criterion. Separate models were formulated for monthly tonnage and weekly rendement for the periods January to June and July to December. In the models, the climatic influence tends to be manifested in sequences of occurrence rather than the absolute value of the weather factors. The various area models indicate different controlling weather factors on growth and yield.

Model verification using 1970 production data yielded a close agreement between the estimated and actual tonnage. However, there were slight discrepancies between the estimated and actual rendement. Possibly, this can be attributed to the effect of residual fertilizer from previous crops.

Models for generating weather factors were developed for the two areas of the district. Determination of rainfall occurrence in the Victorias area was by a Monte Carlo technique using second-order Markov probabilities. The amount of rainfall was determined from a probability density function derived for the area. Sunlight and maximum and minimum temperatures were generated from regression equations in lagged values of the variables. The choice of the regression equation to use on a given day depends on the first-order rain-no rain state in the area. For the second area, rainfall occurrence was also determined by the Monte Carlo technique. Here, the probability of rain depends only on the rain-no rain state in the Victorias area for the same day. The models for sunlight and temperatures consist of regression equations with lagged values of the variables. The choice of the equation to use depends on the first-order rain-no rain state in this area and the present rain-no rain state in the Victorias.

Two simulations were made to obtain preliminary indications of alternative cropping cycles. One simulation used the historical weather records and another used stochastically generated weather factors. This also provided a test of the performance of the stochastic weather generator in production simulation applications. Summary statistics on yields and revenues for each month and pair of months were calculated. Five annual sets of monthly prices were used in calculating revenue. The calculated mean yields and revenues with the two simulations were in close agreement with each other.

There are strong indications, based on yield and revenue, that the November-December period is not the best time to cease operations in the district.

Conclusions derived from these results included:

1. The tonnage and rendement models developed are adequate for production simulation applications.
2. The weather simulator is adequate for production simulation applications.
3. There is an annual time trend of increasing tonnage and decreasing rendement in the three areas of the district.

6. RECOMMENDATIONS

The results of this project suggest the need for further work in simulation analysis of alternative cropping cycles for the Victorias milling district. Future studies can utilize the yield and stochastic weather models developed here. Additional factors that should be considered in future simulation studies are:

1. Shift in market orientation from export towards domestic markets.
2. Field operational requirements based on tractability.
3. Farm and factory labor supplies
4. Marketing lag times
5. Inventory costs.

The trend of decreasing rendement in the district suggests the need to appraise current cultural practices. Particular attention should be given to fertility programs in the area.

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APPENDIX A

ACTUAL AND SIMULATED WEATHER VALUES

Actual Weather values--Victorias

	Mean					Standard Deviation				
	Rain		Temperature		Sun-	Rain		Temperature		Sun-
	Monthly	Daily	Max.	Min.	light	Monthly	Daily	Max.	Min.	light
Jan.	6.86	0.35	28.51	22.61	5.28	4.90	0.75	1.62	1.29	3.23
Feb.	3.71	0.24	28.90	22.33	6.15	1.96	0.39	1.51	1.09	3.45
Mar.	4.18	0.31	30.12	22.71	7.04	2.57	0.44	1.59	1.14	3.24
Apr.	3.67	0.37	31.93	23.38	8.58	2.70	0.66	1.47	1.12	2.51
May	7.33	0.52	32.65	23.59	7.05	5.65	0.94	1.73	0.99	3.03
June	8.15	0.46	32.12	23.26	5.14	3.10	0.68	1.80	0.86	2.84
Jul	9.87	0.52	31.41	23.14	4.88	4.82	0.81	1.61	1.17	2.89
Aug	9.73	0.50	31.24	23.06	4.90	2.75	0.67	1.64	0.84	3.04
Sept.	8.43	0.48	31.41	22.98	4.78	3.20	0.61	1.70	0.81	2.91
Oct.	13.60	0.63	31.15	22.86	5.99	5.83	0.91	1.57	0.84	2.94
Nov.	14.53	0.68	30.16	23.00	5.68	5.94	1.09	1.65	1.05	3.31
Dec.	11.92	0.55	28.90	22.80	4.89	6.11	0.87	1.60	1.03	3.12

Simulated weather values--Victorias

	Mean					Standard Deviation				
	Rain		Temperature		Sun-	Rain		Temperature		Sun-
	Monthly	Daily	Max.	Min.	light	Monthly	Daily	Max.	Min.	light
Jan.	6.52	0.35	28.85	22.67	5.56	2.39	0.45	1.46	1.13	3.06
Feb.	4.06	0.27	29.11	22.66	6.10	1.47	0.34	1.48	1.17	3.06
Mar.	4.10	0.32	30.28	22.98	7.12	2.06	0.43	1.63	1.15	2.92
Apr.	5.18	0.39	31.34	23.22	7.10	2.55	0.55	1.72	1.05	2.91
May	7.42	0.48	32.05	23.39	6.35	3.15	0.64	1.76	0.97	2.92
June	7.84	0.47	32.03	23.35	5.58	3.14	0.59	1.73	0.93	2.85
Jul.	9.50	0.52	31.50	23.20	5.07	3.41	0.65	1.62	0.98	2.79
Aug.	9.65	0.50	31.26	23.06	5.03	3.27	0.61	1.53	0.94	2.81
Sept.	9.52	0.50	31.16	22.97	5.27	3.15	0.61	1.51	0.85	2.84
Oct	12.45	0.62	30.68	22.93	5.34	3.98	0.75	1.55	0.86	2.91
Nov.	13.44	0.65	29.90	22.90	5.22	4.36	0.79	1.66	0.95	2.96
Dec.	11.09	0.55	29.28	22.85	5.41	3.61	0.67	1.62	1.06	2.98

