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EVALUATION OF THE PROFITABILITY OF FAST-GROWING TROPICAL TREES

NOPEAKASVUISTEN TROOPPISTEN PUIDEN KASVATUKSEN KANNATTAVUUS

THE SOCIETY OF FORESTRY IN FINLAND
THE FINNISH FOREST RESEARCH INSTITUTE

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EVALUATION OF THE PROFITABILITY OF FAST-GROWING TROPICAL TREES: *EUCALYPTUS CAMALDULENSIS*, *ACACIA MANGIUM* AND *MELIA AZEDARACH* AS PLANTATION TREE CROPS IN THAILAND

Nopeakasvuisten trooppisten puiden kasvatuksen kannattavuus: *Eucalyptus camaldulensis*, *Acacia mangium* ja *Melia azedarach* puuviljelmien lajeina Thaimaassa

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Olli Saastamoinen & Suree Bhumibhamon

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The profitability of fast-growing trees was investigated in the northeastern and eastern provinces of Thailand. The financial, economic, and tentative environmental-economic profitability was determined separately for three fast-growing plantation tree species and for three categories of plantation managers: the private industry, the state (the Royal Forest Department) and the farmers. Fast-growing tree crops were also compared with teak (*Tectona grandis*), a traditional medium or long rotation species, and Para rubber (*Hevea brasiliensis*) which presently is the most common cultivated tree in Thailand.

The optimal rotation for *Eucalyptus camaldulensis* pulpwood production was eight years. This was the most profitable species in pulpwood production. In sawlog production *Acacia mangium* and *Melia azedarach* showed a better financial profitability. Para rubber was more profitable and teak less profitable than the three fast-growing species. The economic profitability was higher than the financial one, and the tentative environmental-economic profitability was slightly higher than the economic profitability.

The profitability of tree growing is sensitive to plantation yields and labour cost changes and especially to wood prices. Management options which aim at pulpwood production are more sensitive to input or output changes than those options which include sawlog production. There is an urgent need to improve the growth and yield data and to study the environmental impacts of tree plantations for all species and plantation types.

Nopeakasvuisten puulajien liiketaloudellista, kansantaloudellista ja suuntaa-antavaa ympäristötaloudellista kannattavuutta tutkittiin koillis- ja itä-Thaimaassa erikseen kolmen omistajaryhmän (metsäteollisuus, valtion metsähallinto sekä yksityiset maanomistajat) puuviljelmillä. Nopeakasvuisten metsäpuiden kannattavuutta vertailtiin lisäksi kauemmin viljeltyihin tiikkiin ja kumipuuhun.

Tulosten perusteella *Eucalyptus camaldulensis* -lajia oli kannattavinta kasvattaa massapuuna, jolloin sen optimikiertoaika oli kahdeksan vuotta. Kuitenkin sahapuun kasvatuksessa *Acacia mangium* ja *Melia azedarach* olivat kannattavuudeltaan eukalyptusta parempia. Kansantaloudellinen kannattavuus oli liiketaloudellista kannattavuutta parempi ja suuntaa-antava ympäristötaloudellinen kannattavuus oli hieman kansantaloudellista kannattavuutta parempi.

Herkkyysanalyysistä saatujen tulosten mukaan puuviljelmien kannattavuus riippuu ensisijaisesti puusta maksetusta hinnasta, mutta myös pinta-alayksikköä kohti saadusta puuntuotoksesta ja työvoimakustannuksista. Tuotannon kannattavuus on herkempi panosten ja tuotosten muutoksille massapuun tuotannossa kuin sahapuun tuotannossa. Jatkotutkimusten kannalta ensisijaiset tarpeet kohdistuvat parempiin puulajeittaisiin kasvu- ja tuotostietoihin samoin kuin metsänviljelyn ympäristövaikutuksien arviointiin.

Keywords: development forestry, profitability, tree plantations, cost-benefit analysis, environmental impacts, Thailand.
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Abbreviations and units

IRR	Internal rate of return
FIRR	Financial internal rate of return
EIRR1	Economic internal rate of return
EIRR2	Environmental-economic internal rate of return
NPV	Net present value
B/C-R	Benefit to cost ratio
OC	Opportunity cost
MAI	Mean annual increment
CAI	Current annual increment
rai	0.16 ha
ha	Hectare = 6.25 rai
B	Baht (1 US$ = 26.9 Baht)
PHP	Philippine Peso (1 US$ = 23 PHP)
RFD	Royal Forest Department
km	Kilometre

Foreword

This study was made possible through the existing and well-established cooperation between the University of Helsinki in Finland and Kasetsart University in Bangkok, Thailand. Forestry research and forestry education are fields in which joint Finnish-Thai efforts have been undertaken since 1966. The launching of the Thai Forestry Sector Master Plan in 1990 as a result of an agreement between the Governments of Finland and Thailand has given the joint Finnish-Thai forestry research increased actuality.

As the third institutional partner, apart from the two universities mentioned above, the present investigation also includes the University of Joensuu where the first author (AN) presented an M.Sc. thesis at the Faculty of Forestry, based on the main initial results of this report. The other three authors have selected the topic, guided the field material collection in Thailand and participated in the final analysis of the results, as well as in the compilation of the present report.

We wish to express our sincere thanks to the numerous people who have provided their kind guidance and assistance during the course of the present work especially in Thailand. In particular, we want to express our gratitude to Dr Ladawan Atipanumpai, Faculty of Forestry, Kasetsart University; Dr Winai Sirikul, Royal Forest Department, Bangkok; Mr Rauno Laitalainen, Team Leader, Thai Forestry Sector Master Plan, Bangkok; and last but not least to Mr Surajit Vannajan, Department of Botany, Srinakharonwirot University.

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1 Introduction

1.1 General remarks

Forestry in Thailand is presently undergoing profound changes. These changes reflect a reformation of the political power structure and a general democratization process.

As elsewhere, forestry and forest-related development in Thailand depend not only on the public awareness but also on political decisions. In Thailand, a crucial factor seems to be how different interest groups conceive that their voices are heard in development planning. This is especially true for the rural population and those agencies which act on their behalf. Unsolved political problems have in the past blocked attempts to develop the forestry sector effectively in Thailand. Among these problems particularly important is the unsatisfactory land reform, which neither gives sufficient security to landless farmers nor allows substantial land allocation for plantation-based industrial forestry.

Land management problems have not appeared suddenly. Instead, they can be seen as a series of consecutive stages, already well documented and discussed not only for Thailand but for the whole Southeast Asian region as well (cf. Poffenberger 1990).

The complex forestry situation in Thailand has recently been analyzed, for example, by the Thai Forestry Sector Master Plan (Master Plan... 1989, Thai Forestry... 1992, 1993a & b).

As in many countries, also in Thailand much of the essential forest management information is lacking or obsolete. The exploitation of forest resources, including the conversion of forest to farmland, has been uncontrolled. Therefore, one of the most important forestry sectors in which accurate analyses are needed is plantation development (Recommendations... 1992). Previous attempts for national syntheses on land-use problems in Thailand (cf. Pantumvanit and Panayotou 1990) have already indicated how important the availability of accurate information would be for an improved national forest policy and for development efforts in general.

1.2 Forestry in Thailand: historical perspective

According to Pragtong and Thomas (1990), the forestry development in Thailand can be divided into three distinct phases prior to the recent rapid succession of events since 1988.

The first phase (1896–1953) initially consolidated the political power of the central government through regulation of the teak timber trade and forest revenue collection. This was achieved through the establishment of the Royal Forest Department (RFD) in 1896 and the gradual build-up of a regional forestry administration.

Forestry development gained momentum after the transition to constitutional monarchy as the form of government in 1932, through the adoption of new forestry laws and the starting of professional forestry education. By the early 1950s the population density was still low, averaging 33 persons/km^2, and the forest cover varied from 70 % in the North to 60 % in the Central Region and 40 % in the Northeast and the South (Pragtong and Thomas 1990).

The second phase (1954–1967) saw the introduction of laws which strengthened the central administration in matters related to land use and land development. In 1962 the five-year National Economic and Social Development Plans were introduced; they first defined a 50 % forest cover as a national target, following an FAO recommendation of 1948.

In the 1950s and 1960s conflicts in land use began to appear especially between the forestry administration, which had a commitment to put all reserved forests under stronger government control, on one hand, and the farmers who began to settle in these reserved forests on the other.

While the earlier rate of forest clearance could be defined as "socially optimal" (Hafner 1990, in reference to the Northeast), during the second half of the century uncontrolled settlement and forest encroachment proceeded too rapidly. This situation was the result of contradictory agricultural promotion which favoured export-oriented crop production but did not offer land security for the new settlers.

It is worth noticing, however, that the slowest deforestation rate during this period occurred in the North where most of the industrial logging took place, while the Northeast with its dense farming population and poorest natural resources started to lose its forest cover at an accelerating pace. On average over the whole country the population density had increased to 62 persons/km^2 by the end of this period (Pragtong and Thomas 1990).

The third and most controversial phase in forestry development in Thailand, according to Pragtong and Thomas (1990), began in 1968. That year the first 30-year logging concessions were granted. Soon half of the total land area of the country was under these concessions. Serious but mostly unsuccessful attempts were made to use the selection system and to follow the scientific silvicultural principles earlier developed especially for teak forest management in Thailand (Champion 1961, Mungkorndin 1991).

In concession areas replanting was required when insufficient natural regeneration occurred, but the silvicultural guidelines were not properly followed (cf. Samapuddhi 1990). Even without any silvicultural measures logging alone did not cause deforestation, but combined with other factors it resulted in gradual depletion and disappearance of the forests. The accelerating forest encroachment and the government-endorsed land clearing for agriculture were the key factors in deforestation.

The Royal Forest Department became actively involved in land development especially during the short period of the democratic government in 1973–1976 which, among other things, pardoned the illegal settlers in the reserved forests from prosecution but did not give them permanent land security. This policy may have speeded up further forest encroachment (Pragtong and Thomas 1990).

In the late 1970s, when the Indochina war situation calmed down, the Thai forestry administration, continuing the established cooperation with the military, could more effectively concentrate its efforts on rural development work. However, old controversies, especially between the forest dwellers and the central administration, were hard to overcome because of the previous political situation. Direct conflicts continued in the form of land-use disputes. In particular, plantations with fast-growing trees, established by the Royal Forest Department and parastatal or other industrial enterprises in degraded reserved forests, after shifting cultivation, became a heated national issue by the late 1980s.

Even though the five-year National Economic and Social Development Plans stressed the importance of tree planting, the total planting area was only 52 % of the target (Bhumibhamon 1989).

1.3 Present forestry situation and tree plantations

A flood disaster in southern Thailand in 1988 led to intense national debate on environmental issues. In 1989 the Cabinet declared a ban on all commercial logging in natural terrestrial forests.

The forest industry had to rely solely on imported timber and, most notably, on *Hevea* wood from rubber plantations. In fact, the ensuing utilization of rubberwood represents a major re-orientation of the mechanical wood industry in Thailand and indicates how flexibly the industry can react to a new situation as the result of policy decisions and market forces (cf. Urapeepatanapong 1989). As an example, the export value of rubberwood furniture, estimated at 6116 million Baht in 1990, increased to 8293 million Baht in 1991; the predicted further increase in 1992 is 25 % (reported by Wattachak newspaper in 1992).

Illegal logging has long been a major and complex problem in Thailand. As much as 50–75 % of the industrial wood used in the country has at times been estimated to originate from illegal operations. The cutting of trees in reserved forests, particularly for domestic use, still continues and causes forest degradation. However, the Royal Forest Department (Forestry statistics... 1992) has reported that the annual deforestation rate has dropped to about 20 000 ha annually.

An obvious reason for the slower deforestation rate is a change in international agricultural commodity markets which discourages the planting of such crops as cassava; another similar factor is the gradually higher supply price that forest land used for conversion represents for a migrant farmer (Tongpan et al. 1990).

Land tenure remains the single most important rural development issue in Thailand. It is estimated that still 1.7 million families, totalling nearly 10 million people (out of a population of 56 million) dwell on a total of 6 million ha of reserved forest land without having formal recognition of their land use. A process of granting usufruct certificates by the Agricultural Land Reform Office since 1975 and by the Royal Forest Department since 1982 has resulted in recognizing the farmers' land use on 630 000 ha in the former and 1.1 million ha in the latter programme, including a total of nearly 1 million families by 1989 (Tongpan et al. 1990). This process is clearly too slow for solving the whole land tenure problem, and, most notably in the case of usufruct certificates granted by the RFD, it does not give permanent security of land use to the farmers concerned.

Another attempt, by the Army, to coordinate the resettlement in degraded reserved forests (the "Kor Jor Khor" project) has also failed. This is another indication of how land use is presently one of the main national development problems in Thailand (cf. Laitalainen 1992).

The first significant attempts to promote tree plantation establishment activities in Thailand were the forest villages first (since 1967) established by the parastatal Forest Industry Organization of Thailand (FIO) and (since 1975 when the forestry administration was given a stronger land development profile) by the Royal Forest Department. The FIO forest villages aimed primarily at sustained industrial raw material production under centralized management, while also providing stable livelihood for the participating farmers. The RFD forest villages started with a more integrated approach and especially aimed at providing social and economic benefits for the rural population through plantation establishment (Tongpan et al. 1990).

During the 1980s tree planting on individually owned farmland spread particularly in areas where the demand was good, for instance, in the Central plain (eucalypt and *Casuarina* poles for construction and eucalypt pulpwood) and in the Northeast around the pulp and paper industries in Khon Kaen (eucalypt and cultivated bamboo).

Unfortunately, forest villages today cover only a tiny fraction of the total forest area of Thailand: FIO villages about 10 000 ha and RFD villages a total of 44 000 ha. The total reforested area today in Thailand is 714 000 ha, while the forest area lost through deforestation in 1961–1989 amounts to 13 million ha (Forestry statistics... 1992).

Forestry extension work which activates the farmers in forest management, provided by the Royal Forest Department, has to date created a well functioning system which has reached around 400 new villages annually. As pointed out by Tongpan et al. (1990, p. 111), this programme is still proceeding too slowly to have a major national impact. Its potential drawbacks also include the heavy emphasis on fuelwood production, while the needs and especially the market conditions clearly anticipate a more versatile approach. For faster results, more local participation with the support from governmental or non-governmental organisations or farmer associations, is clearly needed.

Forest policy development in Thailand is now at a dynamic stage not only because of the favourable political atmosphere but also as a result from new legislation. The newest, somewhat unpredictable factors consist of the Forest Plantation Act and the draft of Communal Forest Act, both introduced in 1992 (cf. Ruangpanit 1992). Both acts will undoubtedly promote forest plantation establishment; they are important steps in the transformation from dis-incentives and restrictions towards incentives and encouragement as forest policy tools.

