OPTIMIZED AGRICULTURAL PLANNING OF SUGARCANE USING LINEAR PROGRAMMING

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ABSTRACT
Optimized agricultural planning is a fundamental activity in business profitability because it can increase the returns from an operation with low additional costs. Nonetheless, the use of operations research adapted to sugarcane plantation management is still limited, resulting in decision-making at management level being primarily empirical. The goal of this work was to develop an optimized planning model for sugarcane farming using a linear programming tool. The program language used was General Algebraic Modelling System (GAMS) as this system was seen to be an excellent tool to allow profit maximization and harvesting time schedule optimization in the sugar mill studied. The results presented support this optimized planning model as being a very useful tool for sugarcane management.

KEY WORDS: OR in agriculture, Cutting, Decision support systems, Scheduling.

MSC: 90C90

RESUMEN
El planeamiento agrícola óptimo es una actividad fundamental en la sostenibilidad económica del negocio porque este puede incrementar los ingresos a partir de tener bajos costos adicionales de operación. Sin embargo el uso de la Investigación Operacional, adaptado al manejo de plantación de azúcar de caña está aun limitado, resultando en un manejo de nivel primario en la toma de decisiones empírico... El objetivo de este trabajo fue desarrollar un modelo de planeamiento optimal para las actividades agrícolas de la caña de azúcar usando como herramienta la Programación Lineal... El lenguaje de programación usado fue General Algebraic Modeling System (GAMS) pues este sistema es visto como una herramienta excelente que permite la obtención de la maximización de la ganancia y la optimización del plan de las fechas de cosecha en el ingenio azucarero estudiado. El resultado presentado soporta este modelo de planeamiento optimal es una útil herramienta para el manejo de la caña de azúcar.

1. INTRODUCTION

Brazil is among the world leaders in the production of sugarcane, sugar and alcohol fuel and the most efficient of all major producers. In order to keep the production's efficiency, optimized agricultural planning is a fundamental activity in business profitability, because it can increase returns of an operation with low additional costs (Beauclair and Penteado, 1984; Higgins et al., 2004; Scarpari et al., 2008). Despite this, the use of operations research adapted to sugarcane plantation management is poorly developed, resulting in decision-making at the management level being primarily empirical.

For optimization of harvest operation scheduling with reliable estimates of productivity, it is recommended the use of yield-predicting models such as PREDPOL (Scarpari, 2007) in Brazil or CANESIM (Singels and Donaldson, 2000) in South Africa. Also, such models based mainly on weather variables or physiologic parameters (Barbieri, 1993), can supply more reliable results in optimized agricultural planning. Raw material quality predicting models are important tools in sugarcane cropping planning (Jiao et al., 2005; Scarpari and Beauclair, 2004), for they are aimed at characterizing management alternatives, creating more realistic scenarios for decision analysis simulations and optimization in sugar mills, increasing the efficiency of management and strategic decision making during the cropping season. Within this context, the planning of sugarcane harvest aims to optimize crop economic return (Beauclair and Penteado, 1984; Salassi et al., 2002) based on the concept that sugarcane present, during the crop season, a period known as optimal peak maturity for harvesting, at which the maximum concentration of sucrose occurs in stalks. Grunow et al. (2007) structured this problem in a

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hierarchical fashion with cultivation of the haciendas, harvesting and dispatching of the harvesting crews and equipment.

The goal of this work was to develop a model for the scheduling optimization of the sugarcane harvest operation, analyzing the season months (May-December) using a linear programming tool. The language used was GAMS - General Algebraic Modelling System (Brooke et al., 1992).

2. MATERIAL AND METHODS

This study was undertaken in Piracicaba, State of São Paulo, Brazil during 2003/04. The site's coordinates area are 22°42' Latitude S and 47°38' Longitude W. Average temperature is 21.5°C, while the average annual precipitation is 1276 mm, and the average altitude is 546 m.

The analysis of whole industry options for alternative cane supplies required a methodology that is able to provide a common basis for comparing options, assess potential gains in profitability for one option versus another and simultaneously account for complex structure costs and constraints on the system within any given option. To address these requirements, operations research techniques for optimization was used (Higgins and Muchow, 2003) and to apply this methodology, the classification of the sugarcane farms in homogeneous areas is required (Prado et al., 2002).

