OPTIMUM ECONOMIC ROTATION FOR *EUCALYPTUS CAMALDULENSIS* PLANTATIONS IN THAILAND

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ABSTRACT

The optimum economic rotation age for eucalypt (*Eucalyptus camaldulensis* Dehn.) plantations established by forest industries and small woodlot owners using intercropping with cassava (*Manihot esculenta* Cantz), was assessed. With a chosen of 10 % discount rate, the economic soil expectation value was maximised with a 10 year rotation age. For the evaluation of an environmental-economic optimum rotation age, on-site benefits in erosion control, costs of water and nutrient consumption, and benefits in carbon sequestration were tentatively valued. The maximum environmental-economic soil expectation value was reached with a 11 year rotation period. The optimum economic rotation age for *Eucalyptus camaldulensis* Dehn. in Thailand was approximately two times longer than presently applied in pulpwood production.

INTRODUCTION

Choice of a rotation age is considered by some as the most important single decision made by a forest manager (Nautiyal, 1988). The rotation age, that denotes the period of time at which even-aged crops are planned to be harvested, influence especially on the mean and maximum growth and yield, quality and size of harvested trees, and economic return on implemented forestry investments. If forestry is run with the objective of maximising profit, the decision on optimum rotation length must be made on an economic basis.

The aim of the study was to evaluate the optimum rotation age for eucalypt (*Eucalyptus camaldulensis* Dehn.) plantations established by forest industries and small woodlot owners using intercropping with cassava (*Manihot esculenta* Cantz) in Thailand. The optimum rotation period was aimed to be evaluated from the points of view of maximum sustainable yield, and financial, economic and environmental-economic profitability.

MATERIAL

Growth and yield assessment

Pohjonen and Pukkala (1994) and Marjokorpi (1995), for example, have

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studied the growth and yield of *Eucalyptus camaldulensis* plantations in Thailand. The study of Marjokorpi (1995) proved to be more significant for this paper, since it was based on systematic field measurements from different site and plantation establish–ment densities.

For plantations established using inter-cropping methods (the so called *taungya* model), growth and yield rates were estimated according to the relative area available for each species. It was assumed that trees will spread their canopies and roots approximately half a meter every year, therefore diminishing the area available for, cassava cultivation (Petmak, 1994; pers. comm.). Intercropping was assumed to be practiced for three years in establishment densities of 2 x 8 (625 seedlings ha^{-1}) and 2 x 4 (1,250 seedlings ha^{-1}) meters, and for one year in an establishment density of 2 x 2 (2,500 seedlings ha^{-1}) meters (Figure 1). The initial estimate for cassava's growth and yield was 13,588 kg $ha^{-1}yr^{-1}$ (Ministry of Agriculture 1993). It was assumed to diminish with the same share as the area for cropping diminished. The growth and yield rate for trees planted with intercropping was assumed to decrease by 15 % from those rates without intercropping.

Financial cost and price data

Financial cost data for industrial refore-station was similar to that used in Thai Forestry Sector Master Plan (Royal Forest Department, 1993). The cost data for tree component in intercropping was derived from Forestry Research Centre (1994), and for cassava cultivation from Wannawong (1989). Material costs were reduced in proportion to plantation density or as the area under cultivation diminished.

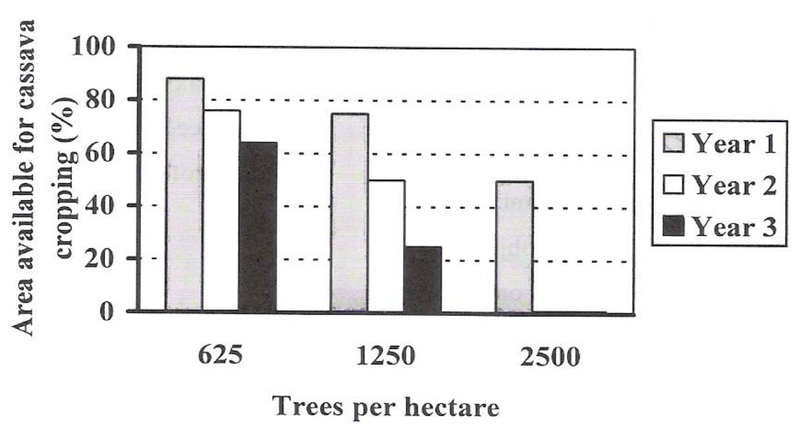

Figure 1. Area available for cassava cropping (%) during the first three years of plantation development at various plantation establishment densities.

