Growth and carbon sequestration potential of plantation forestry in Indonesia: I *Paraserianthes falcataria* and *Acacia mangium*[1].

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Abstract

The development of plantation forests in Indonesia is an ongoing activity, with planting of fast-growing species, such as *Paraserianthes falcataria* and *Acacia mangium*. The establishment of exotic fast-growing trees is one way of rehabilitating unproductive forest lands, which are usually covered by bushes, weeds or alang-alang grass (*Imperata cylindrica*). This paper explores the carbon-sequestration potential of two tree species. This is achieved by estimating their growth rates and performing economic analysis when carbon-credit payments are available. The effect of different carbon-accounting methods on the economic performance of plantation forests is analysed. The paper shows that carbon-credit payments may increase the net present value of a plantation by 11% to 20 % above the timber value alone. Discount rates are shown to have an important effect on economic performance of plantation forests, the effects of carbon prices and baseline settings are not as important.

Keywords: Forestry, Carbon Sequestration, Indonesia, Economic Analysis

1 Introduction

The capacity of trees to absorb carbon dioxide (CO_2) through photosynthesis has received much attention in recent years. The initial driver of this has been the Kyoto Protocol (KP), but there has also been increasing interest on the environmental services that forests provide. The three services that have received the most attention are carbon sequestration, biodiversity and water quality. This paper deals only with carbon sequestration. There is a very large literature on the Kyoto Protocol, and its attempt to control global warming by setting commitment periods and greenhouse-gas emission targets for developed countries. None of this literature is reviewed here, an important reference on this topic is the IPCC report on land use, land-use change and forestry (LULUCF) by Watson *et al*. (2000).

In this paper we present economic analyses of Indonesian plantation forests when carbon-credit payments are available. Under the Clean Development Mechanism (CDM) of the Kyoto Protocol, payments are based on Certified Emission Reductions (CERs); we do not use this term. Here, we use the term C-credit to represent a payment received per tonne of carbon (Mg C) sequestered. Payments are measured in (Rp'000/Mg C). Our analysis is general in the sense that it abstracts away from current international policy debate and the many uncertain rules and definitions. A C-credit, as used here, could represent a payment by mechanisms other than those proposed by the Kyoto Protocol and the IPCC, such as a direct payment by a sustainable-development project or an independent deal between a power company and a plantation project.

This paper presents a fairly simple analytical approach to perform financial analyses from the standpoint of an individual who has access to a plot of land to plant trees and may receive C-credit payments for the carbon sequestered by those trees. The analysis is based on simple tree-growth curves and a few biophysical and economic parameters. The model is applied to two tree species in a variety of sites. Two methods of accounting for carbon are evaluated in

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[1] Working paper CC08, 2003, ACIAR project ASEM 1999/093, http://www.une.edu.au/febl/Econ/carbon/

terms of net present value (NPV), optimal cycle length and amount of carbon sequestered. The effects of baselines, discount rates and carbon prices are analysed.

2 Analytical approach

The analytical approach used in this paper is based on a simple mathematical model of tree growth linked to one of three possible economic models. The economic models represent either timber harvest only (no C-credit payments) or two alternative methods to pay for carbon sequestered. The carbon-accounting methods are designed to deal with the permanence problem (see Cacho *et al*. 2003 and references therein).

2.1 Tree growth

In this study the growth of a plantation is represented with the Chapman-Richards equation (Harrison and Herbohn 2000, p. 75):

$$v_t = \theta\left[1 - \exp\left(-\gamma(1-\beta)\cdot t\right)\right]^{1/1-\beta} \tag{1}$$

where v_t is the volume (m^3/ha) of timber in year t, and the maximum volume at steady state is given by θ, as:

$$\theta = \left(\frac{\alpha}{\gamma}\right)^{1/1-\beta} \tag{2}$$

The parameters α, β and γ are specific to a given tree species and are partially determined by climatic and soil characteristics. Factors such a soil moisture, fertility and texture may have important effects on the values of these parameters. The planting density also affects the volume per hectare.

Once the tree-growth curve (1) is known, two useful measures, the mean annual increment (MAI) and current annual increment (CAI), can be derived by applying the formulas:

$$MAI_t = \frac{v_t}{t} \tag{3}$$

$$CAI_t = \frac{\Delta v_t}{\Delta t} = v_t - v_{t-1} \tag{4}$$

MAI is the average annual growth in any particular year, and CAI is the change in volume between two ages (Δv_t) divided by the number of years between those ages (Δt). With annual time steps $\Delta t = 1$ and CAI is simply the annual increment in volume as represented in (4). For more details on these formulas and their application see Leuschner (1990). In economic terms MAI represents the average product of time and CAI represents the marginal product of time (Hartwick and Olewiler, 1998).

