THE ECONOMIC OPTIMIZATION OF HARVESTING AND PLOUGHING SUGAR CANE FIELDS

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ABSTRACT - Management of large areas of sugar cane plantations require decisions on which areas should be ploughed out, which sugar cane variety should be planted in the ploughed areas, and which field should be harvested first. To answer these questions in an optimal way a linear programming (LP) model has been developed and a software written to generate the LP matrix. Model results for an hypothetical case are in good agreement with generally accepted management practice.

Key words: Large areas management, Sugar cane management.

Introduction

Managing large areas of sugar cane plantation is a complex task. Decisions must be continually made regarding which area (field) to plough out, which area to harvest first, the timing of the harvesting ie. whether to harvest in the beginning, middle or last part of the harvest season, and which variety of sugar cane is to be planted in the ploughed fields.

To determine the timing of the harvesting, one must take into consideration the relative richness of the total sugar contents (POL) at harvesting time, when the previous harvesting occurred (a minimum of 11 months and a maximum of 16 months must have elapsed before a field can be re-harvested) and the daily sugar mill and/or alcohol distillery requirement.

The life cycle of a sugar cane variety is dependent on insect attack and the growth of new races of fungus, virus and other disease causing organisms. Consequently, research institutions must continually develop new varieties of sugar cane that can be substituted for older, less productive, ones. As such new varieties become available, it must then be decided where to plough them out, taking into special consideration the soil fertility of the fields and the POL richness curve of the variety. During the harvest season a typical sugar cane variety has a quadratic POL richness curve as a function of time. It is possible to classify each sugar cane variety according to the categories "early", "middle" and "late". The classification is dependent on the timing of the maximum of the POL richness and the tendency of the variety to flourish.

Sugar cane can be ploughed out in two periods. The so called "one year cane" is ploughed from September to November and can be harvested in the last part of the next harvesting season. The "eighteen months cane" is ploughed from December to April and is not harvested during the next harvest season. However, it can be harvested anytime during the following harvest season ant its yield is much greater than the one year cane.

Sugar cane mills and/or alcohol distilleries in Brazil manage areas from a minimum of 6000 hectares (ha) to a maximum of 50,000 - 100,000 ha of sugar cane fields. To plan the ploughing and harvesting of such large areas, the areas are divided into hundreds or thousands of homogeneous areas. Each homogeneous area is assumed to have the same type of soil fertility, sugar cane variety and management regime.

Generally sugar mills and/or alcohol distilleries produce most of their own required quota of sugar cane. The purchasing of sugar cane from independent producers is a marginal activity due to economies of size (Margarido e Peres, 1992) even though legal requirements force farmers, that rent their land to the mills, to declare that they are independent producers.

Managers of large sugar cane areas face, therefore, several challenges that they have been answering on a trial and error basis: (a) which homogeneous areas should be ploughed out; (b) which variety should be cultivated in the ploughed area; (c) when the ploughing should take place - to produce one year or eighteen months cane; (d) when each homogeneous area should be harvested - either the beginning, middle or last part of the harvest season, and (e) which is the ideal variety profile for that specific agroindustry.

The aim of this study is to report the building of a decision model that allows managers to answer questions (a) to (e) of last paragraph in an optimal way. Furthermore, these answers must accord to the sugar mill and/or alcohol distillery daily needs of sugar cane - which are constrained by both a minimum and maximum daily consumption - and to operational and financial availabilities of the business.

The paper is further divided into three parts. The first presents the linear programming (LP) model. The second describes the hypothetical case used to test the software written to generate the LP matrix and to evaluate the solution given by the model. Finally, some conclusions and suggestions for further developments are presented.

The Model

Questions (a) to (e) of the first section can be answered in an optimal way using linear programming (LP) modeling. Such models have been used by several authors to solve similar problems in forest management (Clutter et alii, 1983; Lima, 1988 and Rodriguez e Moreira, 1989) and in sugar cane specific cases management (Crane, 1979 and Brugnaro et alii, 1988. The shortcoming of the approach is that LP matrices can become very large.

