PROGRAM FOR SIMULATING YIELDS OF CRUSHING AND HARVESTING OPERATIONS

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Abstract

A computerised model for analysing and predicting the cane crop for a given mill area is described. The starting point of the model is the age distribution of the present areas under cane. The seasonal operations are simulated month-by-month by harvesting these areas in step with the intended crushing rate. Past and expected future rainfalls are used in an empirical equation to calculate the applicable tons cane/hectare harvested yields, and re-growth of the harvested fields is likewise simulated. The season ends according to one of these limits; tons cane crushed, hectares harvested or season-end date.

Two versions were developed: One for long term projections for the industry and one for more detailed short term runs on individual mills. These models have been used to: predict the effect of drought and plan for its consequences; analyse long term industry trends and project them into the future; and show the longer term effects of abnormalities during a season.

This paper deals mainly with the long term industry version.

Introduction

A need was identified for a computerised model to simulate the basic sugar industry cycle of: planting or ratooning the field; growth of the crop; harvesting the crop; crushing; planting or ratooning the field. The starting point for such a model is the state of the industry or milling area at a given time, with regard to the age distribution of standing cane crops and the respective areas in hectares which they cover. From there, the model simulates over one or more seasons the effect of controllable variables or policies on the system, such as starting date of season and crushing rate, as well as the effect of uncontrollable variables, particularly rainfall. An important characteristic is that it shows the effect of present crushing policy on future cane availability.

Although the principle of such a model is fairly straightforward, there does not appear to be much published literature on this subject. Early[1] describes a model for irrigated areas in the Phillipines. In the S.A. industry, Landrey, Schorn and Truen describe their program which goes into the detail of individual fields,[4] and a private grower also developed a similar model (unpublished). Other models for cane sugar industry operations have also been described, such as Sorensen and Gilheany's stochastic simulation,[8] as well as models for optimising the crushing program during a season, such as the linear programming method of Morales[6] or the dynamic programming method of Hoekstra.[2]

The model developed here was called the Program for Simulating Yields of Crushing and Harvesting Operations, with the acronym PSYCHO.

Two versions were developed. One is suitable for an individual mill, and prints out results on a month-by-month basis. The other is for analysing long term trends of the industry and summarises the results per season.

PSYCHO has been used for the following purposes:

- On an individual mill basis, as an aid for planning under conditions of a severe drought.
- On an industry basis, to analyse long term trends of past sugar production, and to predict production in the near and medium term.
- To show the long term effect on the industry of any abnormalities, such as severe drought or drastic over-cutting during a season.

Because the previously published work deals mainly with an individual mill and its supplying growers, the details and discussion of this paper will centre on the use of PSYCHO for industry analysis, although the underlying principles are much the same for an individual mill.

Description of Simulation by PSYCHO

At the start of the first season to be simulated, an estimate is made of the distribution of hectares under cane per ratoon or plant month. Such statistics can usually not be obtained directly, but can be inferred from the crushing operations, given the following: % area harvested, monthly cane tonnages crushed and starting and ending dates of the past two seasons; hectares under cane (HuC) at the start of the current season; the average number of ratoons before plough-out (estimated to be 3); and the average fallow period (assumed to be 4 months). An example of the calculation is given in Appendix 1.

The distribution per month of hectares under cane is shown in Figure 1a.

The cumulative environmental effects to which each of these areas under cane has been subjected can be calculated from past records. An empirical relationship between this and the tons cane per hectare harvested (TCHH) is used in PSYCHO, and will be further discussed later in 'Parameter for yield vs. rainfall relationship.' The potential yields, in tons standing cane per hectare for each of the areas are shown in Figure 1b. Multiplication gives the total tons cane available at that time on each of the areas, and is shown in Figure 1c.

The mill starts crushing. When simulating an individual mill, an hourly crushing rate and availability must be specified for each month. In the case of industry simulation, the mills are assumed to crush at a constant tons cane per month rate during a season, determined from:

$$\text{Crushing rate} = \frac{\text{Total industry tonnage cane produced during the season}}{\text{Weighted mean season length}}$$

PSYCHO draws strictly from the oldest cane first, and at a rate of:

$$\text{Hectares harvested (HH)/month} = \frac{\text{Crush rate, in tons/month}}{\text{Tons cane yield per HH}}$$

The denominator is calculated as in Figure 1b.

$$\text{Of the HH, a fraction} = \frac{\text{Average number of ratoons}}{1 + \text{Average number of ratoons}},$$

representing the average proportion of fields which will be ratooned, immediately becomes available as the youngest HuC. The remainder is to lie fallow for an average period of 4 months, after which it starts as new HuC.

When the oldest cane has been exhausted, harvesting operations will move into the next oldest area under cane.