1.4 Tree plantations and future Thai forest policy

The national forest policy adopted in 1985 had confirmed the 40 % forest coverage as an overall goal and defined private industrial tree plantations as a major measure to achieve this goal. A reforestation plan of 1989 calculated the need for new plantations as 7.2 million ha by the year 2021. The category of production forests would have comprised an additional 5.6 million ha of existing, mainly natural forests and together they would have corresponded to 12.8 mill ha or 25 % of the total land area. The remaining 7.7 million ha (15 % of the land area) would have been classified as conservation forests (DANIDA 1990).

The 1985 National Forest Policy clearly gave too narrow a role to plantation forestry: it was to be practised mainly through promotion of industrial plantations, for keeping up with the 40 % forest cover target.

It has already been recognised that the role of tree plantations must be seen in a wider context. The 40 % target cannot be a goal as such; it must be justified by clear development objectives, particularly taking into account the needs of the rural population (Bonita 1992).

In addition, the role of plantations in reducing the pressure on natural forests is not as straightforward as earlier often presumed, for the following reasons (Thai Forestry... 1991):

(1) Natural forests continue to provide many of the basic (forest-based) needs of the population in the form of fuelwood, wood for charcoal, construction wood, material for other domestic uses, and, finally, products and raw materials for cash income. The fuelwood demand alone is estimated at 40 million m^3 annually (FAO Regional Office, Bangkok, unpublished; this figure is of the same magnitude as the estimate of 33 million m^3 given for fuelwood and other domestic wood combined, by Sukwong 1991). Even if much of the domestic wood comes from outside the reserved forests, the natural vegetation is still the principal source in one form or another. No plantation establishment programme or legal measure can immediately change this dependence on natural forests.

(2) Fast-growing plantations and natural forests essentially yield different types of commodities and benefits; these forest categories cannot readily replace each other.

(3) Natural forests need protection and management for other than industrial use purposes. Sustained economic utilization of natural forests outside the strictly protected conservation areas would also offer more conservation benefits than conversion to tree plantations. Commercial utilization of natural forests is not, however, possible according to the prevailing forest legislation in Thailand.

Plantation development that is tied to the solving of the problems of land use rights and the subsistence needs of the rural population is clearly more relevant than planting trees only for the industrial demand. Besides, plantations are also a measure to counteract deforestation, if seen from this point of view.

Plantation forestry has been suggested as a type of crop production similar to rubber or oil palm cultivation and close to agricultural land management. Such an approach would, however, necessitate a clear and urgent demarcation between natural forests and other land categories, including forest plantations, as well as an agreed definition for terms like "natural forest" and "plantation" (Thai Forestry... 1991).

Tongpan et al. (1990) present a plausible scenario in which slower agricultural growth is expected in Thailand in the 1990s. The forest cover continues to decrease if no pre-emptive measures are undertaken. A reduction in absolute poverty in the country will also occur, although the income gap continues to widen.

Slower agricultural growth is caused by a rising economic price of forest land available for land clearing in shifting agriculture. At the same time, agricultural production per unit of land area has also begun to drop, because more marginal areas have been taken into cultivation. This further prompts development efforts to focus on new, more innovative and more sustainable forms of land use than represented by cassava or maize cultivation alone. Consequently, if both agriculture and forestry should aim at an increased production per unit area of land, tree plantations will have a crucial role in forestry and rural development in Thailand.

The demand for plantation-grown wood was estimated at about 1 million t in 1990 and 4.8 million t for 2005, representing a five-fold increase in 15 years. Given the relationship between land area and wood yield, the total land requirement for fast-growing tree plantations can be calculated. A minimum requirement for annual plantation areas has been estimated by the Royal Forest Department to be 77 000 ha in 1990 and it would increase to 216 000 ha by 2005 (Potential of... 1989). In this quite optimistic scenario the rotation time is five years and the MAI 21 t/ha; this, however, seems to be too high an estimate (Bhumibhamon, unpublished data).

On the other hand, wood is needed to satisfy the demand for fuelwood, construction wood and raw material for pulp. From the forest industry viewpoint, tree plantations are the principal option for future development, apart from wood imports (which are unlikely for other than sawwood logs), the import of paper products or the use of substitute raw materials.

More accurate information of the real needs and the economic, environmental and social consequences of tree plantation establishment is obviously needed for the formulation of the forest policy in Thailand. Such additional information (cf. Thai Forestry... 1993a & b) will also help to avoid mistakes which were made in the past. Besides, new data will allow choices from a sufficiently wide range of forest management options for the varying socio-economic and ecological situations which occur within Thailand.

With the foregoing considerations in mind the present study strictly limits itself to analysing different types of tree plantations and does not try to make any attempt at economic, environmental or social comparisons between (managed) natural forests on one hand and plantations on the other.

2 Objectives

2.1 Specific aims

The specific aim of the present work was to calculate the financial and economic profitability of tree growing in the northeastern and eastern provinces of Thailand. The additional aim was, however, also to experiment with an analysis which goes further than a traditional profitability analysis: to estimate the environmental-economic profitability of forest plantations by adding some of the assumed environmental impacts of tree plantations into the economic analysis.

Economic comparisons were made between the tree species studied, i. e. *Eucalyptus camaldulensis*, *Acacia mangium* and *Melia azedarach*, as well as two other common tree crops traditionally used in Thailand: Para rubber (*Hevea brasiliensis)* and teak (*Tectona grandis*). A further objective was to clarify whether intensive or extensive methods of establishing tree plantations would be the most profitable ones.

2.2 Hypotheses

It was assumed that plantation managers cultivate crops which are most profitable to grow. *Eucalyptus camaldulensis* is the most widely planted exotic fast-growing tree species in Thailand and Para rubber is the most widely planted tree in Thailand. Therefore it could be assumed that these two tree crops are the most profitable to grow.

According to the Master Plan for Forestry Development in the Philippines (1990), the environmental-economic profitability of reforestation is higher than the economic or financial profitability. The situation can be assumed to be the same in Thailand. In summary, the hypotheses for the present investigation were:

(1) *Eucalyptus camaldulensis* is more profitable to grow than other fast-growing industrial tree species.

(2) Of the all tree crops, Para rubber is the most profitable one.

(3) The economic profitability for all species is higher than the financial profitability, but lower than the environmental-economic profitability.

3 Methodology and data

3.1 General methods

Several possible methods are available to measure investment profitability. According to Price (1989) a profitability criterion must indicate the acceptability criterion (whether the investment is profitable or not) and the selection criterion (how profitable the investment is in relative terms). Three standard methods are used here: NPV, IRR and B/C-R. Recent reviews of the use of these methods in forestry investment problems include, Nautiyal (1988), Price (1989) and Pearce (1990).

Net present value (NPV) is calculated by discounting revenues and costs to the present. The remainder of discounted incomes and costs is the NPV of the investment. The standard formula of the net present value of the investment is as follows:

$$NPV = \sum_{j=0}^{n}\left[(Rj - Cj)/(1+r)^{j}\right]$$

where

NPV = net present value
Rj = revenue in year j, j = 1,2,...,n
Cj = cost in year j, j = 1,2,...,n
r = interest rate.

The investment is profitable when NPV is greater than or equal to zero. Where there are alternative ways of using some fixed resource such as a tract of land, and the task is to find the one that generates the highest return, NPV provides the appropriate guide (Pearce 1990). NPV is a suitable measure to describe profitability in situations where monetary values of inputs are approximately equal. NPV gives the investment net value when the interest rate is known, and furthermore, meets the acceptability criterion. However, a common problem in the NPV method is the choice of the interest rate used. According to Price (1989) the monetary interest-earning opportunities are the basis for interest rate in economic calculations.

A common solution is to use the market rate of interest. In Thailand the common market interest rate is 18 % or higher. As this represents nominal rate, the (real) interest rate in the calculations was chosen to be 12 %, i.e. the level often recommended by funding institutions. The influence of the interest rate on NPV was studied in a sensitivity analysis.

The problem of ex ante choice of discounting rate can be avoided when the internal rate of return (IRR) is used. IRR gives the rate of interest when NPV is equal to zero. IRR is usable as an estimator for comparing alternatives when the monetary values of inputs are not equal. IRR fulfils the selection criteria.

Open land is a presumption in IRR calculations, because the first investment cannot be negative (income). There is some discussion about the problems related to IRR (e.g. Sedjo 1983, Price 1989) which does not support using it as the sole criterion. Nautiyal (1988) points out that this criterion might be acceptable, apart from private enterprises, for developing countries with small forest resources wanting to accumulate capital very quickly.

The benefit/cost-ratio (B/C-R) provides information on what the ratio between the net present value of benefits and the net present value of costs is (Dixon et al. 1988). The higher the B/C-R is, the higher is also the profitability of the investment.

B/C-R is a suitable estimator for comparing investments where monetary inputs are not equal; thus, it meets the selection criterion in addition to the acceptability criterion. Pearce (1990) suggests that for establishing priorities for public investments, the B/C-R will most likely be the appropriate criterion.

An economic analysis also needs to recognise and explicitly treat the uncertainty. In the present work, after the main sources of uncertainty were identified, a sensitivity analysis was carried out using various combinations of assumptions.

3.2 Growth and yield data

Generally speaking, detailed growth and yield studies on different soil types and different species and planting densities have not been carried out in Thailand. However, several separate measurements of growth and yield in Northeast Thailand are documented. According to Cadiente (1987) *Eucalyptus camaldulensis* will yield 54 t/ha of total above ground biomass every five years on cultivated land without fertilising and 80 to 160 t/ha of total above ground biomass every five years with the use of high technology and fertilisers.

Pohjonen (1992) has compiled provisional growth tables for *E. camaldulensis* in Northeast Thailand. According to these tables, the mean annual increment (MAI) and current annual increment (CAI) are equal in the twelfth year after planting, when the total stemwood yield equals 170 m^3/ha. This rotation option was found to be optimal for maximising the growth. The growth tables mentioned above were also used as a source for basic growth information on *E. camaldulensis* in the present study.

According to Yoda et al. (1990), at the age of five years the total above ground biomass is 51 t/ha, while the growth and yield tables of Pohjonen (1992) present the total growth as 52.5 t/ha in similar stand densities.

Acacia mangium was not planted in Thailand until 1984. Growth information on this species is available from Malaysia where it has been found to grow at a rate of 30 m^3/ha/a (Liang 1986). In Bangladesh, *A. mangium* has produced, on average, 21 m^3/ha/a even on poor sites; in economic calculations the yield was estimated at being 100 t/ha every five years (Someswar 1984). The total sawlog production for this species was estimated to be 300 m^3/ha at the age of 15 years, averaging 20 m^3/ha annually.

The total above ground biomass production of *Melia azedarach* at the age of four years in Thailand is, on average, 30.9 t/ha (Bhumibhamon 1985). In the economic calculations of the present investigation the growth was estimated to be 55 t/ha for a five year period. When *M. azedarach* is grown for sawlog production in Thailand, the yield is 85 m^3/ha of stemwood at the age of ten years (Deputy Managing Director Winai Thavorn, Thai Plywood Co., Bangkok, pers. comm.).

Teak (*Tectona grandis*) is grown on long or medium rotation. In the present study, rotations used in economic calculations for teak were 25, 45 and 60 years; the total yield was 181.3, 256.3 (Kaensingha 1989) and 468 (Thaiutsa et al. 1985) m^3/ha respectively.

Para rubber (*Hevea brasiliensis*) yields both latex and wood, and both products were considered in the present profitability analysis. Within a normal rubber plantation rotation, the period of latex production is from the seventh to the 25th year. The average annual rubber production is 1500 kg/ha (Suchare 1985). The harvestable amount of timber at the end of the rotation is, on average, 190 m^3/ha (Urapeepatanapong 1989).

In Thailand the amount of pulpwood is calculated by weight (t/ha) and sawlog production is measured by volume (m^3/ha). By using specific weight values, 0.6 for *Eucalyptus camaldulensis*, 0.56 for *Acacia mangium* (Firewood crops 1980) and 0.66 for *Melia azedarach* (Firewood Crops 1983), it was possible to calculate the volume when the weight is known and vice versa.

3.3 Cost data

In the present investigation three categories of forest managers i. e. the industry, the state owned forestry administration (RFD) and private land owners, were studied separately. The industry and the RFD use more mechanized methods in plantation establishment, while the farmers use labour-intensive and simpler methods. Differences in total costs among these manager groups are caused by plantation and management costs. However, due to the lack of information, the yield was assumed to be the same for all three ownership categories. Normally, mechanized methods result in better growth but, to some extent at least, the intensive tending of seedlings by farmers may increase the survival of trees. Costs and benefits were converted so as to correspond to 1990 values using the wholesale price index for financial, economic and environmental-economic calculations. In the case of roundwood and other raw materials, the prices were converted using the producer price index. Index values used are shown in Appendix, Table 17.

Profitability calculations were based on the most cost-effective establishment methods; these are shown in the annexed tables by species. Using the cheapest reforestation option the total establishment, land, harvesting and transportation costs for an industrial tree plantation are indicated in Tables 9–14. Teak production costs incurred over one rotation were calculated as 118 120 Baht/ha for a rotation of 25 years (Table 15). Costs incurred for a rubber plantation were found to be 153 909 Baht/ha over one rotation (Table 16).

Harvesting costs were estimated at 60 Baht/m^3 (Deputy Managing Director Winai Thavorn, Thai Plywood Co., Bangkok, pers. comm.) or 70 Baht/t of greenwood (Cadiente 1987); and transportation costs at one Baht/m^3 or ton per kilometer (Bhumibhamon, unpublished). The ratio between log volume and total volume used was 0.6. Wood residues are used in pulp production.

Other values used in calculations were seedling prices, 0.7 Baht per seedling for *E. camaldulensis* (Report of the research... 1985, Policy of reforestation... 1987), and 1.0 Baht per seedling for *A. mangium* and *M. azedarach* (Deputy Managing Director Winai Thavorn, Thai Plywood Co., Bangkok, pers. comm.). Land rent was assumed to be 938 Baht/ha (Policy of reforestation... 1987). Labour wages were 40 Baht/man-day for unskilled and 55 Baht/man-day for trained workers (Report of the research... 1985). The factory price used for green pulpwood was 600 Baht/t (Cadiente 1987). The distance between the plantation and the factory was fixed at 200 km.

3.4 Financial profitability

A private person or a company usually undertakes reforestation to make a profit or to increase the possibilities to make future profits. As stated by Gregory (1972), the maximisation of the net revenue is supposed to meet the profit motive of the private investor. In the present calculations financial profitability represents the point of view of a private investor, whether it in actual case will be a farmer, a firm or a public agency.