2.2 Biomass and carbon content

Tree biomass consists of leaves, fruit, twigs, branches, and stem. Sanches (1993) (in Mindawati (2000)) stated that total biomass (dry weight) in tropical forests for a cutting cycle is between 200 and 400 Mg/ha. Research in several countries (Zaire, Ghana, Panama, and Puerto Rico) has showed that biomass distribution in a forest is relatively stable, with 75 % in stems including branches, 15-20% in roots, 4 % in the leaves, and 1-2 % in the litter (Mindawati, 2000).

The biomass in the timber (Mg/ha) can be calculated by multiplying the volume (m^3/ha) times the density of the tree (δ), measured in metric tonnes per cubic meter (Mg/m^3). About one half of the biomass is composed of carbon (Brown 1997). Given that stems represent about 0.75 of forest biomass and using the lower value for roots (0.15) given above, the carbon content of forest biomass is:

$$b_t = \left[\frac{0.5 \cdot \delta \cdot v_t}{0.75}\right] \cdot 1.15 \qquad (5)$$

where b_t is the carbon content of biomass (Mg C/ha), including the roots, but excluding the carbon content of soil.

2.3 Economic Model

With no C-credit payments and no maintenance costs, the present value of a single forestry cycle of T years is:

$$NPV_T = v_T \cdot p_v \cdot (1+r)^{-T} - c_E \qquad (6)$$

where NPV_T is the net present value of a forest harvested in year T after planting, p_v is the price of timber (Rp 1,000/m^3) net of harvesting costs, r is the discount rate, c_E are forest-establishment costs and v_t is given by equation (1). Maximising equation (6) with respect to T gives the optimal time to harvest when only a single forestry cycle is considered; which assumes that the land has no value to the landholder after the forest is harvested. In reality, keeping the trees in the ground has an opportunity cost and this should be included in the economic model by considering a series of forestry cycles in perpetuity. The solution to the infinite-cycle problem was derived by Faustmann in the 19th century and has been well documented (i.e. Samuelson 1976). The model was extended by Hartman (1996) to account for the positive externalities provided by trees (see Cacho 2001 for more details).

In this paper we use a single cycle, which would apply if a private individual, a company or a community is granted use of government land for a forestry project, with no commitment to renew the permit once the trees are harvested. This would reflect the uncertainty regarding future government policy and changes in land-use priorities as population grows. This paper presents a financial analysis from the standpoint of a (temporary) landholder, rather than an economic analysis considering a plantation-forestry in perpetuity. Given the high discount rates in Indonesia the former is not very different from the later.

If the landholder represented in equation (6) were to enter the market for C credits, the profit function would change. The actual form of the profit function depends on the system used to account and pay for carbon sequestration. Several accounting methods have been proposed to deal with the possible non-permanent nature of forestry projects. These methods were reviewed and analysed by Cacho *et al.* (2003). In this paper we consider two of those methods: the “ideal” system and the “tonne-year” approach, both of which are explained below.

The ideal carbon-accounting system

In an ideal C-accounting system, payments for carbon sequestration occur as the service is provided and, if the carbon is released back into the atmosphere (eg. because of fire or harvest), the value of the C released must be paid back by the forest owner (C credits must be redeemed). This method is explained in more detail in *et al.* (2003). With annual payments for C sequestration, and under the ideal accounting system, the profit obtained from the forest plantation, in present-value terms, for a single cycle of T years is:

$$NPV_{I,T} = v_T \cdot p_v \cdot (1+r)^{-T} + \sum_{t=0}^{T} \left[\Delta b_t \cdot p_b \cdot (1+r)^{-t} \right] - c_E - b_T \cdot p_b \cdot (1+r)^{-T} \qquad (7)$$

where $NPV_{I,T}$ is the net present value (NPV) of a forest harvested in year T after planting and receiving C-credit payments under the ideal accounting system. This is an extension of equation (6); the sum term within brackets represents the present value of the total flow of carbon sequestered in the interval (0, ...,T), p_b is the price of biomass carbon and the remaining variables have been previously defined.

The state variables v_t and b_t are the timber volume (m^3/ha) and the carbon contained in aboveground biomass (Mg/ha), respectively, in year t. The term Δb_t represents the annual change in biomass (the annual flow of carbon between atmosphere and trees) and can be positive (C sequestration) or negative (C release). The last term in the equation ($b_T \cdot p_b (1+r)^{-T}$) is the present value of the C credits redeemed at harvest.

The tonne-year approach

The tonne-year approach, proposed by Moura-Costa and Wilson (2000), is based on the concept of absolute global warming potential (*AGWP*). This approach uses a time horizon of 100 years as proxy for a permanent emission offset. Given the decay path of CO_2 in the atmosphere, each tonne of C sequestered must be kept off the atmosphere for 46.4 years (the “equivalence time”) to make it equivalent to a permanent emission offset (Fearnside at al. 2000). From this value, an “equivalence factor” (E_f) is derived as $E_f = 1/46.4 = 0.0215$. More details on this method are presented in Cacho et al. (2003).