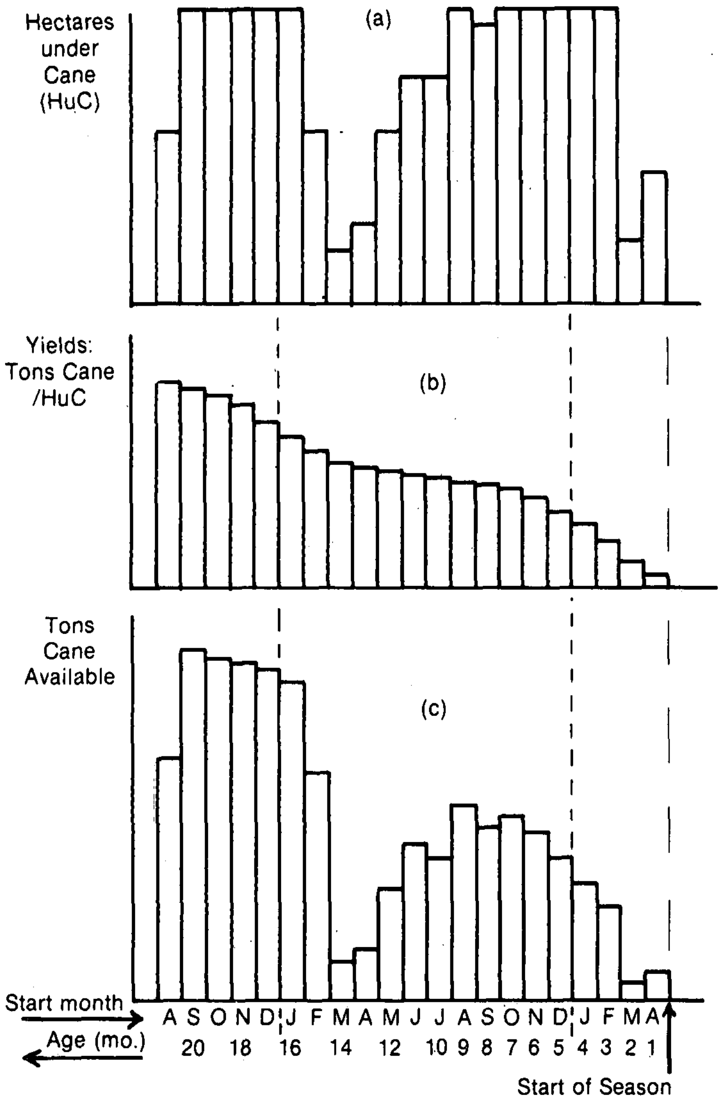

FIGURE 1 Position at start of season

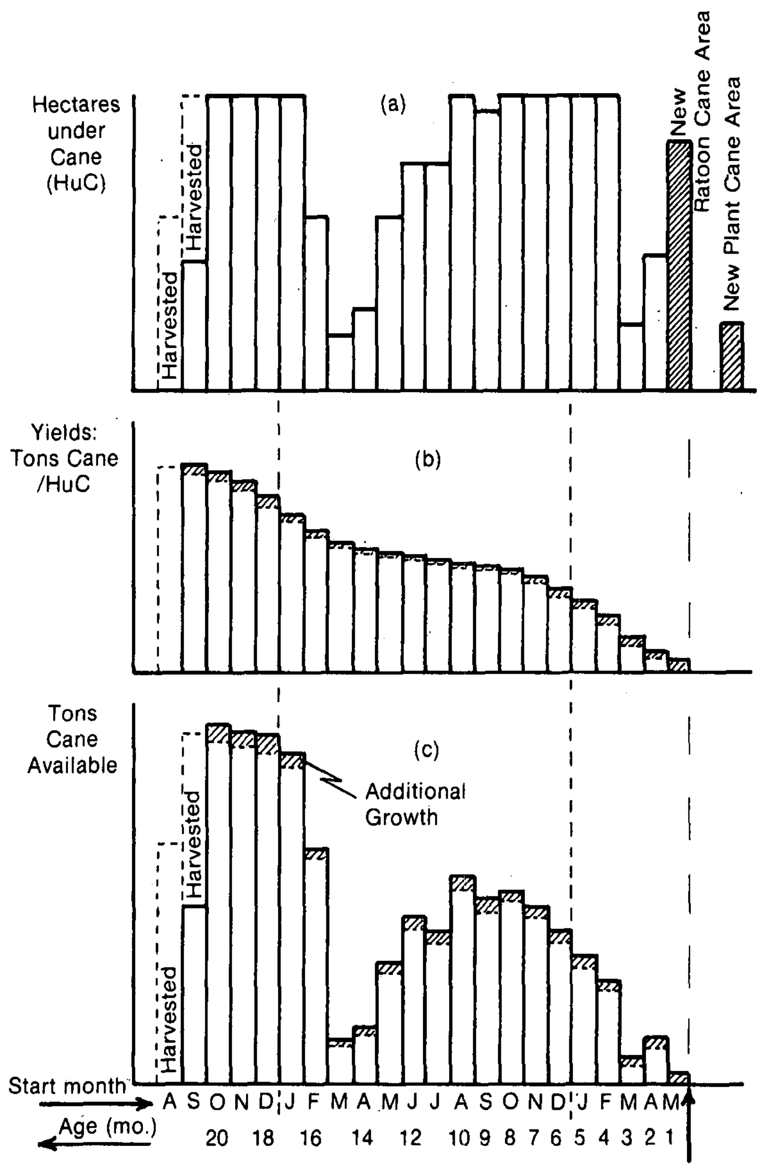

FIGURE 2 Position after 1 month of crushing

At the end of the first crushing month of the season, the cumulative environments of all the existing HuC are updated, and so are the potential yields of the respective HuC. The situation is illustrated in Figures 2a, b and c, showing the now updated HuC, tons cane per HH yields and tonnages of cane.

The simulation continues month by month until one of 3 limits has been reached:

- The end date of the season: This could be determined by considerations such as that the sucrose % cane contents are becoming too low, particularly after January, or that growers are not willing to harvest after Christmas, or that the mill has exceeded its allowable crushing weeks per season.
- HH to date: This would be a consideration when there is a danger of overcutting, to the detriment of yields in the following season.
- Tons cane produced to-date: This would be a consideration when there are quota restrictions on the industry.

For application to an individual mill, additional limits are also available:

- Cane age has dropped below a specified minimum.
- Cane yield has dropped below a specified minimum.

One does not have to specify all the above limits, because PSYCHO will test only against the given limits.

The simulation can extend over several years into the future. When crushing commences for the next season, the distribution of HuC per ratoon or plant month will already be available from the simulated operations of the previous season.

When used for long term industry simulation, PSYCHO makes provision for adding new areas brought under cane during the course of the season, thus updating the age distribution of total HuC.

Overview on Fitting PSYCHO to S.A. Sugar Industry Performance

For long term predictions (say up to the year 2000) of S.A. sugar industry production, the method thus far had been to fit a trend line by multiple linear regression analysis to historical yields, expressed as tons sugar or alternatively tons sucrose per hectare under cane per year, and project it into the future. Total area under cane was considered to be the 'productive unit', and the extent of its hectares its 'size'.

The HuC applicable to the season April of year n to March of year (n+1) was the recorded (corrected, where necessary) HuC as on 1 May of year (n−1), the argument being that any new areas under cane would require about 1½ years before being harvested.

