THE OPTIMAL TIME FOR SUBSTITUTION OF *Eucalyptus* spp. PLANTATIONS – THE TECHNOLOGICAL PROGRESS CASE

José Luiz Pereira de Rezende[1], Álvaro Nogueira de Souza[2], Antônio Donizete de Oliveira[1]

(recebido: 21 de dezembro de 2002; aceito: 10 de janeiro de 2005)

ABSTRACT: The importance of technological progress for the Brazilian forest enterprises cannot be denied. Its influence comprehends all the activities, but can be summarized in the increase of income via yield increase or cost reduction and, mainly, in the two cases occurring together. Technological effects influence, among other aspects, the cutting age and the optimal time to renewal (a new plantinting or “reforma”) *Eucalyptus* plantations. Studies to determine these times are not so common in the literature since it requires both forestry and economic knowledge. Before renewing an Eucalyptus stand, it is necessary to technically and economically to define the optimal cut age the original planting and the coppicings and after how many cuttings the substitution of the plantations should be done. This study aimed at studying the optimal time to substitute *Eucalyptus spp.* Plantations, considering the gains earned through technological progress; to determine the cutting age of the population, the income being increasing and the cost being decreasing; to propose and verify the efficiency of a mathematical model which allows modeling the effects of technological progress; to study the substitution chain between 1960 and 2000 and between 2000 and 2040, considering technological progress; and to test the results in a case study. The Gompertz Function was employed to obtain the volumes at the various ages. The criterion employed for the economic evaluation of the projects was the Presente Net Value (PNV). The proposed model allowed the calculation of yields and costs through time, study the effect of yield increase and cost reduction and determine the rates of these increase and, or, reductions as well as determining rates which served as moderators so that the yield and costs did not reach unreal values. It was concluded that: The rotation, with current values, is at 7 years of age; the model proved to be efficient for estimates up to 40 years; with the income and costs from the sixties, considering technological progress from that point on, the number of cuttings before the renewal is currently 2; the substitution chain showed that the optimal substitution time went down with time, going from 18 cuttings in the sixties to 4 cuttings in the eighties, currently getting to 2 cuttings; a tendency to stick with 2 cuttings before substitution was verified for future cultivation, although little technological improvement in the coppice yield brings the optimal substitution Point to after the third cutting.

Key words: Technological progress, cutting age, forestry economy.

MOMENTO ÓTIMO DE SUBSTITUIÇÃO DE POVOAMENTOS DE *Eucalyptus* spp – O CASO DO PROGRESSO TECNOLÓGICO

RESUMO: *A importância do progresso tecnológico para as empresas florestais não pode ser negada. Sua influência abrange todas as atividades, mas pode ser resumida no aumento das receitas via aumento da produtividade ou na redução dos custos, bem como e, principalmente, ocorrendo juntamente nos dois casos. Os efeitos da tecnologia influenciam, entre outros aspectos, a idade de corte e o momento ótimo de reformar povoamentos de Eucalyptus. Estudos para determinar esse momento não são muitos na literatura, uma vez que requerem conhecimentos silviculturais e econômicos. A reforma não pode ser efetuada a qualquer tempo, sendo necessário definir técnica e economicamente a idade ótima de se fazer o corte do alto fuste ou das talhadias e, após quantos cortes, se deve fazer a substituição do povoamento. Com este trabalho objetivou-se estudar o momento ótimo de substituir povoamentos de Eucalyptus spp, considerando os ganhos proporcionados pelo progresso tecnológico; determinar a idade de corte do povoamento sendo a receita crescente e o custo decrescente; propor e verificar a eficiência de um modelo matemático que permita modelar os efeitos do progresso tecnológico; estudar a cadeia de substituição entre 1960 e 2000 e prever sua ocorrência entre 2000 e 2040, considerando o progresso tecnológico; testar os resultados em um estudo de caso. Para obtenção dos volumes nas várias idades, foi utilizada a Função Gompertz . O critério utilizado para a avaliação econômica dos projetos foi o Valor Presente Líquido. O modelo proposto permitiu calcular as produtividades e os custos ao longo do tempo, estudando o efeito do aumento da produtividade e a redução dos custos e determinar as taxas desse aumento e dessa redução, bem como determinar as taxas que serviram como moderadores para que a produtividade e os custos não atingissem valores irreais. Concluiu-se que a rotação, com valores atuais, se encontra em 7 anos; o modelo se mostrou eficiente para estimativas de 40 anos; com as receitas e os custos da década de 60, considerando o progresso tecnológico a partir daquele ponto, o número de cortes antes da reforma, atualmente, é 2; o estudo da cadeia de substituição mostrou que as épocas ótimas de substituição caíram ao longo dos anos, passando dos 18 cortes na década de 60 para 4 cortes na década de 80,*

[1] Professor do Departamento de Ciências Florestais da Universidade Federal de Lavras/UFLA – Cx.P. 3037 – 37.200-000 – Lavras, MG – jlprezen@ufla.br, donizete@ufla.br
[2] Professor da Fundação Integrada Municipal de Ensino Superior – Rua 22, setor aeroporto – 75.830-000 – Mineiros, GO.

chegando, atualmente, a 2 cortes; para os futuros plantios, verificou-se uma tendência de permanecer os 2 cortes antes da substituição, porém pequena melhora tecnológica na produtividade das talhadias passa o ponto ótimo de substituição para após o 3º corte.

Palavras-chave: Progresso tecnológico, reforma de Eucalyptus, economia florestal.

1 INTRODUCTION

Technological change in the eucalyptus plantation was remarkable in the last decades of the XX century. From $10m^3$/year.ha in 1960 it reached more than $50m^3$/year.ha in the year 2000. Establishment cost went down from US$1,500.00/ha in the 60's to less than US$600.00/ha in the year 2000. These facts may affect rotation age and the number of coppicings of each plantation. Studies on this area are scarce because they require knowledge both on the silvicultural and economic side.

Davis (1966) defined rotation as the time span between stand establishment and its harvesting. If the optimal rotation age is not observed net profit will not be maximized, Rezende *et al.* (1987a).