For the financial analysis, the unit cost of non-educated labour was set at the rural minimum wage rate of 94 baht per day (Bank of Thailand, 1992). The minimum wage rate was used in the study to allow the comparison of reforestation to other investment possibilities, where the minimum rate applies. The mill gate price of eucalypt wood was estimated to be 1,080 baht ton^{-1}, which was equal to financial stumpage price of 750 baht ton^{-1}, when combined with the estimated transportation costs (Thailand Development Research Institute, 1989; Niskanen *et al.* 1993). The average farm gate price of cassava pellets was 2.3 baht kg^{-1} (Ministry of Agriculture, 1993).

Economic cost and price data

It is acknowledged that economic profitability of reforestation may considerably differ from financial profitability if market prices include price effects of distortions due to market or policy failures (e.g. Nautiyal, 1988). Since *a priori* these price effects were assessed to impact on unit pricing of goods and factors of production also in Thailand, the financial and economic analyses were carried out separately. For economic analysis market prices of factor inputs were replaced by their shadow prices. Principally, price adjustments in shadow pricing were similar to a conventional cost-benefit analysis aimed for finding economically efficient solutions (Little and Mirrlees, 1974; Gittinger, 1982; Squire and van der Tak, 1988; Price, 1989; Ward and Deren, 1991 and Gregersen and Contreras, 1992). The estimated shadow prices were from 0.6-1.1 of the respective market prices (Table 1).

Table 1. The market prices and economic values for land transportation, urea-fertilizer, eucalypt wood, labour and land opportunity cost in Thailand, 1993[1]

Item	Financial (baht)	Economic (baht)	Conversion factor
Land transportation on local roads (m^3 km^{-1})	5.5	4.5	0.82
Land transportation on national roads (m^3 km^{-1})	1.25	1.0	0.80
Urea-fertlizer (kg)	7.0	5.3	0.75
Cassava pellets (kg)	2.3	2.3	1.00
Eucalyptus stumpage (ton)	750	818	1.09
Labour (day)	94	57	0.61
Land (ha)	-	350	-

[1] Niskanen and Saastamoinen (1996)

VALUATION OF ENVIRONMENTAL IMPACTS

Four environmental impacts of tree plantations were valued: on-site benefits in erosion control, costs of water and nutrient consumption, and benefits in carbon sequestration. Including in the assessment was the economically optimum rotation age for *Eucalyptus* plantation.

On-site benefits in erosion control

Although eucalypt trees may impede the growth of understorey vegetation, it is obvious that *Eucalyptus* plantations can reduce soil erosion when compared to occasionally burned and grazed grasslands. The amount of soil erosion with and without reforestation was estimated with the modified universal soil loss equation, MUSLE. Other values for the parameters of MUSLE were similar to those from the study by David (1988) for the Philippines, except the rainfall erosivity index, which was assumed to be only half (R=120) of that in the Philippines (R=240). The estimated gross soil erosion rates were low since the sloping of the soil was cautiously assumed rather moderate (0-18 %) (Table 2).

The replacement cost method (Hufch–midt, 1983; Francisco, 1986; 1994 and Niskanen, 1996) was used to estimate the on-site costs of soil erosion. This involved pricing of the amount of commercial fertilizers that were needed to replace the lost nutrients in eroded material (Niskanen, 1996). It has been assessed that one ton of soil contains 2.3, 0.062 and 0.758 kilograms of nitrogen, available phosphorus, and exchangeable potassium, respectively (Salzer, 1993). In a fertilizer equivalent this means that one ton of soil erosion contains nutrients similar to 5.11, 0.13 and 0.91 kilograms of urea, P_2O_5, and K_2O, respectively, and is economically worth approximately 29.8 baht.