For the effect of differing rainfalls, the total rainfall over the period June of year (n−1) to May of year n, was taken as a linear and a quadratic term and applied to the season April of year n to March of year (n+1).

Originally, a straight line was fitted to the yields, but in view of recent statistical evidence that the rate of yield increase is dropping, a curve was used. These projected yields were then multiplied by the estimated future HuC to give the predicted industry tonnages.

This method does not take into account the current situation, which obviously must have an effect on short and medium term projections, nor does it compensate for the effect of artificially created abnormalities such as quota restrictions. For these reasons, the industry version of PSYCHO was developed to simulate the performance of the S.A. sugar industry over a period of as long as 21 years, which includes past years (to see how well it fits), as well as up to 5 years into the future (to predict what will happen then).

Historical records of tonnages and areas

Because payments for cane are based on accurately weighed cane tonnages and sucrose contents obtained by laboratory analyses, and payments for sugar are likewise made on exact quantities produced, all historical tonnage data can be taken as being correct.

The HuC and the HH had to be obtained from various sources, which were not always reliable. Members of the S.A. Sugar Association had to make corrections to past data to the best of their knowledge. The weakest link in the statistical analysis of past performances therefore is the inaccuracy of the recorded area data.

Environmental Variables which can Affect Yields

Environmental variables which can affect yields include:

- Rainfall (total amount as well as its pattern of occurrence)
- Ratoon stage
- Age of cane
- Month of season starting crop
- Month of season of harvest
- Cane variety
- Fertiliser application
- Radiation
- New cane growing regions

Ideally, one should have a rigorous input/output model of material and energy balances to simulate the yields of sugar growing areas, such as the model developed by Tovey and Bull,[9] which would require accurate statistics on all of the above as well as probably on additional variables. On an industry-wide basis this is quite impossible, not only because of the volume involved and the problem of averaging, but also the lack of data. Furthermore, with the principal dependent variable, yield/HH, being subject to a comparatively large error due to questionable accuracy of area statistics, it was felt that the model might as well be kept simple by cutting down on the number of environmental variables.

Some of these variables, such as ratoon stage, cane variety, fertiliser application and new cane growing regions will not vary much from one season to the next. Where there is a gradual trend in such variables over the years, this could partly account for any observed yield improvement.

For cane tonnage yield, age as a variable was abandoned, because of its close correlation with cumulative rainfall received. Month-of-season of starting the crop will have a large spread, because of the wide range of cane ages at the time of harvest found in the sugar industry.

In the end, the only environmental variables used in the model were cumulative monthly rainfall to determine cane tonnage yields/HH, and age and month of harvest to determine sucrose % cane. These will be discussed in subsequent sections.

Fitting of Model to Historical Results

The parameters which have to be determined for the model relate to:

- The standard tons cane per HH yield, and its rate of increase over the years
- The relationship between tons cane per HH yield and rainfall received
- The harvest age effect on sucrose % cane
- The effect of month-of-season on sucrose % cane

The parameters for sucrose % cane, were determined directly by multiple linear regression analysis on historical data. This is discussed later in the Paper.

The determination of the parameters for tons cane per HH yield, is more complicated, and for this purpose PSYCHO has to be fitted to historical results. The technique is to vary the values of these parameters by trial and error, aiming to achieve the best fit of predicted to actual cane tonnages harvested.

Criteria for best fit

The criteria for best fit of predicted vs. actual tons cane harvested (or crushed) for the season were defined to be:

(i) The algebraic sum of the deviations between predicted and actual cane tonnages should be 0 (or very close to it), meaning that the positive and negative deviations should, in total, cancel each other out. This however is not a sufficient criterion, because there could still be a large positive or negative deviation in an individual year. Therefore we have an additional criterion.

(ii) The sum of the squares of the deviations between predicted and actual cane tonnages must be a minimum. There is no question of cancelling out, because any deviation becomes positive when squared.

At the end of a run, the mean sums of the errors and of the squared errors are printed out.

To obtain a reliable set of parameter values, the simulation was performed over a large number of historical seasons, namely 21 from 1962/63 to 1982/83 inclusive.

The parameters relating to tons cane per HH

Parameters for standard cane yield: For these purposes, standard cane yield is defined as the tons cane yield per HH when it has received a total of 1 600 mm of rain.

As mentioned earlier, multiple linear regression analyses over all the records available, from 1950/51 have shown strong evidence that, although the yield is increasing, the rate of yield increase is declining. For our purposes the standard yield was assumed to increase linearly, i.e. in a straight-line form, for the following reasons:

- The period of the PSYCHO simulation only goes back to the 1962/63 season, thereby cutting out earlier seasons, the considerably lower yields of which had contributed to the observed curvature.
- As PSYCHO is only used for predicting within the next 5 years, any possible error in assuming a straight line should be negligible.
- A curve would require an additional parameter.

The best fit was for a standard yield of 76,7 tons cane/HH applying to 1962/63, with a rate of increase of 0,15 tons cane/HH from that season onwards.

Parameter for yield vs. rainfall relationship: One can illustrate the relationship between tons cane per HH and cumulative rainfall (in mm) in graphical form, as shown in Figure 3.