Under the tonne-year approach the objective function is:

$$NPV_{Y,T} = v_T \cdot p_v \cdot (1+r)^{-T} + \sum_{t=0}^{T} \left[b_t \cdot E_f \cdot p_b \cdot (1+r)^{-t} \right] - c_E \qquad (8)$$

This method has the appeal because no guarantee is required to ensure that the project will last for 46 years, as the annual payments are adjusted by the equivalence factor. If the project is abandoned and the carbon is released there is no need to recover payments.

2.4 Parameter estimation

The model described above can be implemented on a spreadsheet if the values of the parameters are known. There are four biophysical parameters: (α, β, γ and δ) and four economic parameters (p_v, p_b, r and c_E). The parameters α, β and γ can be estimated statistically, through nonlinear regression, if growth data are available. Values of δ for many species are available in the literature (Brown 1997). Values for economic parameters can be obtained from either primary (survey) or secondary (i.e. government statistics) sources, or can be based on plausible assumptions (i.e. the value of the discount rate). Values for biophysical parameters were estimated based on available data using a purpose-built spreadsheet model for nonlinear parameter estimation. Other parameters were obtained from various sources as explained for each species below.

3 Tree Species and Locations

3.1 Sengon (*Parserianthes falcataria*)

Paraserianthes falcataria belongs to the Leguminosae family. The tree has various local names, including: Jeunjing laut (West Java), Kalbi, Sengon landi, Sengon laut, Sengon sabrang (Central Java), Seia (Ambon), Sikat (Banda), Tawa (Ternate), Gosoi (Tidore), Bae bai, Wahogon, Wai and Wikkie (Irian Jaya). The tree is fast growing and popular in farm-forestry systems in Indonesia.

The natural distribution of sengon spans Java, Maluku, South Sulawesi, and Papua, and is considered a prospective tree species for every part of Indonesia (Pratiwi, 2000). The tree grows to a height of up to 45 m, and a diameter of 100 cm; it has a cylindrical bole, gray bark and smooth wood, a prism-form canopy, and is always green (Pratiwi, 2000).

The preferred site characteristics for Sengon include: (i) elevation of 0 - 500 m, (ii) rainfall of 2000-4000 mm per year, (iii) air temperature of 20-34 0C, (iv) soil pH from acid to neutral, (v) good drainage and humidity (Ginting, et. al., 1996). The tree tolerates a range of soil textures, from light to heavy, but it is intolerant of shade (requires high light input). Sengon flowers throughout the year and produces fruit in June- December; it can be propagated by seed or stump (Pratiwi, 2000). The rotation cycle is generally less than 15 years in order to prevent rotten root.

The advantages of Sengon as a main tree in plantation forests and agroforestry systems are:

1. It has a clear bole height of 10 – 30 m and diameter up to 80 cm; by year six it yields 156 m^3/ha and by year 15 it yields 372 m^3/ha; average increment is about 28 m^3/ha/year.

2. Can be planted in agroforestry systems and is able to improve land condition because of its high nitrogen content and it ability to fix atmospheric nitrogen (Ginting, et.al., 1996).

3. Although it has a lower yield of charcoal, it is the best species for activated charcoal production because of its high quality (Pari, 1996).

4. It is a potential tree to be planted as urban/town forestry to reduce air pollution because of it has Pb adsorption of 39.04 μg/g dry weight leaves.

5. Its sawn timber can be used by the light-construction, packaging, and furniture industries. Its log can be used as firewood, charcoal, long-fiber pulp, veneer, plywood, and for wood carving (Ginting, *et.al.,* 1996).

6. It is suitable as raw material for the pulp and paper industry, as indicated by chemical analysis (based on cellulose, lignin, and pentosan contents) (Pari, 1996).

The economic analysis of sengon plantations in this paper is based on site-index data. A site index (bonita) indicates the quality of a particular site to produce trees. Site indices have been published for many species in Indonesia (Suharlan, *et.al*., 1975). The process of estimating a site index is explained by Suharlan, *et.al.* (1975). The site index ranges from 1 to 4. With an index of 4 representing excellent land to grow a given tree species, and an index of 1 representing marginal land.

Pratiwi (1999) uses the following criteria to describe site quality: (i) In a good growing site (e.g. Sirih Agung district) trees exhibit normal growth, green leaves, relatively straight trunk, and no symptoms of disease, (ii) in a "medium" growing site (e.g. Rahmah district) there is less normal growth, less green leaves, less straight trunks, (iii) in a bad growing site (Tabah Jemekeh district) trees show abnormal growth, less green leaves, and relatively less straight trunks.

3.2 Mangium (*Acacia mangium*)

Acacia mangium (Wild) is a fast-growing tree species belonging to the Leguminosae family, sub-family Mimosoideae; the local (Indonesian) trading name is Mangium. It is a popular tree in forest plantations because it is easy to grow and is tolerant of a wide range of site characteristics. *A. mangium* is a native species of eastern Australia (Queensland), Papua New Guinea and the eastern part of Indonesia; it is found in Sulawesi, Seram, Aru Island and Irian Jaya.