To illustrate the size problem of LP matrices one hypothetical case can be considered. If a firm cultivates only seven varieties of sugar cane, has three kinds of soil fertility (high, average, and low fertility soils), has fields with only six harvesting regimes (ploughed out fields, one year cane, eighteen months cane, first, second, and third harvested ratoon cane), has three distances from fields to the plant and considers three periods for the harvesting season (beginning, middle, and late harvesting), the LP matrix will have a minimum of 315 homogeneous areas if each one of all combinations are present only once. When one adds the possible alternatives of conducting policy for each homogeneous area, this number rapidly increases to tens of thousands activities (columns) in the matrix. Fortunately, several combinations can be disregarded, based on agronomic considerations, and the problem can be solved in a mainframe computer or workstation.

Large LP models may require long periods of computing time in order to be solved. One way to increase the computing efficiency is to decrease the number of matrix rows at the expense of increasing the number of columns. Such a consideration has been included here in the writing of the software used to generate the LP matrix. The number of restrictions has been kept to a minimum. Furthermore, in generating the activities (columns) several simplifications have been adopted.

The first simplifying assumption used to reduce the number of columns in the LP matrix has been to limit the number of harvesting season sub-period divisions. Only three harvesting sub-periods have been considered. The beginning period corresponds to May and June; the middle period corresponds to July and August and the final to September, October and November. Furthermore, the constraint that a minimum of 11 months and a maximum of 16 months must have elapsed before ratoon canes can be re-harvested, has also been employed.

Another simplifying assumption concerns the management regime for each kind of soil. In low fertility soils, sugar cane will be harvested for a minimum of 3 times to a maximum of 4 times, before being ploughed out. In medium fertility soils, a minimum of 3 and a maximum of 5 harvests will be allowed. In high fertility soils the number of harvests may vary from 3 to 6. Harvesting either less than 3 times of more than 6 times before ploughing out the field may occur but it is not considered to be normal practice.

The third simplifying assumption used to reduce the number of columns in the LP matrix concerns the number of sugar cane varieties that are considered in the hypothetical case. Only seven varieties have been allowed to be cultivated (NA56-79, SP70-1143, SP71-1406, SP71-799, SP71-6163, SP70-1284, and SP71-1081). Up to 1992, they account for 84% of the sugar cane cultivated area of the State of São Paulo. Except for NA56-79 they show a tendency to increased use in the last years. Low fertility soils can only be planted with SP70-1143, NA56-79, and SP71-1081. Medium fertility soils can be planted with SP71-1406 and SP71-6163, as well as the three former varieties. For high fertility soils all seven varieties can be used in the ploughing out process.

Increasing the number of management policies that can be conducted in each homogeneous area results in an overwhelming increase in the size of the LP matrix. Data entry for each homogeneous area includes the size of the field (in ha), the distance to the industry plant (in km), the kind of soil fertility, the cultivated variety and the present management regime - one year cane, eighteen months cane, first to sixth ratoon cane, and what was previous year sub-period harvest season. The policy generator sub-routine then creates all allowed combinations of policy management for that homogeneous area for the following years.

Table 1 shows part (a small part) of the generated policies for a given homogeneous area with medium fertility soil in its second harvest season. In the column Management Policies the entries indicate the planned alternative regimes for the area. The following two columns show the year of the first and second ploughing out of the area. The last column illustrates the objective function coefficient (in US Dollars) for that specific policy. The first entry line, for instance, indicates that this homogeneous area (block 88) can e harvested twice - in 1992 and 1993 harvesting seasons - in the last sub-period of the harvesting season (Cf Cf), then ploughed out in the second year with cultivating variety A using eighteen months cane (An). Subsequently it may be harvested at the beginning of the harvesting season for the next three years (Ai Ai Ai) and then be harvested in the middle of the harvesting season in the following year (Am). A new ploughing out will occur in the 7th year (third column). All management policies end with a <u>VET</u> indication. This indication relates to the permanent use of the homogeneous area and will be explained in more detail when the