Simões *et al.* (1981) pointed out that one of the most common problems in managing eucalyptus plantations is to decided after each harvest whether to manage another copping or to establishe a new plantation. This is known in the Brazilian forest literature as a "reforma" (substitution). Silva (1990) defined "reforma" as the establishment of a new eucalyptus stands plantation in substitution to an old stand with low productivity. There are few researches discussing the economic problem of "reforma" in the literature. The commonly related are Silva (1990), Rezende *et al*. (1987a), Rezende *et al*. (1987b) and Souza (1999). However, as pointed out by Rezende (1987a), the theoretical problem of "reforma" is similar to that of "equipment substitution" largely available in the economic literature mainly in the "economic engineering", for ex: Grant (1960); Jelen (1970); Gupta & Cozzolino (1974); Szonyi *et al*. (1982); Hess *et al*. (1985); Valverde *et al*. (1997).

Silva (1990) studied the problem of "reforma" considering three situation similar to those discussed by Massé (1962); a) Terminal cycle; b) Partial reform; c) Substitution chain. However it was done in a static world in which technology never changed, i.e, the cost of establishing future plantations and their productivity wold be the same as those of the current stands.

Therefore the objective of this research was to determine the optimal number of coppicings of eucalyptus stands in a dynamic world.

Specifically this research aimed at:

- Determining the optimal economic cutting age considering the effect of the technological change;
- Proposing and testing the efficiency of an economic model;
- Establishing the optimal Point in time for substituting eucalyptus plantations (reforma) considering decreasing costs and increasing productivity;
- Testing the model in a case study.

2 MATERIALS AND METHODS

2.1. Economic evaluation criterion

The present discounted value (PDV) is the criterion used. This criterion is rigorous and correct, theoretically, (DE FARO**,** 1969; CONTADOR, 1996).

The objective is, to maximize PDV,

$$PDV = \sum_{x=0}^{nt} R_x (1+r)^{-x} - \sum_{x=0}^{nt} C_x (1+r)^{-x}$$

Where:
C_x = costs in year x;
R_x = revenue in year x;
r = annual discount rate;
t = rotation age in years;
n = cuttings between establishment of the stands (original planting and coppicings);

2.2. Production function

For estimating wood production the Gompertz function was used.

$$y = k(1 - e^{-a.e^{b.m}}) \quad (1)$$

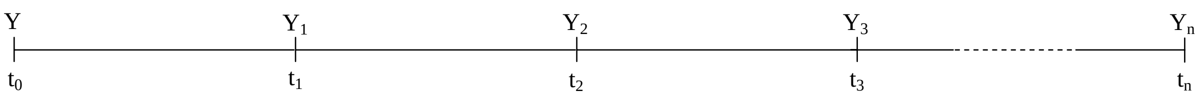
where:
K; a; and b = are coefficients
m = the age of the stand in months
e = The base of neperian logarithms
Y = Wood production volume in mst/ha.

As it stands now, the volume (Y) would be the same for the some age projected to future plantations. In order to depict the dynamic situation wanted (technological progress), it is necessary to modify the production function adequately. A certain level of technological change always exists. It seems reasonable to think about a periodical rate of volume increase overtime to model technological progress. Thus starting with equation (1), if Y is constant, the production of any original plantation would be the same, but if Y increases with technology, then in the next cycle we woud have $Y_1 = Y + \Delta Y$. To simplify and facilitate modeling we may imagine ΔY as the annual rate of increase in Y and rewrite equation (1) as:

$$y_i = y(1 + j_i)^{t_i} \quad (2)$$

where:
j_i = the annual rate of increase in Y
t_i = rotation age in years.

Below, it is shown a situation in which volume increases:



Where:

$Y_1 = Y(1+j_1)^{t1}$;

$Y_2 = Y(1+j_1)^{t1}(1+j_2)^{t2}$;

:

$Y_n = Y(1+j_1)^{t1}....(1+j_n)^{tn}$.

Where Y_1, Y_2,..., Y_n are the volume (productivities) of original plantations. Considering that the rotations are equal (period of parcels occurrence), then, simplifying for sake of modeling, we have:

$$j_1 = j_2 = j_3 = \ldots\ldots\ldots\ldots = j_n = j$$

$$t_1 = t_2 = t_3 = \ldots\ldots\ldots\ldots = t_n = t$$

Then:

$Y_1 = Y(1+j)^t$;

$Y_2 = Y(1+j)^{2t}$;

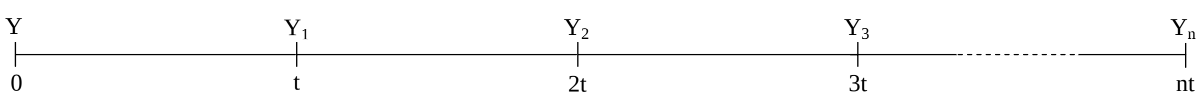
:

$$Y_n = Y(1 + j)^{nt} \quad (3)$$

Where:
n = number of plantings;
nt = years between the first planting and the last cutting.

The production of the coppicings benefits, only indirectly, of the technological progress. Each coppicing is related to the volume of the plantation that originates it, here assumed to be a fix percentage of the original planting volume. Therefore, when the rate of technological progress is higher, it is expected that the number of coppicings between plantations decrease, because the volume of the new planting will benefited from the new technology.

If substitution (reforma) occurs after the first harvesting (no coppicing) in "n" plantations, then:



Where:

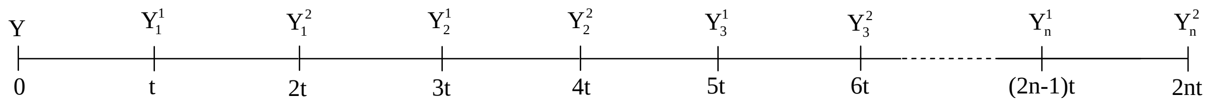
$Y_1 = Y(1+j)^t$

$Y_2 = Y(1+j)^{2t}$

:

$Y_n = Y(1+j)^{nt}$

If substitution occurs after two harvesting (one coppicing) in "n" plantations, then:



Where:

$Y_1^1 = Y(1+j)^t$

$Y_1^2 = Y.\beta(1+j)^t$

$Y_2^1 = Y(1+j)^{3t}$

$Y_2^2 = Y.\beta(1+j)^{3t}$

$Y_3^1 = Y(1+j)^{5t}$

$Y_3^2 = Y.\beta(1+j)^{5t}$

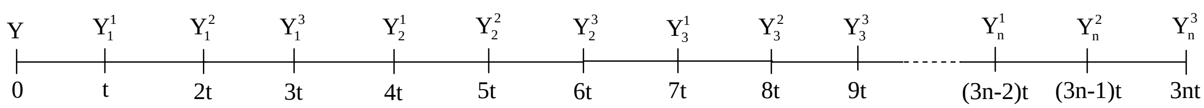
⋮

$Y_n^1 = Y(1+j)^{(2n-1)t}$

$Y_n^2 = Y.\beta(1+j)^{(2n-1)t}$

Where β is the factor that corrects or related the volume of the plantation to the first coppicing or the volume of one coppicing to the following one. For the case study developed here β was set at 0.90 (or 90%).