The functional objective of program is to define harvesting times to maximize the enterprise profit for 30 homogeneous areas being considered:

$$MAX \sum_{i}^{I}\sum_{j}^{J}\sum_{k}^{K}\sum_{l}^{L} C_{ijkl}\left(Pacu_{j}.ATR_{ij}.Q_{ij}.ARS_{i} + Palc_{j}.PTalc_{ij}.Q_{ij}.ARS_{i}\right) - \left(CI.Q_{ij}.ARS_{i} + CT_{ik}.DS_{i}.Q_{ij}.ARS_{i} + CVT_{ilj}.Q_{ij}.ARS_{i}\right) \quad (1)$$

Subject to:

$$\sum_{i}^{I} C_{ijkl} = 1 \quad (2)$$

$$\sum_{k}^{K} C_{ijkl}.Q_{ij}.ARS_{i} \leq COR_{ilj} \quad (3)$$

$$\sum_{i}^{I}\sum_{k}^{K}\sum_{l}^{L} C_{ijkl}.Q_{ij}.ARS_{i} \leq CAR_{j} \quad (4)$$

$$\sum_{l}^{L} C_{ijkl}.Q_{ij}.ARS_{i} \leq DISAMB_{ikj} \quad (5)$$

where:

$C_{i,j,k,l}$ = positive variable being the proportion of homogeneous areas i, harvested in month j, with transport by truck k, and either mechanical or manual cutting l,
$Pacu_j$ = prices of sugar in the month j (prices were obtained consulting the index CEPEA/ESALQ in kilogram),
$ATR_{i,j}$ = Total Recoverable Sugars of homogeneous areas i, in the month j, in kilogram sugar per tonne of sugarcane,

$Q_{i,j}$ = productivity of cane stalk in homogeneous areas i, in the month j, in tonnes of sugarcane per hectare,
ARS_i = homogeneous areas i, in hectares,
$Palc_j$ = prices of alcohol fuel in the month j (prices were obtained consulting the index CEPEA/ESALQ in liters),
$PTalc_{i,j}$ = productivity of residual alcohol fuel in homogeneous areas i, in the month j, in litres per tonne of sugarcane,
CI = factory cost to crush sugarcane in variable dollar (US$) per tonne of sugarcane,
$CT_{i,k}$ = cost of sugarcane transport in homogeneous areas i, for the truck k, in variable Dollar (US$) per tonne of cane as a function of the distance to the plant,
DS_i = distance of homogeneous areas i, of the plant in kilometres,
$CVT_{i,l,j}$ = cost of cut in homogeneous areas i, with cut l, and month j, in variable dollar (US$) per tonne of sugarcane,
$COR_{i,l,j}$ = cutting capacity of homogeneous areas i, with cut l, in the month j, in tonnes of cane,
CAR_j = loading capacity of the own sections in the month j, in tonnes of sugarcane including the sum of the manual and mechanical cutting,
$DISAMB_{i,k,j}$ = transport capacity in homogeneous areas i, with truck k, in the month j, in function of the number of available trucks, distance, trips and expressed medium speed in tonnes of sugarcane.

The maximization objective function represented by equation (1) is subjected to the proportion restriction of homogeneous areas to be harvested by equation (2), where in this case we solved the problem considering the linear programming. Harvest restrictions (equation 3), loading (equation 4) and transport (equation 5) also considered in this model and $C_{i,j,k,l}$ coefficient was included in this equations because it represents the proportion of all homogeneous areas harvested in function of restrictions.

The major problem in the agricultural planning is to coordinate mainly the sugarcane transport to a mill to pre-empt possible problems. Common of these is the delay in the reception of sugarcane to the milling station. This invariably results in queuing and waiting. This problem has been addressed in attempt to optimize the use of vehicles in sugarcane transport (Higgins, 2006; Higgins et al., 2004), since the transport is responsible for approximately 12% of total production costs. Modeling the transport as performed in the equation (5), considering the number and type of available trucks for one homogeneous area, trips and medium velocity in function of distance does not result in the best solution because the variation concerning the allocation of vehicles along the day depends on the need and efficiency of other vehicles involved in the system, and thus it is considered a minimization problem (Milan et al., 2006). Adopting algorithms that minimizes the transport use in South Africa, suggested that the number of trucks in the fleet could immediately be cut back by at least 60%, provided that a central officer controls vehicle movements and that all hauliers serve all growers in an equitable fashion (Giles et al., 2005).

The objective is to achieve maximum profit, optimizing agricultural planning as a whole and not just the transport, thus. As a result, the transport model was simplified. Some sugar mills in Brazil adopt road-satellite systems for the best route decision and allocation is made quickly during the day. Any change in transport planning involves new scenarios and new searches of maximum profit.