Table 1 - Output of the Policy Generator Program

Block: 88 Soil Fertility: middle
Management regime: second harvest ratoon cane

Management Policy	Year of 1st Ploughing	Year of 2nd Ploughing	Objective Function
CfCfAnAiAiAiAm+vet	2	7	5314,68
CfCfAnAiAiAmAf+vet	2	7	5382,23
CfCfAnAiAmAfAf+vet	2	7	5467,16
CfCfAnAiAmAmAf+vet	2	7	5453,68
CfCfAnAmAfAfAf+vet	2	7	5572,12
CfCfAnAmAmAfAf+vet	2	7	5555,84
CfCfAnAmAmAmAf+vet	2	7	5542,36
CfCfBnBiBiBiBm+vet	2	7	5249,39
CfCfBnBiBiBmBf+vet	2	7	5323,17
CfCfBnBiBmBfBf+vet	2	7	5423,71
CfCfBnBiBmBmBf+vet	2	7	5398,69
CfCfBnBmBfBfBf+vet	2	7	5554,43
CfCfBnBmBmBfBf+vet	2	7	5520,39
CfCfBnBmBmBmBf+vet	2	7	5495,36
CfCfCfAnAiAiAmAf+vet	3	8	5505,41
CfCfCfAnAiAmAfAf+vet	3	8	5581,24
CfCfCfAnAmAfAfAf+vet	3	8	5674,95
CfCfCfAnAmAmAfAf+vet	3	8	5660,41
CfCfCfBnBiBiBmBf+vet	3	8	5452,68
CfCfCfBnBiBmBfBf+vet	3	8	5542,44
CfCfCfBnBmBfBfBf+vet	3	8	5659,16
CfCfCfBnBmBmBfBf+vet	3	8	5628,76
CfCfCfCfAnAiAmAfAf+vet	4	9	5682,62
CfCfCfCfAnAmAfAfAf+vet	4	9	5766,29
CfCfCfCfBnBiBmBfBf+vet	4	9	5647,98
CfCfCfCfBnBmBfBfBf+vet	4	9	5752,18
CfCfCfCfCnCiCmCfCfCf+vet	4	10	5774,04
CfCfCfCfCnCmCfCfCfCf+vet	4	10	5881,19
CfCfCfCfDnDiDmDfDfDf+vet	4	10	5926,70
CfCfCfCfDnDmDfDfDfDf+vet	4	10	6022,10
CfCfCfCfEnEiEmEfEfEf+vet	4	10	6180,12
CfCfCfCfEnEmEfEfEfEf+vet	4	10	6295,52
CfCfCfCnCiCiCmCfCf+vet	3	9	5593,36
CfCfCfCnCiCmCfCfCf+vet	3	9	5683,63
CfCfCfCnCmCfCfCfCf+vet	3	9	5803,65
CfCfCfCnCmCmCfCfCf+vet	3	9	5771,08
CfCfCfDnDiDiDmDfDf+vet	3	9	5779,13

Cn, Ci, Cm, and Cf means, respectively, do not harvest (n), harvest at the beginning (i), middle (m), or later (f) sub-period of the harvesting season with variety C;
C, A, B, D, and E stand for different varieties.
Source: Barata, 1992

objective function is discussed.

The number of restrictions have been kept to a minimum with only five groups of restrictions being considered. The first group of restrictions are equality constraints to assure that each homogeneous area will be entirely managed during the six years of the planned horizon. Even though Table 1 shows that more than six years are considered in determining policy alternatives for each field, restrictions are imposed only for the first six years. One restriction has been created for each homogeneous area.

The second group of restrictions constrain the amount of sugar cane produced. There are 18 minimum amount restrictions of sugar cane and 18 maximum amount restrictions, one for each sub-period (3) of the harvest season of each year (6).

The third and fourth groups of restrictions limit the total area to be ploughed out per year and the number of hectares that can be ploughed out for one year cane, respectively. One year cane is ploughed from September to November which coincides with the last part of the harvesting season. The industry capacity to plough during this period is, therefore, limited. There are six restrictions for each of these two groups of restrictions.

The last group of restrictions (7) limit the amount of area that can be ploughed out with a given variety. Sugar mills and/or alcohol distilleries have, in a given year, a limited amount of nursed cane to be used in ploughing out areas. Therefore, the availability of nursed cane of a given variety will be constrained only for the first year of the planned horizon. The model results will indicate nursed cane needs for the forthcoming years and management can prepare its required nursery.

The objective function to be maximized is the net present value of the profit margin of each management policy. The present value has been calculated using a discount rate of 12% per year. Since different policy managements require different time horizons, comparisons between them are impossible on net present value basis. It is necessary to look either for a horizon with the minimum factor product number of years or for an infinite repetition of the best available policy for each homogeneous area. The infinite horizon approach has been chosen (the **VET** term of Table 1).