If substitution occurs after three cuttings (two coppicings) and n plantations, then:



Where:

$Y_1^1 = Y(1 + j)^t$

$Y_1^2 = Y.\beta(1 + j)^t$

$Y_1^3 = Y.\beta^2 (1 + j)^t$

$Y_2^1 = Y(1 + j)^{4t}$

$Y_2^2 = Y.\ \beta\ (1 + j)^{4t}$

$Y_2^3 = Y.\ \beta^2\ (1 + j)^{4t}$

$Y_2^3 = Y.\ \beta^2\ (1 + j)^{4t}$

$Y_2^3 = Y.\ \beta^2\ (1 + j)^{4t}$

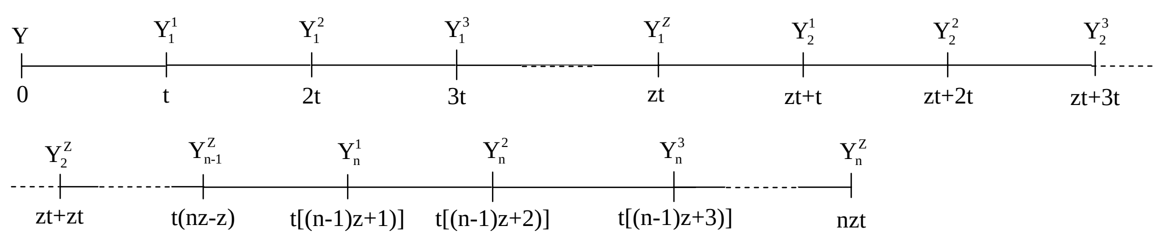
⋮

$Y_n^1 = Y(1 + j)^{(3n-2)t}$

$Y_n^2 = Y.\ \beta\ (1 + j)^{(3n-2)t}$

$Y_n^3 = Y.\ \beta^2\ (1 + j)^{(3n-2)t}$

Generalizing, if we have "z" cuttings and "n" plantations, then:



Where:

$Y_1^1 = Y(1 + j)^t$

$Y_1^2 = Y.\beta\ (1 + j)^t$

$Y_1^3 = Y.\beta\ ^2(1 + j)^t$

$\vdots$

$Y_1^z = Y.\beta\ ^{z-1}(1 + j)^t$

$Y_2^1 = Y(1 + j)^{t(z+1)}$

$Y_2^2 = Y.\beta(1 + j)^{t(z+1)}$

$Y_2^3 = Y.\beta^2(1 + j)^{t(z+1)}$

$\vdots$

$Y_2^z = Y.\beta^{z-1}(1 + j)^{t(z+1)}$

$Y_3^1 = Y(1 + j)^{t(2z+1)}$

$Y_3^2 = Y.\beta(1 + j)^{t(2z+1)}$

$Y_3^3 = Y.\beta^2(1 + j)^{t(2z+1)}$

$\vdots$

$Y_3^z = Y.\beta^{z-1}(1 + j)^{t(2z+1)}$

$\vdots$

$Y_n^1 = Y(1 + j)^{t[(n-1)z+1]}$

$Y_n^2 = Y.\beta(1 + j)^{t[(n-1)z+1]}$

$Y_n^3 = Y.\beta^2(1 + j)^{t[(n-1)z+1]}$

$\vdots$

$Y_n^z = Y.\beta^{z-1}(1 + j)^{t[(n-1)z+1]}$

Where:

Y_1^1 is the volume of the first cutting of the first plantation;

Y_1^2 is the volume of the second cutting of the first plantation;

Y_n^z is the volume of the z-th cutting of the n-th plantation;

However, as it stands, equation (3) does not represent the real world given that the rate "j" does not have the same behavior along the time. It was necessary to introduce a moderator that applied to the rate "j" allowed the volume to increase at a decreasing rate, avoiding the volume to reach unreal values.

The last squeme started with the volume Y that refers to the outgoing plantation. In the case of substitution after 2 cuttings (one copping) we have that Y_1^1 represents the volume of the first cutting of the first plantation, Y_1^2, Y_n^2 represents the volume of the second cutting of the "n" plantation.

$$Y_1^1 = Y\left[1 + j(1-u)^t\right]^t$$

$$Y_1^2 = Y.\beta\left[1 + j(1-u)^t\right]^t$$

$$Y_2^1 = Y.\left[1 + j(1-u)^{3t}\right]^{3t}$$

$$Y_2^2 = Y.\beta\left[1 + j(1-u)^{3t}\right]^{3t}$$

$$Y_3^1 = Y.\left[1 + j(1-u)^{5t}\right]^{5t}$$

$$Y_3^2 = Y.\beta\left[1 + j(1-u)^{5t}\right]^{5t}$$

$$\vdots$$

$$Y_n^1 = Y.\left[1 + j(1-u)^{(2n-1)t}\right]^{(2n-1)t}$$

$$Y_n^2 = Y.\beta\left[1 + j(1-u)^{(2n-1)t}\right]^{(2n-1)t}$$

where "u" is the rate of decrease in "j".

