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Can native tree species plantations in Panama compete with Teak plantations? An economic estimation

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Abstract Panama has the highest rate of change in the area of primary forests within Central America. However, to meet growing timber demands, it became popular over the last decades to establish plantations made up of foreign species such as *Tectona grandis* or *Pinus* spp. In the majority of the cases the species used are well known; their characteristics such as growth performance have been reviewed intensively and can be accessed in numerous publications. Characteristics of Panama's native tree species of commercial relevance such as *Hieronyma alchorneoides*, *Swietenia macrophylla* and *Terminalia amazonia* are largely unknown and have been investigated within the study at hand. Using valuation methods of financial mathematics, the competitive position of these three indigenous species was assessed, the results compared to those of *T. grandis* stands in the same area. Land costs and taxes were not considered, as they would be the same for all species. Financial estimates for indigenous species will enlarge their acceptance for use in reforestation and plantation projects. Using the NPV method and applying the standard scenario, the profitability of *T. grandis* is lower than that of *T. amazonia* and *S. macrophylla* and lies only slightly above the profitability calculated for *H. alchorneoides*. This result clearly indicates that the investigated native tree species are comparable with *T. grandis* regarding their economic profitability. Besides its ecological impact, growing native tree species is now also economically legitimate. By calculating land expectation values for all tree species, ideal rotation lengths could be determined. For these species, considerable flexibility exists regarding the optimal rotation length.

Keywords Reforestation · Financial analysis · Land expectation value · Net present value · Growth · Yield · Profitability

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Introduction

In the countries of Central America, traditional culling of tropical timber from primary forests is expected to come to a standstill within the next years, due to the depletion of remaining stands (Solorzano-Soto 1995). Especially in Latin America and the Caribbean, featuring high population densities, the timber trade forms an important economic factor and an important source of income for the rural population, just as it is in temperate regions. Growing difficulties of timber supply as well as increasing demand for land have led lead to rapid deforestation in these countries, according to FAO (2005).

As the country with the highest rates of change within its existing primary forest the study at hand subjects Panama to an exemplary closer inspection:

In Panama there are 1.2 Mha of land suitable and available for plantation establishment (Boyd 1998). Because of ongoing deforestation, this area is expected to increase. In 1990, Panama, with a total land surface of 7.5 Mha, still had 3.7 Mha of primary forests. In 2005, only 3.0 Mha were left. According to the FAO (Food and Agriculture Organisation of the United States) (2005) the annual deforestation rate is 1.23%. Accordingly, Panama's primary forests are heavily declining. To protect the remaining tropical primary forests, mainly two alternatives are discussed:

(1) Establish plantation forests (Günter et al. 2008; Cubbage et al. 2007; Pandey and Ball 1998; Lamprecht 1989),
(2) Sustainably manage remaining natural forests (Günter et al. 2008; Cubbage et al. 2007; Finegan 1992; Quesada Mateo 1990).

The driving force for all activities in forest management, environmental protection and investment is cost-effectiveness. Comparing the management of natural forests with plantations financially, plantations often seem to be the better option. Natural forests tend to show a lower productivity, which leads to a lower cost-effectiveness, while plantations tend to show a higher cost-effectiveness (Cubbage et al. 2007). The establishment of a plantation however, also requires substantial initial investment. Alternative financing models can be a solution. Investment opportunities that offer competitive rates of return while also showing low risks are in demand. With growing environmental awareness, considerations of long term stability and real investment versus pure monetary values come to the forefront more and more. Many large-scale investors already are aware of this situation. The UBS AG (Union Bank of Switzerland), the world's largest asset manager, also is one of the largest forest owners worldwide (Kollmansberger 2006). In spite of growing interest in non market values, so called Ecosystem Services, the return of investment still ranks first for investors. Estimates of rates of return are often based on optimistic assumptions to spark interest in forest plantations as an investment opportunity. Furthermore, in the majority of cases, operations are limited to monocultures of exotic species. Often, even for timber of indigenous tree species with a market, no published financial optimization in terms of forest management exist (Nichols et al. 2006).

In Panama, *Tectona grandis* is frequently planted (Simmons et al. 2002). The following hypothesis is therefore to be tested with a particular focus on this tree species for Panama:

H_1: The profitability of Teak plantations cannot be equalled by planting native tree species.