Another difficulty to be solved is cane productivity estimate (Q), Total Recoverable Sugars (ATR) and alcohol fuel (PTalc) of a given crop. It was only considered for analysis in some production areas in function of varieties, mechanized or manual harvesting and transport using Treminhão or Rodotrem (high capacity vehicles of 45 and 55 tons respectively). Production areas were divided in homogeneous areas (Prado et al., 2002) consecutively numbered and not identified for strategic management. Prices of sugar and alcohol fuel for Brazil were obtained consulting the index CEPEA/ESALQ (http://www.cepea.esalq.usp.br/acucar/).

3. RESULTS AND DISCUSSION

The optimized harvesting schedule is presented in Table 1. It is apparent that all the 30 homogeneous areas were harvested in their totality, not accounting for surpluses in actual sugarcane production. Interestingly, there is a homogeneous pattern in crop production that results in excellent integration of harvesting with milling requirements. Following this crop harvesting schedule, the maximum gross income realizable is US$25.6 million. As other crop production expenses were not considered, this value just represents the maximum possible gross return that could be achieved under the studied conditions for any production area. Finally, the highest marginal returns for the crop are in the months of August, September and October, which is consistent with results found by Barata (1992). Due to the high price of sugar and alcohol fuel ($Pacu_j$ and $PTalc_{i,j}$) already at the beginning of harvest (May), higher values of ATR is interesting and the use of ripeners in early maturing varieties is recommended.

In Table 1, it is apparent that harvest of early maturing cultivars is noted in rows 4, 7, 14, 18, 28 and 30 and the later maturing cultivars are harvested during June to December.

Not surprisingly, fields furthest away from the sugar mill (24 to 30), shouldered significantly more transport costs and invariably had negative marginal values. The findings indicate that cane transport was economically unviable from fields beyond 20 km from the sugar mill. For these distant fields, the search for more efficient trucks with lower transport costs, smaller number of trips and optimized repairs is necessary. Where there are no restrictions on harvesting date, fields 24, 25 and 26 produced positive marginal values. Thus, planting cultivars that will maintain high sucrose content over a long period during harvesting is likely to help offset high transport costs arising from long distance. Running the optimized model without use of restriction in the harvesting capacity, an increasing of 14% was observed in the objective function value. The increasing turned 26% when the loading capacity restriction was applied, indicating that both factors have been set restricted in the supply-chain, leading to lowering the profit in the sugarcane chain industry. The transport capacity restriction had the smallest restriction factor and almost had not been influenced the final objective function value.

In this research could be noticed that an excess of trucks have been used in those sections of the sugarcane chain. On the other hand, the loaders, cutting machines and workers were restrictive. Simulating an increasing of 10% in the loading capacity, 3% of increasing in the profit was observed. This action justifies more loaders allocated in the sections. Higgins et al. (1998) increased the milling capacity in 12% and found an increasing of 5% in the liquid income.

With the remove of the most suitable time to harvesting according to the varieties, the profit increased 9% regarding the usual method with the restrictions made by the improvement programs, indicating that some varieties are more prone to economic aspects in not suitable time. This punctual decision supposes to be or not to be achieved according to by its own changes in the system itself, once the main problems in tillering are going to appear in the next crop season.

Aiming to shift the empirical form of harvesting decision, along with implanting the use of this model of optimized planning, the sugar mill should grant all the involved costs. Additionally, the sugar mill has to agree with the process of implementation that involves the data base from agricultural area, industry and financial departments. Auditions carried out previously in those areas could drive for the followed steps, seeking for optimization. Besides the harvesting decision, the linear programming techniques can be a helpful tool in the allocation of varieties considering the environment (Scarpari et al., 2008), distribution of the working groups for harvesting, allocation of trucks for the transport (Higgins, 2006; Milan et al., 2006) and replacement of sugarcane field (Barata, 1992; Crane et al., 1982).

The research in this project is designed as a direct result of the needs of the stakeholders. By working through the planning process will lead to direct outcomes, build local capacity and provide a basis for developing improved participatory and integrated approaches to resource management throughout the sugar industry within a regional framework (Chalmers et al., 2006).