Actual weather values--Manapla

	Mean					Standard Deviation				
	Rain		Temperature		Sun-	Rain		Temperature		Sun-
	Monthly	Daily	Max.	Min.	light	Monthly	Daily	Max.	Min.	light
Jan.	7.03	0.38	28.47	22.91	4.89	3.88	0.68	1.28	0.94	3.22
Feb.	4.08	0.28	28.99	22.90	5.93	2.42	0.47	1.39	1.08	3.41
Mar.	4.13	0.32	30.10	23.28	7.01	2.36	0.48	1.47	0.95	3.11
Apr.	3.87	0.34	31.72	23.95	8.39	2.69	0.54	1.28	1.05	2.50
May	7.34	0.50	32.32	24.14	7.12	4.75	0.79	1.55	1.00	2.82
June	8.56	0.49	31.87	23.67	5.30	2.61	0.66	1.59	0.91	2.77
Jul.	9.42	0.53	31.29	23.39	5.12	4.31	0.70	1.39	0.92	2.93
Aug.	8.68	0.50	31.23	23.54	5.10	3.46	0.65	1.52	0.98	3.08
Sept.	8.78	0.54	31.35	23.42	5.18	4.43	0.77	1.49	0.98	3.01
Oct.	13.83	0.66	30.91	23.34	6.09	4.97	0.86	1.24	0.94	2.93
Nov.	13.50	0.65	30.11	23.42	5.68	5.40	0.97	1.32	1.18	3.11
Dec.	12.03	0.57	28.89	23.33	4.55	7.74	1.11	1.33	0.95	3.04

Simulated weather values--Manapla

	Mean					Standard Deviation				
	Rain		Temperature		Sun-	Rain		Temperature		Sun-
	Monthly	Daily	Max.	Min.	light	Monthly	Daily	Max.	Min.	light
Jan.	6.76	0.37	28.76	22.97	5.53	2.47	0.46	1.34	1.69	3.02
Feb.	4.30	0.30	28.83	22.97	6.04	1.76	0.35	1.34	1.71	3.07
Mar.	4.14	0.33	30.08	23.07	7.26	1.88	0.38	1.43	1.21	2.85
Apr.	5.03	0.38	31.32	23.77	7.41	2.23	0.47	1.46	1.01	2.73
May	7.45	0.48	31.90	23.89	6.72	2.84	0.58	1.46	0.96	2.77
June	8.10	0.48	31.85	23.73	5.93	2.93	0.57	1.47	0.96	2.80
Jul.	8.99	0.52	31.49	23.56	5.51	3.00	0.61	1.41	0.95	2.82
Aug.	8.78	0.51	31.34	23.44	5.49	2.90	0.59	1.40	0.96	2.88
Sept.	9.51	0.55	31.24	23.38	5.73	3.12	0.61	1.37	0.96	2.91
Oct.	12.61	0.63	30.76	23.32	5.73	3.74	0.71	1.35	0.96	2.85
Nov.	13.40	0.66	29.97	23.37	5.45	4.16	0.77	1.40	1.02	2.90
Dec.	11.33	0.56	29.25	22.90	5.34	3.78	0.72	1.36	1.17	2.95

APPENDIX B

TYPHOON LOSS ADJUSTMENT

AND

RENDEMENT CONVERSION FACTOR

Typhoon loss adjustment factor*--Tonnage

Months	1951	1952	1954	1955	1962	1963	1966	1967	1968	1969
January		1.095		1.110		1.095		1.040		1.190
February		1.095		1.110		1.095		1.040		1.190
March		1.095		1.110		1.095		1.040		1.190
April		1.095		1.110		1.095		1.040		1.190
May		1.095		1.110		1.095		1.040		1.190
June		1.080		1.090		1.080		1.020		1.165
July		1.070		1.080		1.070		1.015		1.145
August		1.101		1.010		1.010				1.019
September		1.010		1.010		1.010				1.019
October		1.010		1.010		1.010				1.019
November		1.010		1.010		1.010				1.019
December	1.090		1.100		1.090		1.025		1.180	

Typhoon loss adjustment factor*--Rendement

Months	1962	1963	1968	1969
January		1.035		1.059
February		1.035		1.059
March		1.035		1.059
April		1.035		1.059
May		1.035		1.059
June				
July				
August				
September				
October				
November				
December	1.035		1.059	

* Multiplied with the reported value to get adjusted value.

Factor needed to convert district rendement into rendement for each of the three areas:

$$FACTOR_{ij} = \frac{TON_{i,j} \times \sum_{i=1}^{3} SUGAR_{ij}}{SUGAR_{ij} \times \sum_{i=1}^{3} TON_{ij}}$$

where:

FACTOR = factor to be multiplied with the district weekly rendement to get weekly rendement for area i, during month j. If the week extends to the next month, it is considered part of the month having the most number of days in the particular week.

TON = amount of cane produced in area i, during month j. This is equal to the product of the tonnage and area harvested.

SUGAR = amount of sugar produced in area i during month j. This is equal to the product of the cane produced and rendement for area i during month j.

i = 1, 2, 3 referring to Victorias lowland, Victorias upland and Manapla respectively.

j = 1, 2, ... 12 months.