If substitution occurs after three cuttings and "n" plantations with "j" decreasing at the rate of "n", we have:

$$Y_1^1 = Y\left[1 + j(1-u)^t\right]^t$$

$$Y_1^2 = Y.\beta\left[1 + j(1-u)^t\right]^t$$

$$Y_1^3 = Y.\beta^2\left[1 + j(1-u)^t\right]^t$$

$$Y_2^1 = Y\left[1 + j(1-u)^{4t}\right]^{4t}$$

$$Y_2^2 = Y.\beta\left[1 + j(1-u)^{4t}\right]^{4t}$$

$$Y_2^3 = Y.\beta^2\left[1 + j(1-u)^{4t}\right]^{4t}$$

$$\vdots$$

$$Y_n^1 = Y.\left[1 + j(1-u)^{(3n-2)t}\right]^{(3n-2)t}$$

$$Y_n^2 = Y.\beta\left[1 + j(1-u)^{(3n-2)t}\right]^{(3n-2)t}$$

$$Y_n^3 = Y.\beta^2\left[1 + j(1-u)^{(3n-2)t}\right]^{(3n-2)t}$$

If we have "z" cuttings and "n" plantations, then:

$$Y_1^1 = Y\left[1 + j(1-u)^t\right]^t$$

$$Y_1^2 = Y.\beta\left[1 + j(1-u)^t\right]^t$$

$$Y_1^3 = Y.\beta^2\left[1 + j(1-u)^t\right]^t$$

.
.
.

$$Y_1^z = Y.\beta^{z-1}\left[1 + j(1-u)^t\right]^t$$

$$Y_2^1 = Y\left[1 + j(1-u)^{t(z+1)}\right]^{t(z+1)}$$

$$Y_2^2 = Y.\beta\left[1 + j(1-u)^{t(z+1)}\right]^{t(z+1)}$$

$$Y_2^3 = Y.\beta^2\left[1 + j(1-u)^{t(z+1)}\right]^{t(z+1)}$$

.
.
.

$$Y_2^z = Y.\beta^{z-1}\left[1 + j(1-u)^{t(z+1)}\right]^{t(z+1)}$$

$$Y_3^1 = Y\left[1 + j(1-u)^{t(2z+1)}\right]^{t(2z+1)}$$

$$Y_3^2 = Y.\beta\left[1 + j(1-u)^{t(2z+1)}\right]^{t(2z+1)}$$

$$Y_3^3 = Y.\beta^2\left[1 + j(1-u)^{t(2z+1)}\right]^{t(2z+1)}$$

.
.
.

$$Y_3^z = Y.\beta^{z-1}\left[1 + j(1-u)^{t(2z+1)}\right]^{t(2z+1)}$$

$$\vdots$$

$$Y_n^1 = Y\left[1 + j(1-u)^{t[(n-1)z+1]}\right]^{t[(n-1)z+1]}$$

$$Y_n^2 = Y.\beta\left[1 + j(1-u)^{t[(n-1)z+1]}\right]^{t[(n-1)z+1]}$$

$$Y_n^3 = Y.\beta^2\left[1 + j(1-u)^{t[(n-1)z+1]}\right]^{t[(n-1)z+1]}$$

$$\vdots$$

$$Y_n^z = Y.\beta^{z-1}\left[1 + j(1-u)^{t[(n-1)z+1]}\right]^{t[(n-1)z+1]} \qquad (4)$$

Equation (4) represents proposed model for determining the volume of n-th plantation with z-th cuttings each, considering that the volume of each plantation increases at the rate "j", which in turn decreases at the rate "n" per year.

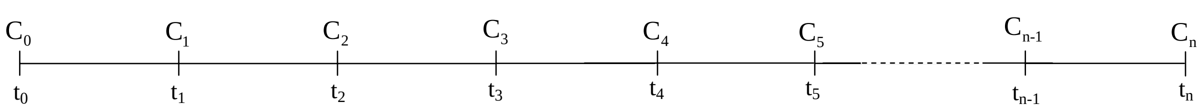
2.3. Revenues

The gross revenue (RB) is obtained by:

$$RB = Y * P \qquad (5)$$

Where "P" is the market price per unit of Y.

The discounted net worth (DNW) of RB of equation (5) is:



(6)

It is worth keeping in mind that the value between { } is the equivalent value of the volume in the period considered.

2.4. Costs

The costs that occur in a wood production cycle can be divided as follows:

- Initial costs: occur in the year "0" or at the very land preparation, pest control, fertilizers, seedlings, planting, ant control, chemical weed cleaning, etc.

- Maintenance costs: these costs are incurred from year 1 till the harvesting, encompassing silvicultural inventory, administration, harvesting, etc.

- Regeneration costs: are the costs incurred with the maintenance of coppicings. Are very much the same types of the maintenance costs.

Table 1 shows the cost level used. They represent the average cost of forest enterprise of the cerrado area in Minas Gerais State.

Other costs used were:

- Discount rate: 8% p.a.
- Lumber price: US$ 15.00/mst
- Lumber price in the 60's: US$ 12.00/mst
- Harvesting cost in the 60's: US$ 6.00/mst.
- Harvesting cost: US$ 2.00/mst
- Area cleaning before harvesting: US$ 48.00/ha (in the 60's)
- Area cleaning before harvesting: US$ 16.00/ha

One must be aware that the cost flow is somewhat different from the revenue one. While the revenue captures the effect of technological progress at the end of each rotation, the costs may capture these effects along the rotation period.

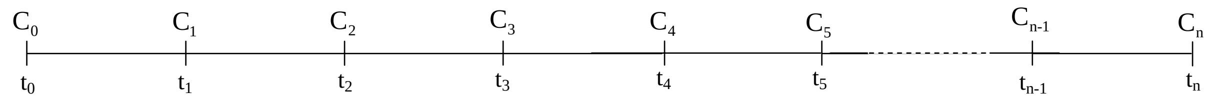
Table 1 – Costs incurred.

Tabela 1 – *Planilha de custos.*

Planting cost	Costs in the 60's (US$/ha)	Current cost (US$/ha)	Year of occurrence*
Land preparation	331.11	110.37	0
Chemical weed cleaning	134.19	44.73	0
Fertilizer	192.60	64.20	0
Seedlings	357.54	119.18	0
Planting	87.72	29.24	0
Others	696.84	232.28	0
Maintenance cost	**Costs in the 60's (US$/ha)**	**Current cost (US$/ha)**	**Year of occurrence**
Silvicultural operations	253.95	84.65	1
	95.61	31.87	2
	16.08	5.36	3 a t
Fertilizer	98.97	32.99	1
	16.62	5.54	2
Weed control	24.63	8.21	1 to t
Fire control	10.20	3.40	1 to t
Forest inventory	6.15	2.05	1 to t
Other	61.05	20.35	1
	22.17	7.39	2
	8.85	2.95	3 to t
Regeneration cost	**Costs in the 60's (US$/ha)**	**Current cost (US$/ha)**	**Year of occurrence**
Silvicultural operations	60.63	20.21	1
	123.33	41.11	2
Fertilizer	561.06	187.02	1
Weed control	37.56	12.52	1
	24.63	8.21	2 to t
Fire control	10.20	3.40	1 to t
Forest inventory	6.09	2.03	1 to t
Other	107.7	34.90	1
	25.47	8.49	2
	6.33	2.11	3 to t

*Year.