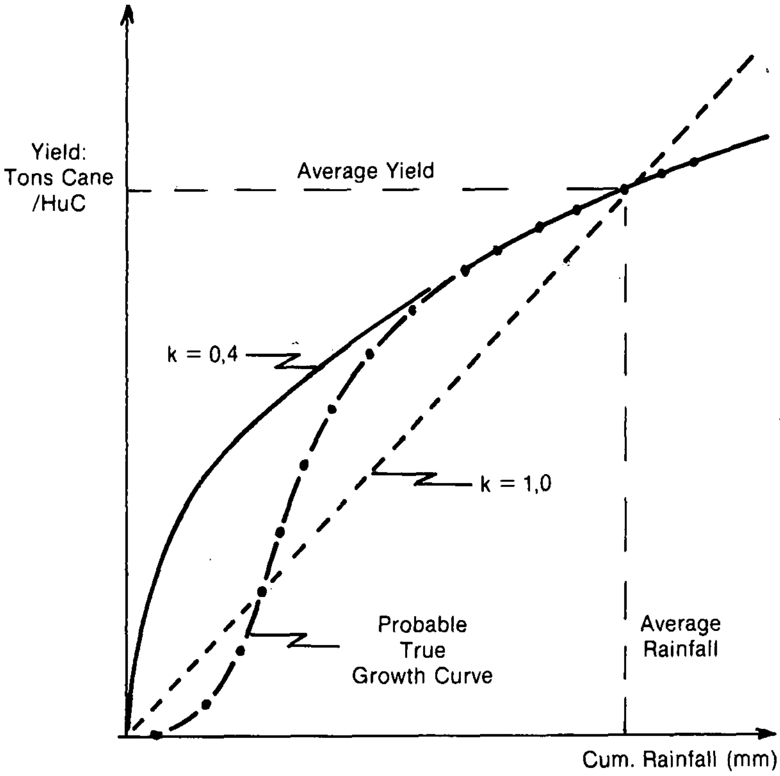

FIGURE 3 Yield - rainfall relationships

The point (Average tons cane per HH, Average cumulative rainfall) is easy to calculate. The problem is to determine the rest of the relationship. The popular rule of thumb has always been 'x tons cane per HH per 100 mm of rainfall received', implying a straight-line relationship through the origin, as given by the dotted line in Figure 3. This obviously is not realistic, because it implies that yields would continue increasing at the same rate, no matter how long the field is left standing. For an individual field, a truer representation is probably in the form of an S-curve, such as discussed by Tovey and Bull[9] and by McMartin.[5] This is shown by the chain line.

Such a curve will however have at least 3 parameters, which will be difficult if not impossible to determine from the data which have a large scatter and do not have any points close to the origin. Besides, an individual field is not being dealt with, but a large number of fields of different growth rates and rain utilisation efficiences, as well as some irrigated areas, the combined effect of which would no longer be a true growth curve.

It was therefore arbitrarily decided to express yields by the following equation:

$$\text{Yield (tons cane/HH)} = \text{Std. yield} \times \left(\frac{\text{Cum. rainfall}}{\text{Std. Cum. rainfall}}\right)^k$$

where Std. cum. rainfall = 1 600 mm, by definition,

and k = a value between 0 and 1.

If k = 1, we have the straight-line relationship.

This equation has 2 parameters, namely k and Std. yield, and meets the commonsense requirement that Yield = 0 when Cum. rainfall = 0. The way it approaches the origin might not be realistic, but such low cumulative rainfalls or yields are unlikely to occur for the industry as a whole.

By trial and error the best fit was for k = 0,4, as shown in Figure 3.

This value might seem low, but fitting a similar relationship to yield results from a north coast estate, ranging over a period of almost 30 years, gave an even lower k = 0,34.

To summarise, the predicted relationship for tons cane/HH yield in any season is:

$$\text{TCHH} = (76{,}7 + 0{,}15\,(t - 62))(\text{Cum. rainfall}/1600)^{0.4}$$

where t = 82 for 1982/83, etc.
and TCHH = Tons cane/HH.

Annexure 1 shows the Output Summary to Run IND18. For brevity, the Input Summary, which includes the monthly rainfalls and monthly additional areas under cane, was omitted.

The actual and the predicted values for tons cane produced/season are shown in Figure 4.

Determination of Parameters for Sucrose % Cane

In the historical data, pol % cane instead of sucrose % cane was recorded for the seasons 1973/74 to 1980/81. For consistency, pol % cane values were converted to sucrose % cane by multiplying by a factor 1.01.

As mentioned earlier, these parameters relate to:

Effect of age:

Separate statistical analyses of this corrected data showed that sucrose % cane declined over the years, and that it also declined with reduced age of cane at harvest. An attempt to analyse both effects on sucrose % cane simultaneously was unsuccessful, because age at harvest showed a declining trend over the years. No significant rainfall effect could be observed.

For the purposes of PSYCHO it was assumed that the declining sucrose content was caused by the declining trend of age at harvest.

Effect of month-of-season

This can be represented by a trigonometric function, as described by Hoekstra.[3]

A multiple regression analysis was performed on the year-by-year Industry average monthly sucrose % cane values to determine simultaneously the age and the month-of-season effects on sucrose % cane. The resultant relationship is:

$$\text{S \% C} = 14{,}30 - \frac{33{,}5}{\text{AGE} + 1} + 0{,}99 \cos(30(\text{MONTH} - 8{,}9))$$

where AGE is in months,

and MONTH is on basis: April = 4, May = 5, etc. and the argument of the cosine function is in degrees.

For 20-month old cane, this gives a rate of increase in sucrose content with age as 0,076%/month. Regression analysis of data from individual fields of Darnall Estates, which took into account the age as well as the time-of-season effect, gave a corresponding value of 0,075%/month, so that the above relationship appears reasonably realistic.

Prediction Runs

The predicted runs were allowed to pass through the historical data of the seasons 1973/74 to 1982/83 so that any error in estimating the initial HuC distribution by age would have worked itself out by the time the predictive part (1983/84 and beyond) was reached. The same parameters as obtained in fitting to 21 years of historical data, were used. The following remarks on some of the inputs for the future predictions apply:

Season start date: An analysis of actual 1983/84 season dates showed a weighted mean starting data of 5,7 i.e. about 21st May 1983. For subsequent years the start date was assumed to be 4,3 each year, i.e. about 10 April each year.

Rainfalls: Not being able to predict future rainfalls, the long term average monthly rainfalls for industry had to be used in the predictions.

Crush rates: The crushing rate of cane for 1984/85 onwards was taken to be the approximate average for the past 10 years, and for 1983/84 about 5% below that.