Under the infinite horizon approach, the coefficient of the objective function for each policy management of a given homogeneous area is evaluated as the sum of two discounted values. The first is the net present value of the flow of returns from selling the final product (sugar or alcohol), the costs of factory production and agricultural production having been deducted. The second is the present value of the capitalized flow of net returns associated with the best management regime evaluated for the homogeneous area (VET). In evaluating the best management regime for an homogeneous area, all possible policies are enumerated and the one with best net present value is chosen.

In writing the software for the matrix generations the Summer 87 version of Clipper for microcomputers has been used. The software reads the relevant data and generates the LP matrix. It then writes the matrix in IBM MPSX format to be solved in a mainframe computer.

The Working of the Model

A hypothetical agroindustry with 15,750 ha of cultivated land has been used to test the model. It is assumed that the area is composed of soils with low, medium and high fertility. The homogeneous areas are located at three distances from the plant: 10, 20, and 30 km. Each homogeneous area has 50 ha.It is assumed that initial ploughing is made gradually throughout the years. Therefore, there is a smooth flow of sugar cane going to the sugar mill (or alcohol distillery). Furthermore, all seven varieties are evenly planted during the years and in all kinds of soils, subject only to fertility requirements.

Input data on yields for each variety in the three kinds of soil fertility, and on sugar richness (POL) during the different sub-periods of the harvesting season, come from the Copersucar Variety Census. The basic scenario generated a 81,774 columns by 370 rows matrix (315 homogeneous areas, 36 sugar cane requirements, 12 limits of the ploughing out capacity, and 7 nursed cane availabilities for the first year). Following the running of the model the questions posed in the first part have been answered. Although the planned horizon is of six year, one could raise doubts on the usefulness of the model for more than one of two years in a changing economy, such as the Brazilian economy.

This kind of multi-year discretely dynamic model can and should be viewed as an adaptive planning process with a long run horizon. It is applicable in the case where management makes decisions based on long run views but change or adjust their views every year. Therefor, the model should be re-run every year such that the management will always be executing the first year prescriptions of the plan.

In general, the results are in good agreement with generally accepted management practices. As an example, the results give a predominance of eighteen months cane over one year cane as a general tendency. Another interesting aspect of the model is the tendency to yield just one policy management regime for each homogeneous area. Only one homogeneous area among the 315 considered has been managed by the model with more than one single policy for the first planned year. Although the same variety was ploughed, it was suggested to plough 45 ha of one homogeneous area (No. 314) with one year cane and the other 5 ha with eighteen months cane. Since the splitting of an homogeneous area is not practical, all the area should be ploughed with one year cane.

Results of the model suggest some pattern for variety management. Beginning with NA56-79 one can see that it tends to be harvested at the beginning of the harvest season. Variety SP70-1143 starts to be harvested during the later part of the harvest season but gradually moves toward the middle part of the harvest season. It is a variety that has its area reduced in the model. Varieties SP70-1284 and SP71-1106 tend to be harvested either in the beginning or in the final sub-period of the harvest season. SP71-799 does not show a clear pattern of harvesting management. Varieties SP71-6163 and SP71-1081 show tendencies to increase in cultivated areas. SP71-6163 tends to occupy most of the cultivated area and is evenly harvested during the harvest season.

When the model is run without a minimum requirement of sugar cane per sub-period, the results show a clear tendency to concentrate harvesting in the last two sub-periods of the harvest season. Of course, agricultural considerations are not sufficient to justify reduction of the harvesting season.

Finally, it can be seen that the yields of sugar and alcohol per ha are always increasing from the start of the third planned year. This shows the increase in the agricultural and economic aspects of the agribusiness.

Conclusions

The writing of a software to generate LP matrices allows the use of normative models to help managers to optimize their decision making process on harvesting and ploughing out sugar cane fields. The matrix generator software uses data that are generally available in most large sugar mill and/or alcohol distilleries. The model has been used in several sugar mills and/or alcohol distilleries and demand for its results is increasing.

In order to run the LP model, mainframe computers or workstations have to be used due to the matrix size. It is desirable to have the problem solved by microcomputers. The next stage of software development will be to write the same problem in GAMS language and to use a potent solver to run the LP problem.

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