Table 2. The cover factor C (t ha^{-1} yr^{-1}) and gross soil erosion rates (mm yr^{-1}) for different reforestation options on grassland

Land use option	Cover factor (C) in MUSLE	Erosion	
		(t ha^{-1} yr^{-1})	(mm yr^{-1})
Grazing and occasional burning (*status quo*)	0.3	29	2.3
Industrial reforestation	0.08	8	0.6
Intercropping of eucalyptus and cassava	0.2	19	1.5

Costs of nutrient loss in harvesting

The nutrients accumulated in and removed with the harvested trees were also valued with the replacement cost technique. The relative amount of nitrogen, phosphorus, and potassium accumulated in trunks was estimated to be equal to 0.2 %, 0.02 %, and 0.15 % of the stem oven-dry weight, respectively (derived from Evans, 1992, p. 207). Cassava roots were assumed to contain, 15.0, 8.0, and 5.7 kilograms of nitrogen, phosphorus, and potassium, respectively, for every harvested ton (Salzer, 1993) (Table 3).

In Thailand, harvesting of eucalypt wood is often based on whole tree removal. Kimmins (1977) estimated that in whole tree harvesting 1.5 to 4 times more nutrients are removed than in bole only harvesting (cf. Sawyer, 1993). The lowest estimate (1.5) was applied in this study to estimate the total nutrient loss in *Eucalyptus* harvesting.

Costs of transpiration

One way to estimate the transpiration rate of plants is to use a water use efficiency (WUE) ratio, which describes the volume of water (H_2O) in litres that is consumed by a plant during the growing season per kilogram of dry matter (DM) produced. Larcher (1980) estimated that the WUE ratio for C_3 plants would be from 1.25-1.43 g DM l^{-1} H_2O. Jones (1992) estimated that, in general, the transpiration ratio for C_3 plants can vary between 0.88 and 2.65 g DM l^{-1} H_2O. For *Eucalyptus*, the transpiration ratio was set at 1.3 g DM l^{-1} H_2O.

A unit value of water depends on local demand and supply; it could at one end of the scale be equal to zero, and at the other end, to the price of drinking water. In this study the unit value of water was assessed by assuming that the transpired water could be used for irrigation; therefore having relatively constant demand, and value. The net annual value of irrigated rice cultivation was assessed at approximately 2,022 baht ha^{-1} higher than that of non-irrigated rice cultivation (Ministry of Agriculture, 1993). Assuming that 13,000 m^3 of water are required to irrigate rice per hectare per year (Cruz *et al*., 1988) it was possible to estimate the value of the loss-of-earnings (Hufchmidt *et al*., 1983 and Niskanen, 1996) in agriculture due to water consumption in *Eucalyptus* plantations.

Benefits in carbon sequestration

Quantification of annual carbon flows in *Eucalyptus* plantations was based on an assumption that the carbon sequestration by different structures of trees (trunk, foliage, etc.) is depended on the annual stem volume increment (Nabuurs and Mohren, 1993). Decomposition of detritus vegetation and the residence time of carbon in end products

Table 3. The value of nutrients lost due to harvesting (baht ton^{-1})

Species	N	Urea	P	P_2N_5	K	K_2O	Value of lost nutrients (baht)
Eucalyptus (kg t^{-1})	1.8	4.1	0.2	0.5	1.4	1.7	26.0
Cassava (kg t^{-1})	15.0	33.3	8.0	17.3	5.7	6.8	309.2

(Karjalainen *et al.*, 1994), were also included into the estimation of the net carbon flows. It was assumed that the average carbon storage in the existing vegetation on grasslands is equal to 18 Mg C ha^{-1} (Woodwell, 1978 and King *et al.*, 1992), and that it decomposes within four years after plantation establishment. *Eucalyptus* wood was assumed to be used solely for pulp manufacturing.

