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Industry: **agribusiness**
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MATHEMATICAL PROGRAMMING ACCELERATES IMPLEMENTATION OF AGRO-INDUSTRIAL SUGARCANE COMPLEX

The typical sugar cane industry dynamics often has limited the implementation of agro-industrial complexes by a sugarcane cycle (e.g.: 6 years). This work presents a methodology that can be used to speed up the implementation considering the long-term effects of an irregular plantation schedule. The effect of the acceleration has been computed in two real cases and the outcome was a significant value enhancement of the company.

ABSTRACT

With the current demand for Brazilian sugarcane, the importance to investors of a faster implementation of agro-industrial complexes has been increasing. Estimates suggest that a 4-year implementation may enhance financial value creation by 10% when compared to the usual 6-year implementation. Given a desired production and a target implementation horizon, the quadratic programming model presented in this paper offers a feasible plantation schedule with minimum deviation from the plan. The model was used as an important tool in two business plans.

KEY WORDS: OR in agriculture; OR in developing countries; Quadratic programming; Farm planning; Sugarcane scheduling; Valuation.

1 INTRODUCTION

Since the 16th century sugarcane has been one of the Brazilian economy's most important drivers. Sugar had been the primary sugarcane product until the 1970's when the Brazilian government introduced a program called Pro-Álcool to stimulate ethanol production and consumption. The success of the program can still be observed today when one considers that Brazil has the largest ethanol-based fleet in the world, and accounted for around a third of the world's production of 52,500 million cubic meters in 2007.

Along with the success of ethanol usage in Brazil since there are no light vehicle fuel options besides E25 and E100 (Ex means x% of ethanol in the fuel blend), Brazilian exports of sugar have been increasing over the last 10 years, and in 2006 Brazil accounted for about 40% of the total world sugar trade [1].

Juice and bagasse are the two products generated after crushing sugarcane. Juice is the raw material of the distillery and the sugar factory. Different processes transform sugarcane juice into either ethanol or sugar. Bagasse, on the other hand, is used to feed boilers and, in the end, to supply all the energy required by the factory during the harvest season. Over time, energetic efficiency has been improving causing a generation surplus, with mills and distilleries starting to sell energy to the grid. Energy generation has become the third most economically relevant sugarcane derivative.

Several other reasons such as global warming and security issues related to the main oil producing areas have been further stimulating the global adoption of ethanol as a feasible fuel alternative. Countries and Regions such as China, EU, India, Thailand, and the US have increased their ethanol usage as a mandated blending fuel, and consequently, producers are expecting a structural shift in the product's price and consumption in the years to come.

The reasons described above have been motivating sugarcane growers and millers to increase production: between 20 and 30 new green field projects are expected to be concluded in the Central and Southern Region of Brazil in the 2008/2009 season and production is expected to continue growing by more than 10%/year on average, a growth rate that has been observed since 2000.

In this exciting context, the author has been helping companies to evaluate the implementation and financial standing of such enterprises. One of the most critical issues is the creation of a plantation schedule that speeds up the production ramp-up phase. The model and issues related to it are described in detail below.

2 SUGARCANE CYCLE

Sugarcane is a semi-perennial crop, with an optimized economic life cycle of about 6 years. Depending on the growing region, yields, and economical constraints, one can find optimal life cycles ranging from 4 to 10 years. The grower decides the optimal cycle by identifying the number of cuts that would generate the best financial margin.

It is considered in this paper that within a cycle of T years, sugarcane is harvested T-1 times, i. e., once a year except for the first year since it is advisable to rest land for six months, and the most profitable varieties of sugarcane grows for around 18 months before the first harvest.

Sugarcane can be divided into two classes of crop: a plant crop (plant grows for 18 months before harvesting) and a ratoon crop (around 1 year after the previous harvest). A ratoon is the sugarcane re-growth after the harvest. After the 4th ratoon and the 5th harvest, land is ploughed and another sugarcane cycle starts. Higgins and Muchow [2] offer a broader overview of the terms and processes associated with the sugarcane plantation.

The main component of the recommended sugarcane cycle is the sugarcane yield which is composed by land and sugar yields. Sugar yields (kg of extractable sugar per ton of cane) are reasonably constant over the sugarcane lifespan, although it is strongly influenced by the harvest time during the harvest season. Land yields, on the other hand, decrease over time as crop ages. Table 1 presents a typical decay of land yields in the Central and Southern Region of Brazil.