Indigenous tree species have some advantages compared to fast-growing exotic species. Native species are adapted to the site conditions and are therefore also more tolerant towards natural risks, while achieving comparable growth rates (Piotto et al. 2004a). Many native species can be grown on a broader scale of sites than exotic species. All these features may lead to a competitive edge for the less well known native species over the exotic *Tectona grandis*. But there are also risks in growing native species. Besides testing the hypothesis above on the basis of the available data, possible risks as well as chances related to growing indigenous tree species are to be discussed. In addition to *Tectona grandis* being considered for the reforestation in the investigation area, indigenous species have also been used. Alongside the species *Anacardium exelcium* (Espavé), *Cordia aliodora* (Laurel), *Xantoxilum sp*. (Tachuelo), *Sterculia apetala* (Panamá), *Calicophylum candidisimun* (Madroño), *Didimopanax morototori* (Pava), *Cedrela odorata* (Cedro), *Miconia gobulifera* (Pipi), *Cassia mochata* (Cañafistula) and *Byrsonima crasifolia* (Nance), that mainly answer the purpose of enriching biodiversity, are these three indigenous species of commercial value: *Hieronyma alchorneoides*, *Swietenia macrophylla* and *Terminalia amazonia*.

Many studies also show that by varying rotation lengths, the productivity of forest plantations can be considerably improved (e.g. Brazee and Mendelsohn 1988). Using the data available for the study at hand, a second hypothesis is therefore to be verified:

H_2: By varying rotation lengths, financial productivity can be increased.

Valuing plantations of native forest species

Establishment of forest plantations generally increases the contribution of forestry to the national economy (Alam et al. 2010). By establishing plantation forests on degraded areas that are abandoned such as former cattle ground, timber can be provided for the market and the impact of exploitation of natural forests can be mitigated. Furthermore, environmental conditions in the country are positively influenced and therefore upgraded (Gutierrez and Diaz 1999).

In the year 1990 forest plantations covered 10,000 ha of Panama's land area, of which 7,000 ha where established using *Pinus caribaea* (INRENARE (Institute for the Management of Renewable Natural Resources) 1990). In 1997 plantations already covered around 30,000 ha, of which 14,000 ha consisted of *Tectona grandis* and another 10,500 ha of *Pinus caribaea* both in monoculture. But choosing different tree species for the species composition in a forest plantation project is an important silvicultural instrument that will later heavily influence the susceptibility for risks. By homogenising ecosystems to gain short term benefits, negative effects on biodiversity are generated, which often lead to a diminished financial robustness of the ecosystem, especially if natural risks exist (Knoke 2008). In this connection, Knoke and Hahn (2007, p. 312) assert:

> (···) against the background of different production risks of tree species, comparison with a portfolio of shares stands to reason. In a forest stand that is made up of various tree species, effects that are subsumed as «diversification of risk» or «balancing of portfolio» may occur (···)

Planting a combination of tree species that are adapted to site conditions therefore is useful for ecological and financial aspects as well as for mitigating risks. But to fully embrace portfolio aspects in mixed species stands, prospective indigenous species have to be economically assessed.

Existing literature about the economy of plantation forestry in the tropics concentrates on economically productive species, most usually exotics, such as *Pinus* sp., *T. grandis* or

Eukalyptus sp. (Cubbage et al. 2007). *Tectona grandis* is a well known species, whose characteristics such as growth performance have been reviewed intensively and can be accessed in numerous publications. But the characteristics of Panama's native tree species of commercial relevance like *Hieronyma alchorneoides, Swietenia macrophylla* and *Terminalia amazonia,* are largely unknown. Regarding native species, we can at the most and if anything at all, find information about growth behaviour (Lamb 1966; Piotto et al. 2004b; Redondo-Brenes and Montagnini 2006). A comprehensive case study that measures mixed stands and projects growth performance over entire production periods and delivers an economic evaluation is initially provided by the present study.

Materials and methods

The study area

The study was carried out on the Pacific coast of the Central American republic of Panama. In Las Lajas, Province of Chiriquí (81°53' W, 8°15' N) at an elevation of about 8–50 m above sea level. The region is part of the tropics with an average annual precipitation of 3,000–3,500 mm and average annual temperature of 26.7°C. The 3–4 month dry season lasts from January to April (Worldwide Bioclimatic Classification System 1996–2009).