Shadow price of carbon sequestration can be assumed as being positive; although any exact or core estimates are impossible to determine at present (Price and Willis, 1993; Niskanen *et al.*, 1996). Since plantation forests clearly offer an opportunity for emission control investments, the emission control costs in energy production were chosen as an approach for the valuation. This approach is supported also because international funding (e.g. Global Environmental Facility, GEF) is essential to investments that have an objective to reduce the carbon dioxide concentration of the atmosphere (like emission control and afforestation) in developing countries. The shadow price for carbon flows - 25 USD Mg^{-1} C^{-1} - was therefore similar to the value recommended in the policy paper by GEF for 1993 (Andersson and Williams, 1994). It was assumed to be constant as were the wood prices.

ROTATION FOR MAXIMUM SUSTAINABLE YIELD

The rotation period that maximises total growth and yield of *Eucalyptus* plantations was 12 years in all studied site classes and tree growing densities. Before the 12th year, current annual increment (CAI) was higher than mean annual increment (MAI). At the age of 12 years, the dominant height of *Eucalyptus* plantations was 25.3, 23.5 and 21.8 meters in site classes one, two and three, respectively (Figure 2).

OPTIMUM ECONOMIC ROTATION

The basic principle in the search for an economically optimum rotation period is that it should maximise net present value (NPV) of an investment, or, if multiple rotations are considered, soil expectation value (SEV). The SEV is the present value