APPENDIX C

WEATHER MODEL PARAMETERS

VICTORIAS WEATHER PARAMETERS

Bimonthly Transition Probabilities $(P_i^{j_{i-1}})$

Periods	j_{i-1}: 1	2	3	4
Jan-Feb	0.702	.696	0.416	0.406
Mar-Apr	.600	0.526	0.322	0.338
May-Jun	0.652	0.528	0.476	0.400
Jul-Aug	0.716	0.667	0.496	0.464
Sept-Oct	0.714	0.716	0.505	0.496
Nov-Dec	0.795	0.672	0.553	0.512

Monthly A_i and μr_i

	Jan	Feb	Mar	Apr	May	June
A_i	0.429	0.493	0.456	0.474	0.383	0.364
μr_i	0.591	0.446	0.545	0.665	0.824	0.698
	Jul	Aug	Sept	Oct	Nov	Dec
A_i	0.369	0.324	0.331	0.305	0.284	0.336
μr_i	0.801	0.728	0.700	0.898	0.942	0.815

$f(S_i^{l_i})$

	$as_i^{l_i}$	$bs_i^{l_i}$	$cs_i^{l_i}$	$ds_i^{l_i}$	$es_i^{l_i}$	$\sigma s_i^{l_i}$
Jan-Feb	2.640	.372	-.747	0.000	0.000	2.843
Mar-Apr	3.492	.400	-1.453	0.000	0.000	2.794
May-Jun	2.076	.513	-.432	0.000	0.000	2.405
Jul-Aug	13.634	.366	-.887	0.000	-.477	2.418
Sept-Oct	2.246	.515	-.419	0.000	0.000	2.589
Nov-Dec	2.318	.484	-.368	0.000	0.000	2.720

$f(X_i^{l_i})$

	$ax_i^{l_i}$	$bx_i^{l_i}$	$cx_i^{l_i}$	$dx_i^{l_i}$	$ex_i^{l_i}$	$\sigma x_i^{l_i}$
Jan-Feb	15.855	.395	.259	-.191	0.000	1.007
Mar-Apr	18.000	.332	.307	0.000	0.000	1.083
May-Jun	20.093	.307	.359	0.000	0.000	1.507
Jul-Aug	25.405	.255	.359	-.260	-.172	1.097
Sept-Oct	20.090	.301	.285	-.247	0.000	1.264
Nov-Dec	16.323	.395	.261	0.000	0.000	1.167

$f(Y_i^{l_i})$

	$ay_i^{l_i}$	$by_i^{l_i}$	$cy_i^{l_i}$	$dy_i^{l_i}$	$ey_i^{l_i}$	$\sigma y_i^{l_i}$
Jan-Feb	8.287	.517	0.000	0.000	.094	.851
Mar-Apr	13.948	.256	0.000	0.000	.110	.834
May-Jun	17.582	.231	.075	-.194	0.000	.725
Jul-Aug	16.205	.287	.042	-.144	0.000	.754
Sept-Oct	15.190	.327	.057	-.113	0.000	.692
Nov-Dec	14.406	.379	0.000	-.140	0.000	.790

$f(S_i^{2_i})$

	$as_i^{2_i}$	$bs_i^{2_i}$	$cs_i^{2_i}$	$ds_i^{2_i}$	$es_i^{2_i}$	$\sigma s_i^{2_i}$
Jan-Feb	2.586	.481	0.000	0.000	0.000	2.820
Mar-Apr	2.314	.630	0.000	0.000	0.000	2.427
May-Jun	2.612	.456	0.000	0.000	0.000	2.471
Jul-Aug	2.959	.328	0.000	0.000	0.000	2.518
Sept-Oct	16.541	.383	0.000	0.000	-.585	2.536
Nov-Dec	2.540	.488	0.000	0.000	0.000	2.554

$f(X_i^{2_i})$

	$ax_i^{2_i}$	$bx_i^{2_i}$	$cx_i^{2_i}$	$dx_i^{2_i}$	$ex_i^{2_i}$	$\sigma x_i^{2_i}$
Jan-Feb	8.041	.686	.158	0.000	0.000	.806
Mar-Apr	9.176	.667	.143	0.000	0.000	.790
May-Jun	15.216	.497	.194	0.000	0.000	1.190
Jul-Aug	20.184	.323	.259	0.000	0.000	1.019
Sept-Oct	15.302	.486	.196	0.000	0.000	.997
Nov-Dec	8.539	.687	.127	0.000	0.000	.908

$f(Y_i^{2_i})$

	$ay_i^{2_i}$	$by_i^{2_i}$	$cy_i^{2_i}$	$dy_i^{2_i}$	$ey_i^{2_i}$	$\sigma y_i^{2_i}$
Jan-Feb	12.676	.446	0.000	0.000	0.000	.875
Mar-Apr	12.498	.450	.060	0.000	0.000	.802
May-Jun	15.478	.340	0.000	-.240	0.000	.835
Jul-Aug	9.957	.548	.065	0.000	0.000	.795
Sept-Oct	14.718	.348	.067	-.225	0.000	.714
Nov-Dec	12.464	.464	0.000	-.243	0.000	.804