To show how technological progress affects each cost type would be difficult and complex, so for the sake of modeling we will reduce all costs to the average establishment cost of the Eucalyptus spa. Therefore, the establishment cost will have the following behavior along time:



Where:
C = planting cost of 1 ha of *Eucalyptus* sp;
n = number of plantings (establishments);
t = rotation in years.

As shown above establishment cost are fixed along time don't benefiting from the reduction brought about by the technological progress. The effect of the technological progress on cost change the situation in which $C_0 = C_1 = C_2 = ... = C_n$ to a situation in which $C_1 = C_0 - \Delta C_0$; $C_2 = C_1 - \Delta C_1$, etc. For sake of modeling we may take the cost reduction along time as a percentage rate "h" along time and write that:

$$C_1 = C_0(1 - h_i)^{t_i} \qquad (7)$$

Where:
C_0 = original establishing cost
C_1 = cost of the first planting after the original establishment;
h_i = annual rate of decreasing in cost (C) in the period t_i (rotation);

Then, it can be written that:

$C_1 = C_0 (1 - h_1)^{t1}$
$C_2 = C_0 (1 - h_1)^{t1} (1 - h_2)^{t2}$
$C_3 = C_0 (1 - h_1)^{t1} (1 - h_2)^{t2} (1 - h_3)^{t3}$
$\vdots$
$C_n = C_0 (1 - h_1)^{t1} (1 - h_2)^{t2} (1 - h_3)^{t3} ...... (1 - h_n)^{tn}$

For the sake simplification and modeling, it is assumed that:

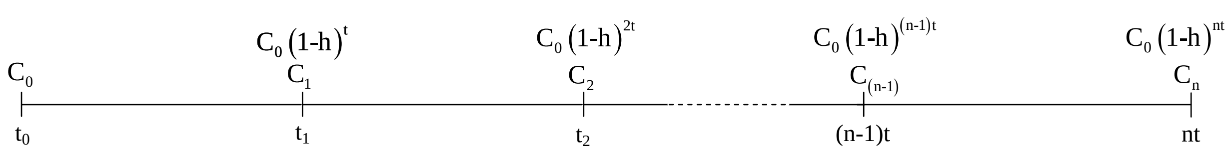
$h_1 = h_2 = h_3 = ... = h_n = h$
$t_1 = t_2 = t_3 = ... = t_n = t$

Then:

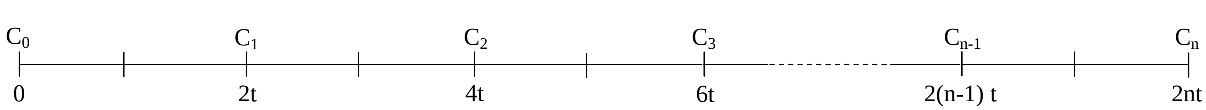
$C_1 = C_0 (1 - h)^t$
$C_2 = C_0 (1 - h)^{2t}$
$\vdots$
$C_n = C_0 (1 - h)^{nt}$

Surely one could specify each cost type and model the situation accordingly. The various situations in which substitution (reforma) may occur are specified below:

For the case of substitution after each cutting (no coppicing) we can write:



If substitution occurs after two cuttings (one coppicing) then we may write:



So that;

$C_1 = C_0(1 - h)^{2t}$

$C_2 = C_0(1 - h)^{4t}$

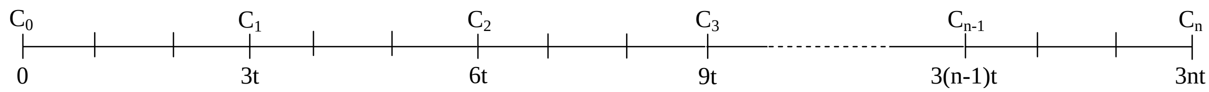
$C_3 = C_0(1 - h)^{6t}$

$\vdots$

$C_{n-1} = C_0(1 - h)^{2(n-1)t}$

$C_n = C_0(1 - h)^{2nt}$

For the case in which substitution occurs after three cuttings (2 coppicings) Then:



Then:

$C_1 = C_0(1 - h)^{3t}$

$C_2 = C_0(1 - h)^{6t}$

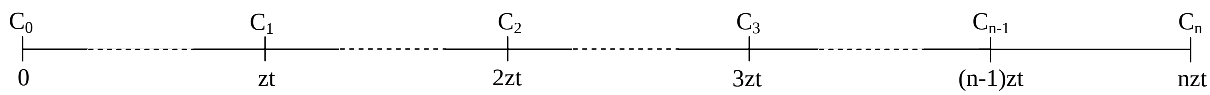
$C_3 = C_0(1 - h)^{9t}$

$\vdots$

$C_{n-1} = C_0(1 - h)^{3(n-1)t}$

$C_n = C_0(1 - h)^{3nt}$

For the case of substitution occurring after "z" cuttings ("z-1" coppicings) we may write:



Then:

$C_1 = C_0(1 - h)^{zt}$

$C_2 = C_0(1 - h)^{2zt}$

$C_3 = C_0(1 - h)^{3zt}$

$\vdots$

$C_{n-1} = C_0(1 - h)^{(n-1)zt}$

$C_n = C_0(1 - h)^{nzt}$

Equation 7, however, does not represent the real world, because the rate of decrease in cost "h" does not have the same behavior along time. As was done for the volume we need to introduce a factor of correction in this rate in order to make the cost to decrease at a decreasing rate, avoiding the cost (c) to reach unreal values (too low). Therefore we may say that "h" decrease at the rate "w" by year. Then for the case of substitution after one cutting (no coppicing) we can write:

Where:

$$C_1 = C_0\left[1 - h(1 - w)^t\right]^t$$

$$C_2 = C_0\left[1 - h(1 - w)^{2t}\right]^{2t}$$

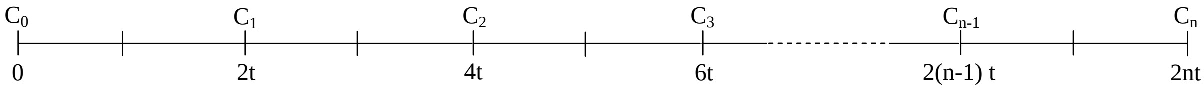
$$C_3 = C_0\left[1 - h(1 - w)^{3t}\right]^{3t}$$

$\vdots$

$$C_{n-1} = C_0\left[1 - h(1 - w)^{(n-1)t}\right]^{(n-1)t}$$

$$C_n = C_0\left[1 - h(1 - w)^{nt}\right]^{nt}$$

For the case of substitution after 2 cuttings (or coppicing) then:



Where:

$$C_1 = C_0\left[1 - h(1-w)^{2t}\right]^{2t}$$

$$C_2 = C_0\left[1 - h(1-w)^{4t}\right]^{4t}$$

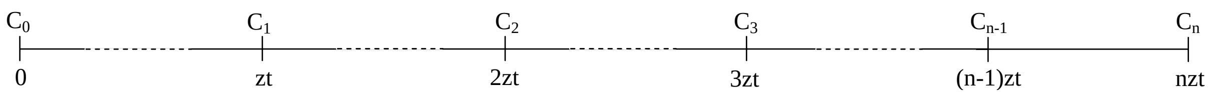
$$C_3 = C_0\left[1 - h(1-w)^{6t}\right]^{6t}$$

$$\vdots$$

$$C_{n-1} = C_0\left[1 - h(1-w)^{2(n-1)t}\right]^{2(n-1)t}$$

$$C_n = C_0\left[1 - h(1-w)^{2nt}\right]^{2nt}$$

If substitution is done after "z" cuttings, then:



Where:

$$C_1 = C_0\left[1 - h(1-w)^{zt}\right]^{zt}$$

$$C_2 = C_0\left[1 - h(1-w)^{2zt}\right]^{2zt}$$

$$C_3 = C_0\left[1 - h(1-w)^{3zt}\right]^{3zt}$$

$$\vdots$$

$$C_{n-1} = C_0\left[1 - h(1-w)^{(N-1)zt}\right]^{(n-1)zt}$$

$$C_n = C_0\left[1 - h(1-w)^{nzt}\right]^{nzt} \quad (8)$$

Where all variables are as defined before.

Equation 8 is the proposed model for capturing the effect of decreasing cost in the future. So, The Present Worth of Cost (PWC) is given by:

$$PWC = C_0 + C_1(1+r)^{-zt} + C_2(1+r)^{-2zt} + C_3(1+r)^{-3zt} + \ldots + C_n(1+r)^{-nzt} \quad (9)$$

To test the validity and accuracy of the model a case study considering the cost and volumes of 1 ha of *Eucalyptus spp.*, in cerrado region of Minas Gerais State is considered. Volumes and costs were taken along the time span 1960-2000 and using the proposed model projected to the period 2000-2040. With these information "j"and "h" and "u"and "w" will be determined for the period of 1960 till 2000.

3 RESULTS AND DISCUSSION

3.1 The Model

For modeling volume increase and cost reduction along time (1960-2000), Table 2, data from IBDF (1974) and on going data were used. The first step was to determine the average rate of volume increase "j" and cost decrease "h" in the period. It was found j = 15% p.a. and h=3% p.a. However, as can be derived from Table 2, these rates did not maintained constant along the period but were declining with time. So, as explained in the methodology a moderator rate factor, respectively, for volume increase and cost decrease, "u" and "w" were calculated using the model. It was found that u = 2.3% p.a. and w = 0,26 p.a. For projecting these rates for the future the same criteria was used. However, the volume and costs for 2,040 were considered not to exceed the values of around 400 mst/ha at rotation age and costs not below US$ 400.00/ ha. This figure is considered by entrepreneurs and technicians to be the limit achievable. So, the values encountered were 0.7218%; 0.1%; 1.00% and 0.05% p.a., respectively for j, u, h, and w.

The model presents the shortcoming of not bringing about consistent result for periods longer than 40 years. This happens because the expressions $[1+j(1+u)^{nt}]^{nt}$ and $[1-h(1-w)^{zt}]^{zt}$ increases and decrease with nt and zt, respectively up to certain values, however this expected behavior reverts after certain joing in which volume decrease and cost increases. Figures 1 and 2 show, respectively, the behavior of volumes and costs along time.

It is worth to keep in mind that those limitations are valid for Cerrado of Minas Gerais State, for other regions they are, surely, different.

The proper route of technological progress explains the higher rates for the period of 1960-2000 as compared to those of the period 2000-2040. The very high rates obtained at the 60's and 70's prove that technology of wood production at that time were incipient.

In the period 1960-2000 the volume/ha increased rapidly, showing that technology was poor and far from the potential. For the period 2000-2040 the rate of technological progress decreased substantially tending to stabilization.

Figure 2 shows that establishment costs behave other way round as compared to volume, i. e. decreased with time. Again the cost declined quite rapidly between 1960 and 2000 due to the higher rate of technological progress, decreasing and tending to stabilize in the period 2000-2040.

3.2 Rotation age

The optimal economic rotation age was determined at first. The knowledge of this of parameter is the starting point for the determination of the optimal substitution cycle (reforma). The optimal rotation age was determined using the PNW criterion, taking in an infinite horizon, discount rote at 8% p.a. and the coefficient of the production functions as:

k = 200st/ha
a = -0.07849
b = 0.0370

Table 3 shows that the economic rotation age is set at 7 years of age when the NPW is at its maximum (US$ 1,818.94/ha). This rotation age was taken as constant both for original plantation and coppicings, taking into consideration that for practical purposes this is the case, Lopes (1990). The fact that NPW was positive indicates that the project is economically feasible.

3.3 Substitution chain

The study of the substitution chain was taken step by step. At first the effect of the technological progress considering the productivity and costs at the starting point of the research, i.e., at 1960. Then, the optical substitution time or cycle (reforma) was determined using current data (2000); finally, using the model proposed the optimal substitution age for 40 years in the future, considering the estimated technological progress was determined.

Table 2 – Technological effect and volume production and establishment cost of 1 (one) ha of *Eucalyptus spp* in the periods 1960-2000 and 2000-2040.