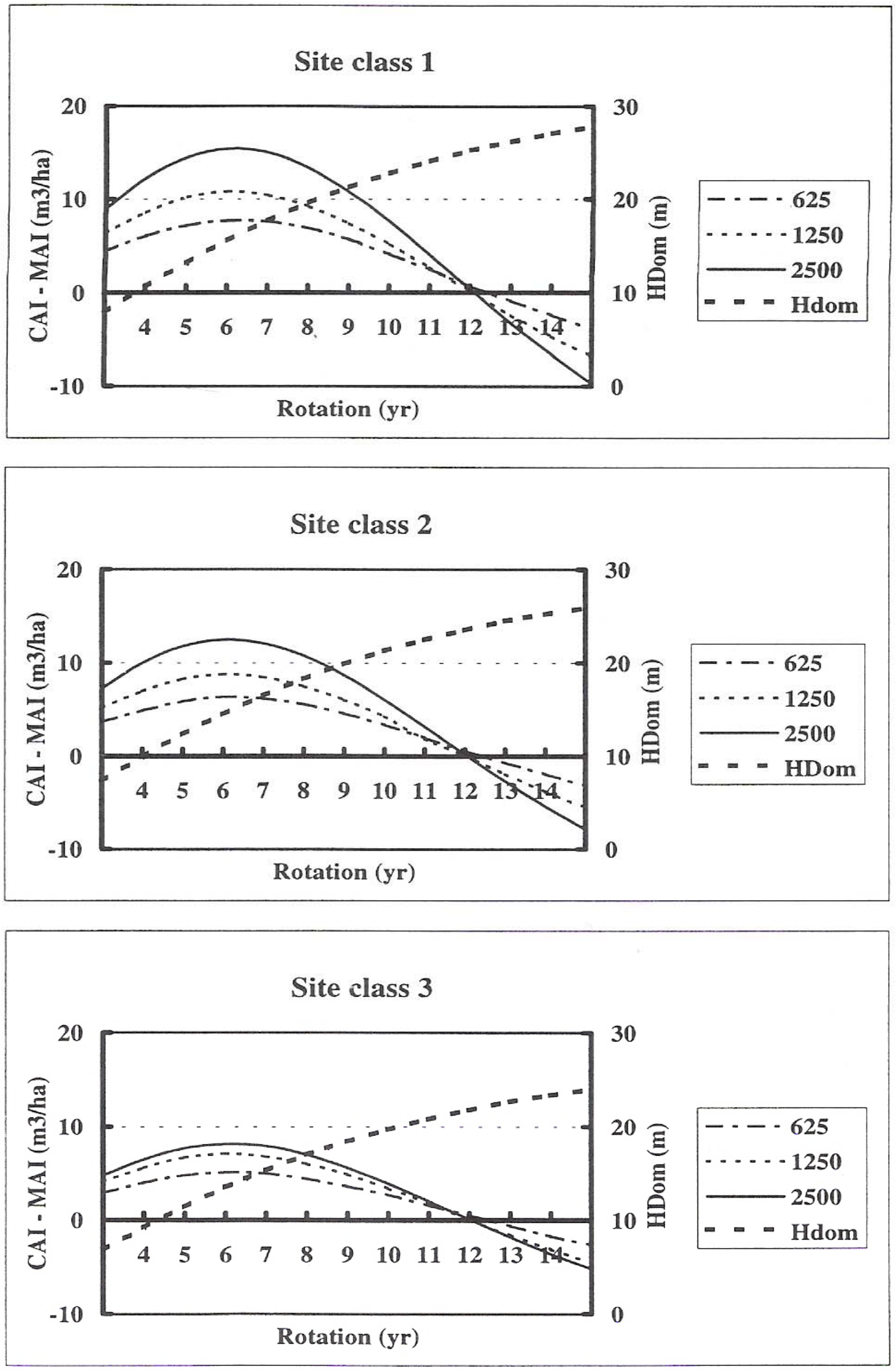

Figure 2. Current annual increment (CAI) minus mean annual increment (MAI) and dominant height (H_{Dom}) at various site classes, rotation periods, and plantation establihment densities. The rotation period that maximises sustainable yield is reached when the CAI minus MAI is equal to zero.

for a perpetual periodic series of the NPVs of single forest rotations. The SEV was assessed with a 10 % discount rate in this study.

$$SEV = NPV((1+r)^t - 1)^{-1}$$

where

SEV Soil expectation value (baht)

NPV Net present value (baht)

r Discount rate (%)

t Rotation age (yr)

On site class one and with a 10 % discount rate, the SEV was highest with 10-12 year rotations and with a growing density of 2,500 trees per hectare. The optimum rotations were shortest when economic profitability criteria was applied, and longest with financial profitability criteria. Especially in intercropping, where the economic costs of nutrient consumption were highest at the beginning, and the economic benefits of carbon sequestration at the end of the rotation, the decrease in the SEV was minor even when the rotation age was increased (Figures 3 and 4).

In industrial reforestation the SEV was higher than in agroforestry based reforestation. This was mainly due to high production costs and low farm gate prices of cassava. An additional reason was the assumed 15 % decrease in the growth and yield of *Eucalyptus* trees in intercropping. Due to lower production costs, *Eucalyptus* planting was economically rather than financially more profitable (Figure 3).

In agroforestry based reforestation the SEV was highest with a growing density of 2,500 trees per hectare. The benefits provided by cassava cropping with lower densities were not able to compensate the assumed 15% decrease in *Eucalyptus* growth (Figure 4).

SENSITIVITY ANALYSIS

Discount rate

With the growing density of 2,500 trees per hectare, the optimum rotation age, with from 5-15 % discount rates, varied between nine and fourteen years. The shortest optimum rotation ages were found with the highest discount rates in economic analysis (Table 4).

Table 4. The optimum financial, economic and environmental-economic rotation age (yr) with 5, 10 and 15 % discount rates.

Afforestation	Discount rate (%)		
option	5	10	15
Industrial reforestation			
Financial	14	12	10
Economic	12	10	10
Environmental-economic	12	11	11
Agroforestry based reforestation			
Financial	12	11	10
Economic	11	10	9
Environmental-economic	10	11	11