In a financial analysis the costs and prices are generally those met by a single firm. The differences between financial and economic profitability analyses and data as applied in this study are explained in the following chapter.

3.5 Economic profitability

Public reforestation programmes are associated with a motive to increase the aggregate of goods and services available for the society from the use of the nation's limited resources. Economic efficiency analysis in this case represents profitability from the point of view of the society. Benefits are valued by their contribution to human welfare, and scarce resources used as factors of production are valued at their opportunity cost.

Market prices can be used in economic analysis to the extent that they reflect true economic value. When market prices do not provide acceptable measures of economic value, shadow prices have to be developed. Theoretically, all inputs and outputs should be shadow priced. In practice most market prices are accepted as proxies for the economic values or a rough estimate is used for an appropriate shadow price.

Inputs were shadow priced by using opportunity cost (OC), the benefit foregone by not being able to use resources in the next best alternative use. Outputs were shadow priced mainly on the basis of their ability to supply additional export earnings or in order to modify the domestic prices due to market failures.

The wages of trained workers in competitive markets are supposed to reflect the opportunity costs of trained labour. For untrained workers the normal wage rate is not acceptable (Price 1989). Drivers were referred to as trained workers in this study.

The opportunity cost of untrained labour was calculated using the real income opportunities as basic information. According to Chalamwong (1990) the average working time on a small farm is 151.5 hours per month. The average annual farm income is 16 054 Baht and the average number of persons working in a family is 3.3 (Tongpan et al. 1990). The average net income is then 2.67 Baht per hour. With 260 working days a year and a working day of 7 hours, the net income is 7 · 2.27 Baht or 18.7 Baht per man-day, which value was used as an opportunity cost of untrained labour of the present study.

In the economic analysis the opportunity cost (OC) of land is the net benefit forgone by displacing the existing land use (Price 1989). In this study the land opportunity cost was derived from the production of cassava (*Manihot esculenta*) as alternative land-use. The average cassava production cost in Northeast Thailand is 0.326 Baht/kg (Agricultural marketing... 1984). In 1987–1989 the average price for cassava roots was 0.634 Baht/kg and the yield per hectare 14 138 kg (Agriculture statistics... 1989).

The total net income in cassava production is thus 4 354 Baht/ha. This was adopted as the land opportunity cost used in the economic calculations in the first year. However, cassava production has a negative impact on the soil nutrient balance and therefore the production decreases in the following years. Due to this, the opportunity cost was assumed to decrease linearly over five years reaching the value of 1 000 Baht per hectare. After this, a ten-year fallow period will occur and the soil properties are supposed to reach the same level as before cassava cultivation. The land rent was stated to equal zero in economic calculations.

The price of saw- and pulpwood was higher in economic calculations than in financial calculations. For pulpwood this difference was estimated to be 100 Baht/t of greenwood. This was as high as the difference between the economic and the financial price of *Eucalyptus camaldulensis* sawlogs. Using a transportation distance of 200 km in economic calculations, the factory price was calculated as 700 Baht/t of greenwood.

Table 1. Sawlog prices (Baht/m^3) in financial and economic calculations.

Species	Price in financial calculations	Price in economic calculations
E. camaldulensis	800	900
A. mangium	1 000	3 817
M. azedarach	2 000	4 390
Teak		
1 st thinning	800	800
2 nd thinning	2 500	2 500
3 rd thinning	6 000	8 218
harvesting, age 45	12 000	12 000
harvesting, age 60	12 000	12 000
Rubber	2 737	3 215

Source: Calculated from Forestry statistics of Thailand (1989).

If produced wood will substitute import and the amount of foreign currency earned and goods and services purchased is 1:1, then the net import price describes the economic price of wood (Gregersen and Contreras 1979). In this study, economic prices of wood equalled prices for imported saw logs for the species in question. For example, the economic price of teak (8 218 Baht/m^3) and para rubber logs (3 215 Baht/m^3) was set to be equal to the import price (Forestry statistics... 1989). However, the economic price of teak before a third thinning (800 and 2 500 Baht/m^3) was set to be as high as the price in financial calculations, since the small size teak logs were not thought to be substituted by imported logs. Similarly, the average import price was not supposed to describe the economic price of teak logs after the third thinning, because otherwise the economic price would have been lower than the financial price, and for larger logs this was not assumed to be possible. Thus, the financial price (12 000 Baht/m^3) was chosen to be an estimate of the economic price after the third thinning (Table 1) (Forestry statistics... 1989).

In the case of *M. azedarach*, the economic price (4 390 Baht/m^3) was set to be the average import price of five high quality species (Yang, Keruing, Kra-Bak, Teng and Rang). Likewise, the economic price of *A. mangium* (3 817 Baht/m^3) was calculated by using the price of other imported wood qualities (Table 1). The group, other imported wood, was chosen to best describe the import substituting, since *A. mangium* is an exotic tree species in Thailand. Both of the estimates are near the average import price of all species (4 238 Baht/m^3) (Forestry statistics... 1989). This procedure was estimated to be realistic, since Thailand has simultaneously experienced a total logging ban and a deficit of wood for domestic consumption.

The economic price of *E. camaldulensis* (900 Baht/m^3), on the other hand, was based on the export price since log import did not exist (Forestry statistics... 1989). The calculated financial and economic prices of sawlogs are shown in Table 1. The economic price for rubber used in this study (0.98 USD/kg) was calculated using the average of export prices over three years (1988–1990) (FAO Trade Yearbook 1990).

3.6 Environmental-economic profitability

The issue of environmental-economic profitability of reforestation is highly relevant to Thailand, where reforestation is commonly perceived as having the improvement of land use or the environment as its main objective.

In environmental-economic analysis the environmental impacts are valued and added to the calculations. An example of a positive influence of reforestation is reduced erosion, which is valued as a benefit in the environmental-economic calculations.

In the case of environmental-economic profitability, valuing costs and benefits is difficult and it can only be done tentatively and with few impacts. However, as Andersson (1987) points out, even if the results of environmental-economic analysis are approximates, they may be useful for outlining a national forest policy.

Those environmental impacts (costs and benefits) which the present monetary analysis attempted to cover (and those which were excluded) are discussed or mentioned in the following; in any other respect the calculations of environmental-economic profitability were the same as those in economic analysis. NPV, the Environmental-Economic Internal Rate of Return (EIRR2) and B/C-R were used as profitability criteria also in this approach.

The natural forests of Thailand disappeared at the rate of 0.42 million ha/a during the period

Table 2. Environmental costs and benefits of reforestation by species.

Environmental variable	E. cam.	A. man.	M. azed. (Baht/ha/a)	Rubber	Teak
Water supplies	–156	0	0	0	0
Nutrient balance	0	+156	0	0	0
Erosion and nutrient loss					
on-site benefits	+200	+200	+200	0	+200
off-site benefits	+167	+167	+167	0	+167
Decreased pressure					
on natural forests	+436	+436	+436	+436	+436
Total	+647	+959	+803	+436	+803

between 1976 and 1989 (Forestry statistics... 1989). It can be assumed that concomitantly with reforestation the pressure on natural forests will decrease. Both positive and negative environmental impacts of reforestation in Thailand have been identified but their economic importance is not known. It is generally believed that the positive environmental effects of reforestation are greater than the negative ones (Tangtham 1991).

Here a preliminary attempt was made to assess some environmental impacts in monetary terms and include them in the economic analysis.

The environmental costs and benefits of reforestation used in calculations are the following: the impact on water supplies, the impact on nutrient balance, erosion and nutrient loss control, and the decreased pressure on natural forests. Their approximated values are shown in Table 2 and related assumptions are presented and discussed in the following. Other environmental effects of reforestation, not included in the calculations, are protection against heavy rains or winds, and wildlife protection.

According to Tongpan et al. (1990), the negative impact of *E. camaldulensis* on water supplies is 25 Baht/rai (156 Baht/ha). It was assumed that the impact of *Acacia mangium* on nutrient balance is also 25 Baht per rai (Table 2). The positive effect of *A. mangium* on nutrient balance is based on the nitrogen fixing capacity of this species (Mangium and other... 1983).

The control of soil erosion is generally felt to be the greatest positive environmental impact of reforestation. Measurements from the North and Northeast of Thailand indicate that the erosion rate is much higher on bare soils than on lands with a vegetation cover. The annual soil erosion caused by water run-off has been estimated at 51.9 t/ha on bare soil, 14.2 t/ha in cassava fields, and 1.4 t/ha in *E. camaldulensis* plantations, when the spacing is 625 trees/ha and the slope between 8 and 10 % (Tangtham 1991). The amount of erosion is highly dependent on the degree of slope. However, this estimate of slope is typical of forest plantations in the northeastern and eastern provinces of Thailand.

No national evaluation of erosion costs has been carried out in Thailand yet. According to the Master Plan for Forestry Development in the Philippines (1990), the average off-site costs of erosion amount to 3 Filipino pesos (3.3 Baht) per ton of erosion material. This figure is the result of a preliminary estimate of the off-site costs of soil erosion and a rough estimate of total erosion (Master Plan for Forestry Development in the Philippines 1990, Saastamoinen 1991). If either of the two estimates changes, a unit cost will change as well, which in turn apparently makes a direct comparison more inaccurate. However, other nationwide sources were not available.

If the annual erosion rate is 50.5 t/ha smaller on reforested areas than on bare soil, the off-site benefits of erosion control are 167 Baht/ha. This value was also used as a rough estimate of the off-site benefits of erosion control in the northeastern and eastern provinces of Thailand.

In a case study, Attaviroj (1986) estimates that the off-site erosion costs in North Thailand are 2 274 Baht per hectare annually due to lost timber production, income lost from irrigated rice, the depletion of hydroelectric capacity and the siltation of downstream water supplies. The figure used in this study was considerably lower and more likely an underestimate than an overestimate.

There are many alternative methods for the evaluation of the on-site costs of soil erosion (Dixon et al. 1988, Saastamoinen 1992). An agricultural production loss was the basis for the approach chosen here. The on-site benefits of the control of erosion and nutrient loss were calculated using a comparison between two alternatives. The first one consisted of sustainable cassava cultivation without erosion or nutrient depletion when a five-year production and ten-year fallow cycle was used. In this case the income was on average 1 070 Baht/ha/a for the whole 15-year period. The second alternative was a pure cassava cultivation with a 2.2 % annual decrease of production due to erosion and nutrient loss. This decrease rate was derived from the fact that the average yield of cassava in encroached forest areas dropped by 2.2 % per year between the periods 1980–1984 and 1985–1989 (Tongpan et al. 1990).

The difference between the above two alternatives describes the loss of land productivity. That is the on-site cost of erosion and nutrient loss. The on-site costs of erosion were 24 Baht per hectare in the first year; accumulating annually, and eventually totalling 4 002 Baht in the year 20. Thus, the average on-site erosion costs were 200 Baht/ha/a (Table 2). However, in calculations the actual, not average, annual values were used.

The avoidance of erosion costs was handled as an environmental benefit of reforestation. In the case of rubber, the off-site and on-site benefits of erosion control and nutrient loss control were estimated to equal zero. This was due to the shallow root system of the rubber tree which does not bind the soil surface as effectively as deep roots. When the off-site and on-site benefits of erosion control and nutrient loss control were combined, the total benefit of zero for rubber and 367 Baht/ha for other species was obtained (Table 2).

Sedjo (1983) describes reforestation as one of the best methods of protecting natural forests. In the northeastern and eastern provinces of Thailand the preservation of natural forests is one of the main objectives of reforestation. This is also an aim of the national forest policy, according to which 25 % of total land area is planned to remain as conservation forests.

The objective of the forest policy is to satisfy most of the domestic wood consumption by plantation forestry. The conservation of the remaining natural forests is thus regarded to be more valuable than the opportunity of wood production. It can be then assumed that the value of conservation is at least as high as the value of the growth of the natural forests. Here, a cautious impact estimate was made, assuming that one hectare of plantation forests conserves the growth of one cubic meter of natural forests.

This conservation effect is due to decreased forest encroachment. Plantation forestry creates new work opportunities (plantation establishment, maintenance and harvesting work) and cash needs are thus partially satisfied. Attaviroj (1986, see Dixon et al. 1988) presents an estimate that the value of wood production on 0.224 million ha is 330 million Baht annually, 1 473 Baht/ha. According to Sterk and Ginneken (1987) the annual timber production of the dry dipterocarp forest is, on average, 1.85 m^3/ha when a 30-year harvesting cycle is used. The value of one cubic meter of natural forests was thus calculated to be 796 Baht/m^3 (1 473/1.85) measured at mill gate level.

It is possible to calculate the economic rent (real stumpage price) by deducting the harvesting and transportation costs from the wood price. Harvesting costs are 60 Baht/m^3 (Deputy Managing Director Winai Thavorn, Thai Plywood Co., Bangkok, pers. comm.) and transportation costs 300 Baht/m^3 when the transportation distance is 300 km. The annual value of the conservation of the remaining natural forests due to the establishment of one hectare of plantation forest was 436 Baht/ha (796–60–300).

The annual value of environmental impacts was estimated to be +647, +959, +803, +476 and +803 Baht/ha for *E. camaldulensis*, *A. mangium*, *M. azedarach*, rubber-tree and teak, respectively (Table 2).

4 Results

4.1 Financial profitability

An examination of the optimal rotation time for *Eucalyptus camaldulensis* was carried out using the criterion of maximum net present value (NPV). It was found that the optimal rotation in pulpwood production was eight years for the options used by the industry or private farmers. With the methods used by the RFD, the optimal rotation was extended to nine years. When *E. camaldulensis* was grown for sawlog production, the optimal rotation was ten years (Table 3). The ratio between the log volume and the total volume of the tree was assumed to be 0.5 when the age of the trees was below ten years and 0.6 when the age exceeded ten years. The optimal rotation did not change even if the calculation was made from present to infinity. As there was a lack of growth and yield information, rotations for other species were not analyzed.

Table 3 shows that the NPV was highest when *E. camaldulensis* was grown for pulpwood and the farm forestry option was used. This illustrates the fact that the most decisive factor determining the profitability of reforestation is the plantation establishment cost. With financial internal rate of return (FIRR) as the criterion the optimal rotation was seven years in the case of industry and eight years in the case of RFD. For a private farmer, an optimal rotation which maximized the FIRR was five years. FIRR and NPV were found to be higher in the pulpwood than in the sawlog production of *E. camaldulensis* (Table 3).

Table 3. Financial NPV (Baht/ha) and FIRR (%) for *E. camaldulensis* plantations with different rotation lengths and manager categories over a single rotation.