$f(S_i^{3_i})$

	$as_i^{3_i}$	$bs_i^{3_i}$	$cs_i^{3_i}$	$ds_i^{3_i}$	$es_i^{3_i}$	$\sigma s_i^{3_i}$
Jan-Feb	5.255	.267	0.000	0.000	0.000	2.736
Mar-Apr	5.393	.400	0.000	0.000	0.000	2.548
May-Jun	4.584	.409	0.000	0.000	0.000	2.420
Jul-Aug	4.999	.203	0.000	0.000	0.000	2.790
Sept-Oct	4.581	.352	0.000	0.000	0.000	2.508
Nov-Dec	3.997	.454	0.000	0.000	0.000	2.561

$f(X_i^{3_i})$

	$ax_i^{3_i}$	$bx_i^{3_i}$	$cx_i^{3_i}$	$dx_i^{3_i}$	$ex_i^{3_i}$	$\sigma x_i^{3_i}$
Jan-Feb	12.809	.383	.168	0.000	.179	.932
Mar-Apr	14.321	.501	.142	0.000	0.000	.963
May-Jun	20.226	.356	.123	0.000	0.000	1.055
Jul-Aug	24.946	.169	.238	0.000	0.000	.930
Sept-Oct	24.218	.204	.154	0.000	0.000	.992
Nov-Dec	14.615	.501	.086	0.000	0.000	1.154

$f(Y_i^{3_i})$

	$ay_i^{3_i}$	$by_i^{3_i}$	$cy_i^{3_i}$	$dy_i^{3_i}$	$ey_i^{3_i}$	$\sigma y_i^{3_i}$
Jan-Feb	5.936	.728	0.000	0.000	0.000	1.082
Mar-Apr	9.687	.577	0.000	0.000	0.000	.906
May-Jun	12.017	.495	0.000	0.000	0.000	.901
Jul-Aug	10.339	.564	0.000	0.000	0.000	1.073
Sept-Oct	12.141	.470	0.000	0.000	0.000	.875
Nov-Dec	10.304	.545	0.000	0.000	0.000	.983

$f(S_i^{4_i})$

	$as_i^{4_i}$	$bs_i^{4_i}$	$cs_i^{4_i}$	$ds_i^{4_i}$	$es_i^{4_i}$	$\sigma s_i^{4_i}$
Jan-Feb	3.377	.567	0.000	0.000	0.000	2.340
Mar-Apr	4.323	.526	0.000	0.000	0.000	1.768
May-Jun	4.241	.475	0.000	0.000	0.000	2.187
Jul-Aug	4.009	.410	0.000	0.000	0.000	2.412
Sept-Oct	4.330	.380	0.000	0.000	0.000	2.357
Nov-Dec	4.025	.481	0.000	0.000	0.000	2.400

$f(X_i^{4_i})$

	$ax_i^{4_i}$	$bx_i^{4_i}$	$cx_i^{4_i}$	$dx_i^{4_i}$	$ex_i^{4_i}$	$\sigma x_i^{4_i}$
Jan-Feb	8.878	.678	.097	0.000	0.000	.815
Mar-Apr	7.132	.781	0.000	0.000	0.000	.905
May-Jun	14.862	.534	.099	0.000	0.000	1.146
Jul-Aug	20.448	.463	.162	0.000	-.169	.826
Sept-Oct	13.498	.567	0.000	0.000	0.000	.960
Nov-Dec	5.943	.812	0.000	0.000	0.000	.987

$f(Y_i^{4_i})$

	$ay_i^{4_i}$	$by_i^{4_i}$	$cy_i^{4_i}$	$dy_i^{4_i}$	$ey_i^{4_i}$	$\sigma y_i^{4_i}$
Jan-Feb	10.718	.518	0.000	0.000	0.000	1.176
Mar-Apr	10.080	.561	0.000	0.000	0.000	1.142
May-Jun	15.891	.329	0.000	0.000	0.000	.972
Jul-Aug	9.586	.596	0.000	0.000	0.000	.894
Sept-Oct	13.886	.397	0.000	0.000	0.000	.831
Nov-Dec	9.546	.574	0.000	0.000	0.000	1.168

MANAPLA WEATHER PARAMETERS

Monthly P_i, Q_i, μ_i, w_i*

	Jan	Feb	Mar	Apr	May	June
P_i	0.838	0.825	0.773	0.742	0.749	0.830
Q_i	0.826	0.850	0.862	0.813	0.759	0.776
μ_i	0.618	0.450	0.509	0.601	0.813	0.741
w_i	0.198	0.231	0.130	0.205	0.203	0.240
	Jul	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
P_i	0.797	0.815	0.820	0.842	0.865	0.869
Q_i	0.800	0.876	0.868	0.691	0.747	0.765
μ_i	0.761	0.692	0.723	0.902	0.907	0.878
w_i	0.240	0.231	0.327	0.226	0.179	0.102

* P_i = probability of rain in Manapla given rain in Victorias.

Q_i = probability of no rain in Manapla given no rain in Victorias.

μ_i = daily mean rain given rain greater than 0.10 in Manapla given rain in Victorias.

w_i = daily mean rain given rain in Manapla given no rain in Victorias.