4. CONCLUSIONS

Sugar industries are a complex integrated system involving the growing, harvesting, transport, milling and marketing sectors (Higgins and Muchow, 2003). This study has shown that optimized agricultural planning promotes a homogeneous distribution of raw material along the months of crop obtaining the maximum possible profit. An easy-to-use management tool is the best way to explore several harvesting options to maximize profits. The use of a yield-predicting model would give better support in the scenarios creation for optimization, mainly the maturation of sugarcane (Scarpari and Beauclair, 2004). The transport restriction does not reproduce faithfully what happens in farming, demanding a more complex analysis. We suggested the adoption of road-satellite systems where the best decision route and allocation is made quickly along the day. In terms of future work, the inclusion of a model predicting productivity will be considered, since the data used in this study was related to a crop that had already been harvested. The goal is to get the future values and to accomplish the optimization. Without the use of effective forecasting tools, the application of modeling software in strategic planning can result in solutions with less realism, because "average values" do not represent what actually happens in a crop, particularly regarding the maturation of the sugarcane (Scarpari and Beauclair, 2004).

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REFERENCES

[1] BARATA, M. Q. F. **(1992):** Otimização econômica do corte e reforma de canaviais**. Piracicaba, 124p. Dissertação (Mestrado) - Escola Superior de Agricultura "Luiz de Queiroz"; Universidade de São Paulo.**

[2] BARBIERI, V. (1993): Condicionamento climático da produtividade potencial da cana-de-açúcar (*Saccharum* spp.): um modelo matemático-fisiológico de estimativa. Piracicaba, 142p. **Tese (Doutorado) - Escola Superior de Agricultura "Luiz de Queiroz"; Universidade de São Paulo**

[3] BEAUCLAIR , E. G. F. and de, PENTEADO, C. R. (1984): Cronograma de corte da cana-de-açúcar através da Programação Linear. In: **Seminário da Tecnologia Agronômica 2, Piracicaba**, 424-434.

[4] BROOKE, A., KENDRICK, D. and MEERAUS ,A. (1992): **GAMS: a user's guide, release 2.25**. The Scientific Press: San Francisco.

[5] CHALMERS, D., WEBB, V. and WALKER, D. (2006): Integrated resource use planning in the Australian sugar industry: a participatory planning approach. (http://www.regional.org.au/au/apen/2001/n/ChalmersD.htm#TopOfPage)

[6] CRANE, DR., SPREEN, T. H., ALVAREZ, J. and , KIDDER, G. (1982): An analysis of the stubble replacement decision for Florida sugarcane growers. **University of Florida: Gainesville**..

[7] GILES, R. C., BEZUIDENHOUT, C. N. and LYNE, P. W. L.(2005): A simulation study on cane transport system improvements in the Sezela Mill area. In: **Proceedings of South African Sugarcane Technologists' Association**, 79, 61.

[8] GRUNOW, M., GÜNTHER, H. O. and WESTINNER, R. (2007): Supply optimization for the production of raw sugar. **International Journal of Production Economics**, 110, 224-239.

[9] HIGGINS, A. (2006): Scheduling of road vehicles in sugarcane transport: A case study at an Australian sugar mill. **European Journal of Operational Research**, 170, 987-1000.

[10] HIGGINS, A. J, HAYNES, M. A, MUCHOW, R. C and PRESTWIDGE, D. B.(2004): Developing and implementing optimised sugarcane harvest schedules through participatory research. **Australian Journal of Agricultural Research**, 55, 297-306.

[11] HIGGINS, A. J. and MUCHOW, R. C. (2003): Assessing the potential benefits of alternative cane supply arrangements in the Australian sugar industry. **Agricultural Systems**, 76, 623-638.

[12] HIGGINS, A. J, MUCHOW, R. C., RUDD, A. V. and FORD, A. W. (1998): Optimising harvest date in sugar production: A case study for the Mossman mill region in Australia I. Development of operations research model and solution. **Field Crops Research**, 57, 153-162.

[13] JIAO, Z., HIGGINS, A. J., PRESTWIDGE, D.B. (2005): An integrated statistical and optimisation approach to increasing sugar production within a mill region. **Computers and Electronics in Agriculture**, 48, 170-181.

[14] MILAN, E. L., FERNADEZ, S. M., PLÀ, L. M. (2006): Sugar cane transportation in Cuba, a case study. **European Journal. of Operational Research**, 174, 374-386.

[15] PRADO, H., LANDELL, M. G. A. and ROSSETTO, R. (2002): A importância do conhecimento pedológico nos ambientes de produção de cana-de-açúcar. In: **Reunião Brasileira de Manejo e Conservação de Solo e Água 14, Cuiabá. CD-ROM.**

[16] SALASSI, M. E., BREAUX, J.B. and NAQUIN, C. J. (2002): Modeling within-season sugarcane growth for optimal harvest system selection. **Agricultural Systems**, 73, 261-278.