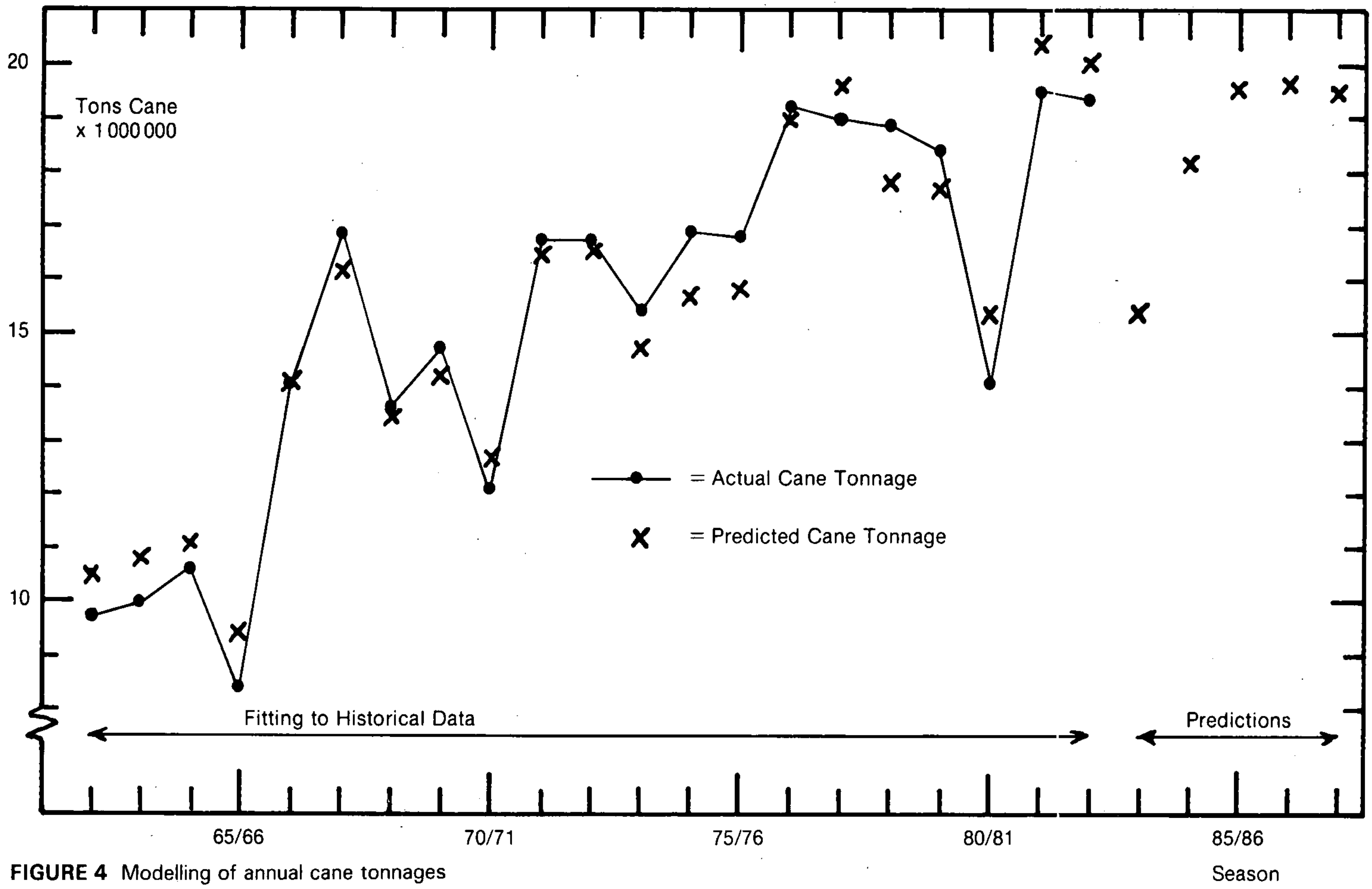

FIGURE 4 Modelling of annual cane tonnages

% Area under cane harvested: The limit used for determining the end of the season was total hectares harvested. General opinion was that the % area harvested for 1983/84 would be about 57%.

Overall Recovery: The overall recovery values were, for these purposes, based on tel quel sugar and not sucrose in sugar. For all future years, an overall recovery value of 86% was assumed.

Annexure 2 shows the Output Summary of Run IND21, which was made with historical crop data being available up to the end of the 1982/83 season, and rainfall data up to June 1983. The predicted values for the seasons 1983/84 to 1987/88 are plotted on the right-hand side of Figure 4.

Long Term Effect of Disturbances in the Usual Pattern of Operations

One of the applications of PSYCHO is to show the long term effect on the sugar industry of any drastic changes that could take place, such as a severe drought. It would, for example, be difficult to isolate from historical records the true effect of a drought in subsequent seasons because of the many other variations which will occur in the conditions of operation.

The method was to choose, as a base case, 15 successive seasons of operation under identical conditions of rainfall, starting date, crushing rate, hectares under cane and hectares harvested. Five seasons were allowed for the model to achieve steady-state operation. In the 6th season (the 'disturbance season') a drastic change would be made, and its effect would then be shown in the rest of the seasons. To avoid confusion, the standard cane yield was held constant at 80,0 tons cane per HH without any improvement per year.

In the examples which follow, the controllable variable to be held constant over the seasons subsequent to the disturbance season was chosen to be the % area harvested, although the effect of other policies, such as holding the tons cane harvested constant in all subsequent seasons, could also be tested by using the alternative criteria in PSYCHO for season end limits, as discussed earlier.

Three cases of disturbances were investigated:

In each case, the % area harvested and the tons sugar produced as % of the steady-state annual production are plotted with reference to time in Figure 5.

Case 1: Increase in cane production for one season only.

This represents the situation where for example the industry takes advantage of a high world sugar price by cutting more cane than usual, or overcuts in anticipation of quotas. No increase in monthly crushing rate is assumed, so that the increased cane production is achieved by crushing later into the season. The % area harvested was increased from the steady 59,9% to 65,9% for the one season, after which it reverted back to 59,9% for all subsequent seasons.

The converse of this, where severe quota restrictions are applied, would result in a more or less inverted response to that shown in Figure 5.

Case 2: Increase in cane production for all subsequent years.

This could happen when, for one reason or another, the industry suddenly were to decide on a younger age at harvest. The % area harvested was increased from 59,9% to 65,9%, and kept there for all subsequent seasons.