Although land yield decreases as the number of harvests increases, sugarcane quality is about the same if harvested on the same date, and the price paid per ton of cane remains the same over the entire cycle. In fact, sugarcane pricing is a complex issue but its main component is defined according to the sugar yield of a sample of cane stalks upon delivery.

For the case under analysis, Figure 1 shows the financial margins according to different sugarcane planting cycles. It is easy to see that a cycle length of 6 years present the better performance, while 5 years has also shown a comparable result.

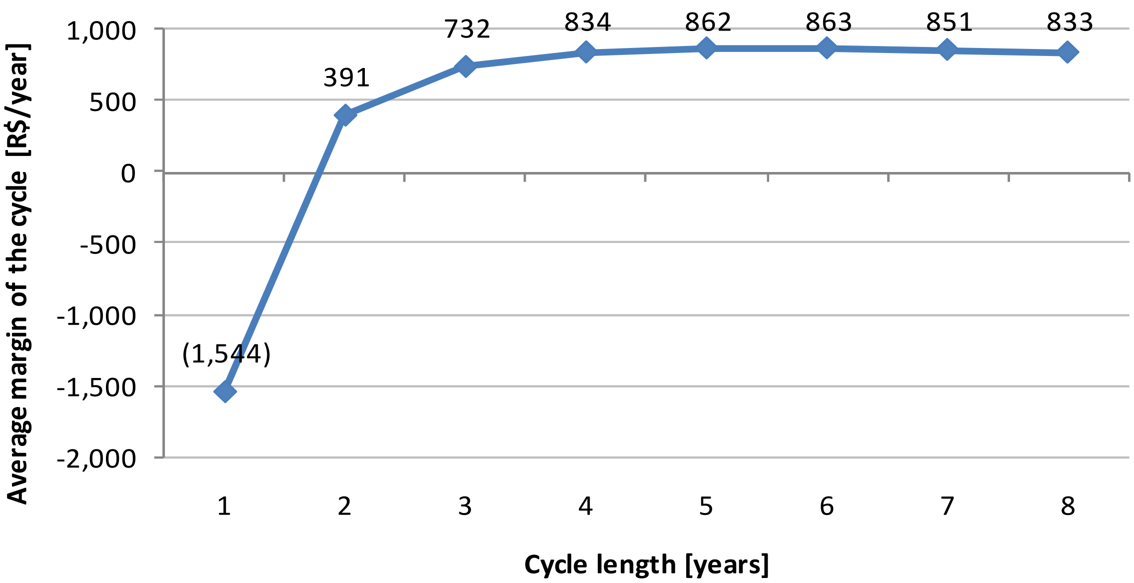

Figure 1: Financial margins according to different sugarcane planting cycles; R$ stands for ‘Real’, the Brazilian currency

3 PLANTATION PLANNING AND SCHEDULE

Plantation planning has long been studied. One of the earliest examples of linear programming application deals with farm planning and is due to Heady [3]. Glen [4] offered a thorough revision of mathematical models in farm planning with dozens of applications, and Weintraub and Romero [5] offer a more recent review of the literature available. The problem continues to require new approaches [6, 7]. Recent application of OR methods in the sugarcane field can be found in [8, 9].

On the other hand, historically, the sugarcane plantation schedule has not been an issue. Brazilian mills used to grow financed by internal resources and hence growth rates were easily manageable. Considering the 6-year cycle of sugarcane, a company has to plant of the total area to reach production stability by the end of the sixth year. Figure 2 shows sugarcane production for the first 9 years after the start of the enterprise, for a property producing 2.2 million tons of cane per year. Production of the same area (same color of the bars in Figure 2) decreases over time, as the number of harvests increases and yields decrease. For the schedule shown in Figure 2, Figure 3 presents the implied yield, that is, the average yield achieved in the harvested area.