Rotation length (a)	Industry		RFD		Farm forestry	
	NPV	FIRR	NPV	FIRR	NPV	FIRR
Pulpwood						
4	84	13.4	239	12.5	5 528	27.9
5	4 683	19.7	3 697	17.7	8 986	30.0
6	6 284	20.0	6 301	19.4	11 591	29.4
7	8 931	20.9	7 962	19.6	13 251	27.9
8	9 751	20.1	9 885	20.3	14 054	26.1
9	8 502	18.1	9 982	19.2	13 307	23.8
Sawlog						
9	2 876	14.3	1 618	13.4	6 983	20.2
10	5 082	15.9	4 256	15.1	9 622	21.1
11	4 552	15.1	3 726	14.5	9 092	19.8
12	3 751	14.4	2 926	13.8	8 291	18.5
13	2 746	13.6	1 920	13.1	7 286	17.3

As seen in Table 4 the most profitable reforestation option for the industry, when fast-growing trees are used, was the production of high-value *Melia azedarach* timber over a ten-year rotation; the NPV was 12 914 Baht/ha and the FIRR was 21.0 %. The production of latex and rubberwood on a 25-year rotation was even more profitable. The NPV of a rubber plantation was 107 816 Baht/ha and the FIRR was 28.2 % (Table 4).

Of the options used by the RFD the most profitable one was the production of *M. azedarach* timber on a ten-year rotation. In this case, the NPV was 12 748 Baht/ha and the FIRR 20.7 %. With *E. camaldulensis*, pulpwood production over a rotation of nine years was more profitable than the sawlog production. The NPV of an *E. camaldulensis* pulpwood plantation was 9 928 Baht/ha; the FIRR was 19.2 %. With *A. mangium*, sawlog production was more profitable than pulpwood production; the NPV was 8 416 Baht/ha and the FIRR was 15.9 % (Table 4).

When establishment methods were labour-intensive and simple, as in the case of farm forestry, the production of sawlogs over a ten-year rotation was the most profitable aim for an *M. azedarach* plantation. In this case an NPV of 16 788 Baht/ha and an FIRR of 26.1 % were found. With *A. mangium*, high-value timber production was more profitable than pulpwood production; the NPV was 13 099 Baht/ha and the FIRR 19.0 %. With *E. camaldulensis*, pulpwood production over an eight-year rotation was more profitable (NPV 14 054 Baht/ha and FIRR 26.1 %) than sawlog production (Table 4).

The most cost-effective reforestation options occurred in *M. azedarach* sawlog production, with B/C-R equalling 1.61, 1.60 and 1.98 for industry, the RFD and farm forestry respectively. The cost-effectiveness of farm forestry was created by lower plantation establishment costs as compared to those found in the case of industry or the RFD. The B/C-R for teak on a 25-year rotation was 3.00; for rubber on a 25-year rotation the same value was 3.27 (Table 4).

Table 4. Financial NPV, EIRR1, B/C-R over one rotation and NPV calculated from the present to infinity of different reforestation options. The rank order of profitability is shown in parenthesis.
Explanations: ind, industry; RFD, Royal Forest Department; far, farm forestry.

Option no.	Species/ product	Rotation (a)	NPV (Baht/ha)	FIRR (%)	B/C-R	NPV, infinity (Baht/ha)
1	*E. cam.*/ind/pulp	8	9 751 (10)	18.9 (12)	1.28 (14)	18 478 (8)
2	*A. man.*/ind/pulp	5	2 058 (20)	15.1 (18)	1.07 (20)	11 575 (13)
3	*M. aze.*/ind/pulp	5	–2 922 (22)	7.3 (22)	0.89 (22)	–5 495 (22)
4	*E. cam.*/ind/log	10	5 082 (15)	15.4 (17)	1.19 (15)	7 959 (18)
5	*A. man.*/ind/log	15	8 637 (12)	16.1 (14)	1.30 (11)	10 786 (14)
6	*M. aze.*/ind/log	10	12 914 (7)	21.0 (6)	1.61 (5)	19 513 (7)
7	*E. cam.*/RFD/pulp	9	9 928 (9)	19.2 (9)	1.30 (11)	17 290 (10)
8	*A. man.*/RFD/pulp	5	2 458 (19)	15.8 (16)	1.09 (19)	10 502 (16)
9	*M. aze.*/RFD/pulp	5	–2 215 (21)	8.3 (21)	0.92 (21)	–3 830 (21)
10	*E. cam.*/RFD/log	10	4 256 (16)	15.1 (18)	1.16 (16)	6 730 (19)
11	*A. man.*/RFD/log	15	8 416 (13)	15.9 (15)	1.29 (13)	10 515 (15)
12	*M. aze.*/RFD/log	15	12 748 (8)	20.7 (7)	1.60 (6)	19 824 (6)
13	*E. cam.*/far/pulp	8	14 054 (5)	26.1 (3)	1.49 (7)	23 135 (4)
14	*A. man.*/far/pulp	5	7 791 (14)	27.4 (2)	1.34 (10)	18 395 (9)
15	*M. aze.*/far/pulp	5	3 286 (17)	19.1 (10)	1.16 (16)	8 877 (17)
16	*E. cam.*/far/log	10	9 622 (11)	21.1 (5)	1.44 (9)	14 654 (12)
17	*A. man.*/far/log	15	13 099 (6)	19.0 (11)	1.49 (7)	14 938 (11)
18	*M. aze.*/far/log	10	16 788 (4)	26.1 (3)	1.98 (3)	25 227 (3)
19	Teak / -	25	55 813 (2)	19.4 (8)	3.00 (2)	60 383 (2)
20	Teak / -	45	2 633 (18)	12.3 (20)	1.10 (18)	2 827 (20)
21	Teak / -	60	18 201 (3)	16.4 (13)	1.64 (4)	22 359 (5)
22	Rubber / -	25	107 816 (1)	28.2 (1)	3.27 (1)	114 551 (1)

Calculating the financial profitability from present to infinity using the Faustmann formula (Holopainen 1976, Gregory 1972), the land expectation values of different reforestation options were as shown in the last column of Table 4. This method assumes that the next tree generation is achieved directly after harvesting. For calculation purposes *A. mangium* and *E. camaldulensis* were assumed to coppice twice before a new seedling generation was established by replanting. Growth was estimated to decrease by 20 % in both successive coppicing cycles. Finally, it was assumed that weeding was normally carried out on plantations managed by the industry or farmers, whereas in the practise adopted by the RFD weeding was not carried out from the third year onwards on coppice plantations.

The present-to-infinity NPV of reforestation in industry-managed pulpwood production with *E. camaldulensis* using an eight-year rotation increased from 9 751 Baht/ha, found in the single-rotation calculation, to 18 478 Baht/ha. When reforestation for a single rotation was not profitable, it did not turn out to be profitable for several rotations either. At the RFD, the NPV of *M. azedarach* pulpwood production on a five-year rotation decreased from –2 215 Baht/ha to –3 830 Baht/ha (Table 4). When *Acacia mangium* was assumed to coppice twice in pulpwood production, the profitability was remarkably better when the calculation period was from present to infinity than with single rotation (see Options 2, 8 and 14, Table 4).

4.2 Economic profitability

The highest economic NPV in *Eucalyptus camaldulensis* pulpwood production, 11 855 Baht/ha, was found in farm forestry. In economic calculations, the optimal rotation in pulpwood production that maximized NPV was eight years in the case of industry and private farmers and nine years in the case of the RFD. The optimal rotation in sawlog production was ten years (Table 5).

The profitability criteria of economic calculations are shown in Table 6. Of the fast-growing species, *A. mangium*, when grown for sawlogs, was found to be the most profitable from an economic viewpoint. The NPV of one rotation

Table 5. Economic NPV (Baht/ha) and EIRR1 (%) of *E. camaldulensis* for different rotation lengths and manager categories over a single rotation.

Rotation length (a)	Industry		RFD		Farm forestry	
	NPV	EIRR1	NPV	EIRR1	NPV	EIRR1
Pulpwood						
4	−2 432	6.6	−2 471	7.0	1 101	14.6
5	2 638	16.0	1 331	13.9	4 903	20.0
6	6 027	18.7	4 659	16.9	8 306	22.0
7	8 287	19.3	6 919	17.8	10 492	21.4
8	9 576	19.0	8 208	17.7	11 855	21.4
9	9 159	17.9	8 637	17.2	11 363	19.2
Sawlog						
9	194	12.2	−770	11.4	2 717	14.5
10	2 250	13.6	1 285	12.9	4 773	15.7
11	2 020	13.3	1 055	12.6	4 543	15.1
12	1 396	12.8	541	12.3	4 029	14.6
13	774	12.4	−190	11.9	3 294	13.9

was 92 200, 91 567 and 94 455 Baht/ha for the options used by the industry, RFD and a private farmer, respectively. *E. camaldulensis* was more profitable when grown for pulpwood than when grown for sawlogs. The EIRR1 was 19.0 % in pulpwood production using the industry options, while that for sawlog production was 13.6 %. The planting of *M. azedarach* was more profitable for sawlogs than for pulpwood; the EIRR1 of sawlog production varied between 29.4 and 32.4 % in this species.

The economic profitability of teak was highest when using a rotation of 25 years; the EIRR1 was 19.3 %. The NPV of rubber-plantation production was as high as 138 681 Baht/ha (Table 6).

The net present values reflecting the economic profitability as calculated from present to infinity can be seen in the last column of Table 6. The NPV of *E. camaldulensis* on an eight-year rotation in farm forestry was 23 822 Baht/ha. The economic profitability of *M. azedarach* and *A. mangium* sawlog production was 72 242 and 112 676 Baht/ha, respectively, in forest industry. The economic NPV of a teak plantation with a 25-year rotation was 61 603 Baht/ha. A rubber plantation managed for latex and wood production with a 25-year rotation had an NPV of 149 421 Baht/ha (Table 6).

It was assumed that every third rotation of *A. mangium* and *E. camaldulensis* was grown from planted seedlings in pulpwood production; the two remaining rotations would then be grown from coppice. The growth was estimated to de-

Table 6. Economic NPV, FIRR, B/C-R over a single rotation and NPV calculated from present to infinity of different reforestation options. The rank order of profitability is shown in parenthesis.

Option no.	Species/ product	Rotation (a)	NPV (Baht/ha)	EIRR1 (%)	B/C-R	NPV, infinity (Baht/ha)
1	*E. cam.*/ind/pulp	8	9 576 (11)	19.0 (10)	1.27 (11)	22 092 (10)
2	*A. man.*/ind/pulp	5	2 526 (15)	15.9 (13)	1.09 (15)	18 215 (13)
3	*M. aze.*/ind/pulp	5	–4 381 (21)	5.2 (21)	0.84 (21)	2 133 (20)
4	*E. cam.*/ind/log	10	2 250 (16)	13.6 (16)	1.09 (15)	6 365 (18)
5	*A. man.*/ind/log	15	92 200 (3)	28.2 (6)	4.35 (2)	112 676 (3)
6	*M. aze.*/ind/log	10	46 765 (7)	30.0 (3)	3.12 (7)	72 242 (6)
7	*E. cam.*/RFD/pulp	9	8 637 (12)	17.2 (12)	1.21 (12)	19 426 (12)
8	*A. man.*/RFD/pulp	5	39 (18)	12.1 (18)	1.00 (18)	13 413 (15)
9	*M. aze.*/RFD/pulp	5	–4 799 (22)	4.7 (22)	0.83 (22)	1 680 (21)
10	*E. cam.*/RFD/log	10	1 286 (17)	12.9 (17)	1.05 (17)	4 883 (19)
11	*A. man.*/RFD/log	15	91 567 (4)	27.8 (7)	4.25 (3)	111 938 (4)
12	*M. aze.*/RFD/log	10	46 153 (8)	29.4 (5)	3.03 (8)	71 035 (7)
13	*E. cam.*/far/pulp	8	11 855 (10)	21.4 (8)	1.36 (10)	23 822 (9)
14	*A. man.*/far/pulp	5	3 640 (14)	17.3 (11)	1.14 (14)	19 681 (11)
15	*M. aze.*/far/pulp	5	–1 156 (19)	10.0 (20)	0.95 (19)	10 271 (16)
16	*E. cam.*/far/log	10	4 773 (13)	15.7 (14)	1.20 (13)	10 026 (17)
17	*A. man.*/far/log	15	94 455 (2)	29.7 (4)	4.74 (1)	115 545 (2)
18	*M. aze.*/far/log	10	49 063 (6)	32.4 (1)	3.47 (5)	75 324 (5)
19	Teak / -	25	58 059 (5)	19.3 (9)	3.26 (6)	61 603 (8)
20	Teak / -	45	–2 029 (20)	11.7 (19)	0.92 (20)	–2 039 (22)
21	Teak / -	60	14 923 (9)	15.3 (15)	1.57 (9)	14 943 (14)
22	Rubber / -	25	138 681 (1)	30.2 (2)	3.99 (4)	149 421 (1)

Table 7. Environmental-economic NPV, EIRR2, B/C-R over a single rotation and NPV calculated from present to infinity of different reforestation options. The rank order of profitability is shown in parenthesis.

Option no.	Species/ product	Rotation (a)	NPV (Baht/ha)	EIRR2 (%)	B/C-R	NPV, infinity (Baht/ha)
1	*E. cam.*/ind/pulp	8	10 841 (11)	21.8 (10)	1.38 (12)	26 387 (11)
2	*A. man.*/ind/pulp	5	5 854 (15)	21.6 (11)	1.25 (16)	25 124 (12)
3	*M. aze.*/ind/pulp	5	–1 694 (21)	9.3 (21)	0.93 (21)	7 744 (20)
4	*E. cam.*/ind/log	10	5 430 (17)	15.9 (18)	1.23 (17)	10 660 (18)
5	*A. man.*/ind/log	15	98 122 (4)	30.5 (6)	5.54 (3)	119 455 (3)
6	*M. aze.*/ind/log	10	50 870 (7)	32.6 (2)	3.83 (6)	77 832 (6)
7	*E. cam.*/RFD/pulp	9	9 474 (12)	20.1 (13)	1.32 (13)	23 719 (13)
8	*A. man.*/RFD/pulp	5	3 368 (19)	16.9 (16)	1.13 (19)	20 280 (15)
9	*M. aze.*/RFD/pulp	5	–2 112 (22)	8.7 (22)	0.92 (22)	6 268 (21)
10	*E. cam.*/RFD/log	10	5 478 (16)	16.0 (17)	1.28 (15)	9 166 (19)
11	*A. man.*/RFD/log	15	98 951 (3)	30.1 (7)	5.76 (2)	118 713 (4)
12	*M. aze.*/RFD/log	10	50 258 (8)	31.9 (4)	3.70 (7)	76 567 (7)
13	*E. cam.*/far/pulp	8	13 046 (10)	24.9 (8)	1.50 (10)	28 092 (9)
14	*A. man.*/far/pulp	5	6 969 (14)	24.0 (9)	1.31 (14)	26 545 (10)
15	*M. aze.*/far/pulp	5	1 530 (20)	14.8 (19)	1.07 (20)	15 856 (16)
16	*E. cam.*/far/log	10	8 601 (13)	19.1 (14)	1.48 (11)	14 307 (17)
17	*A. man.*/far/log	15	100 553 (2)	32.5 (3)	6.24 (1)	122 324 (2)
18	*M. aze.*/far/log	10	53 167 (6)	35.5 (1)	4.38 (5)	80 854 (5)
19	Teak / -	5	63 908 (5)	20.5 (12)	3.46 (8)	66 904 (8)
20	Teak / -	45	4 255 (18)	12.7 (20)	1.18 (18)	3 556 (22)
21	Teak / -	60	21 244 (9)	17.3 (15)	1.81 (9)	20 538 (14)
22	Rubber / -	25	143 083 (1)	31.2 (5)	4.42 (4)	153 625 (1)

crease by 20 % in both of the two coppicing cycles.