$f(S_i^{l_i})$

	$as_i^{l_i}$	$bs_i^{l_i}$	$cs_i^{l_i}$	$ds_i^{l_i}$	$es_i^{l_i}$	$\sigma s_i^{l_i}$
Jan-Feb	2.292	.364	-.654	0.000	0.000	2.755
Mar-Apr	2.681	.403	0.000	0.000	0.000	3.048
May-Jun	2.030	.451	0.000	0.000	0.000	2.515
Jul-Aug	2.254	.348	0.000	0.000	0.000	2.672
Sept-Oct	2.311	.457	0.000	0.000	0.000	2.755
Nov-Dec	4.015	0.000	0.000	0.000	0.000	3.137

$f(X_i^{l_i})$

	$ax_i^{l_i}$	$bx_i^{l_i}$	$cx_i^{l_i}$	$dx_i^{l_i}$	$ex_i^{l_i}$	$\sigma x_i^{l_i}$
Jan-Feb	15.461	.277	.284	-.214	.166	.900
Mar-Apr	12.974	.338	.289	0.000	.220	.931
May-Jun	18.840	.352	.317	-.261	0.000	1.193
Jul-Aug	24.017	.170	.302	0.000	0.000	1.181
Sept-Oct	26.562	.234	.266	-.240	-.187	1.001
Nov-Dec	18.300	.328	.270	0.000	0.000	.993

$f(Y_i^{l_i})$

	$ay_i^{l_i}$	$by_i^{l_i}$	$cy_i^{l_i}$	$dy_i^{l_i}$	$ey_i^{l_i}$	$\sigma y_i^{l_i}$
Jan-Feb	12.649	.266	0.000	0.000	.147	.795
Mar-Apr	14.299	.252	0.000	-.336	.119	.829
May-Jun	15.945	.313	.071	-.218	0.000	.782
Jul-Aug	17.582	.235	.045	-.181	0.000	.731
Sept-Oct	12.644	.453	.054	-.145	0.000	.770
Nov-Dec	14.071	.394	.054	-.154	0.000	.826

$f(S_i^{2i})$

	as_i^{2i}	bs_i^{2i}	cs_i^{2i}	ds_i^{2i}	es_i^{2i}	σs_i^{2i}
Jan-Feb	1.761	.475	0.000	0.000	0.000	2.982
Mar-Apr	1.755	.666	0.000	0.000	0.000	2.453
May-Jun	3.345	.369	0.000	0.000	0.000	2.409
Jul-Aug	15.238	.440	0.000	0.000	-.537	2.562
Sept-Oct	2.777	.450	0.000	0.000	0.000	2.608
Nov-Dec	13.651	.453	0.000	0.000	-.460	2.432

$f(X_i^{2i})$

	ax_i^{2i}	bx_i^{2i}	cx_i^{2i}	dx_i^{2i}	ex_i^{2i}	σx_i^{2i}
Jan-Feb	16.760	.379	.199	0.000	0.000	.762
Mar-Apr	6.587	.746	.151	0.000	0.000	.696
May-Jun	15.523	.476	.211	0.000	0.000	1.042
Jul-Aug	21.202	.299	.158	0.000	0.000	1.056
Sept-Oct	12.616	.550	.244	0.000	0.000	.879
Nov-Dec	11.235	.593	.157	0.000	0.000	.748

$f(Y_i^{2i})$

	ay_i^{2i}	by_i^{2i}	cy_i^{2i}	dy_i^{2i}	ey_i^{2i}	σy_i^{2i}
Jan-Feb	12.701	.242	0.000	-.407	1.709	.773
Mar-Apr	10.858	.337	0.000	0.000	.161	.856
May-Jun	12.959	.432	.100	-.326	0.000	.791
Jul-Aug	23.378	0.000	0.000	0.000	0.000	.833
Sept-Oct	12.623	.437	.085	0.000	0.000	.769
Nov-Dec	15.658	.332	0.000	0.000	0.000	.733

$f(S_i^{3_i})$

	$as_i^{3_i}$	$bs_i^{3_i}$	$cs_i^{3_i}$	$ds_i^{3_i}$	$es_i^{3_i}$	$\sigma s_i^{3_i}$
Jan-Feb	5.310	0.000	0.000	0.000	0.000	3.251
Mar-Apr	5.062	.341	0.000	0.000	0.000	2.249
May-Jun	3.237	.560	0.000	0.000	0.000	2.207
Jul-Aug	3.240	.445	0.000	0.000	0.000	2.657
Sept-Oct	5.428	0.000	0.000	0.000	0.000	2.873
Nov-Dec	3.376	.449	0.000	0.000	0.000	2.323

$f(X_i^{3_i})$

	$ax_i^{3_i}$	$bx_i^{3_i}$	$cx_i^{3_i}$	$dx_i^{3_i}$	$ex_i^{3_i}$	$\sigma x_i^{3_i}$
Jan-Feb	17.301	0.000	.228	0.000	.434	.800
Mar-Apr	16.435	.419	.197	0.000	0.000	.913
May-Jun	22.328	.262	.202	0.000	0.000	1.011
Jul-Aug	30.048	0.000	.220	0.000	0.000	.953
Sept-Oct	22.892	.232	.154	0.000	0.000	.794
Nov-Dec	22.511	.203	.200	0.000	0.000	.945

$f(Y_i^{3_i})$

	$ay_i^{3_i}$	$by_i^{3_i}$	$cy_i^{3_i}$	$dy_i^{3_i}$	$ey_i^{3_i}$	$\sigma y_i^{3_i}$
Jan-Feb	10.061	.571	0.000	0.000	0.000	.992
Mar-Apr	9.107	.623	0.000	0.000	0.000	.721
May-Jun	5.833	.389	0.000	0.000	.281	.806
Jul-Aug	13.559	.434	0.000	0.000	0.000	.898
Sept-Oct	14.483	.385	0.000	0.000	0.000	.985
Nov-Dec	12.830	.459	0.000	0.000	0.000	.816