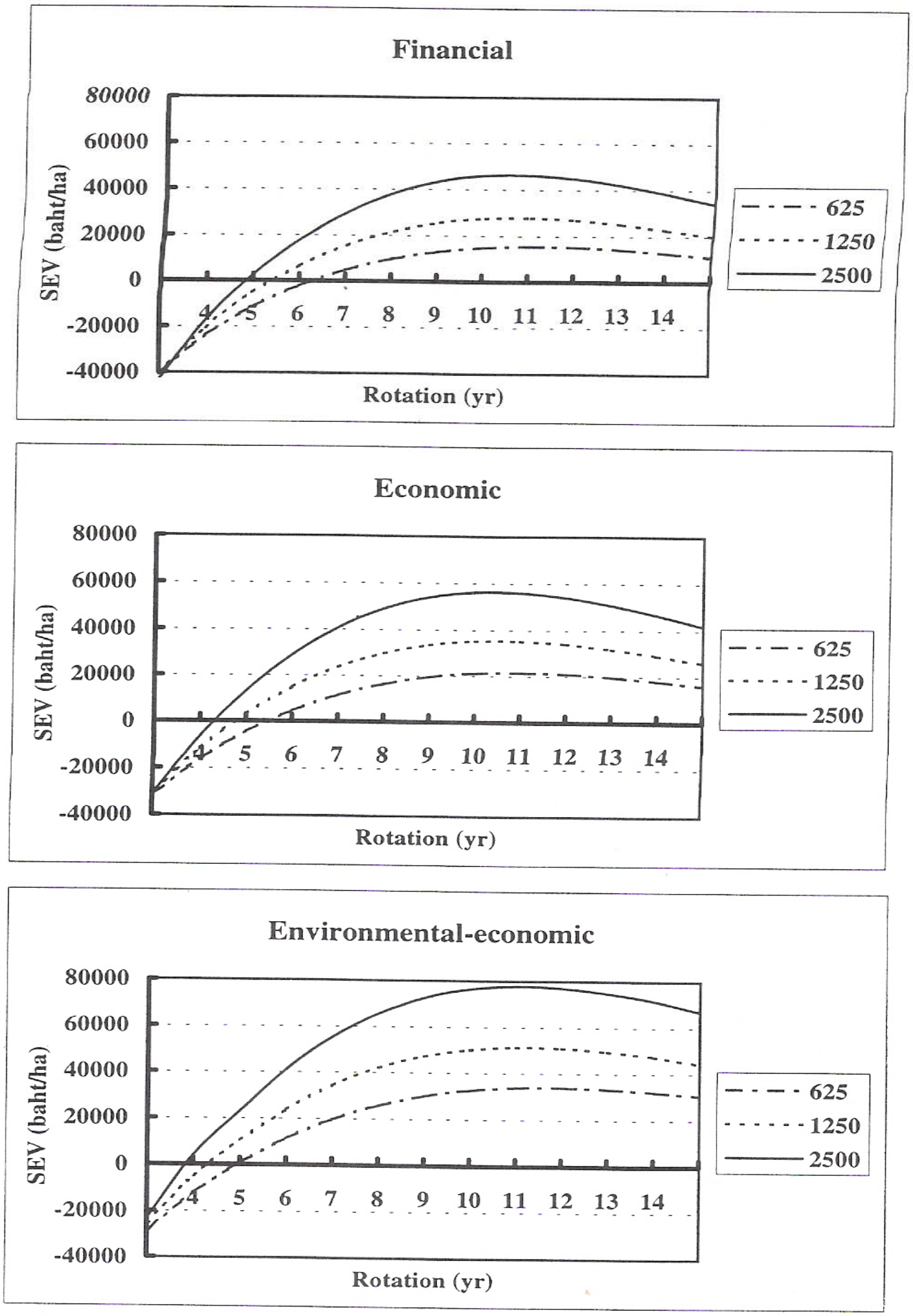

Figure 3. Financial, economic and environmental-economic soil expectation value in industrial contract reforestation at various rotation periods, and different plantation establishment densities on site class one.