Tabela 2 *– Efeito do progresso tecnológico na produtividade e nos custos de implantação de 1 há de floresta de Eucalyptus spp entre os períodos de 1960-2000 e 2000-2040.*

Decade	Volume (st/ha)	Cost (US$/ha)	Decade	Volume (st/ha)	Cost (US$/ha)
1960	30,00	1,800.00	2000	300,00	600.00
1970	92,23	1,337.75	2010	322,14	542.89
1980	181,52	1,009.42	2020	345,43	491.67
1990	259,99	772.86	2030	369,88	445.71
2000	300,00	600.00	2040	395,53	404.42

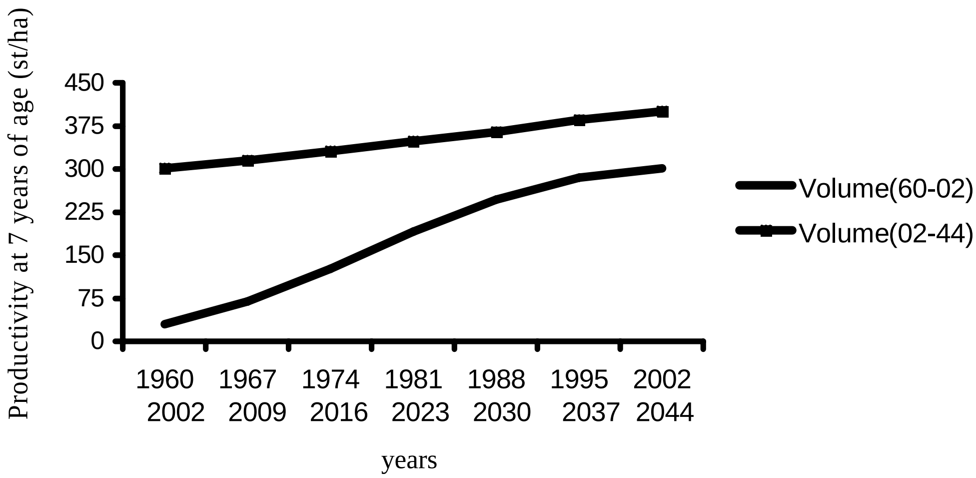


Figure 1 – Volume/ha evolution from 1960-2000 and its projection for the period 2000-2040 for *Eucalyptus* spp in the cerrado area of Minas Gerais State.

***Figura 1** – Evolução da produtividade volumétrica de Eucalyptus spp em áreas de cerrado no estado de Minas Gerais para o período 1960-2000 e sua projeção para o período 2000-2040.*

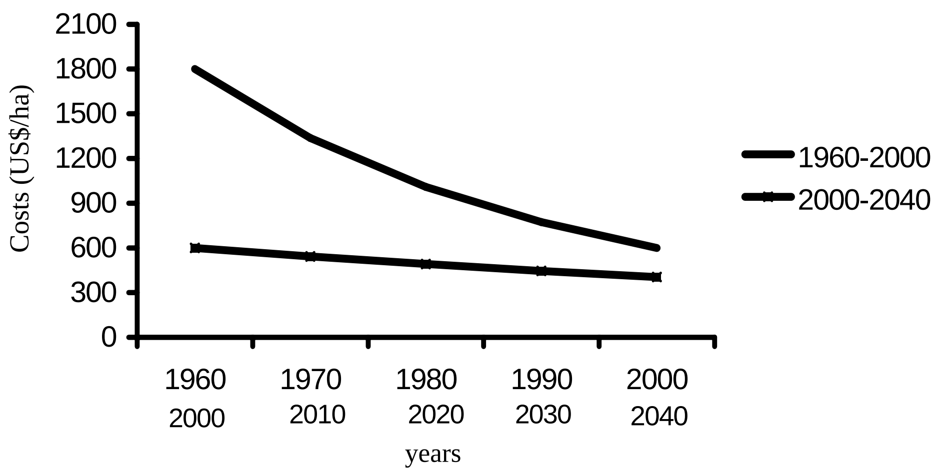


Figure 2 – Establishment cost reduction in the period 1960-2000 and its projection for the period 2000-2040 for *Eucalyptus* spp in the Cerrado of Minas Gerais State.

***Figura 2** – Decréscimo dos custos de implantação de florestas de Eucalyptus spp em áreas de cerrado no estado de Minas Gerais para o período 1960-2000 e projeção do decréscimo para o período 2000-2040*

The productivity in 1960 was taken as 92.23 st/ha, at rotation age. The cost were considered as been 3 times the on going cost, exception was made to the land cost that was taken as the annual interest cost at the rate of 8% p.a. Table 4 shows how the optimal substitution time, or cycle, was determined for an *Eucalyptus spp.* stand established in the 60's.

It can be seen that the Present Worth of Costs decreases as the number of cutting (coppicings) between plantation increases. This is so because as the number of coppicings increases, the number of substitutions decreases in the same planning horizon (infinite) and coppicing costs are lower than establishment costs.

Table 3 – NPW and volume for several ages of *Eucalyptus* spp. stands, for a discount rate of 8% p.a.

***Tabela 3 –** VPL e volume para diversas idades de um povoamento de Eucalyptus spp, para uma taxa de desconto de 8% a.a.*

age (years)	Volume (st/ha)	NPW (US$/ha)
1	28,16	-6,219.11
2	44,18	-2,785.85
3	68,10	-1,172.02
4	12,11	-72.29
5	146,86	806.83
6	198,80	1,470.12
7	248,19	1,818.94
8	282,44	1,787.15
9	296,94	1,470.01
10	299,82	1,075.04

Table 4 – The optimal substitution time (reforma) of *Eucalyptus* spp plantation established in 1960, in Minas Gerais State.

***Tabela 4 –** Momento ótimo de substituição (reforma) de povoamentos de Eucalytpus spp implantados na década de 80, no estado de Minas Gerais.*

Cutting number	Revenue (US$/ha)	Costs (US$/ha)	NPW_{∞} (US$/ha)
1	5,462.89	5,091.74	371.23
2	5,261.59	4,301.91	959.62
3	5,261.59	4,042.90	1,070.63
4	5,007.67	3,920.88	1,086.78
5	4,933.98	3,855.07	1,078.90

Table 5 shows the behavior of the optimal substitution time in the period 1960 to 2000.