Ideal site characteristics for mangium include: (i) elevation of 0- 300 m, (ii) rainfall 1000-2100 mm per year, (iii) air temperature of 13-32 ^{0}C, (iv) medium soil texture, (v) soil pH from acid to neutral, (vi) drainage of seasonal flooding and humidity (Ginting, *et. al.,* 1996).

The wood of *Acacia mangium* can be used for sawn timber, moulding, furniture, veneer, charcoal and firewood. It is also used for particleboard, pulp and paper (Silitonga, 1987). Its leaves can be utilized as fodder and medicine materials (Ginting, *et.al.,* 1996). Valade and Law (1998) in Hardiyanto and Kuncoro (1999) pointed out that the tree (less than 10 years old) can produce pulp of good quality compared to mixed hardwood species growing in Canada.

Kliwon, et.al. (1999) reported that *Acacia mangium* can be manufactured into plywood and bonded with urea formaldehyde glues. The bonding strength of acacia plywood meets with Indonesian and Japan plywood standards. The bark can also be used for making a tannin formaldehyde glue.

As firewood, mangium has a calorific value of 4900 Kcal/kg and its charcoal has a calorific value of 6600 Kcal/kg. Pari (1996) investigated the activated charcoal quality of Acacia (with specific gravity of 0.53) and found that the yield of charcoal produced from *Acacia mangium* is 37.5%. This yield is higher than the yield from *Paraserianthes falcataria* (with specific gravity of 0.39). This may be caused by the higher specific gravity of mangium, so that the carbonization and activating process is slower than with wood of low specific gravity.

The tree is intolerant of shade (requires medium light input); it can be planted in agroforestry systems and it is able to control erosion. Alrasyid et al. (2000) reported on the success of trial plantings of dry field rice under *Acacia mangium* at Parung Panjang, West Java. They also list the decrease of rice production at different ages of Acacia stands (2, 3, 4, and 5 years old).

The biomass production of mangium planted at spacing of 3 m x 2.5 m at PT. Wirakarya Sakti, Jambi (Tanjung Jabung district) is presented in Table 1 (Wibowo, 1996). Biomass was collected on the forest floor under the standing trees.

Table 1. Biomass production of *Acacia mangium* for different ages at the forest floor

No	Age	Average diameter (cm)	Average tree height (m)	Litter (Mg/ha)	Twigs (Mg/ha)
1.	7 months	4.2	3.8	6.1	-
2.	1 year	5.7	5.0	6.7	-
3.	3 years	11.8	10.7	8.2	2.6
4.	4 years	18.6	16.3	8.7	5.0
5.	5 years	19.7	17.8	10.1	5.1

Source: Wibowo (1996).

The ground of the plantation was dominated by Alang-alang (*Imperata cylindrica*), Kaso (*Andropogon halepensis*), *Melastoma affine*, and *Mikania spp*. These shrubs disturb the growing condition of the main trees. One of the weeds is *Mikania micrantha*, which can squeeze the trunk and cover the top crown. It the long run, the weed will cause tree death because it stops the assimilation process (Nazif, 1997).

Pudjiharta (1995) studied biomass production of an 8-year-old *Acacia mangium* stand and found leaf-litter production of 569 g/m^2 for a 9-month period or 76.1 g/m^2 per month. Seed production was 45 g/m^2 for a 9-month period. Trunk, branches and twigs yielded about 83 t/ha after nine years. Mindawati (2000) reports litter production of 19.5 g/m^2/wk, or 9.3 Mg/ha/yr, with a rate of decomposition of 2.3%.

4 Data Sources and Parameters

Parameter values used in the model are presented in Table 2. Growth parameters for each species are presented separately in the sections below.

Table 2. Base parameter values used for both tree species

Parameter	Value	Units	Description	Source
Pb	100	Rp'000/Mg C	Price of carbon	b
r	15	%	Discount rate	a
Ef	0.0215	1/year	Equivalence factor	c

Sources: a: Samsudi (2000); b: Cacho et al (2003); c: Fearnside et.al. (2000).

4.1 Sengon

Secondary data were obtained from yield tables for sengon (Suharlan, *et. al*, 1975) Tree growth parameters estimated for different sites are presented in Table 3The parameter α tends to increase with increases in site index, while β and γ change in the opposite direction. The parameter θ, calculated based on equation (2), was the same for all sites, this occurred because data fitting was subject to the constraint that maximum volume achievable could not exceed that of the higher-quality site (eg. the value of θ in site 3 had to be less than or equal to the value of θ in site 4 and so on for sites 2 and 1). This was necessary to avoid unrealistic results caused by the lack of data for older trees. The growth curves associated with these parameters are presented in Figure 1 A.