4.3 Environmental-economic profitability

Due to the high environmental benefits of *Acacia mangium* it was found to be almost as profitable to grow for pulpwood as *E. camaldulensis* from an environmental-economic viewpoint. The EIRR2 was 21.8 % for *E. camaldulensis* and 21.6 % for *A. mangium* in the case of industrial pulpwood production. In labour-intensive farm forestry, the most profitable option was *A. mangium* sawlog production; in this case the NPV was 100 553 Baht/ha. The environmental-economic profitability of rubber was 143 083 Baht/ha and that of teak on a 25-year rotation 63 908 Baht/ha (Table 7).

When the environmental-economic NPV was calculated from present to infinity, of the alternatives other than rubber, Option 17 was the most profitable one (*A. mangium* grown for sawlog in farm forestry); the NPV was 122 324 Baht/ha. *M. azedarach* pulpwood production had the lowest profitability; in this case the NPV varied between 6 268 and 15 856 Baht/ha, depending on which establishment method was used (Table 7).

4.4 Comparisons between financial, economic and environmental-economic profitability

The results on financial, economic and environmental-economic profitability for *Eucalyptus camaldulensis*, *Acacia mangium*, *Melia azedarach*, teak and rubber are shown together in Fig 1. Options 17, 5 and 11 were the most profitable ones, representing *A. mangium* sawlog production in farm forestry, in industry and at the RFD, respectively (Fig. 1).

Fig. 2 shows the financial internal rate of return (FIRR), the economic internal rate of return (EIRR1) and the environmental-economic internal rate of return (EIRR2) for the different reforestation options. It can be seen that *E. camaldulensis* is more profitable to grow for pulpwood than for sawlogs, but *A. mangium* and *M. azedarach* are more profitable in sawlog production. In *M. azedarach* pulpwood production the FIRR is as low as 7.3 %, when the industry

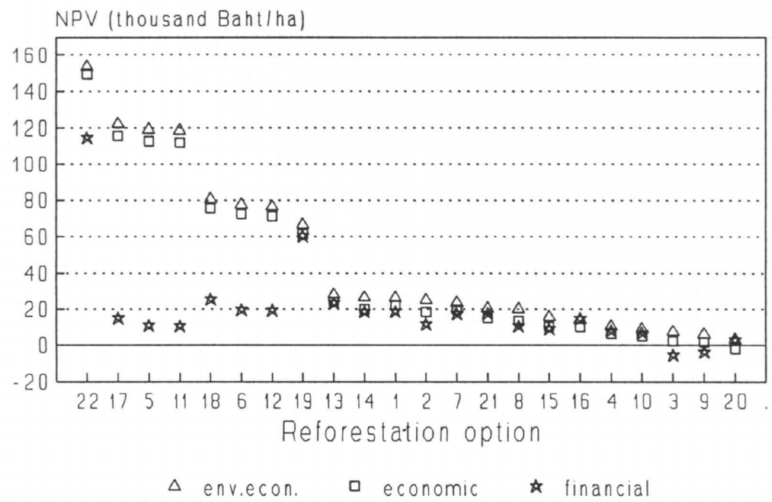

Fig. 1. The financial, economic and environmental-economic NPV of different reforestation options at 12 % interest rate. The X-axis shows the NPV per hectare for reforestation calculated from present to infinity. The reforestation options are the same as in Table 7.

reforestation practice is used (Fig. 2E).

Fig. 3 shows the benefit to cost ratio (B/C-R) for different reforestation options. *A. mangium* and *M. azedarach* were generally more cost effective when grown for sawlogs, whereas *E. camaldulensis* was more profitable to grow for pulpwood than for sawlogs. In the case of *A. mangium* or *M. azedarach* sawlog production, the economic B/C-R was higher than the financial B/C-R. In pulpwood production the economic B/C-R was only slightly higher than the financial B/C-R (Fig. 3).

4.5 Sensitivity analysis

The sensitivity analyses presented in this study were limited to a few major, potential sources of uncertainty: labour costs, yield, wood price, interest rate and distance between plantation and factory. Results were calculated over a single rotation.

Mainly *Eucalyptus camaldulensis* pulpwood plantations and *Melia azedarach* sawlog plantations were chosen for sensitivity analyses since these reforestation options were the most profitable ones in pulpwood or sawlog production. Sensitivity analyses were carried out both in financial and economic calculations. The distance between plantation and factory and the influence of interest rate were dealt with only in the case of financial sensitivity analysis.

Fig. 4 illustrates the influence of labour cost on the FIRR and EIRR1. The change in EIRR1 actually presents a sensitivity analysis for shadow-priced labour costs. Thus, the influence of labour cost was higher on the FIRR than on the EIRR1. A 20 % reduction in labour costs would cause a 1.9 to 2.3 percentage point increase in the FIRR of *Eucalyptus camaldulensis* pulpwood production (Figs. 4A–4C) and a 1.1 to 1.5 percentage point increase in that of *Melia azedarach* sawlog production (Figs. 4D–4F). The effect of labour cost was smallest when the more mechanized reforestation methods of the industry were used and greatest when the RFD practices were used (Fig. 4).

Fig. 5 shows the influence of plantation yield on the FIRR and EIRR1. In the case of *E. camaldulensis*, only pulpwood yields were analyzed, but in the case of *M. azedarach*, both sawlog and residual pulpwood yields were studied.

The effect of yield on the profitability of reforestation was greatest in *E. camaldulensis* pulpwood production. A 10 % increase in yield would cause a 1.6 to 2.3 percentage point increase in the FIRR and a 1.7 to 2.3 percentage point increase in the EIRR1 (Figs. 5A–5C). When the yield of *M. azedarach* improves by 10 %, the FIRR increases by 1.2 to 1.7 percentage points; similarly the EIRR1 will change by 1.2 to 1.7 percentage points (Figs. 5D–5F).

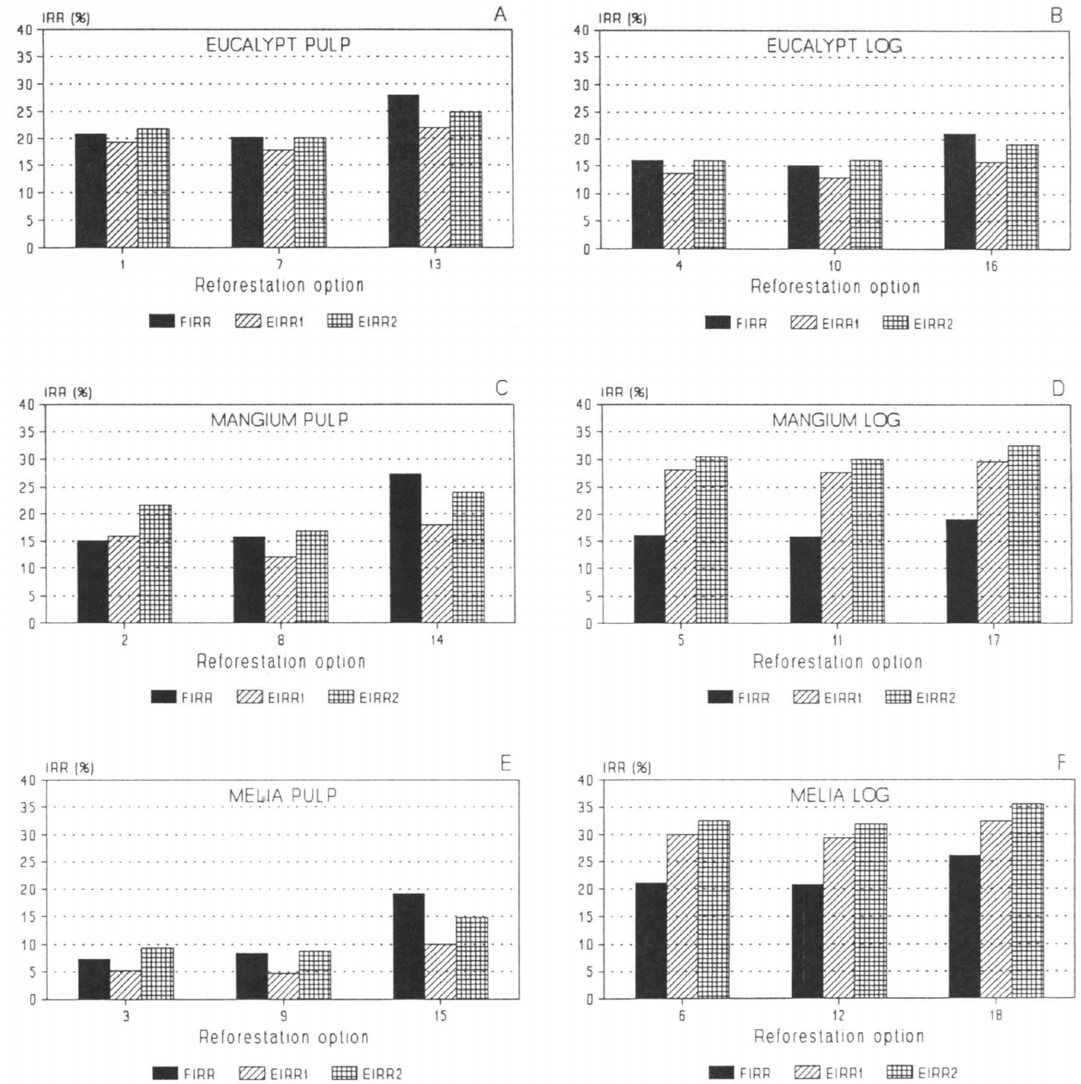

Fig. 2. The FIRR, EIRR1 and EIRR2 values of different reforestation options. The Y-axis shows the IRR for reforestation calculated over a single rotation. Fig. 2A shows the pulpwood and Fig. 2B the sawlog production of *E. camaldulensis*. Fig. 2C shows the pulpwood and Fig. 2D the sawlog production of *A. mangium*. Fig. 2E shows the pulpwood and Fig. 2F the sawlog production of *M. azedarach*. The reforestation options are the same as in Table 7.

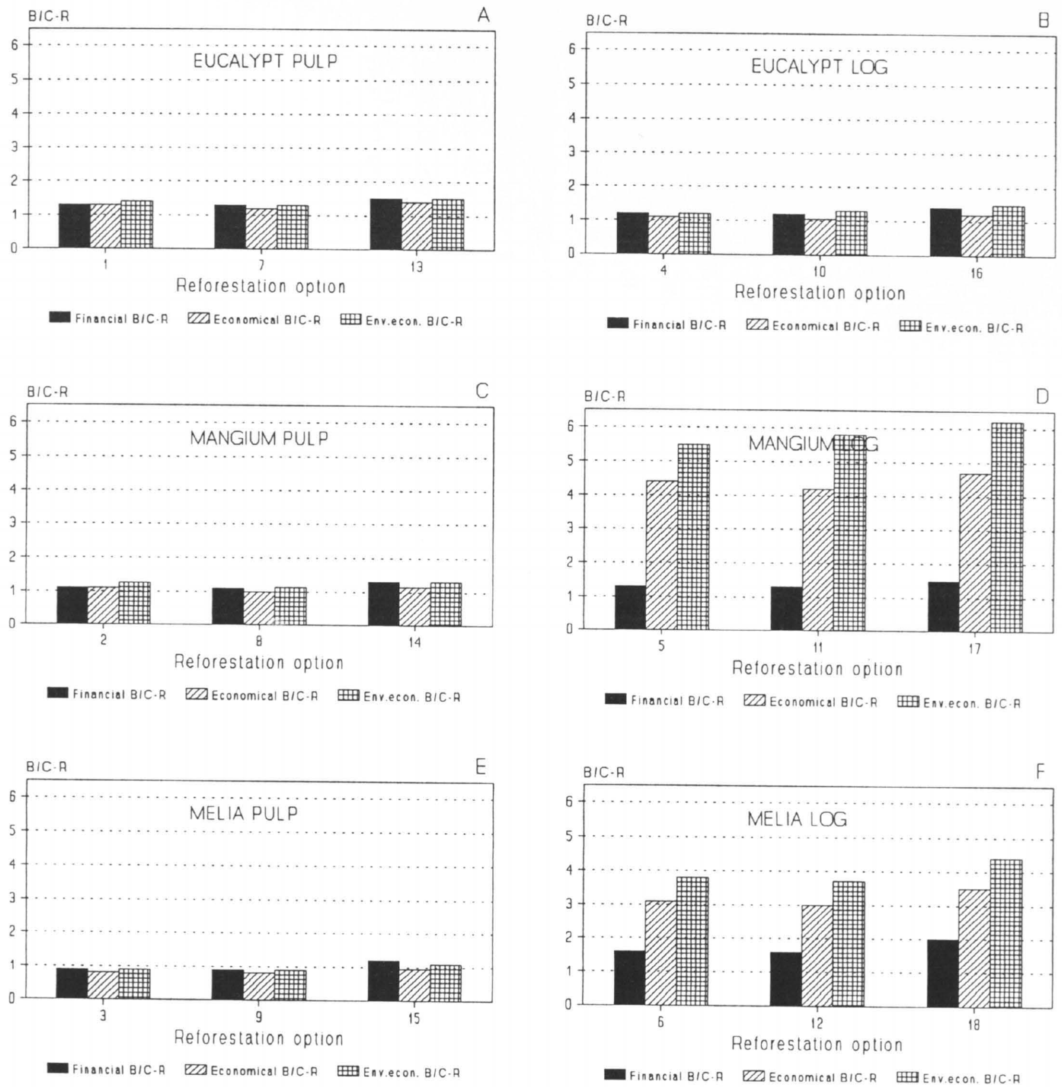

Fig. 3. The financial, economic and environmental-economic B/C-R of different reforestation options. The Y-axis shows the B/C-R for reforestation calculated over a single rotation. Fig. 3A shows the pulpwood and Fig. 3B the sawlog production of *E. camaldulensis*. Fig. 3C shows the pulpwood and Fig. 3D the sawlog production of *A. mangium*. Fig. 3E shows the pulpwood and Fig. 3F the sawlog production of *M. azedarach*. The reforestation options are the same as in Table 7.