Note that, although Case 2 indicates a 'permanent' increase in sugar production, it does not necessarily imply that it is better for the sugar industry to increase the % area harvested, because certain cost increases will work contrary to the increase in sugar revenue, particularly total annual costs of establishing new crops. Examples are increased costs of weeding, harvesting and transporting per ton of sucrose, and lower factory capacity utilisation due to the higher fibre and non-sucrose relative to the sugar recovered.

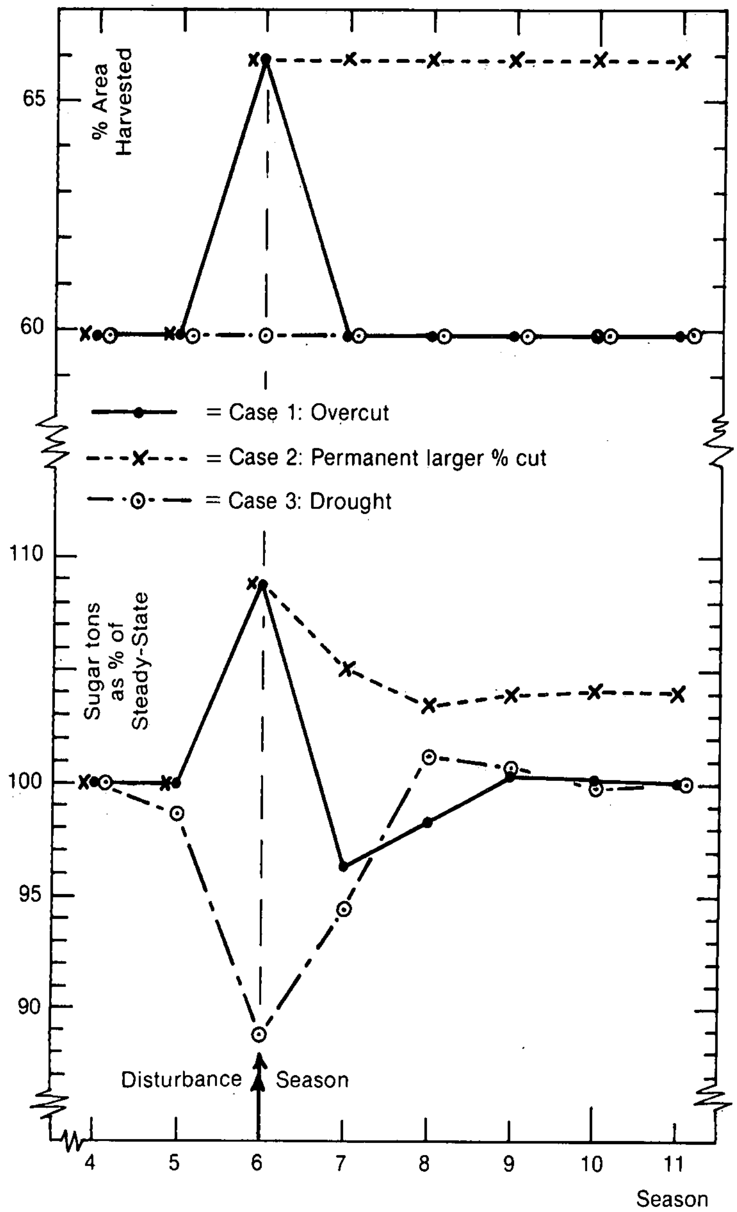

FIGURE 5 Response of industry performance to disturbances

Case 3 Rainfall for the season June-May preceding the disturbed season is 40% below average.

The % area harvested is held at 59,9% for all seasons. Note that the drought already starts affecting the season prior to the disturbed season.

In all of the above it is clear that the system needs several seasons to reach equilibrium after a disturbance, and that sugar tonnage shows a damped cyclic response.

Computer Aspects

PSYCHO was written in the language PL/1, and run on a Data General Eclipse S/140 computer with 0,5 Mb of memory and a 25 Mb disc. Running time is about 1 minute. Interactive as well as batch operation is possible.

Avenues for Future Development

Improved relationships between environment and yields

At present the model has only simple relationships to express yields. One or more of the other variables mentioned earlier might be introduced to improve the accuracy of the model.

More reliable data on areas

A weak spot of PSYCHO, particularly the industry version, is unreliable statistics on areas. It is hoped that in the future this aspect will be improved.

Financial values

It would obviously be useful to observe the effects of climate, crushing policy, etc. not only on cane and sugar tonnages, but also on income and expenditure. Reliable information on fixed and variable costs of growing and milling would be required. The effect of the division of proceeds should also be taken into account, but preferably after the ramifications of the Rörich proposals and the proposed multiple pool sugar payments system have been resolved and accepted.

Expected % area harvested in subsequent seasons

When PSYCHO is used to predict production, particularly for the current or immediately following season, much depends on the estimated % area harvested which has to be input into the program. Some form of feed-back is proposed, whereby the respective Mill Group Boards are informed of the effect that these estimated % areas harvested will have on their cane and sugar production, and in the light of that, they might then revise their estimates.

Alternatively, they could request that different estimates of % area harvested be tried out on PSYCHO. For these purposes it would be preferable to have a separate PSYCHO-type model for each individual mill.

Effect of Overall Recovery

For prediction purposes, the overall recovery was simply held at a constant value. A refinement would be to let some of the principal seasonal and age effects on cane be taken into account in a formula which expresses overall recovery, such as described by Smith.[7]

APPENDIX 1

Method of Determining Initial Age Distribution of Areas under Cane

Except for a 100% miller-cum- planter enterprise which keeps adequate records, it will be virtually impossible to obtain the true age distribution of areas under cane as at the start of a season. An approximation could be made for a mill with a reasonably large proportion of own cane, by assuming that the entire cane supplying area has the same relative age distribution as its own estates.

For other cases, a method had to be developed for estimating these areas. The method makes only 2 main assumptions:

- that harvesting is strictly on the basis of oldest cane first
- that the cutting rate, in terms of hectares harvested (HH) per month of crushing season, is constant throughout a given season.

The method will be described by way of an example, in which the age distribution of the cane for the industry as at the start of the 1962/63 season has to be estimated.