Table 3. Parameter values for *Paraserianthes falcataria* in different site indexes

	Site Index			
Parameter	1	2	3	4
biophysical:				
α	3.741	4.372	5.701	8.183
β	0.798	0.755	0.672	0.566
γ	0.966	0.850	0.632	0.446
θ^a	811.4	811.4	811.4	811.4
δ	0.4	0.4	0.4	0.4
economic:				
P_v (Rp'000/m^3)	120	120	120	120
C_E (Rp'000/ha)	3.0	3.0	3.0	3.0

[a] calculated based on equation (2)

4.2 Mangium

Secondary data was obtained from Balikpapan, East Kalimantan and Subanjeriji, South Sumatra. The Balikpapan site had red-yellow podzolic soil, climate type A (average rainfall 2,461 – 3,019 mm/year), elevation of 50-100 m; and the previous land use was natural forest conversion. The site in South Sumatra was similar except the previous land use was *Imperata cylindrica* (Tim Peneliti, 1998).

Based on the site index table (using maximum height as indicator of site index quality), the East Kalimantan site has an index of 2 and the South Sumatra site has a an index of 3. This means the latter site is more fertile than the former site.

Table 4. Parameter values for *Acacia mangium* in two sites

	Site	
Parameter	East Kalimantan	South Sumatra
biophysical:		
α	5.356	8.846
β	0.806	0.864
γ	1.926	4.206
θ^a	194.2	231.9
δ	0.53	0.53
economic:		
P_v (Rp'000/m^3)	165	165
C_E (Rp'000/ha)	3.0	3.0

[a] calculated based on equation (2)

The tree growth parameters for equation (1) at the two growing sites are presented in Table 4. The parameters for the East Kalimantan site are lower than for the South Sumatra site. No constraints were imposed on the maximum volume produced (θ). These estimates (194 and

232 m^3/ha) are lower than those reported by other authors and may be due to the lack of data for older trees. The price of acacia is around Rp. 165,000 per m^3 or (US$ 26) with diameter of 10 – 50 cm at factory gate (Samsudi, 2000).

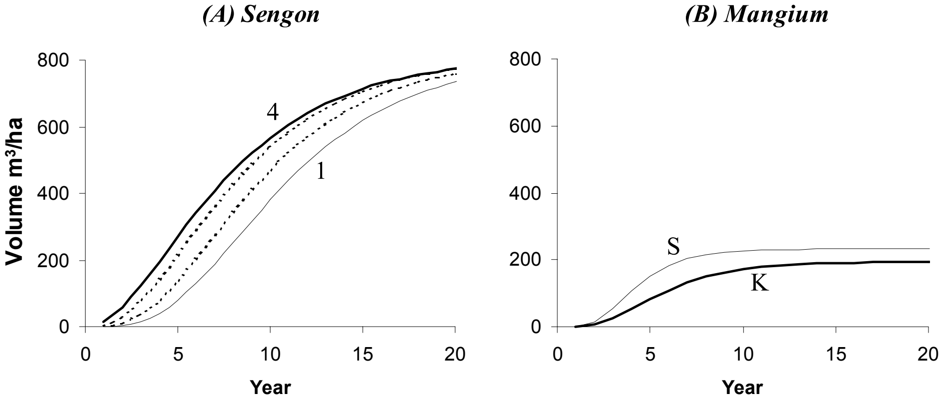

Figure 1. Growth curves for (A) sengon grown in site indexes 1-4 and (B) mangium grown in Sumatra (S) and East Kalimantan (K)

5 Results and Discussion

5.1 Growth

Figure 1 shows the predicted growth curves based on the parameters presented in the previous section. Sengon trees grow quite fast, reaching a volume of about 700 m^3/ha by year 20 (Figure 1A), whereas Mangium grows much slower, reaching a maximum volume of about 200 m^3/ha by year 9 (Figure 1B). According to Effendi (1999) *Acacia mangium* can produce up to 415 m^3/ha at 9 years of age, or about 46 m^3/ha/yr. Our results are less than half this figure, which indicates that the sites on which this study is based were far from ideal for Mangium and/or that poor silviculture was applied.

MAI and CAI were estimated for the above growth curves, using equations (3) and (4). A selection of results is presented in figure 2. The maximum MAI (also the point at which the curves intersect) is the time to harvest under the “traditional forester solution”, which is not economically optimal. Under this criterion, sengon would be harvested in year 14 from site 1 (Figure 2A) and in year 8 from site 4 (Figure 2B); whereas mangium would be harvested in year 8 from the Kalimantan site (Figure 2C) and in year 6 from the Sumatra site. These results are consistent with the recommendations by Tim Peneliti (1998), who pointed out that the optimal rotation age of Mangium is between 6 and 10 years.

5.2 Carbon Sequestration Rates

The carbon sequestration rates for the two species at the various sites are shown in Figure 3. The maximum sequestration rates for sengon range between 63 and 73 Mg CO_2/ha per year (Figure 3A), whereas for mangium they range between 40 and 67 Mg CO_2/ha per year (Figure 3B). The difference between species in carbon sequestration is not as large as in terms of volume, because mangium wood is more dense than sengon wood and therefore has more carbon per unit of volume.