The effect of increasing revenues due to the increase in volume productivity and cost reduction along the studied period was analyzed.Up until 1970 it was negative and the number of cuttings very high. At this time entrepreneurs were minimizing loss rather than maximizing profits. In practice the number of cuttings were never that high, because the tax exemption program was still working, rendering the substitution a better deal than maintaining and old stand of very low productivity through coppicings. When the NPW became positive in the beginning of the 80's the optimal number of coppicings decreased quickly reaching 2 in the 90's.

The reaction of the tax exemption program and its complete extinction is in 1985 according to what is shown in Table 5 is economically sound.

The future situation can be seen in Table 6, is which a similar situation to that shown in Table 5 is depicted, but projected to the future, period 2000-2040.

Table 5 – The effect of technological progress in the number of cuttings of *Eucalyptus* sp stands, before substitution in the period 1960-2000.

Tabela 5 – *Efeito do progresso tecnológico no número de cortes que antecederam à substituição de povoamentos de Eucalyptus spp no período de 1960-2000.*

Decade	Cutting number	Revenues (US$/ha)	Costs (US$/ha)	NPW_∞ (US$/ha)
1960	19	1,699.90	5,011.24	-3,311.45
1970	8	3,326.52	4,227.73	-913.48
1980	4	4,427.22	3,466.40	1,086.80
1990	3	4,708.18	2,764.08	2,426.05
2000	2	3,987.22	2,011.55	2,995.53

Table 6 – The effect of technological progress on the number of cuttings of Eucalyptus spp. plantations before substitution, in the period 2000-2040.

Tabela 6 – *Efeito do progresso tecnológico no número de cortes que antecederão à substituição de povoamentos de Eucalyptus spp no período 2000-2040.*

Decade	Cutting number	Revenue (US$/ha)	Costs (US$/ha)	NPW_∞ (US$/ha)
2000	2	3,987.22	2,011.55	2,995.53
2010	2	4,300.11	1,857.93	3,702.86
2020	2	4,611.00	1,716.84	4,388.15
2030	2	4,937.32	1,552.15	5,132.71
2040	2	5,279.76	1,472.15	5,773.15

The model projects for the next 4 decades a number of 4 cuttings before substitution. However it is necessary to notice that this is so for β = 0.90, i.e., each coppicing produces a volume of 90% of the previous cutting. However, the number of coppicings is very sensitive to the value of β. For β = 0.91 the number of cuttings goes to 3; for β = 0.93 the number of cuttings reaches 3 in 2010's; for β = 0.94, the number of cutting will reach 3 in 2020's and 2030's; the number of cutting will also be 3 for β = 0.96 in the 2040 decade. This is so because the productivity of the original plantation increases over time, so, in order to the management of a coppicing be economically feasible it is necessary that β also increases; otherwise the new plantation can not be postponed.

4 CONCLUSION

The optimal economic rotation at present is at 7 years of age.

The proposed model showed efficient for determining the productivity increase and cost decrease along time from 1960-2000 and to predict the technological progress from to 2040.

In the 60's investment in *Eucalyptus* spa plantation was not feasible. At that time the optimal number of cuttings of each plantation was high decreasing through time to reach 4 cuttings in the 80's and 2 cuttings at present (2000).

For the future the model shows that optimal number of cuttings will be around 2.

The number of cuttings is very sensitive to the value of β (the rate of productivity decrease of each cutting in relation the previous cutting). As β increases the optimal number of cutting also increases.

5 BIBLIOGRAPHIC REFERENCES

CONTADOR, C.R. **Projetos Sociais - Avaliação e Prática.** 3ª ed. Atlas, São Paulo. 1996. 375p.

DAVIS, K.P. **Forest Management: Regulation and Valuation.** 2nd ed. New York, McGraw-Hill, 1966. 519p.

DE FARO, C. **Elentos de engenharia econômica.** São Paulo, APEC, 1972. 338p.

GRANT, E.L. **Princiles of engineering economy.** New York, Ronald Press Company, 1960.574p.

GUPTA, S.K.; KOZZOLINO, J.M. **Fundamentals of operations research for management: na introduction to qauntitative methods.** San Francisco, 1974. 405p.

HESS, G.; MARQUES, J.L.M.; ROCHA PAES, L.C.M.; PUCCINI, A.L. **Engenharia Econômica.** 18ª ed. Difel. São Paulo, 1985.165p.

IBDF. **Zoneamento Econômico Florestal do Estado de Minas Gerais.** Belo Horizonte – MG, 1974. 182p.

JELEN, F.C. **Cost and optmization engineering.** New York, McGraw-Hill, 1970. 490p.

LOPES, H.V.S.; **Análise Econômica dos Fatores que Afetam a Rotação de Povoamentos de Eucaliptos.** Viçosa, U.F.V., 1990. 188p. (Tese M.S.).

MASSÉ, P. **Optimal Investiment Decisions Rules for Action and Criteria Choice.** Prentice. Hall, Inc. 1962. 500p.

REZENDE, J.L.Pa., PAULA Jr., G.G., RIBEIRO, G.A., Técnicas de Análise Econômicas Usadas na Tomada de Decisão Referentes à Reforma de Eucaliptais. In: **Seminário Sobre Aspectos Técnicos e Econômicos da Reforma de Eucaliptais.** Belo Horizonte, U.F.V./S.I.F., 1987.

REZENDE, J.L.Pb.; MINETTE, L.J.; TORQUATO, M.C. **Determinação da Idade Ótima de Corte para *Eucalyptus* spp, para as Regiões Litorânea, Metalúrgica e do Rio Doce.** Revista Árvore, Viçosa – MG. nº 11, V. I, p. 78-89, 1987.

SILVA, A.A.L., **Análise Econômica da Substituição de Povoamentos de *Eucalyptus* spp.** Viçosa, U.F.V., 1990. 109p. (Tese M.S.).

SIMÕES, J.W. **Formação Manejo e Exploração de Florestas com Espécies de Rápido Crescimento.** Brasília, IBDF, 1981.

SOUZA, A. N. **Estudo econômico da reforma de povoamentos de *Eucalyptus* spp – O caso do progresso tecnológico.** Lavras. UFLA. 1999. 140p.

VALVERDE, S.R.; REZENDE, J.L.P Princípios de Substituição de Máquinas e Equipamentos. **Revista Árvore V.21 n. 1**, SIF. Voçosa,1997.