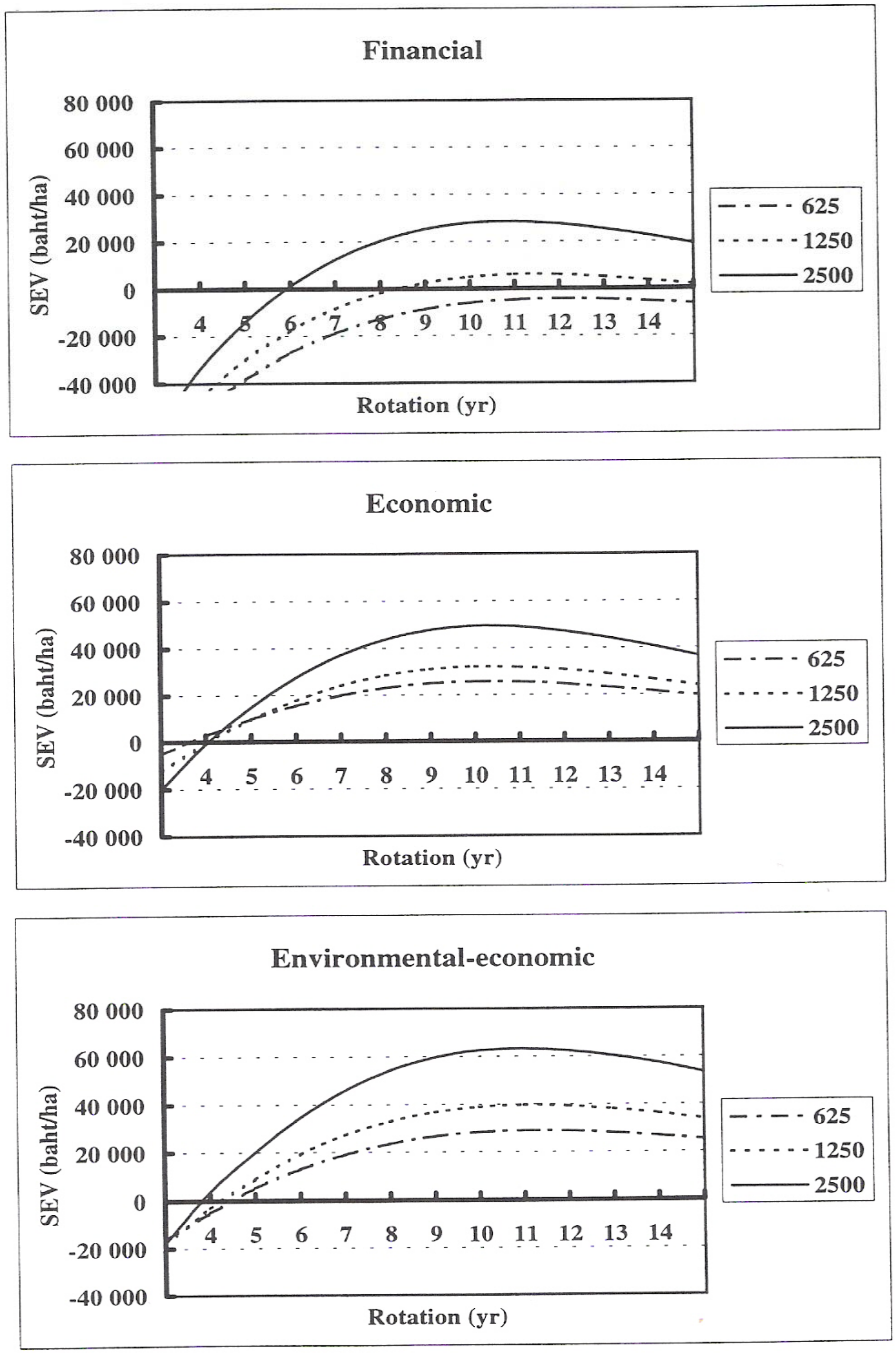

Figure 4. Financial, economic and environmental-economic soil expectation value in agro-forestry based reforestation at various rotation periods, and different plantation establishment densities on site class one.

Unit value of carbon sequestration

The most valuable environmental-economic impact of reforestation was carbon sequestration. It constituted 61 % of the total environmental values of reforestation, compared to that of transpirational water consumption (30 %), nutrient loss in harvesting (6%) and erosion control benefits (3 %). An increase in the constant shadow price for carbon sequestration (25 USD $Mg^{-1}C^{-1}$) lengthened the optimum rotation period. With a growing density of 2,500 trees per hectare, and by neglecting the value of carbon sequestration the optimum rotation age was one year shorter than originally assessed (Table 5).