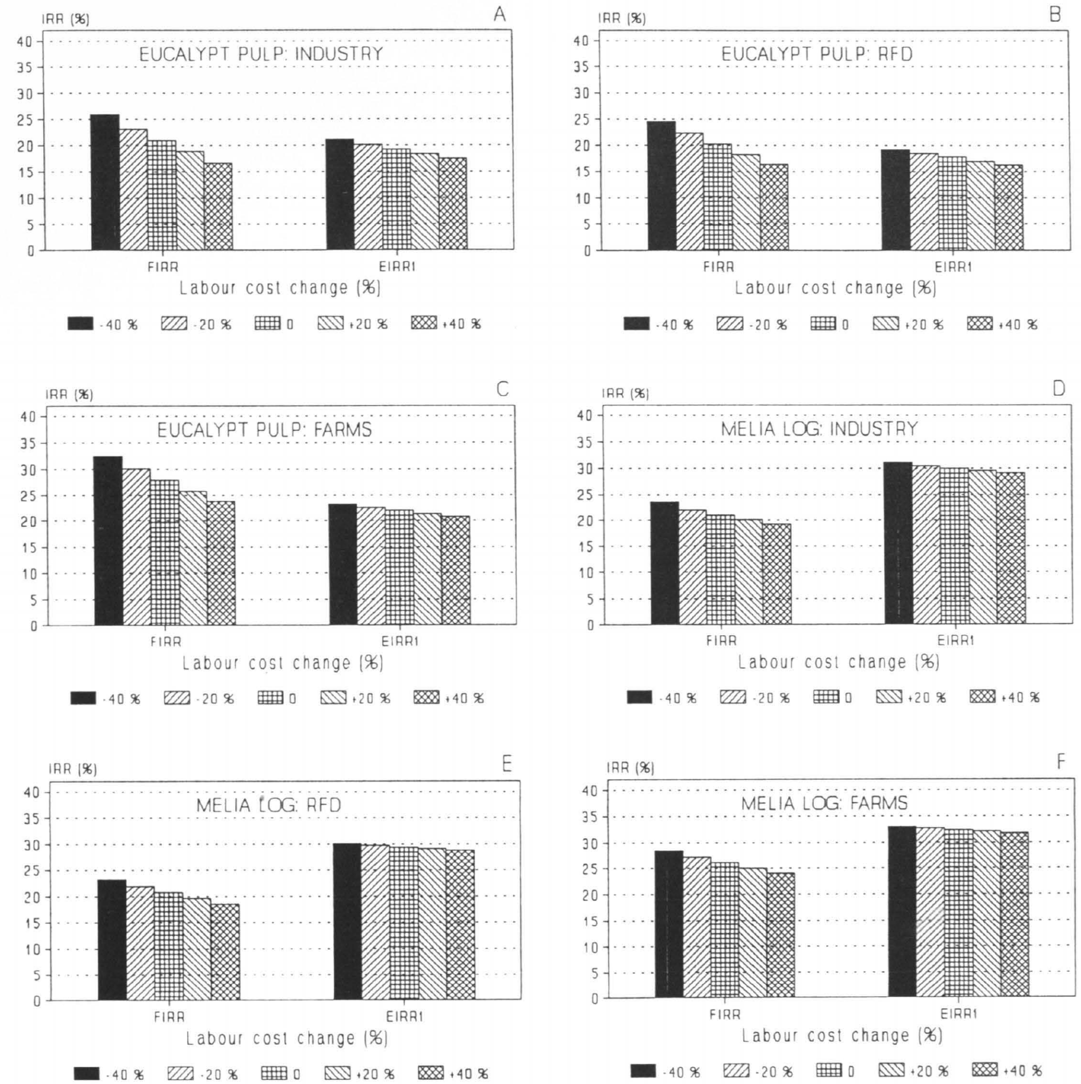

Fig. 4. The columns show the FIRR and EIRR1 when the labour cost changes are –40 %, –20 %, 0 %, +20 % and +40 %. Figs. 4A–4C are for *E. camaldulensis* pulpwood, Figs. 4D–4F for *M. azedarach* sawlog production with the industry, the RFD and farmers as plantation managers, respectively.

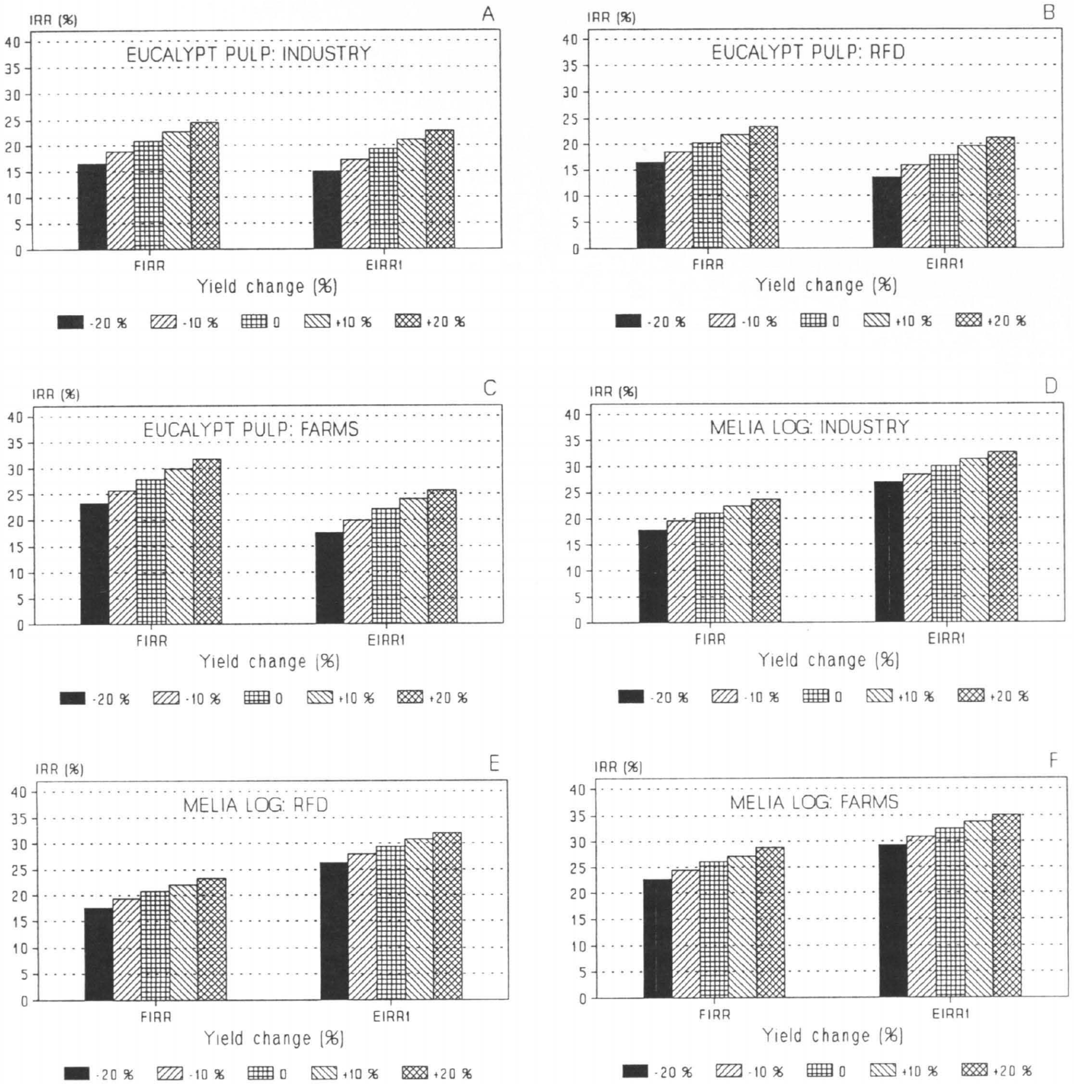

Fig. 5. The values of FIRR and EIRR1 when the plantation yield changes by –20 %, –10 %, 0 %, +10 % and +20 %. Figs. 5A–5C are for *E. camaldulensis* pulpwood and Figs. 5D–5F for *M. azedarach* sawlog production with the industry, the RFD and farmers as plantation managers, respectively.

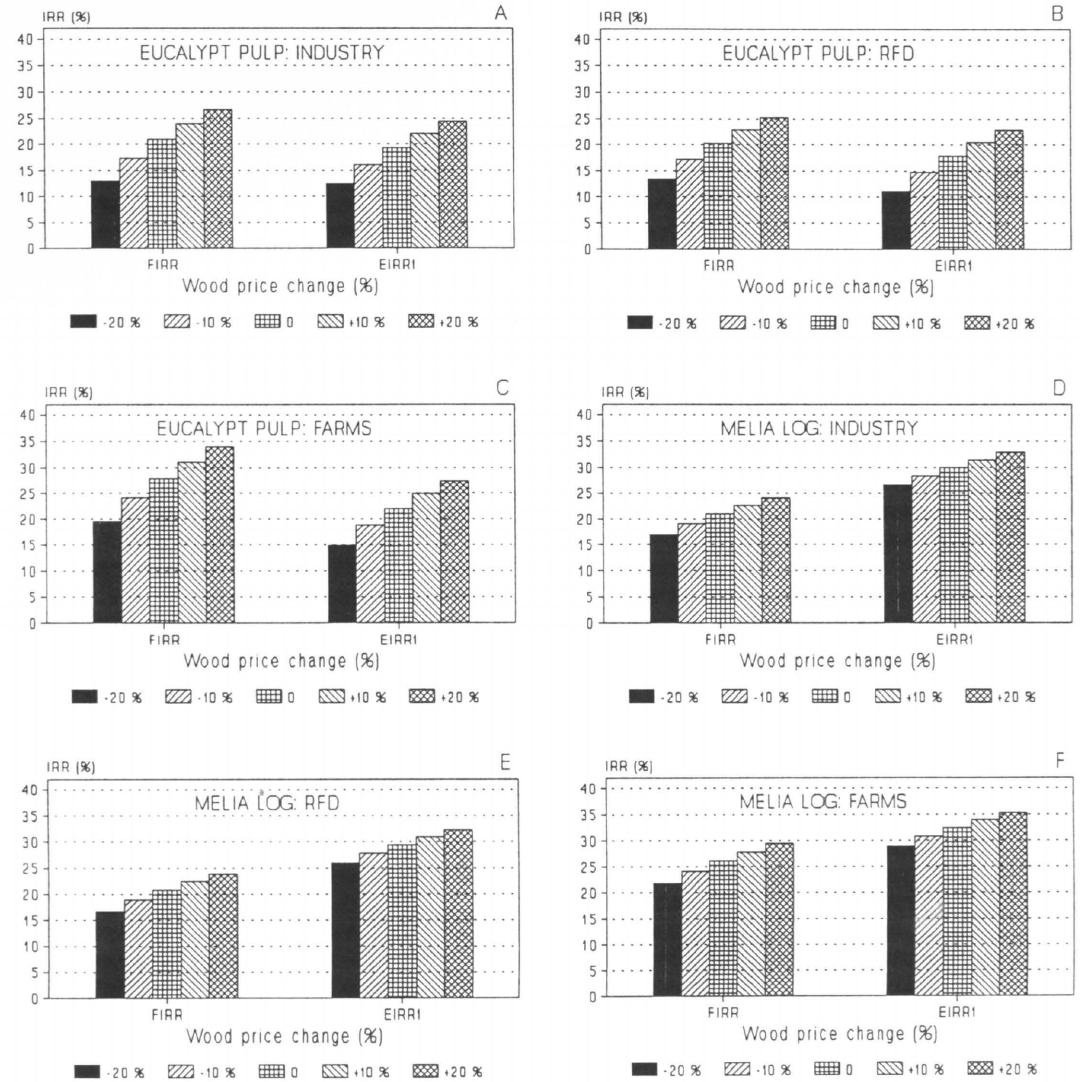

Fig. 6. The values of FIRR and EIRR1 at wood price changes of –20 %, –10 %, 0 %, +10 % and +20 %. Figs. 6A–6C are for *E. camaldulensis* pulpwood, Figs. 6D–6F for *M. azedarach* sawlog production with the industry, the RFD and farmers as plantation managers, respectively.

Table 8. The financial NPV of three reforestation options when the interest rate is 4, 8, 12, 16, 20 and 24 %.

		Interest rate (%)					
		4	8	12	16	20	24
E. cam. pulp	Ind.	25 814	15 871	8 931	4 057	619	–1 811
	RFD	31 008	18 380	9 885	4 131	218	–2 447
	Farm.	30 708	20 461	13 251	8 136	4 480	1 855
A. man. logs	Ind.	57 142	25 098	8 637	133	–4 230	–6 411
	RFD	56 945	24 887	8 416	–94	–4 462	–6 645
	Farm.	61 417	29 100	12 099	3 671	–890	–3 248
M. aze. logs	Ind.	43 385	24 633	12 913	5 526	848	–2 115
	RFD	43 258	24 490	12 758	5 362	677	–2 291
	Farm.	47 788	28 757	16 788	9 179	4 300	1 155

Fig. 6 illustrates the influence of wood price on the FIRR and EIRR1. *E. camaldulensis* is very sensitive to changes in the price of wood; when the price increases by 10 %, the FIRR will increase by 2.4 to 4.5 percentage points (Figs. 6A–6C). A 10 % change in wood price causes a 1.4 to 2.3 percentage point change in the FIRR of *M. azedarach* plantations (Fig. 6D–6F). Despite the fact that the shadow price of wood was found to be higher than the financial price, variations in wood price influence the FIRR more than the EIRR1 (Fig. 6).

The effect of interest rate on the profitability of different reforestation options is presented in Table 8. Interest rates used were 4, 8, 12, 16, 20 and 24 %. Plantation management categories, i.e. the industry, the RFD and farm forestry, were studied separately so as to allow a better comparison among *E. camaldulensis* pulpwood production and *A. mangium* or *M. azedarach* sawlog production.