$f(S_i^{4_i})$

	$as_i^{4_i}$	$bs_i^{4_i}$	$cs_i^{4_i}$	$ds_i^{4_i}$	$es_i^{4_i}$	$\sigma s_i^{4_i}$
Jan-Feb	5.792	0.000	0.000	0.000	0.000	3.130
Mar-Apr	3.905	.479	0.000	0.000	0.000	2.210
May-Jun	17.471	.512	0.000	0.000	-.584	1.921
Jul-Aug	5.813	0.000	0.000	0.000	0.000	2.409
Sept-Oct	24.284	.392	0.000	0.000	-.869	2.486
Nov-Dec	6.604	0.000	0.000	0.000	0.000	2.027

$f(X_i^{4_i})$

	$ax_i^{4_i}$	$bx_i^{4_i}$	$cx_i^{4_i}$	$dx_i^{4_i}$	$ex_i^{4_i}$	$\sigma x_i^{4_i}$
Jan-Feb	11.617	.577	.102	0.000	0.000	.586
Mar-Apr	7.877	.711	.139	0.000	0.000	.782
May-Jun	8.918	.729	0.000	0.000	0.000	.948
Jul-Aug	18.013	.398	.201	0.000	0.000	.672
Sept-Oct	14.035	.515	.178	0.000	0.000	.738
Nov-Dec	8.983	.663	.176	0.000	0.000	.796

$f(Y_i^{4_i})$

	$ay_i^{4_i}$	$by_i^{4_i}$	$cy_i^{4_i}$	$dy_i^{4_i}$	$ey_i^{4_i}$	$\sigma y_i^{4_i}$
Jan-Feb	4.716	.510	0.000	0.000	.236	.755
Mar-Apr	7.540	.356	0.000	0.000	.255	.949
May-Jun	10.999	.544	0.000	0.000	0.000	.900
Jul-Aug	12.415	.484	0.000	0.000	0.000	.814
Sept-Oct	15.293	.355	0.000	0.000	0.000	1.045
Nov-Dec	11.885	.503	0.000	0.000	0.000	.937

$f(S_i^{5_i})$

	$as_i^{5_i}$	$bs_i^{5_i}$	$cs_i^{5_i}$	$ds_i^{5_i}$	$es_i^{5_i}$	$\sigma s_i^{5_i}$
Jan-Feb	4.010	.377	0.000	0.000	0.000	2.483
Mar-Apr	4.387	.377	0.000	0.000	0.000	2.581
May-Jun	3.926	.386	0.000	0.000	0.000	2.323
Jul-Aug	5.667	0.000	0.000	0.000	0.000	2.809
Sept-Oct	6.084	0.000	0.000	0.000	0.000	2.877
Nov-Dec	5.447	0.000	0.000	0.000	0.000	3.070

$f(X_i^{5_i})$

	$ax_i^{5_i}$	$bx_i^{5_i}$	$cx_i^{5_i}$	$dx_i^{5_i}$	$ex_i^{5_i}$	$\sigma x_i^{5_i}$
Jan-Feb	28.258	0.000	.139	0.000	0.000	.762
Mar-Apr	13.951	.513	.143	0.000	0.000	.758
May-Jun	17.749	.406	.174	0.000	0.000	1.002
Jul-Aug	19.847	.332	.216	0.000	0.000	.895
Sept-Oct	30.611	0.000	0.000	1.245	0.000	.934
Nov-Dec	29.015	0.000	.161	0.000	0.000	1.205

$f(Y_i^{5_i})$

	$ay_i^{5_i}$	$by_i^{5_i}$	$cy_i^{5_i}$	$dy_i^{5_i}$	$ey_i^{5_i}$	$\sigma y_i^{5_i}$
Jan-Feb	5.016	.782	0.000	0.000	0.000	.789
Mar-Apr	14.812	.378	0.000	0.000	0.000	.686
May-Jun	13.161	.446	0.000	0.000	0.000	.775
Jul-Aug	23.400	0.000	0.000	0.000	0.000	.890
Sept-Oct	23.013	0.000	0.000	0.000	0.000	.924
Nov-Dec	7.498	.674	0.000	0.000	0.000	.905

$f(S_i^{6i})$

	as_i^{6i}	bs_i^{6i}	cs_i^{6i}	ds_i^{6i}	es_i^{6i}	σs_i^{6i}
Jan-Feb	4.946	.346	0.000	0.000	0.000	1.888
Mar-Apr	3.132	.633	0.000	0.000	0.000	1.811
May-Jun	3.606	.506	0.000	0.000	0.000	1.793
Jul-Aug	6.749	0.000	0.000	0.000	0.000	2.533
Sept-Oct	6.139	0.000	0.000	0.000	0.000	2.231
Nov-Dec	7.045	0.000	0.000	0.000	0.000	2.323

$f(X_i^{6i})$

	ax_i^{6i}	bx_i^{6i}	cx_i^{6i}	dx_i^{6i}	ex_i^{6i}	σx_i^{6i}
Jan-Feb	7.387	.751	0.000	0.000	0.000	.738
Mar-Apr	8.861	.720	0.000	0.000	0.000	.773
May-Jun	10.510	.681	0.000	0.000	0.000	1.015
Jul-Aug	30.583	0.000	.274	0.000	0.000	.940
Sept-Oct	13.915	.565	0.000	0.000	0.000	.806
Nov-Dec	8.593	.712	0.000	0.000	0.000	.675