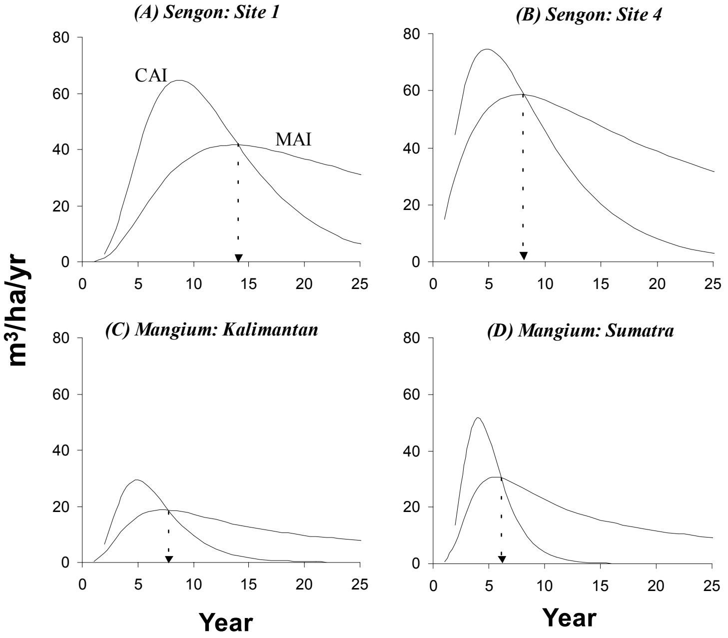

Figure 2. Mean annual increment (MAI) and current annual increment (CAI) of two tree species in different sites. Arrows represent the cycle length based on the traditional forester solution (maximisation of MAI)

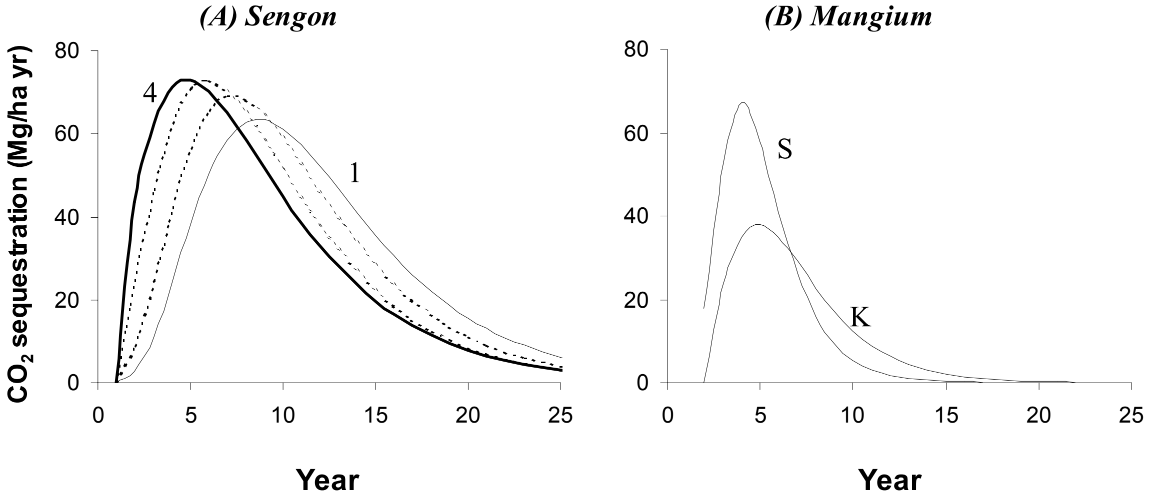

Figure 3. Rates of CO_2 sequestration through time for (A) sengon grown in site indexes 1-4 and (B) mangium grown in Sumatra (S) and East Kalimantan (K)

5.3 Effects of Carbon Accounting System

Carbon-credit payments only apply to the carbon sequestered above the sequestration expected in the absence of the project. Here we assume that the baseline is an *Imperata* grassland with an average carbon stock of 10 Mg/ha. The NPV results for selected cases are shown in Figure 4. NPV values were estimated with equations (6), (7) and (8).