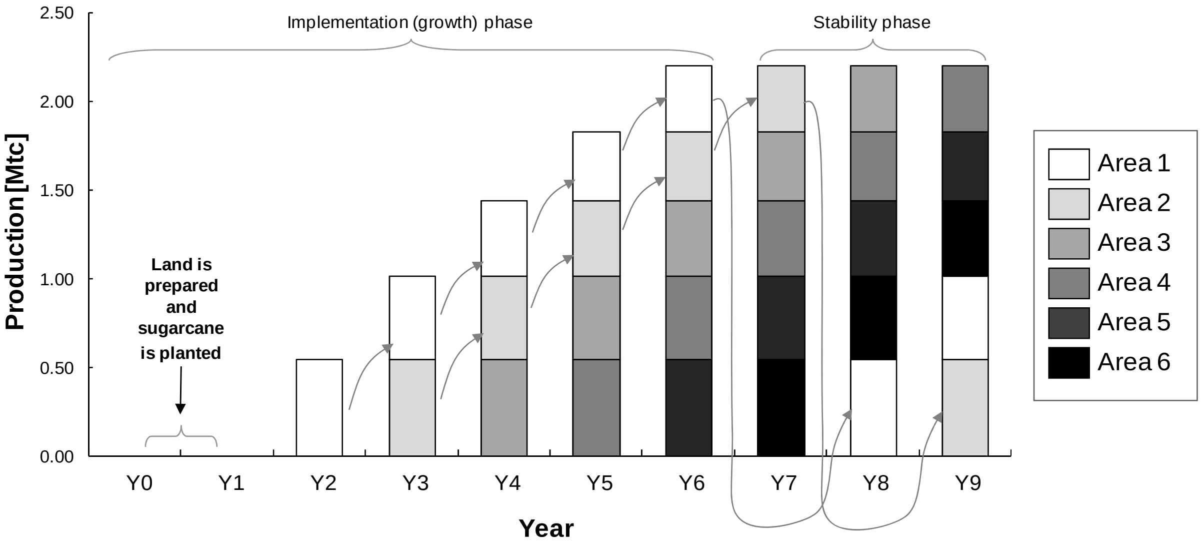

Figure 2: In a typical implementation of an agro-industrial complex, the plantation schedule requires 6 years to reach maximum capacity

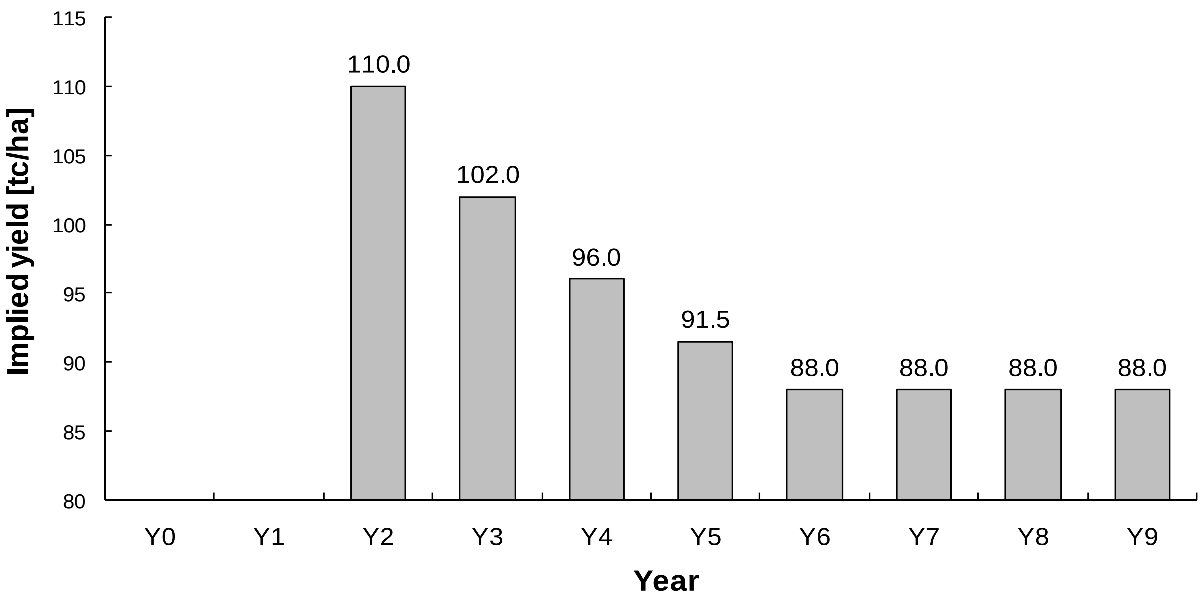

Figure 3: At the beginning of the implementation, effective yields are greater given the higher proportion of high yield land