The necessary information which is available appears in Table 1:

TABLE 1

S.A. Sugar Industry Data Used

Season	Started (calender month*)	Ended (calendar month*)	Length (months)	HuC @ 1 May (in 1 000's)	HH (in 1 000's)
1959/60	5,0	2,0	9,0	249	114
1960/61	6,0	1,2	7,2	256	103
1961/62	5,6	1,2	7,6	258	96
1962/63	5,5			246	

* 5,0 = 1 May, 1,2 = 6 Jan, etc.

The worksheet is Table 2, and the calculation procedure will be discussed column by column. Note that the areas are treated in multiples of 1 000 hectares because the accuracy, for these purposes, is adequate.

TABLE 2

Work Sheet in Calculating Age Distribution of Areas under Cane

Year	Mo.	AREAS IN 1 000's HECTARES							
		Ha Cut during Season (1)	Ha Cut per Month (2)	Of the Ha. Cut: Ratoon 75% in Same mo. (3) = 0,75 × (2)	Of the Ha. Cut: Replant 25% 4 mo. later (4) = 0,25 × (2)	Added (+) Reduced(−) Areas (5)	Total Ha Started (6) = (3) + (4) + (5)	Ha Started, Cumulated Backwards (7) = ∑ (6)	Ha under Cane @ 1/5/62 (8)
	M		12	9			9		
	J		13	10			10		
	J		13	9		+1	10		
1959	A		13	10		+1	11		
	S	114	12	9	3		12		
	O		13	10	3	+1	14	258	2
	N		13	9	4	+1	14	244	14
	D		13	10	3		13	230	13
	J		12	9	3	+1	13	217	13
	F		(114)		3	+1	4	204	4
	M				4	+1	5	200	5
	A				3		3	195	3
	M				3		3	192	3
1960	J		14	11			11	189	11
	J		15	11			11	178	11
	A		14	11		+1	12	167	12
	S	103	14	11			11	155	11
	O		15	11	3		14	144	14
	N		14	11	4		15	130	15
	D		14	11	3	+1	15	115	15
	J		3	2	3		4	100	5
	F		(103)		4		4	95	4
	M				3		3	91	3
	A				3		3	88	3
	M		5	4	1		5	85	5
1961	J		12	9			9	80	9
	J		13	10			10	71	10
	A		13	9		−2	7	61	7
	S	96	13	10	1	−1	10	54	10
	O		12	9	3	−1	11	44	11
	N		13	10	3	−1	12	33	12
	D		12	9	4	−2	11	21	11
	J		3	3	3	−1	5	10	5
	F		(96)		3	−1	2	5	2
1962	M				3	−2	1	3	1
	A				3	−1	2	2	2
	M				0	−1	0	0	
									246

Column (1) : Total hectares harvested (HH) for each of the seasons 1959/60 1960/61 and 1962/63, from given data.

Column (2) : HH per month for each month of season, assuming a constant cutting rate for the season. Part months at the beginning and end of the season are taken into account.

Column (3) : According to informed opinion, the average industry performance is to plough-out after 3 ratoons, which means that 75% of the HH in column (2) immediately becomes available as hectares started for a ratoon crop.

Column (4) : The 25% balance of the area cut is to be replanted after an industry average fallow period of 4 months, and these figures are therefore displaced downwards by 4 months.

Column (5) : From the known hectares under cane (HuC) at 1 May of each season, the HuC added or removed during the intervening season can be calculated by difference. Such additions or removals are assumed to be made at an even rate during the season.

Column (6) : Total HuC started in any month will be: Hectares ratooned, per column (3) + hectares replanted, per column (4) + (−) hectares added (removed), per column (5).

Column (7) : By working backwards from May 1962, the total hectares started are cumulated, until the 246 000 HuC applicable to the start of the 1962/63 season have been reached.

Column (8) : The age distribution of areas under cane at the start of the 1962/63 season is obtained from column (6), using the age limit obtained from column (7).

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HULETT SUGAR LTD. - OPERATIONS RESEARCH DEPT.

Program for Simulating Yields of Crushing and Harvesting Operations (P.S.Y.C.H.O.) (Long_term) DATE: 04AUG83

MILL: INDUSTRY RUN NO. : IND18

OBJECT OF RUN : FIT STD_TCH TREND TO 1962/63-82/83 DATA. RAIN_POWER = 0.4,REVISED CRUSH RATES

SEASON - BY - SEASON OUTPUT SUMMARY.