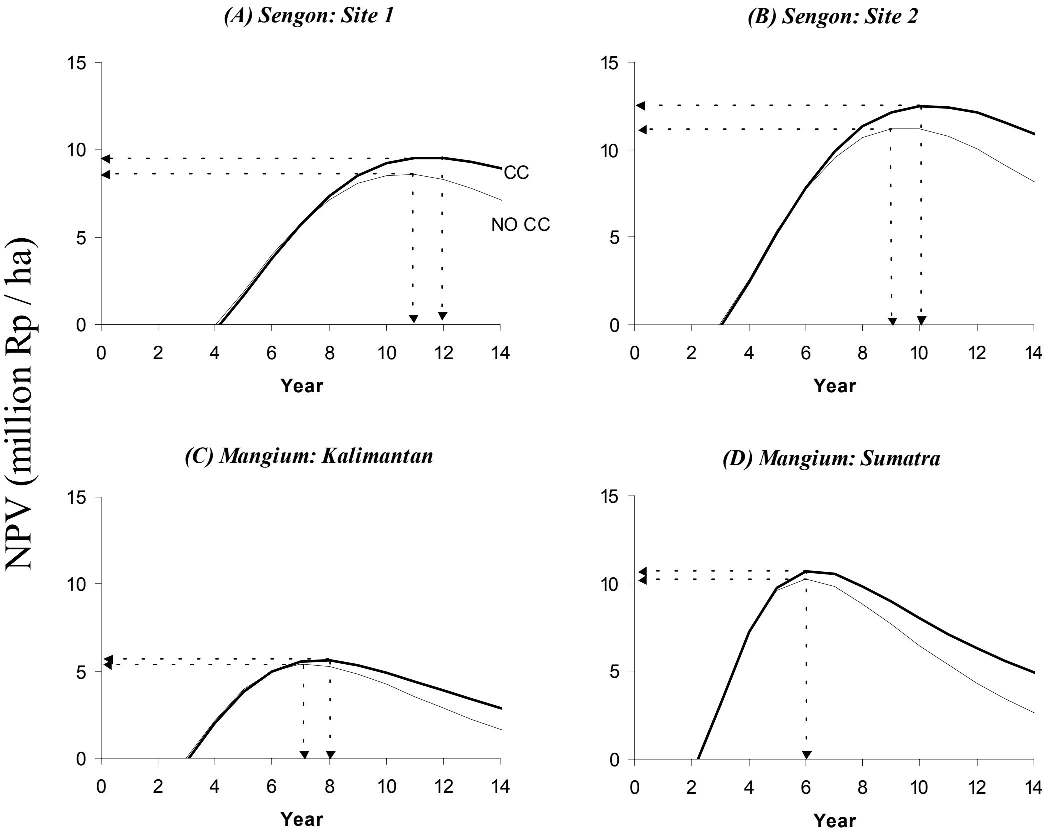

Figure 4. Net present values (NPV) of two species of trees grown in different sites and under two accounting procedures: with no carbon credits (dotted line) or with carbon credits under the ideal accounting system (solid line). Arrows represent the optimal cycle length

The economically-optimal cycle length is the point at which NPV is maximised. From figure 4 it is obvious that carbon credits tend to lengthen the forest cycle, but only by one or two years under the given assumptions. The tonne-year approach provided no incentive to keep trees longer (it overlaps the no-credits case and is not shown in Figure 4). The results corresponding to figure 4 are also shown in Table 5.

Table 5. Optimal cycle length and NPV of Sengon and Mangium for base-case scenarios (baseline of 10 MgC/ha, discount rate of 15 % and carbon price of Rp 100,000 / MgC)

Accounting system	Sengon		Mangium	
	Site 1	Site 2	Kalimantan	Sumatra
	Optimal cycle length (years)			
No CC	11	9	7	6
Ideal	12	10	8	6
Tonne-year	11	9	7	6
	Maximum NPV (M Rp/ha)			
No CC	8.599	11.195	5.388	10.282
Ideal	9.550	12.498	5.685	10.690
Tonne-year	8.608	11.256	5.418	10.333

Carbon accounting methods have a significant impact on the economic performance of the forest plantation. The availability of carbon-credit payments increases NPV. The NPV with the ideal accounting method for Sengon planted at Site 1 is Rp 9,550,000, which is 11 % higher than the NPV with no carbon credits. A similar pattern occurs in the Mangium plantation. However, the increase in NPV with respect to the no carbon-credits case is only about 5%, as shown in Table 5. The ideal accounting method produces the highest NPVs. The tonne-year accounting method produces similar results to the no-credits case. The availability of carbon-credit payments under the ideal system causes a one-year delay in harvest for both species, except in the case of Mangium grown in Sumatra (Table 5).

5.4 Sensitivity Analysis

Sensitivity analysis was undertaken with respect to baselines, carbon price and discount rate; results are presented in Tables 6, 7 and 8.