In 1995 the first plantation was established. It was planted on 23.5 ha former cattle ground. In 1996 and 1999 the plantation was complemented by adjacent and nearby areas, leading to a total plantation area of about 100 ha managed under the same concept.

The history of the research site being former cattle ground makes the site an ideal example, as equivalent sites are typical for future reforestation.

The main criteria for allocation of the different tree species within the area were the preconditions, such as varying soil conditions, of each microsite. Experience in managing the species as well as growth potential and commercial relevance of the species were taken into consideration just as well. The tree species were planted in different mixtures. Areas in which valuable tree species are discretely admixed are spread over the area, tessellated to gain a small-area mixture.

Before planting, the pre-existing vegetation was cleared. Remaining long-standing or valuable trees are mainly of the species *Cassia grandis, C. moschata, Enterolobium cyclocarpum* and *Byrsonima crassifolia.* According to the existing laws, 15 m adjacent to river banks were left unplanted. On these riparian strips and in other areas that are inappropriate for plantation establishment, like gullies, natural vegetation was kept. These areas are thus considered designated sanctuaries (Fig. 1).

The seeds were obtained regarding to the provenance recommendations of CATIE (Centro Agronómico Tropical de Investigación y Enseñanza) in Costa Rica. For both *Tectona grandis* (Teak) and *Hieronyma alchorneoides* (Zapatero) the provenience "Pérez Zeledon" was suitable, delivered by the seed trader "Coopeagri". For the species *Swietenia macrophylla* (Caoba) a Colombian provenience sold by "Semicol" was chosen, for *Terminalia amazonia* (Amarillo) the Panamanian provenience "Carta Vieja", sold by "Particular". Suitable seeds were sown in a nursery close to the plantation area, the seedlings raised for 6 month to a year before being hand planted into a planting pit of 60 × 45 cm. The top soil that accrues during this process is mixed with an organic fertilizer and put back into the planting pit. For 3 years after planting, the organic fertilizer "Bokashi" is deployed around the seedlings. The components of this fertilizer are fermented bird faeces, calcium, rice pellets, saw dust and ash. Furthermore, during the first

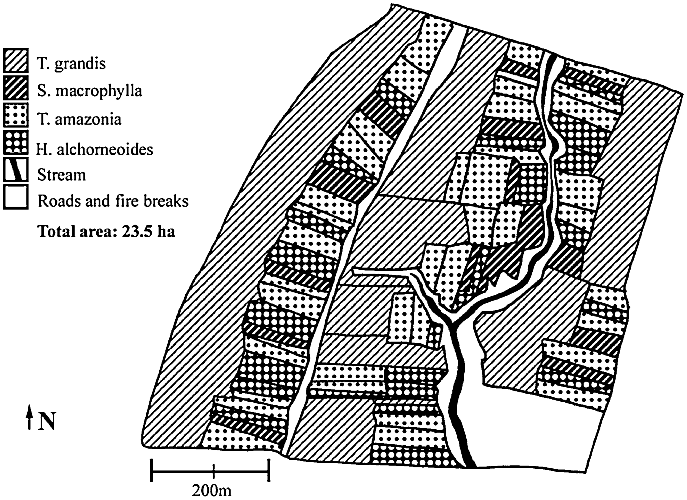

Fig. 1 Plantation layout at the study site

6 years after planting, the site was kept free of weeds by manual cutting six times a year. In the following years, natural regeneration between the planted rows was only cut if it grows directly into the rows of trees.

However, the most important management technique is pruning. Pruning was done during dry season; initially after the trees have reached a height of 4 m, a dbh of at least 10 cm and a branch diameter of more than 3 cm. Branches were removed up to a height of 50% of individual tree height. Thinnings were carried out at age 8 and 10; rotation period has been scheduled to 25 years.

The prescribed approaches to plantation establishment as well as management comply with the actions proposed by Lamb (1998) for the protection of biodiversity in plantations. The reforestation is an approach to sustainable and commercial plantation operation. Therefore, the plantation offers a suitable research area, to evaluate effects of ecologically managed plantations towards the potential of natural regeneration. A study regarding this has been taken in the form of a thesis by Paul (2008).