4 WHY ACCELERATE THE IMPLEMENTATION?

The present, lucrative moment which the sugar and ethanol sector is undergoing has brought in several new and wealthy players such as mutual funds, venture capitalists and a broad range of potential investors from Australia (e.g.: CSR Sugar), Brazil (Brenco, Cosan, Petrobras), Europe (Bunge, Louis Dreyfus, Société Générale, Südzucker, Tereos), Japan (Mitsui), and the US (ADM, Cargill) amongst others. The abundant resources, and the positive moment for the sugar and ethanol industry, have been encouraging the acceleration of investment. As usual, the interest from investors is not only to have a fair return on their investment, but also to receive a payback upon the investment as soon as possible. Investments by operating companies generally pursue early and generous dividends, while financial investors often expect to have a successful and profitable exit strategy.

The interest in accelerating the implementation can be explained by the value enhancement of the agro-industrial complex. A discounted cash flow model indicates that value can be enhanced by at least 10% if the ramp-up phase is accelerated from 6 to 4 years to achieve production at full capacity.

The added value is created by the better use of capital, since in both cases heavy capital expenditures are expected with the launch of the enterprise (mainly land and crushing equipments), and cash flows are generated earlier in the accelerated case. If there is no interest in accelerating the implementation of the enterprise, capital expenditures associated with the sugar factory are postponed.

If value creation, among other factors, is driven by speedy implementation, why not implement in 3 years, 2 years, or even 1 year? Just because specialists and former successful implementations indicate that 4 years seems to be the minimum time required for an operationally feasible implementation. The model suggested in this paper can manage any implementation horizon chosen.

5 ENTERPRISE SIMULATION AND THE MODEL FOR ACCELERATING IMPLEMENTATION

A fundamental step in the process of large and sophisticated investments is the creation of a business plan to assess opportunities and risks associated with them. The business plan building process is an important exercise because it helps to clarify several issues associated with the new investment such as capital requirements, the management team, competitors, expected market share, implementation strategy, etc.

Along with the plan, which comprises organizational, market and financial analyses amongst others, there is a simulation model to operationally and financially evaluate the enterprise. The simulation model is materialized by a typical business valuation model [10, 11] built into a spreadsheet which comprises main assumptions, standard financial statements, value and operating drivers, a sensitivity analysis and the value of the enterprise.

More specifically, V_t, the value of the enterprise at time t can be defined as (see [12, p. 25])

$$V_t = \sum_{s=t+1}^{\infty} \frac{FCF_s}{\prod_{\sigma=t}^{s-1}(1+k_\sigma)} \tag{1}$$

where FCF_t and k_t are the free cash flow to the firm and the cost of capital in t respectively, and Π is the product operator. To avoid too many forecast periods, it is usual to split the equation into two terms: the explicit forecast period value and the terminal value, that is

$$V_t = \sum_{s=t+1}^{\tau} \frac{FCF_s}{\prod_{\sigma=t}^{s-1}(1+k_\sigma)} + \frac{1}{\prod_{\sigma=t}^{\tau}(1+k_\sigma)} \frac{FCF_{\tau+1}}{(k_\tau - g)} \tag{2}$$

where τ is the last period of the explicit forecast horizon and the second term of the equation (2), referred to as continuing value, and is obtained by the convergence of an infinite series of discounted free cash flows with constant growth g, with $k_t > g$.

The decision over τ essentially depends upon two characteristics: the stationarity of the cash flows (if they are stable) and if the forecast power of the analyst justifies an explicit forecast. Two sugarcane cycles plus the ramp up phase, or 16 years, was the time period used for τ in this paper.

In general, obtaining the FCF_t is a hard task given the large number of parameters and details affecting it such as revenues R, costs and expenses C, depreciation D, taxes on profits i, and investments I which include capital requirements. Mathematically, the FCF_t can be defined as

$$FCF_t = (R_t - C_t - D_t)(1 - i) + D_t - I_t. \quad (3)$$

Each variable used in (3) has several arguments. For instance, costs are composed of inputs (fertilizer, lime, etc.), sugarcane transportation, direct and indirect personnel, equipment maintenance and fuel, amongst others. Also, expenses such as administration, sales, headquarters and logistics are all included in the variable C_t.