Table 6. Effect of the baseline on optimal results

		5.4.1. Sengon				Mangium			
Accounting	Baseline	5.4.1. Site 1		Site 2		Kalimantan		Sumatra	
		5.4.1.5.4.1.		5.4.1.		5.4.1.		5.4.1.	
System	(Mg C/ha)		NPV		NPV		NPV		NPV
		(yr)	*(M Rp)*	*(yr)*	*(M Rp)*	*(yr)*	*(M Rp)*	*(yr)*	*(M Rp)*
Ideal	5	12	9.891	10	12.809	8	5.873	6	10.909
	10	12	9.550	10	12.498	8	5.601	6	10.690
	15	12	9.208	10	12.187	8	5.330	6	10.471
Tonne-year	5	11	8.610	9	11.259	7	5.422	6	10.337
	10	11	8.608	9	11.256	7	5.418	6	10.333
	15	11	8.606	9	11.253	7	5.414	6	10.328

The baseline has a small effect on optimal results. The NPV decreases slightly as the baseline increases from 5 to 15 Mg C/ha and the optimal harvest time is not affected (Table 6). This result indicates that reforestation of *Imperata* land is economically attractive under the assumptions of this paper, and small errors in the estimation of the baseline will not affect the result.

Table 7. Effect of carbon price on optimal results

	Carbon	5.4.1. Sengon				Mangium			
Accounting	price	5.4.1. Site 1		Site 2		Kalimantan		Sumatra	
		5.4.1.5.4.1.		5.4.1.		5.4.1.		5.4.1.	
System	(Rp'000)		NPV		NPV		NPV		NPV
		(yr)	*(M Rp)*	*(yr)*	*(M Rp)*	*(yr)*	*(M Rp)*	*(yr)*	*(M Rp)*
Ideal	50	11	9.044	10	11.831	7	5.465	6	10.486
	100	12	9.550	10	12.498	8	5.601	6	10.690
	200	13	10.902	12	14.165	8	5.934	7	11.265
Tonne-year	50	11	8.583	9	11.226	7	5.403	6	10.307
	100	11	8.608	9	11.256	7	5.418	6	10.333
	200	11	8.658	9	11.316	7	5.447	6	10.384

Carbon price affects the optimal harvest time under the ideal accounting system, but not under the tonne-year method (Table 7). For example, as carbon price increases from Rp 50,000 to Rp 200,000 per tonne of carbon, T^* increases from 11 to 13 years for Sengon in Site 1 and from 7 to 8 years for Mangium in Kalimantan. As would be expected, NPVs also increase as the price of carbon increases.

The discount rate has a considerable effect on both optimal harvest time and NPV (Table 8). For example, as the discount rate increases from 5% to 25% and in the absence of carbon credits, T^* decreases from 16 years to 9 years for Sengon in Site 1 and from 10 years to 6 years for Mangium in Kalimantan. The same results occur under tonne-year accounting. Under the ideal accounting system, as the discount rate increases from 5% to 25%, T^* decreases from 17 year to 9 years for Sengon in Site 1 and from 10 years to 6 years for Mangium in Kalimantan.

Table 8. Effect of the discount rate on optimal results

	Discount	5.4.1. Sengon				Mangium			
Accounting	rate	5.4.1. Site 1		Site 2		Kalimantan		Sumatra	
		5.4.1.5.4.1.		5.4.1.		5.4.1.		5.4.1.	
System	(%)		NPV		NPV		NPV		NPV
		(yr)	*(M Rp)*	*(yr)*	*(M Rp)*	*(yr)*	*(M Rp)*	*(yr)*	*(M Rp)*
No CC	5	16	32.795	14	36.190	10	14.469	8	21.134
	15	11	8.559	9	11.195	7	5.388	6	10.282
	25	9	2.464	8	4.255	6	2.058	5	5.523
Ideal	5	17	35.347	15	38.852	10	14.999	8	21.780
	15	12	9.550	10	12.498	8	5.601	6	10.690
	25	9	2.691	8	4.754	6	1.990	6	5.641
Tonne-year	5	16	32.956	14	36.366	10	14.535	8	21.230
	15	11	8.608	9	11.256	7	5.418	6	10.333
	25	9	2.486	8	4.284	6	2.074	5	5.554

6 Summary and Conclusions

This paper has presented an economic model for the evaluation of growth and carbon sequestration of trees in monoculture plantations. The model is applied to two tree species in Indonesia in several sites of different quality. The analysis is undertaken from the standpoint of a landholder who receives carbon-credit payments for the amount of CO_2 sequestered by the plantation. Payments are provided under two alternative carbon-accounting systems: the tonne-year approach proposed by Moura Costa and Wilson (2000) and an 'ideal' accounting system where credits and debits occur each year depending on the amount of CO_2 sequestered or released by the forest.

Results show that the tonne-year approach offers little incentive to plant trees beyond the incentive provided by the timber market, whereas the ideal accounting system offers enough incentive to make it attractive to delay the harvest. These incentives, however, are weaker in lower quality land; which indicates that forest rehabilitation in critical lands may require additional incentives for farmers or businessmen to plant more trees. The design of incentive systems is an important area of research to support the implementation of the Indonesian policy on forest rehabilitation and conservation. Application of our model to other tree species is another important area of research, as this will provide the information required to select the best species for a particular site. The model can also be improved by incorporating the effects of thinning and planting density on growth and carbon sequestration rates, and the associated incentives provided by carbon-credit payments.

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