Financial analysis

To evaluate the economic performance of *Tectona grandis* as well as of the three native species of financial importance, *Hieronyma alchorneoides* (Zapatero), *Swietenia macrophylla* (Caoba) and *Terminalia amazonia* (Amarillo), all management activities from plantation establishment until final harvest have to be collected and financially valued. Costs for purchase of land and taxes were omitted as they would not affect the decision as to choice of species. All expenses arising for plantation establishment and forest management activities were documented by the plantation management and have been used as data basis for all subsequent calculations. Additionally, all expenses arising for the thinning taken out on the plantation in 2005 have been documented and are used in the following calculations. The income gained by timber sales had to be reconstructed.

Costs for plantation establishment

For plantation establishment, the first step was to prepare the site. In year 0 therefore expenses arise for clearing pre-existing vegetation, digging out planting pits, as well as for buying seeds and necessary tools etc. In the following years, expenses arise from management actions like pruning, weed-control, tools and material, fertiliser and herbicides. The necessary management actions were comprehensively described in the section titled "The Study Area" and have been accounted for by the plantation management. An overview of these expenses arising from year 0 to 5 after plantation establishment can be found in the following Table 1.

For the following years 6–25, for which no expenses were documented, an average of the previous years was used for valuation. Following common conventions, annual inflation rates have been disregarded (cp. Sagl 1995) rather all valuations used actual costs and prices.

Costs for thinning and final harvest

All expenses arising from the thinning in 2005 have been documented in detail. For the first thinning, accomplished in 2003, this information was not available. Therefore its financial data was calculated upon the assumption that the expenses are equal to the costs of the later thinning, as was done for annual spending for management activities and material above. Particular expenses arose for activities to keep the chain of custody complete and to later assign the harvested timber to certain parcels. In detail, these are hours of work for applying number tags as well as material costs for the tags themselves. Furthermore, the costs of forwarding the logs three kilometres to the wood yard by tractor are included. Total expenses for the thinnings taken out at age 8 and age 10 are made up of costs for transporting timber to the wood yard, arising costs for harvesting by chainsaw, costs for safety equipment, material and tools, as well as costs for general workings, that form the largest entry. In consideration of the fact that the thinnings are not commercial thinnings in the classical meaning, the expenses per hectare of around US $300 are relatively high.

Expenses for working time during final harvest at age 25 are calculated using the formula developed by Cruz Madariaga (2003):

$$T[s] = \frac{50.03161 + 27.56265 * \text{dbh}[\text{cm}]}{2}$$

T = Working time for logging [sec.], dbh = diameter at breast height [cm].

Using the diameter at breast height of the mean basal area tree at age 25 and the number of trees per hectare the working time for logging is calculated. The expenses for wages are

Table 1 Arising expenses year 0–5 according to plantation management

	(US $)/ha
Site preparation and planting, year 0	974
Management and material year I	748
Management and material year II	871
Management and material year III	871
Management and material year IV	514
Management and material year V	504

set at US $10.14 per day (8 working hours), following average wages paid by the plantation management in 2006 including social security. Additionally, the costs for skidding and material according to the costs arising during thinnings are considered. Total costs for final harvest operations at age 25 are around US $1,300/ha, whereas the costs slightly vary between the tree species due to differences in timber dimensions and numbers of trees per hectare.

Income gained by timber sales

In Panama, the timber price realised for teak logs in 2007 was, according to the timber market report of ITTO, close to the worldwide midrange. For the other three tree species that are grown in the research area no timber market data was available. The timber obtained during thinnings in the research area could be sold irrespective of the species for a uniform price of US $200/m^3 off the wood yard. Considering the growing demand for certified tropical timber and the possible development of market premiums paid for it (Kollert and Lagan 2006), it is assumed that in the following years equal prices will be achieved for all tree species investigated in this study. This view is also supported by personal communication with employees of the plantation management. In view of growing diameters and strong dimensional effects, future timber sales revenues (Table 2) are assumed, according to ITTO timber market reports (ITTO Tropical Timber Market 1998–2010).

It is assumed, that logs of stem wood of all four species, according to the assortment of the thinning in former years, can be sold at one standard price. This assumption is fortified by the comparable physical characteristics of the timber of all four species, shown in Table 3.

Furthermore, a 60% stem wood proportion out of total timber harvested is assumed. For fuel wood a net price of zero US $ is set. This means that the costs for primary conversion of fuel wood are just covered by the attainable revenue for this particular assortment.