$f(Y_i^{6i})$

	ay_i^{6i}	by_i^{6i}	cy_i^{6i}	dy_i^{6i}	ey_i^{6i}	σy_i^{6i}
Jan-Feb	11.485	.493	0.000	0.000	0.000	.776
Mar-Apr	23.917	0.000	0.000	0.000	0.000	.941
May-Jun	10.882	.546	0.000	0.000	0.000	.665
Jul-Aug	23.248	0.000	0.000	0.000	0.000	.820
Sept-Oct	22.983	0.000	0.000	0.000	0.000	.903
Nov-Dec	23.264	0.000	0.000	0.000	0.000	.952

$$f(S_i^{7_i})$$

	$as_i^{7_i}$	$bs_i^{7_i}$	$cs_i^{7_i}$	$ds_i^{7_i}$	$es_i^{7_i}$	$\sigma s_i^{7_i}$
Jan-Feb	6.554	0.000	0.000	0.000	0.000	2.894
Mar-Apr	6.087	.336	0.000	0.000	0.000	2.105
May-Jun	4.381	.443	0.000	0.000	0.000	2.438
Jul-Aug	4.849	.263	0.000	0.000	0.000	2.533
Sept-Oct	5.194	.270	0.000	0.000	0.000	2.630
Nov-Dec	4.001	.431	0.000	0.000	0.000	2.453

$$f(X_i^{7_i})$$

	$ax_i^{7_i}$	$bx_i^{7_i}$	$cx_i^{7_i}$	$dx_i^{7_i}$	$ex_i^{7_i}$	$\sigma x_i^{7_i}$
Jan-Feb	16.912	.396	.124	0.000	0.000	.741
Mar-Apr	10.567	.474	.122	0.000	.204	.757
May-Jun	17.509	.435	.116	0.000	0.000	.944
Jul-Aug	30.416	0.000	.197	0.000	0.000	.911
Sept-Oct	30.656	0.000	.115	0.000	0.000	.853
Nov-Dec	14.328	.528	0.000	0.000	0.000	.982

$$f(Y_i^{7_i})$$

	$ay_i^{7_i}$	$by_i^{7_i}$	$cy_i^{7_i}$	$dy_i^{7_i}$	$ey_i^{7_i}$	$\sigma y_i^{7_i}$
Jan-Feb	10.940	.517	0.000	0.000	0.000	.967
Mar-Apr	12.178	.481	0.000	0.000	0.000	.962
May-Jun	13.685	.415	.080	0.000	0.000	.857
Jul-Aug	12.867	.464	0.000	0.000	0.000	1.030
Sept-Oct	15.876	.321	0.000	0.000	0.000	.925
Nov-Dec	9.894	.575	0.000	0.000	0.000	1.166

$f(S_i^{8_i})$

	$as_i^{8_i}$	$bs_i^{8_i}$	$cs_i^{8_i}$	$ds_i^{8_i}$	$es_i^{8_i}$	$\sigma s_i^{8_i}$
Jan-Feb	4.719	.408	0.000	0.000	0.000	2.195
Mar-Apr	5.164	.432	0.000	0.000	0.000	1.753
May-Jun	4.910	.412	0.000	0.000	0.000	2.002
Jul-Aug	4.831	.315	0.000	0.000	0.000	2.699
Sept-Oct	5.537	.240	0.000	0.000	0.000	2.441
Nov-Dec	4.798	.368	0.000	0.000	0.000	2.333

$f(X_i^{8_i})$

	$ax_i^{8_i}$	$bx_i^{8_i}$	$cx_i^{8_i}$	$dx_i^{8_i}$	$ex_i^{8_i}$	$\sigma x_i^{8_i}$
Jan-Feb	8.865	.675	.107	0.000	0.000	.638
Mar-Apr	4.691	.856	0.000	0.000	0.000	.702
May-Jun	13.408	.574	.106	0.000	0.000	.909
Jul-Aug	20.286	.330	.211	0.000	0.000	.823
Sept-Oct	11.760	.607	.158	0.000	0.000	.768
Nov-Dec	7.981	.739	0.000	0.000	0.000	.923

$f(Y_i^{8_i})$

	$ay_i^{8_i}$	$by_i^{8_i}$	$cy_i^{8_i}$	$dy_i^{8_i}$	$ey_i^{8_i}$	$\sigma y_i^{8_i}$
Jan-Feb	19.604	.414	0.000	0.000	-.211	1.111
Mar-Apr	10.602	.549	0.000	0.000	0.000	.965
May-Jun	12.040	.504	0.000	0.000	0.000	.885
Jul-Aug	13.878	.423	0.000	0.000	0.000	.928
Sept-Oct	11.776	.496	0.000	0.000	0.000	.929
Nov-Dec	8.227	.644	0.000	0.000	0.000	1.205