When the distance between the plantation and the site of utilization increases, the profitability of reforestation decreases. With a transportation cost of 1 Baht/t/km, the decline of profitability was linear, as seen in Fig. 7. When the NPV falls below zero, reforestation becomes unprofitable. The transportation distance limit for NPV to equal zero was found to be approximately 250 km for *A. mangium* managed by the industry for pulpwood production with an interest rate of 12 %.

M. azedarach is more profitable to grow than *E. camaldulensis* when the distance between the plantation and the factory is over 100 km. This is due to the higher unit price of *M. azedarach* wood. In the case of RFD, *M. azedarach* pulpwood production was profitable up to 130 km from the utilization site (Figs. 7A–7C).

A sensitivity analysis where shadow prices were used was carried out for *E. camaldulensis* pulpwood and *M. azedarach* logwood production. The effects of labour cost and wood price on EIRR1 are shown in Figs. 4 and 6, respectively.

The opportunity cost of land was calculated by using cassava (*Manihot esculenta*) cultivation as an alternative use of land. As presented earlier in Chapter 3.5, cassava cultivation causes nutrient depletion and thus the production decreases annually. When the influence of nutrient depletion was 10 % higher than estimated earlier (i.e. the yield of cassava 10 % lower), the EIRR1 decreased by 1.5, 0.8 and 1.2 percentage points in *E. camaldulensis* pulpwood and *A. mangium* and *M. azedarach* logwood production, respectively when the industry method was used.

The sensitivity analysis on the environmental effects of plantation forests showed that when the total environmental benefits increased by 10 %, the EIRR2 increased by 0.3 percentage points in *E. camaldulensis* pulpwood and *A. mangium* and *M. azedarach* sawlog production when the industry reforestation method was used.

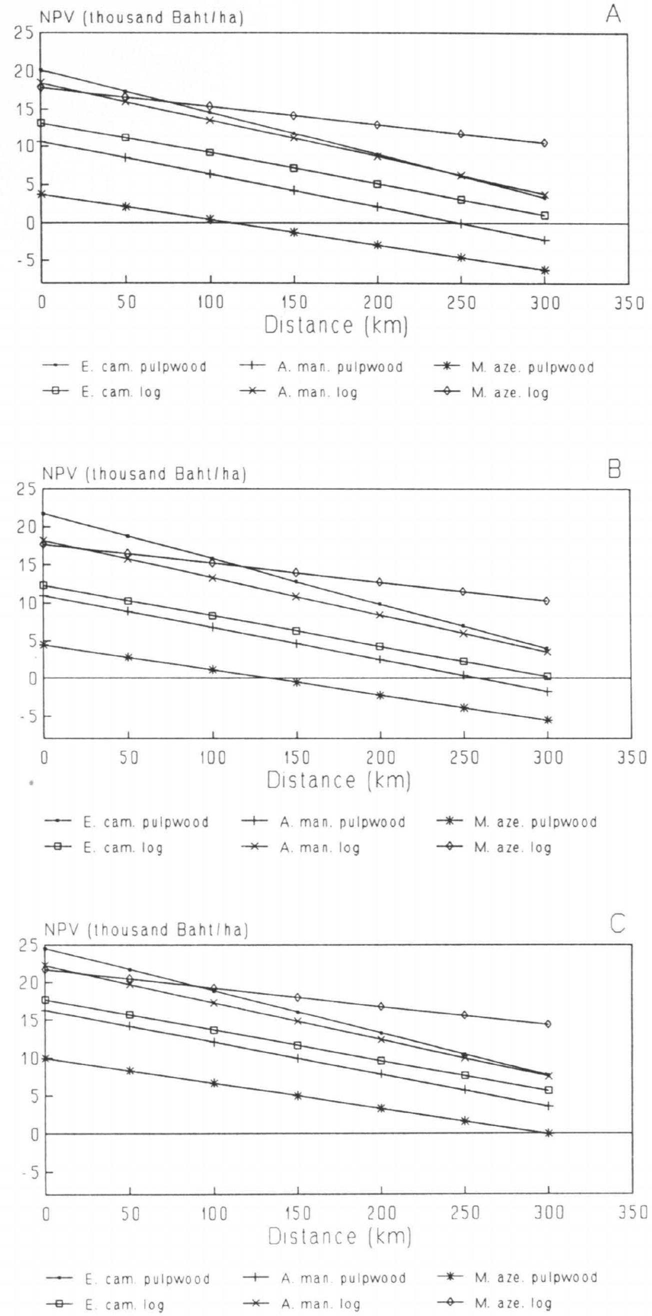

Fig. 7. Financial NPV as a function of transportation distance within the range of 0–300 km. Fig. 7A: industry; Fig. 7B: RFD; Fig. 7C: farm forestry.

5 Discussion and conclusions

The choice of tree species for the present study was based on previous information concerning a total of 90 tree species with a potential for plantation forestry in Thailand (Bhumibhamon 1989). The most promising fast-growing trees selected for this economic analysis included two exotic species (*Eucalyptus camaldulensis* and *Acacia mangium*) and an indigenous one (*Melia azedarach*).

Comparisons with teak (*Tectona grandis*) and para rubber (*Hevea brasiliensis*) were also made so as to offer a wider range of options for actual decision-making. In the future, these five species will be the principal tree crops used in terms of planted areas, taking the country as a whole. The present work aimed at providing information for better justification in selecting among these tree species.

Only in the case of *Eucalyptus camaldulensis* was it possible to examine the optimal rotation length, due to a lack of growth data on the remaining species. Especially in the case of *Acacia mangium* and *Melia azedarach* the existing growth and yield information remains inadequate. The growth estimates presently used for these two species were the best available for the northeastern or eastern provinces of Thailand.

Three basic plantation establishment approaches were analyzed in the present study, representing the practices used by the industry, the Royal Forest Department (RFD) and farm forestry. Growth and yield were not assumed to vary within a given approach. The lowest plantation establishment costs are found in farm forestry, in which labour intensive methods and simple technology are used.

Total costs are much higher in sawlog production than in pulpwood production even if the establishment costs are lower. A longer rotation increases both the total rent paid and the interest costs but also results in a higher yield.

Financially, the optimal rotation for *E. camaldulensis* was found to be eight years. The choice of the rotation period is flexible because the NPV is almost the same between six and nine years in the industrial, RFD or farm forestry approach. This flexibility gives, especially to private farmers, a possibility to start harvesting even before the optimal rotation is reached (Table 3).

A. mangium and *M. azedarach* should be grown for long-rotation saw-wood or veneer log production. In the present study, the rotations applied were 15 and 10 years, but it is not possible to conclude whether the optimal period that maximises the net present value is shorter or longer than these rotations. However, it was found that, for these two species, log production is more profitable than pulpwood production. It can also be predicted that sawlog and veneer log prices will increase more than those for pulpwood because of the growing shortage of natural high-quality logs. It is precisely for this reason that *A. mangium* and *M. azedarach* will have a particularly significant role in the mechanical wood industry.

E. camaldulensis should be grown for pulpwood with short, but not shorter than five-year and not longer than nine-year, rotations. If the time value of money is as high as the market interest rate (18 %), the profitability of wood production is lower than that of cassava cultivation. This limits the land owners' interest in tree farming. However, the baseline interest rate (12 %) used in the study changed the order of profitability and *E. camaldulensis* became more profitable to grow than cassava.

In the case of teak, a short rotation gives a high NPV of reforestation. Despite the fact that the price of teak rises notably when the quality improves and the log size increases, the NPV decreases with longer rotations. Consequently, what should be encouraged in teak plantation management is the improving of the quality of teak, rather than long rotation periods.

Starting in 1992, after the government passed the Tree Planting Act and abolished restrictions associated with indigenous species, farmers have shown more interest in teak cultivation. Intensive farming on private land with teak as a crop component would result in better yields of teak than those obtained in conventional plantations. With the new approach, teak can be harvested at the age of 20 instead of the usual 60 years. This would also reduce many risks presently involved in growing teak (Bhumibhamon, unpublished).

In the future it will also be possible to utilize the vegetative regeneration capabilities of teak, already discussed in the early silvicultural literature (cf. Champion and Griffith 1948). Coppicing of teak for three to five rotations, depending on site conditions and on the level of intensity in management, seems to be a feasible option also in view of the results obtained in the present investigation.

Of the tree crops studied, Para rubber is the most profitable species to grow, as was assumed prior to the present study. Rubber should be planted on sites which climatically and environmentally suit this species and are zoned for plantation tree crops. Rubber is recommendable for private, small-scale farmers as it is a labour-intensive and cash-generating crop during the latex production period.

The environmental-economic profitability was found to be higher than the economic or financial profitability. This general result is due to the environmental benefits assumed in the present calculations.

Because of higher economic prices and the high opportunity cost (OC) of land, especially reforestation options for *A. mangium* or *M. azedarach* sawlog production are economically more profitable than they are financially. The difference between the financial and the economic profitability of these options is so great that the use of government subsidies in these cases seems to be justified. With subsidies, reforestation becomes financially more profitable for private farmers.

In contrast to the initial hypothesis, *Eucalyptus camaldulensis* was not the most profitable fast-growing tree species. *A. mangium* and *M. azedarach* were more profitable than eucalypt for sawlog production. This was the result in each of the three (financial, economical and environmental-economic) sets of analysis. For pulpwood production alone, *E. camaldulensis* was more profitable to grow than either *A. mangium* or *M. azedarach*.

According to the present findings, labour costs affect the financial profitability more than the economic or environmental-economic profitability. It is also to be expected that labour costs will be higher in the future. If a minimum wage is statuted, it will mostly affect the financial profitability. Changes in labour costs influence pulpwood production more than sawlog production. The labour-intensive production systems applied by the Royal Forest Department and the farmers are more sensitive to labour cost changes than those used by the industry.

An additional silvicultural factor deserves a mention in connection with labour costs: of the tree species studied, *A. mangium* has the advantage of causing less weeding costs than, for instance, *E. camaldulensis*, due to the fact that the former species effectively suppresses the ground vegetation from the second year onwards.

The effect of plantation yields on the profitability of reforestation is clear. When trees are grown for pulpwood, a 10 % yield change will cause an up to 2.5 percentage point change in financial profitability. In sawlog production the effect is about 1–1.5 percentage points. This demonstrates the importance of reliable yield data for profitability calculations.

A 10 % change in pulpwood price would result in an up to five percentage point change in FIRR, while a similar change in sawlog price only causes a two point change in FIRR. Wood price and plantation yield thus have a crucial effect on the profitability of reforestation. If both the yield and the wood price increase by 10 %, the total increase in the FIRR is about six percentage points for *E. camaldulensis* pulpwood production and about three points for *M. azedarach* or *A. mangium* sawlog production.

With only a slight improvement in yield in the future the profitability of reforestation can be improved considerably. This would suggest provenance testing and tree breeding as recommendable management measures for the northeastern and eastern provinces in Thailand. Government subsidy to wood prices would evidently result in a considerably increase in the acreage planted with tree crops, even if the subsidy remained small.

When the distance between the plantation and the factory exceeds 100 km, *M. azedarach* rather than *E. camaldulensis* should be grown. If the distance is less than 100 km, *E. camaldulensis* is financially more profitable.

Cadiente (1987) has earlier concluded that reforestation with *E. camaldulensis* for pulpwood production is profitable in Thailand; the NPV was found to be 3 631 Baht/ha with an interest rate of 15 % and the FIRR equalled 20.0 %. Eucalypt fuelwood production resulted in an FIRR figure as high as 63.2 %.

Jeeranantasin (1987) has calculated the profitability of *E. camaldulensis* plantations for a rotation of five years. The FIRR was 25.0 % for a non-agroforestry system and 43.4 % in agroforestry.

Thaiutsa et al. (1985) have investigated the profitability of *M. azedarach* for sawlog production on a 15-year rotation. When the interest rate was 17 %, the NPV of reforestation was 53 500 Baht/ha. In the same study, the NPV of a teak plantation on a 60-year rotation was as low as –9 860 Baht/ha when the interest rate was 17 per cent.

Kaensingha (1989) has studied the profitability of teak plantations managed by the Forest Industry Organization of Thailand (FIO). In this case, the IRR was 24.0 %, 22.0 % and 17.0 % for rotations of 15, 25 and 45 years, respectively. For comparison, in a study by Songanok (1991), the NPV of a rubber plantation was found to be 26 199 Baht/ha when the interest rate was 12 per cent.

The choice of tree species for plantation management in Thailand obviously depends on the quality of the site available and on climatic factors. According to the present results, good sites should be planted with rubber, *M. azedarach* or teak. Dry and poor sites, as those frequently found in areas earlier used for cassava cultivation, cannot be used for these demanding tree crops and should be planted with eucalypt instead.

A. mangium can grow well in deep soil with good drainage. This species can improve the fertility of the site through nitrogen fixing. However, a combination of fertile soil and high rainfall easily leads to heartrot in this species (Bhumibhamon, unpublished).

Due to the closing down of concession areas in Thailand, the wood supply for the mechanical forest industry has become dependent on logs imported from Burma (Myanmar), Malaysia, Laos, Cambodia and Papua New Guinea, and even from North America and Europe. Most likely, Thailand will soon face the problem of a decreasing log import.

For a supply of wood for the future demand, self reliance should be established through the promotion of various tree crop management systems on any land allocated for such a purpose. The present study has not analyzed all of the options available; it concentrated on the economic profitability of industrial plantations or block plantations on farmland only.

Currently, large-scale industrial plantations have not received popular support in Thailand. In particular, the large section of the rural population that still lacks adequate land security has strongly opposed this type of land use. The negative attitude has thus been due to the limited availability of land for farming practices. However, the establishment of small-size block plantations is also possible and this approach should be the main one in plantation management in the country.

Thai farmers are already changing their cropping systems and taking advantage of farm forestry options. For instance, in the province of Chachoengsao (120 km east of Bangkok) farmers have converted cassava farms into tree farms. This has resulted in an increase in the tree cover of this province from 23 % in 1980 to 40 % in 1990. Consequently, the experience to date encourages the recommendation to smallholder farmers to include suitable trees in their farming systems (Bhumibhamon, unpublished).

The present study provides information on the financial and economic justifications of tree growing for the forest managers, since plantation forestry is always connected with the profit motive. In addition, tentative environmental-economic profitability data can provide useful information for policy-makers. Most Thais have always supported the idea of tree planting, but the planting system should be designed so as to meet the real needs of the people.

The development of plantation forestry is interlinked with the development of forest industry and dependent on industrial policy. Raw material supplies for industrial enterprises in Thailand, as well the availability of processed products through imports, are also influenced by the international markets. As discussed above, one of the most critical and unpredictable forest policy factors in the immediate near future in Thailand is the availability of unprocessed wood from Thailand's neighbouring countries; this availability also depends on international political factors.