Yield projections

The information on growth performance presented below provides the basis for all economic calculations. For the inventories taken out annually by the plantation management, permanent monitoring plots for all tree species were established. Each plot measures 20 × 20 m, and is located within the plantation by random selection. In total there are 16 plots of 400 m^2 each. Because the spacing between trees is different for each species, the

Table 2 Round wood revenues and estimated future price trend for bigger sized logs of all four species

Round wood revenues and future price trend		
Circumference (cm)	Diameter (cm)	Average price per m^3 off wood yard (US $)
~44–66	~14–21	200
67–79	22–25	223
80–99	26–34	275
110–130	35–41	335
131+	42+	365

Table 3 Physical characteristics of timber of all four species investigated, taken from Posch et al. (2004), Rijsjdijk and Laming (1994), USDA Forest Service, Center For Wood Anatomy Research (2010)

Species	Density[a] (kg/m^3)	Modulus of elasticity[b] (N/mm^2)	Shrinkage from green to ovendry[c] (%)	Colour
Tectona grandis	0.64	13,740	r: 2.5 t: 5.8 v: 7	Yellow brown
Hyeronima alchorneoides	0.63	22,700	r: 5.4 t: 11.7 v: 17	Chocolate brown
Swietenia macrophylla	0.61	14,200	r: 3 t: 4.1 v:7.8	Red brown
Terminalia amazonia	0.65	23,000	r: 6.4 t: 8.7 v: 14.9	Light brown to reddish yellow

[a] Ovendry

[b] Moisture content 12%, based on 2 cm standard

[c] r = radial, t = tangential, v = volumetric

number of trees per plot is between 10 and 48 individuals. The measured data was later converted to analogous values for hectares.

To evaluate the economic performance of *T. grandis* and *S. macrophylla* data from the permanent inventory plots, yield tables and information from literature was used. Both tree species have frequent appearances in the literature. Because of this advantage, a rather high validity of the results can be assumed. For *H. alchorneoides* and *T. amazonia* only scarce additional information regarding their growth was available from literature (Piotto et al. 2003, Redondo-Brenes and Montagnini 2006). Regarding the reliability of the results it has to be noted that at the research site all four tree species investigated were not planted randomly, but according to their site requirements after a soil sampling was carried out. This leads to systematic differences in site qualities between the tree species. For the growth behavior of the tree species in reality, slight divergences therefore have to be anticipated, that are covered by the optimistic and pessimistic scenarios.

The first thinning was carried out at age 8. During this thinning the number of trees per hectare of each species fell by an amount related to the number of trees planted. In *T. grandis* stands 41% of the trees were cut, for *H. alchorneoides*, the number of trees per hectare fell off by an average of 22%, the average number of *S. macrophylla* trees per hectare was reduced by 6% and in *T. amazonia* stands 40% of the trees were cut.

During the second thinning at age 10 another 14% of *T. grandis* trees, 4% of *H. alchorneoides,* 2% of *S. macrophylla* and 25% of *T. amazonia* were harvested. A detailed overview over yield surveys taken out at the study site and expected future growth can be found in the appendix (Tables 6, 7, 8, and 9).

To classify growth performance at the study site and to extrapolate it into the future beginning with age 11, appropriate yield tables were analyzed. For *T. grandis,* from comparative data by Pérez and Kanninen (2005), expected diameter and height growth at the study site as well as a form factor of 0.45 for round wood calculation was derived.

To forecast further development of growth of the natural forest species *H. alchorneoides*, we had to revert to a study by Redondo-Brenes and Montagnini (2006) and another study by Piotto et al. (2003). Both studies deal with growth performance of the species *H. alchorneoides* and *T. amazonia*. It is assumed that increments at the study site evolutes comparably. To avoid growth prognoses becoming too optimistic, the lower increments for tree height and diameter determined in each of the two studies were used. For calculating the volume of merchantable *H. alchorneoides* timber, a form factor of 0.45 enters into the calculation. This form factor is according to that used for internal calculations by the management and emanates empirical value (Camacho 2008).[1]

According to the approach used for the yield estimation of *T. grandis*, for *S. macrophylla* yield tables from comparable sites were consulted to classify growth performance. For calculating the stem volume of *S. macrophylla* a form factor of 0.65 was used, as determined by Mora-Chacón et al. (2002).