The valuation model includes two business units consolidated as a single company, or

$$V_t^{AIC} = V_t^{PBU} + V_t^{IBU} \quad (4)$$

where V_t^{AIC} represents the value of the agro-industrial complex, and V_t^{PBU} and V_t^{IBU} represent the value of plantation and industrial business units respectively. Equation (4) does not take into account headquarters expenses once they are computed to the value of each business unit.

A mathematical programming model was embedded into the valuation model to create the plantation schedule. The objective of the model is to create a feasible plantation schedule that achieves a steady state for the factory in three years, increasing factory workload from $\frac{1}{3}$ to $\frac{2}{3}$ to full capacity in years 2, 3 and 4 respectively. Some different mathematical programming models were tested, and the preferred model found, in terms of quality of solution, was obtained by a simple quadratic programming model which minimizes deviations between estimated and desired production over the planning horizon (see the Appendix for details).

6 RESULTS AND DISCUSSION

One of the main characteristics of a successful operations research application is the savings generated or the opportunity captured by it. Although the model described in this paper did not generate any savings since it is part of a business plan, it certainly helped to find a way to capture an unrealized opportunity for a new and difficult problem.

The financial valuation model indicates that the acceleration of the factory implementation from 6 to 4 years can increase the value of the sugarcane agro-industrial complex by about 10%. The model outlined in the appendix offers a formal method to accelerate the implementation with little impact in the operational implementation once the schedule proposed generates smooth production (see Figure 4) when compared to other solutions discussed and proposed by agricultural specialists in the two implementations faced by the author. Considering that ideally, mills and distilleries operate at full capacity, an unsmooth schedule necessarily generates idleness in the years with low sugarcane production and loss of productivity in the years with high production because the harvest season has to be extended to the low sugar yield period.

The model was used and outputs discussed extensively in two different engagements. The acceptance of the results was immediate and, as mentioned previously, alternative solutions typically used in the industry do not offer a schedule of comparable quality.

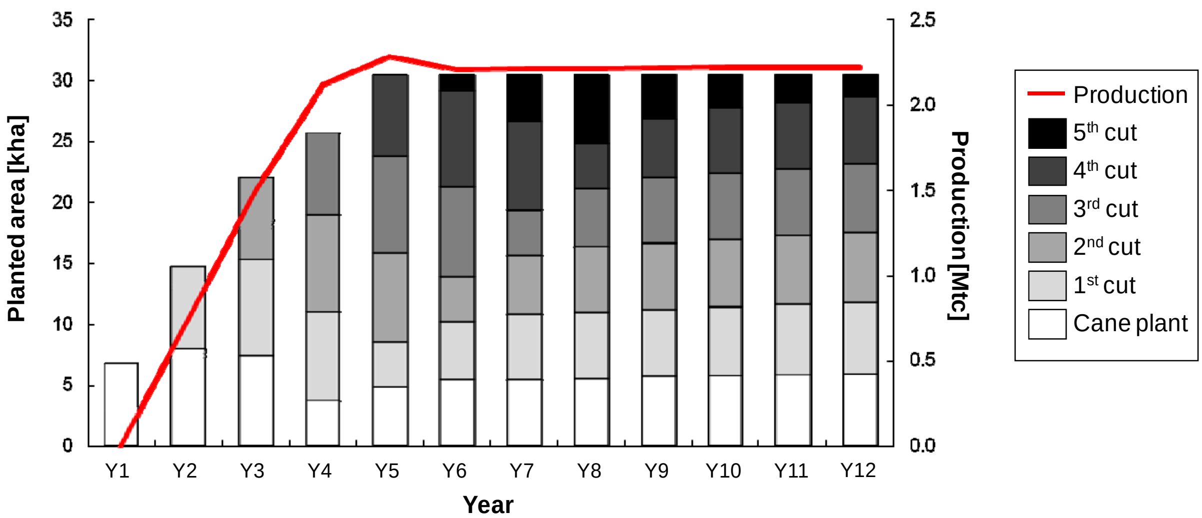

Figure 4: The optimal plantation schedule achieves maximum production within 4 years and keeps production stable from Y4 on

Apparently, the main limitation of the model is the lack of any consideration regarding the use of plantation resources. For instance, there is no consideration of machinery and personnel workload management; implementation acceleration will surely cause a workload unbalance in terms of resources and the company will have to get rid of additional resources used in the accelerated phase as soon as the complex enters into the steady state period. This issue is not very important in the project described because the implementation of several distilleries is expected to be staggered. Therefore, overcapacity used in the early implementations will be used later in other implementations, so in the long run, the company will have more opportunities to balance resources and production. For single complex implementations, the use of third party agricultural (manpower and machinery) service providers might be a good solution to create a better workload management.