International environmental policy is also, to an increasing extent, a factor which affects the forest policy formulation on the national level. This has been one of the key results of the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in June 1992. The global conventions on the climate and on biodiversity already have to be considered in national forest policies, and a global convention on forests, if it becomes a reality, would influence forest management even more in all countries.

From the viewpoint of the processing capacities of the Thai forest industry, plantation-grown wood raw materials differ distinctly from those earlier obtained from indigenous forests or those still available through imports. Therefore, the change of the raw material base has to proceed hand in hand with technological redesign of mechanical wood processing. The fact that this transformation can take place and proceed with market forces as the principal agent is exemplified by the phenomenal growth of rubberwood utilization in Thailand.

Another major political question affecting the future and viability of plantation forestry in Thailand is the future of the pulp and paper industry and, in particular, the necessary choice between self-sufficiency on the one hand and pulp or paper imports on the other. The results of the Thai Forestry Sector Master Plan will hopefully facilitate the political decisions needed on these issues (Thai Forestry... 1992; 1993a & b).

For further economic analysis on tree plantations in Thailand, more information is needed than is presently available. The most significant shortages are found in yield data for different species and sites, biomass equations or tables, and site classification. It is also necessary to estimate market demands and the price development for plantation-grown wood.

In addition, further studies are badly needed for identifying and quantifying the environmental-economic influences of reforestation. In the present study the account of the environmental impact must be seen rather as a tentative and methodological experiment than as research in the strict sense of the word. Furthermore, forestry research in Thailand, as elsewhere, should continue with the traditional and time-consuming work of collecting basic silvicultural and management information on exotic and indigenous tree species used in plantation forestry.

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Appendix

Table 9. Cash flow table for *Eucalyptus camaldulensis* pulpwood production with the industry as plantation manager (Baht/ha).

	Year						
	0	1	2	3	4	..	7
Land rent	1 109 [1]	1 109	1 109	1 109	1 109	..	1 109
Site survey	55 [2]						
Clearing	771 [3]						
Heaping and burning	664 [4]						
Ploughing	1 668 [5]						
Staking	737 [6]						
Digging hole	266 [7]						
Seedlings	1 627 [8]						
Seedling transp.	249 [9]						
Planting	1 162 [10]						
Weeding	1 217 [11]	1 217	1 217				
Replanting	349 [12]						
Others	464 [13]						
Harvesting							12 959 [14]
Transportation							27 880 [15]
Total costs	10 348	2 327	2 327	1 109	1 109	..	40 839 [16]
Total revenue							98 982 [17]
Net revenue	–10 348	–2 327	–2 327	–1 109	–1 109	..	58 143 [18]

Sources: Land rent: Policy of reforestation... (1987).
Yield: Pohjonen (1992).
Wood price, harvesting costs: Cadiente (1987).
Transportation costs: Bhumibhamon (unpublished)
Mortality: 10 %, (Thavorn, pers. comm.)
Other expenses: Report of the research... (1985).

1 938 B/ha · 1/K3
2 1.04 M–D/ha · 40 B/M–D · 1/K1
3 0.8 Ma–D/ha · 735 B/Ma–D · 1/K1
4 12.5 M–D/ha · 40 B/M–D · 1/K1
5 0.78 Ma–D/ha · 1 610 B/Ma–D · 1/K1
6 1 750 stakes/ha · 0.317 B/stake · 1/K1
7 1 750 holes/ha · 0.114 B/hole · 1/K1
8 1 750 seedlings/ha · 0.7 B/seedling · 1/K1
9 1 750 seedlings/ha · 0.107 B/seedling · 1/K1
10 1 750 seedlings/ha · 0.5 B/seedling · 1/K1
11 10.4 Ma–D/ha · 88 B/Ma–D · 1/K1
12 [175 · 0.8 B/seedling (work) + 175 · 0.7 B/seedling (material) · 1/K1]
13 8.74 M-D/ha · 40 B/M–D · 1/K1
14 139.4 t/ha · 70 B/T · 1/K1
15 139.4 t/ha · 200 B/T
16 Sum
17 139.4 t/ha · 600 B/t · 1/K3
18 Total revenue – Total costs
K1 0.753, wholesale price index 1985
K3 0.845, wholesale price index 1987

Table 10. Cash flow table for *Acacia mangium* pulpwood production with the industry as plantation manager (Baht/ha).

	Year					
	0	1	2	3	4	5
Land rent	1 109	1 109	1 109	1 109	1 109	1 109
Site survey	55					
Clearing	781					
Heaping and burning	664					
Ploughing	1 668					
Staking	1 053					
Digging hole	380					
Seedlings	2 500					
Planting	1 660					
Seedling trans.	55					
Weeding	1 217	1 217	1 217			
Replanting	516					
Others	464					
Harvesting						6 956
Transportation						16 800
Total costs	12 422	2 326	2 326	1 109	1 109	24 865
Total revenue						60 379
Net revenue	–12 422	–2 326	–2 326	–1 109	–1 109	35 514

Sources: Land rent: Policy of reforestation... (1987).
Yield: Someswar (1984).
Wood price, harvesting costs: Cadiente (1987).
Transportation costs, seedling price: Bhumibhamon (unpublished).
Mortality: 10 %, (Thavorn, pers. comm.).
Other expenses: Report of the research... (1985).

Table 11. Cash flow table for *Melia azedarach* pulpwood production with the industry as plantation manager (Baht/ha).

	Year					
	0	1	2	3	4	5
Land rent	1 109	1 109	1 109	1 109	1 109	1 109
Site survey	55					
Clearing	781					
Heaping and burning	664					
Ploughing	1 668					
Staking	1 053					
Digging hole	379					
Seedlings	2 500					
Seedling transp.	355					
Planting	1 660					
Weeding	1 217	1 217	1 217			
Replanting	1 547					
Others	464					
Harvesting						5 434
Transportation						13 125
Total costs	13 453	2 326	2 326	1 109	1 109	19 668
Total revenue						32 878
Net revenue	–13 453	–2 326	–2 326	–1 109	–1 109	27 503

Sources: Land rent: Policy of reforestation... (1987).
Yield: Bhumibhamon (1985).
Wood price, harvesting costs: Cadiente (1987).
Transportation costs, seedling price: Bhumibhamon (unpublished).
Mortality: 30 %, (Thavorn, pers. comm.).
Other expenses: Report of the research... (1985).

Table 12. Cash flow table for *Eucalyptus camaldulensis* sawlog production with the industry as plantation manager. (Baht/ha).

	Year 0	1	2	3	4	..	10
Land rent	1 109	1 109	1 109	1 109	1 109	..	1 109
Site survey	55						
Clearing	781						
Heaping and burning	664						
Ploughing	1 668						
Staking	527						
Digging hole	190						
Seedlings	1 162						
Seedling transp.	178						
Planting	830						
Weeding	1 217	1 217	1 217				
Replanting	24						
Harvesting							9 980
Transportation							28 120
Total costs	9 093	2 326	2 326	1 109	1 109		39 209
Total revenue							109 870
Net revenue	–9 093	–2 326	–2 326	–1 109	–1 109		70 661

Sources: Land rent: Policy of reforestation... (1987).
Yield, wood price: Thaiutsa (1985).
Harvesting costs: Cadiente (1987).
Transportation costs: Bhumibhamon (unpublished).
Mortality: 10 %, (Thavorn, pers. comm.).
Other expenses: Report of the research... (1985).

Table 13. Cash flow table for *Acacia mangium* sawlog production with the industry as plantation manager (Baht/ha).

	Year 0	1	2	3	..	15
Land rent	1 109	1 109	1 109	1 109	..	1 109
Site survey	55					
Clearing	781					
Heaping and burning	664					
Ploughing	1 668					
Staking	263					
Digging hole	95					
Seedlings	625					
Planting	415					
Seedling trans.	89					
Weeding	1 217	1 217	1 217			
Replanting	129					
Others	464					
Harvesting						21 294
Transportation						60 000
Total costs	7 574	2 326	2 326	1 109	..	82 403
Total revenue						228 303
Net revenue	–7 574	–2 326	–2 326	–1 109	..	145 900

Sources: Land rent: Policy of reforestation... (1987).
Yield: Someswar (1984).
Harvesting costs: Cadiente (1987).
Transportation costs, seedling price, wood price:
Bhumibhamon (unpublished).
Mortality: 10 %, (Thavorn, pers. comm.).
Other expenses: Report of the research... (1985).

Table 14. Cash flow table for *Melia azedarach* sawlog production with the industry as plantation manager (Baht/ha).

	Year 0	1	2	3	..	10
Land rent	1 109	1 109	1 109	1 109	..	1 109
Site survey	55					
Clearing	781					
Heaping and burning	664					
Ploughing	1 668					
Staking	263					
Digging hole	95					
Seedlings	625					
Seedling trans.	89					
Planting	415					
Weeding	1 217	1 217	1 217			
Replanting	387					
Others	464					
Harvesting						6 033
Transportation						17 000
Total costs	7 832	2 326	2 326	1 109	..	24 142
Total revenue						118 130
Net revenue	–7 832	–2 326	–2 326	–1 109	..	93 988

Sources: Land rent: Policy of reforestation... (1987).
Harvesting costs: Cadiente (1987).
Transportation costs, seedling price, wood price:
Bhumibhamon (unpublished).
Yield, mortality (30 %): (Thavorn, pers. comm.).
Other expenses: Report of the research... (1985).

Table 15. Cash flow table for teak on 25-year rotation (Baht/ha).

Year	Total variable	Total fixed	Total costs	Total revenue	Net revenue
1	8 117	1 613	9 731		–9 730
2	980	1 613	2 593		–2 593
3	980	1 613	2 593		–2 593
4	653	1 613	2 266		–2 266
5	653	1 613	2 266		–2 266
6	653	1 613	2 266		–2 266
7	167	1 613	1 780		–1 780
8	167	1 613	1 780		–1 780
9	2 324	1 613	3 938	6 640	2 702
10	167	1 613	1 780		–1 780
.					
.					
17	167	1 613	1 780		–1 780
18	6 641	1 613	8 254	62 201	53 997
19	167	1 613	1 780		–1 780
.					
.					
24	167	1 613	1 780		–1 780
25	54 117	1 613	55 730	1 245 020	1 189 289
Total	77 785	40 334	118 120	1 313 911	1 197 791

Sources: Yield: Kaensingha (1989).
Costs: Thaiutsa (1985).

Table 16. Cash flow table for a Para rubber plantation when the rotation is 25 years and latex production period extends from the sixth to the 25th year (Baht/ha).

	Year								
	0	1	2	..	5	6	..	25	Total
Costs:									
1) Labour costs									
Land preparation	1 349								1 349
Planting	1 768								1 768
Fertilizing	658	658	658		658	852		852	20 988
Chemical spraying	415	415	415		415				2 490
Pest control						403		403	8 060
2) Factor input costs									
Pesticide	3 037	3 037	3 037		3 037				18 222
Stakes	395								395
Fertilizer	3 156	3 156	3 156		3 156				18 936
Natural rubber seeds	118								118
Branch	1 026								1 026
Legume cover crop	237								237
3) Land rent	1 109	1 109	1 109		1 109	1 109		1 109	28 834
4) Harvesting								13 486	13 486
5) Transportation								38 000	38 000
Total costs	13 269	8 375	8 375		8 375	2 364		53 850	153 909
Benefits:									
4) Rubber production						33 626		33 626	672 520
5) Timber production								525 750	525 750
Net benefits	−13 269	−8 375	−8 375		−8 375	31 262		505 526	1 044 361

Sources: Costs: Songanok (1991).
Rubber production: Maneekul (1985).
Rubber price: Agricultural statistics... (1989).
Wood price: Urapeepatanapong (1989).
Harvesting costs: Cadiente (1987).
Transportation costs: Bhumibhamon (unpublished).

Table 17. Wholesale price index 1985–1991 and producer price index 1982–1991 (1990 = 100).

Year	Wholesale price index	Producer price index
1982	-	79.2
1983	-	86.5
1984	-	81.4
1985	75.3	75.3
1986	77.4	75.2
1987	84.5	83.5
1988	93.4	95.3
1989	98.9	103.3
1990	100.0	100.0
1991, Feb.	106.5	104.1

Source: Consumer price index... (1991).

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Metsäntutkimuslaitoksesta lähtöisin olevien käsikirjoitusten hyväksymismenettelystä on ohjeet Metsäntutkimuslaitoksen julkaisuohjesäännössä.

Muista käsikirjoituksista lähetetään Suomen Metsätieteellisen Seuran toimitukselle kolme täydellistä, viimeisteltyä kopiota, joihin sisältyvät myös kopiot kaikista kuvista ja taulukoista. Originaaliaineistoa ei tässä vaiheessa lähetetä.

Vastaava toimittaja lähettää käsikirjoituksen valitsemilleen ennakkotarkastajille. Tekijän on otettava huomioon ennakkotarkastajien ja toimituskunnan korjausesitykset. Korjaukset on tehtävä vuoden kuluessa siitä, kun käsikirjoitus on palautettu tekijälle. Jos tekijä ei voi hyväksyä korjausesityksiä, hänen on ilmoitettava eriävä mielipiteensä vastaavalle toimittajalle tai toimituskunnalle, joka tarvittaessa ottaa asian uudelleen käsittelyyn.

Acta Forestalia Fennican toimituskunta päättää kirjoituksen julkaisemisesta ennakkotarkastajien lausuntojen ja muiden ilmenneiden seikkojen perusteella. Päätös tehdään kolmen kuukauden kuluessa siitä, kun käsikirjoituksen lopullinen korjattu versio on saapunut toimitukselle.

Hyväksymisen jälkeen käsikirjoitukseen ei saa tehdä olennaisia muutoksia ilman vastaavan toimittajan lupaa. Suuret muutokset edellyttävät uutta hyväksymistä.

Tekijä vastaa kirjoituksen tieteellisestä asiasisällöstä ja kieliasusta. Tekijä ei saa julkaista kirjoitusta muualla ilman Acta Forestalia Fennican julkaisijoiden suostumusta. Acta Forestalia Fennicaan hyväksytään vain aiemmin julkaisemattomia kirjoituksia.

Tekijän tulee antaa lopullinen käsikirjoitus ja kuvaoriginaalit toimitukselle kahden kuukauden kuluessa hyväksymispäätöksestä. Käsikirjoituksen saatteesta pitää selvästi ilmetä, että käsikirjoitus on lopullinen, painoon tarkoitettu kappale. Teksti otetaan mieluiten vastaan mikrotietokoneen levykkeellä, jonka lisäksi tarvitaan paperituloste.

Käsikirjoitusten ulkoasu

Käsikirjoituksen asun tulee noudattaa sarjan kirjoitusohjeita, joita saa toimituksesta.

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