Table 5. The optimum environmental-economic rotation age (yr) with 0, 25 and 50 USD/Mg C shadow price for carbon sequestration

Afforestation option	Shadow price (USD Mg^{-1} C^{-1}) 0	25	50
Industrial reforestation	10	11	12
Agroforestry based reforestation	10	11	12

DISCUSSION

In principle, inclusion of the interest costs of wood and its land for growth may alter the economically optimum rotation age (Duerr, 1960). These opportunity costs of wood production were not included in the assessment of an economically optimum rotation period in this study. Instead, it was studied how an approach for the basis of unit pricing of costs and benefits (shadow pricing or market pricing), and valuation and inclusion of external environmental impacts may change the economically optimum rotation age.

The age at which a *Eucalyptus* plantation is most economical to harvest in Thailand varied between 9 and 14 years. The shortest rotation periods were for maximising economic profitability with a high discount rate (r=15 %), and the longest for maximising either financial or environmental-economic profitability with a low discount rate (r=5 %). If benefits in carbon sequestration are strongly emphasized, and valued with a higher unit price than in this study, the environmental-economic optimum rotation period is lengthened. On the other hand, if costs of transpirational water consumption are emphasized, the environmental-economic optimum rotation age could be shorter than assessed in this study. When wood production was considered without financial or economic pricing (r=0 %), the optimum rotation period was 12 years.

The profitability of industrial reforestation was higher than that of agroforestry based reforestation. Mainly this was due to high labour costs in cassava cultivation. Wage costs were included as direct costs into the investment profitability calculations to improve the comparability of the profitability estimates among land management alternatives. In reality, however, farmers do not pay salaries for themselves, but get compensation for own labour input by selling or using the products they have produced. This, here called, *return to labour* parameter, was actually higher in agroforestry based reforestation than in industrial reforestation, where the return to labour included only salary incomes from plantation establishment, maintenance and harvesting work (Figure 5).

The growth and yield models (Marjokorpi, 1995) applied in this study were developed for seedling rotations. Yield of coppice rotations is obviously higher than that of seedling rotations, although opposite results have been also reported (FAO, 1979). If the yield of coppice rotations is higher than that of seedling rotations, the maximum soil expectation value could be met with shorter rotations than assessed in this study. On the other hand, since coppice rotations do not require as high investments for plantation establishment as seedling rotations, the optimum rotation age could be longer than assessed in this study. From the environmental-economic point of view, high growth and yield in coppice rotations could not only increase the benefits in carbon sequestration, but also the costs of transpiration and nutrient consumption.

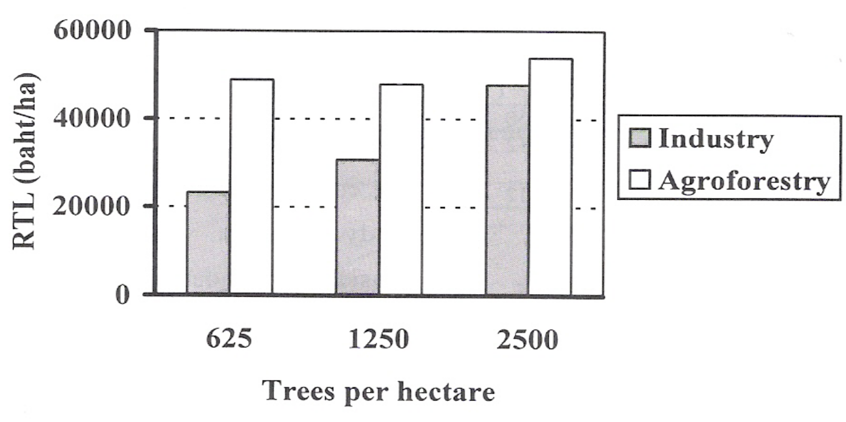

Figure 5. Net present value of the return to labour (RTL) in industrial and agroforestry based reforestation in Thailand, 1993.

Before separate growth and yield models for coppice rotations are developed, it is difficult to draw any accurate conclusions for a constant and single economically optimum rotation period. Obvious conclusion can be drawn, however, that the economically optimum rotation age for *Eucalyptus camaldulensis* in Thailand is much longer than presently applied in pulpwood production.

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