APPENDIX D

YIELD MODEL VERIFICATION DATA

	Rendement		Tonnage		Sugar Production	
	Actual	Simu-lated	Actual	Simu-lated	Actual	Simu-lated
Victorias Lowland						
Jan.	1.67	1.72	92.29	101.91	153.95	175.30
Feb.	1.76	1.74	92.43	95.15	162.98	165.56
Mar.	1.70	1.81	85.07	85.48	144.62	154.72
Apr.	1.71	1.87	86.66	79.77	149.74	149.17
May	1.62	1.83	76.86	72.29	125.17	145.88
June	1.58	1.77	82.62	65.72	129.67	116.32
Jul.	1.37	1.26	84.47	66.23	115.59	83.45
Aug.	1.20	1.25	74.65	68.20	89.87	85.25
Sept	1.47	1.26	79.86	72.22	117.51	90.90
Oct.	1.34	1.35	80.94	75.70	108	102.19
Nov.	1.40	1.36	82.90	79.26	116.06	107.79
Dec.	1.50	1.35	85.00	85.73	128.09	115.23
Victorias Upland						
Jan.	1.55	1.62	78.75	81.45	122.28	131.94
Feb.	1.64	1.62	83.23	80.44	136.70	130.31
Mar.	1.58	1.67	77.54	79.71	123.15	133.11
Apr.	1.60	1.72	76.73	78.61	123.17	135.21
May	1.58	1.71	74.80	78.94	118.76	134.98
June	1.44	1.67	77.27	78.94	111.92	131.82
Jul.	1.32	1.30	83.60	87.14	110.18	113.28
Aug.	1.36	1.23	82.26	84.25	111.45	103.62
Sept	1.44	1.30	79.64	77.72	113.98	101.03
Oct.	1.39	1.29	77.04	81.73	107.47	105.43
Nov.	1.36	1.25	85.21	86.13	116.71	107.66
Dec.	1.41	1.22	84.00	87.13	118.92	106.29
Manapla						
Jan.	1.45	1.43	73.87	81.17	107.02	116.07
Feb.	1.51	1.49	76.52	74.06	117.46	110.35
Mar.	1.47	1.48	74.55	70.85	108.52	104.14
Apr.	1.55	1.55	73.76	69.56	113.89	107.82
May	1.52	1.64	66.05	67.30	101.57	110.37
June	1.38	1.63	72.67	64.00	108.19	104.32
Jul.	1.33	1.50	75.48	71.90	100.24	107.85
Aug.	1.31	1.33	71.29	72.01	93.72	95.77
Sept	1.36	1.27	68.36	65.93	93.05	83.73
Oct.	1.29	1.39	69.03	66.32	89.36	92.18
Nov.	1.23	1.45	80.27	66.68	99.43	96.87
Dec.	1.32	1.40	78.00	68.71	103.27	96.19

APPENDIX E

STANDARD DEVIATION OF SIMULATED YIELDS

MONTHLY STANDARD DEVIATIONS

Victorias Lowland

	Tonnage		Rendement		Sugar Production	
	1*	2*	1	2	1	2
Jan	10.43	11.86	.11	.12	16.49	19.77
Feb	10.68	13.25	.11	.14	17.64	21.49
Mar	11.43	13.81	.11	.13	20.37	22.85
Apr	12.60	13.20	.11	.14	22.48	22.65
May	11.28	13.16	.12	.15	20.50	21.39
Jun	11.87	18.22	.12	.17	19.87	28.17
Jul	11.17	9.42	.15	.15	14.62	12.99
Aug	10.65	7.88	.12	.13	13.16	9.04
Sept	10.43	12.66	.12	.14	12.87	16.39
Oct	11.05	11.27	.12	.14	13.77	13.04
Nov	10.24	11.58	.12	.15	13.81	15.36
Dec	10.44	11.74	.12	.13	14.20	15.17

Victorias Upland

	Tonnage		Rendement		Sugar Production	
	1	2	1	2	1	2
Jan	6.07	4.76	.09	.10	8.30	7.19
Feb	6.31	6.65	.09	.10	8.88	9.49
Mar	6.02	5.31	.09	.12	8.98	7.61
Apr	6.08	8.38	.09	.12	9.46	13.68
May	7.03	7.40	.10	.11	9.92	9.79
Jun	6.35	8.03	.10	.13	8.92	11.81
Jul	7.24	6.90	.12	.14	9.96	7.99
Aug	7.30	7.19	.11	.11	9.26	10.46
Sept	7.57	8.51	.11	.13	9.33	10.24
Oct	7.09	8.60	.11	.12	8.91	10.67
Nov	7.67	7.86	.11	.12	9.47	9.38
Dec	7.38	9.58	.11	.13	9.62	11.91

* 1 = value with simulated weather
* 2 = value with weather records

Manapla

	Tonnage		Rendement		Sugar Production	
	1*	2*	1	2	1	2
Jan	6.35	6.90	.10	.12	8.19	8.75
Feb	6.50	9.31	.10	.12	8.45	11.97
Mar	6.03	6.54	.10	.15	8.77	11.25
Apr	6.07	6.08	.10	.12	8.81	9.57
May	6.38	7.69	.10	.12	8.94	11.69
Jun	6.39	8.33	.09	.14	9.11	9.29
Jul	7.91	9.98	.11	.15	9.02	10.53
Aug	8.67	4.05	.10	.16	9.73	16.87
Sept	7.48	2.65	.10	.11	8.30	13.41
Oct	7.99	9.86	.09	.11	9.17	11.98
Nov	8.00	6.68	.10	.10	9.18	8.06
Dec	7.82	7.44	.10	.13	9.45	9.52

* 1 = value with simulated weather
* 2 = value with weather records