[17] SCARPARI, M. S. and BEAUCLAIR, E. G. F, de. (2004): Sugarcane maturity estimation through edaphic-climatic parameters. **Scientia Agricola**, 61, 486-491.

[18] SCARPARI, M. S. (2007): PREDPOL: Um modelo de previsão da maturação da cana-de-açúcar visando planejamento otimizado. Piracicaba, 120p. Tese (Doutorado em Fitotecnia) - **Escola Superior de Agricultura "Luiz de Queiroz"; Universidade de São Paulo.**

[19] SCARPARI, M. S., PLÀ, L. M. and BEAUCLAIR, E. G.F. de. (2008): La optimización del cultivo de variedades de caña de azúcar. **Revista Investigación Operacional**, 29, 26-34.

[20] SINGELS, A. and DONALDSON, R. A. (2000)Ñ A simple model for unstressed sugarcane canopy development. In: **Proceedings of South African Sugarcane Technologists' Association**, 74, 151-154.

ANNEX

AREA.TRUCKS.CUT	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1.Treminhão.Manual						11905		
1.Rodotrem.Manual			903.538		12252.821	33095	29081	
2.Treminhão.Manual							61	61
2.Rodotrem.Manual					323.077	30000	29939	29939
3.Treminhão.Manual								
3.Rodotrem.Manual			25411		12951.387	30000	11954.553	
4.Treminhão.Manual	18883							
4.Rodotrem.Manual	20883	7193.24						
5.Treminhão.Manual						10044		
5.Rodotrem.Manual			23637		3029.125	31956		
6.Treminhão.Mechanic							3462	21918
6.Rodotrem.Mechanic							23918	23918

AREA.TRUCKS.CUT	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
7.Treminhão.Manual	17662							
7.Rodotrem.Manual	19662	7684.92						
8.Treminhão.Mechanic		5709.02						
8.Rodotrem.Mechanic		20424			26177	4149.714		
9.Treminhão.Manual							6878	6878
9.Rodotrem.Manual						10200	23122	23122
10.Treminhão.Mechanic		12080						
10.Rodotrem.Mechanic		19920	14258.5					
11.Treminhão.Manual		5627						
11.Rodotrem.Manual		20373	20790					
12.Treminhão.Manual								
12.Rodotrem.Manual				18618	19448		5737.752	
13.Treminhão.Manual								
13.Rodotrem.Manual				20967	21965	3165.033	4256.995	1026.353
14.Treminhão.Mechanic	1844							
14.Rodotrem.Mechanic	16156	16303.6						
15.Treminhão.Mechanic			2865					
15.Rodotrem.Mechanic			19135	8529.34	21841.936			
16.Treminhão.Manual								
16.Rodotrem.Manual				28681	29000	11517.61		
17.Treminhão.Manual			8731					
17.Rodotrem.Manual			18269	18819				
18.Treminhão.Manual	18448							
18.Rodotrem.Manual	20448	5402						
19.Treminhão.Mechanic			655					
19.Rodotrem.Mechanic			21345	13252.3	22000			
20.Treminhão.Manual								11914
20.Rodotrem.Manual						12010	23086	23086
21.Treminhão.Manual	4696							
21.Rodotrem.Manual	20304	16791.7						
22.Treminhão.Manual		1509	548					
22.Rodotrem.Manual		19491	20452	4128				
23.Treminhão.Manual								271
23.Rodotrem.Manual				11647.1			20729	20729
24.Treminhão.Mechanic		1212	230					
24.Rodotrem.Mechanic		18788	19770	3358.21				
25.Treminhão.Mechanic								
25.Rodotrem.Mechanic			23000	23000	7011.655			23000
26.Treminhão.Manual								
26.Rodotrem.Manual				22000	22000	22000		11037.647
27.Treminhão.Manual								
27.Rodotrem.Manual				22000	22000	9957.647	22000	
28.Treminhão.Manual	17868							
28.Rodotrem.Manual	19868	7871.23						
29.Treminhão.Manual				2092				
29.Rodotrem.Manual				22908			15774.699	23100
30.Treminhão.Mechanic	2858	667.667						
30.Rodotrem.Mechanic	19142	20154						
TOTAL	218722	207201	220000	220000	220000	220000	220000	220000

Table 1. Optimized harvesting schedule expressed in tonnes per month.