An interesting deployment of the work would shift the focus from an operations oriented to a financial oriented model. The current version of the model helps the executives decide upon implementation speed, maintaining the production smoothness within a certain limit. Although the current version of the model generates a direct impact on value, the model could use the value of the enterprise as the objective function. The same remark and suggestion is valid for other studies in the field of operations research since the majority of the studies use objective functions which are only indirectly connected to value.

7 APPENDIX: MATHEMATICAL PROGRAMMING FORMULATION

The quadratic programming model considers 2 sugarcane cycles $(t = 1, \dots, 2T)$ and 6 land uses: resting and plantation, 1st cut, ..., 5th cut (or $j = 1, \dots, J$). As described previously, the period considered in the real implementation was 16 years and the set $t = 1, \dots, 2T + a$ where $a = 4$ would be a better representation of the cases, but the set $t = 1, \dots, 2T$ is used to avoid unnecessary notation. The decision variable x_{jt} is the planted area of land use j in time period t. The entire model has the following form:

$$min z = \sum_{t=1}^{2T} (d_t - e_t)^2 \qquad (1)$$

Subject to

$$e_t = \sum_{j=1}^{J} x_{jt} y_j \qquad \text{for } t = 1, \dots, 2T \qquad (2)$$

$$2 \geq x_t / x_{t-1} \geq \frac{1}{2} \qquad \text{for } t = 2, \dots, T \qquad (3)$$

$$x_{1t} + x_{Jt} - x_{J-1,t-1} - x_{J,t-1} = 0 \qquad \text{for } t = T + 1, \dots, 2T \qquad (4)$$

$$x_{J-1,T-1} - x_{1T} - x_{JT} = 0 \qquad (5)$$

$$x_{jt} - x_{j-1,t-1} = 0 \qquad \text{for } t = 2, \dots, 2T; j = 2, \dots, J; t \geq j \qquad (6)$$

$$x_{Jt} - x_{J-1,t-1} \leq 0 \qquad \text{for } t = T, \dots, 2T \qquad (7)$$

$$x_{1t} \geq 0 \qquad \text{for } t = 1, \dots, T \qquad (8)$$

$$x_{Jt} \geq 0 \qquad \text{for } t = T, \dots, 2T \qquad (9)$$

where

d_t: desired sugarcane production in t,

e_t: estimated sugarcane production in t,

y_j: sugarcane yield of land use j.

The objective function minimizes the sum of the squared difference between desired and estimated production. The idea to minimize the squared difference instead of the difference is to avoid negative and positive deviations canceling each other out. In the project, the desired factory production was defined as 0, $\frac{1}{3}$ and $\frac{2}{3}$ of full crushing capacity of the agro-industrial complex for years $t = 1,2$ and 3 respectively. From year 4 on, desired production is defined as full crushing capacity. Constraint set (2) defines estimated production, which is plantation area times yield per area for each land use j and each period t. Constraint set (3) guarantees that planting activities are reasonably stable: plantation area of period t can neither increase more than 100% nor decrease more than 50% of the production area of the previous period $t - 1$ for $t = 2, \dots, T$. The limits are defined arbitrarily and should be adjusted in each case to represent the possibilities in the real implementation; if a wide variation in planted area does not cause an operational problem, constraint set (3) could even be eliminated. An important assumption of the model considers whether the 4th ratoon should exist or not, and its extension depends upon the model output. In other words, for a given 3rd ratoon area, the model decides the area that will become the 4th ratoon, and thus the area that will be ploughed (or transformed into cane plant a year later). This rationale is modeled in constraint set (4) and constraint (5). Constraint set (6) guarantees the equivalence between land use j and land use $j-1$, and constraint set (7) guarantees that the area of the 4th ratoon is at most the area of the 3rd ratoon. Constraint sets (8) and (9) specify that the plantation area of any land use, and in any period, is non-negative.

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