YIELDS (TONS CANE/HA.HARVESTED) = STD_TCH *(RAIN/1600)**0.40

RATE OF INCREASE OF STD_TCH = 0.15 TCH/YR

				AGRICULTURAL							FACTORY						
SEASON	START MONTH	END MO.	DURA-TION (MO)	STD TCH/ HA_HV	HA_U_C @START (1 MAY)	HA_HARV	%HARV	AV. AGE (MO)	AV. TCH/ HA_HV	AV. RAIN (MM)	TONS SUGAR (000)	O/ALL RECOV %	TONS SUCR (000)	SUC% CANE	TONS CANE IN 1000 s PRED.	ACTUAL	DIFF.
62/63	5.50	14.48	8.98	76.7	246000	115000	46.7	29.2	90.8	2451	1160	83.6	1387	13.28	10446	9751	695
63/64	5.20	14.09	8.89	76.8	250000	121000	48.4	27.7	88.8	2322	1244	85.5	1455	13.55	10741	9940	800
64/65	5.20	13.98	8.78	77.0	291000	133000	45.7	23.2	83.2	1954	1314	85.4	1538	13.90	11066	10661	405
65/66	5.80	12.86	7.06	77.1	327000	119000	36.4	23.5	79.1	1707	1024	83.7	1223	12.99	9418	8406	1011
66/67	5.30	14.56	9.26	77.3	339000	174000	51.3	25.8	81.0	1803	1634	84.5	1933	13.72	14091	14103	-12
67/68	5.00	15.14	10.14	77.4	337000	200000	59.3	23.8	80.8	1801	1742	83.4	2089	12.92	16166	16912	-746
68/69	5.40	13.50	8.10	77.6	330000	182000	55.1	19.9	73.9	1446	1477	83.7	1764	13.11	13456	13720	-264
69/70	5.90	14.22	8.32	77.7	330000	185000	56.1	20.4	76.7	1553	1561	85.4	1828	12.88	14191	14788	-596
70/71	5.40	12.64	7.24	77.9	330000	165000	50.0	20.7	76.8	1558	1468	85.1	1725	13.61	12672	12144	527
71/72	5.30	14.60	9.30	78.0	345000	198000	57.4	21.2	83.0	1868	1840	86.3	2132	12.97	16435	16751	-316
72/73	5.20	14.25	9.05	78.2	342000	195000	57.0	21.0	85.1	2008	1889	85.9	2200	13.26	16588	16804	-217
73/74	5.20	13.62	8.42	78.3	348000	195000	56.0	19.7	76.8	1537	1678	84.8	1978	13.21	14976	15454	-478
74/75	5.00	13.65	8.65	78.5	361000	200000	55.4	19.8	78.6	1620	1752	84.4	2076	13.21	15717	16894	-1178
75/76	5.00	13.75	8.75	78.6	365000	200000	54.8	20.6	79.2	1649	1696	84.1	2017	12.73	15845	16814	-968
76/77	4.90	14.28	9.38	78.8	366000	215000	58.7	20.6	88.4	2143	2021	84.7	2386	12.55	19010	19220	-210
77/78	4.80	13.57	8.77	78.9	379000	230000	60.7	19.2	85.1	2005	2147	84.6	2538	12.96	19580	19008	570
78/79	4.90	13.09	8.19	79.1	381000	223000	58.5	18.5	79.8	1668	1960	86.2	2274	12.77	17805	18926	-1121
79/80	4.70	13.08	8.38	79.2	394000	231000	58.6	18.9	76.4	1492	1993	86.3	2309	13.09	17639	18412	-772
80/81	4.90	11.63	6.73	79.4	396000	222000	56.1	19.1	69.3	1164	1763	85.1	2072	13.47	15382	14062	1319
81/82	5.30	14.09	8.79	79.5	400000	263000	65.8	19.8	77.4	1495	2142	85.6	2503	12.30	20346	19532	814
82/83	5.10	13.72	8.62	79.7	409000	269000	65.8	18.3	74.6	1414	2207	85.5	2581	12.86	20073	19338	734

ERROR OF FIT TO HISTORICAL DATA :

MEAN SUM OF ERRORS = -0

MEAN SUM OF SQUARED ERRORS = 776

ANNEXURE 1: Determination of cane yield parameters by fitting PSYCHO to historical data.

HULETT SUGAR LTD. - OPERATIONS RESEARCH DEPT.

Program for Simulating Yields of Crushing and Harvesting Operations (P.S.Y.C.H.O.) (Long_term) DATE: 04AUG83

MILL: INDUSTRY RUN NO. : IND21

OBJECT OF RUN : PREDICTION 1983/84 - 87/88, 60% HARVESTED; PARAMS. PER IND18.

SEASON - BY - SEASON OUTPUT SUMMARY.

YIELDS (TONS CANE/HA.HARVESTED) = STD_TCH *(RAIN/1600)**0.40

RATE OF INCREASE OF STD_TCH = 0.15 TCH/YR

				AGRICULTURAL							FACTORY						
SEASON	START MONTH	END MO.	DURA-TION (MO)	STD TCH/ HA_HV	HA_U_C @START (1 MAY)	HA_HARV	%HARV	AV. AGE (MO)	AV. TCH/ HA_HV	AV. RAIN (MM)	TONS SUGAR (000)	O/ALL RECOV %	TONS SUCR (000)	SUC% CANE	TONS CANE IN 1000 s PRED.	ACTUAL	DIFF.
73/74	5.20	13.63	8.43	78.3	348000	195000	56.0	19.8	76.9	1545	1680	84.8	1981	13.21	14998	15454	-455
74/75	5.00	13.68	8.68	78.4	361000	200000	55.4	20.0	78.8	1634	1757	84.4	2082	13.21	15761	16894	-1133
75/76	5.00	13.74	8.74	78.6	365000	200000	54.8	20.6	79.2	1648	1695	84.1	2015	12.73	15832	16814	-982
76/77	4.90	14.28	9.38	78.7	366000	215000	58.7	20.6	88.3	2142	2019	84.7	2384	12.55	18993	19220	-227
77/78	4.80	13.57	8.77	78.9	379000	230000	60.7	19.2	85.1	2005	2145	84.6	2536	12.96	19568	19008	558
78/79	4.90	13.09	8.19	79.0	381000	223000	58.5	18.5	79.8	1668	1959	86.2	2272	12.77	17794	18926	-1131
79/80	4.70	13.07	8.37	79.2	394000	231000	58.6	18.9	76.3	1492	1991	86.3	2308	13.09	17628	18412	-784
80/81	4.90	11.63	6.73	79.3	396000	222000	56.1	19.1	69.2	1164	1762	85.1	2071	13.47	15372	14062	1310
81/82	5.30	14.08	8.78	79.5	400000	263000	65.8	19.8	77.3	1495	2141	85.6	2501	12.30	20333	19532	800
82/83	5.10	13.72	8.62	79.6	409000	269000	65.8	18.3	74.6	1414	2206	85.5	2580	12.86	20061	19338	721
83/84	5.70	12.87	7.17	79.8	413000	235000	56.9	17.8	65.5	995	1694	86.0	1970	12.80	15388		
84/85	4.30	12.38	8.08	79.9	414000	248000	59.9	18.1	73.1	1284	2006	86.0	2333	12.87	18124		
85/86	4.30	12.97	8.67	80.1	414000	248000	59.9	19.0	78.4	1537	2161	86.0	2512	12.92	19440		
86/87	4.30	13.08	8.78	80.2	414000	248000	59.9	19.5	79.3	1580	2192	86.0	2548	12.95	19677		
87/88	4.30	13.03	8.73	80.4	414000	248000	59.9	19.1	78.9	1552	2177	86.0	2532	12.93	19578		

ANNEXURE 2: Using PSYCHO to predict future crop sizes.