To project growth performance of *T. amazonia* according to the approach used for *H. alchorneoides* results gained by Redondo-Brenes and Montagnini (2006) and Piotto et al. (2003) were used. An overestimate of the growth performance is obviated by using the lower increments determined by Redondo-Brenes and Montagnini (2006). A form factor of 0.45 was used, also taken from the calculations used by the forest enterprise and is based on the experience of the on-site forest engineers (Camacho 2008).

Comparative analysis of yield

For years 11–25 for all tree species no further thinnings were planned. The stem number determined for each species in the research area takes into account an annual mortality of 0.5% of the standing trees per hectare in years 11–25 (Camacho 2008). Comprehensively a loss of 20% of the commercial volume is considered, to factor in bark and losses during harvesting to calculate felling value (Camacho 2008). As mentioned before, all potentially commercial timber (80% of standing timber over bark) is then split into 60% stem wood and 40% fuel wood.

In the research area, *Tectona grandis*—compared with *Hieronyma alchorneoides, Swietenia macrophylla* and *Terminalia amazonia*—gained the highest growth performance until age 10. With advancing age, *T. amazonia* and *S. macrophylla* turn out to be more productive. For *S. macrophylla* this traces back to the advantageous stem form and higher form factor arising from it. Whether it is at all possible to grow *S. macrophylla* in plantations for equivalent rotation lengths continues to be debated. In the literature, many reports about failures in *S. macrophylla* stands starting with age 10 exist. In the discussion section of this paper, this problem will be taken up again in detail. For this work, it will be assumed that the species will reach age 25.

Terminalia amazonia displays high increment in other studies as well (Piotto et al. 2003; Redondo-Brenes and Montagnini 2006) a very good growth performance is strongly related to the site quality though (Calvo-Alvarado et al. 2007). A comparative overview is given in Fig. 2.

Ranking method

For Panama, Benitez et al. (2007) estimated risk adjusted discount rates of around 9.9%. International investors aiming at forest investments to diversify existing portfolios come to

[1] Yaels Camacho, Forest engineer at the research site.

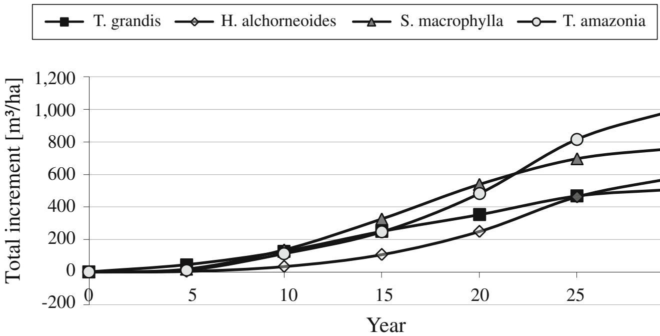

Fig. 2 Total increment of the four tree species in the research area

a much lower receivable interest. Private landowners have very individual receivable interest. As current asset portfolios of private landowners are unknown, a range is necessary to display all possible situations. In South American *Tectona grandis* plantations, Cubbage et al. (2007) assessed rates of return of 5–13%. These values were used as an indication for general assumptions regarding the profitability of plantations as well as to allow general assessment of forest plantations.

Net present value method

The economic performance of the different species is described with an indicator that is derived from capital budgeting. The net present value (NPV) method is a discounted cash-flow method and counts among the methods of capital budgeting. By discounting payments that are made at different points in time to the start date of an investment, payments made at different moments become comparable using the NPV method. The NPV of an investment is the sum of all present values, thus all cash flows, both inflows and outflows of cash that are caused by the investment. It differentiates between absolutely profitable investments, with a NPV greater than or equal to zero and relatively profitable investments with a NPV greater than or equal to the NPV of an alternative investment. The first case answers the question whether or not an investment generally is to be made; the second case answers the question of which of the alternatives is more profitable. It is the latter case that concerns us here.

For calculating the NPVs the following equation according to Thommen and Achleitner (2009) is used:

$$\mathrm{NPV}_0 = \sum_{n \in T} (I_n - O_n) \cdot (1 + i)^{-n}$$

NPV_0 = Net present value, T = years between stand establishment and final harvest, I_n = Cash inflow in year n, O_n = Cash outflow in year n, i = discount rate (in hundredth), n = time after stand establishment in years.

The terms cash inflow and cash outflow that are common in financial mathematics correspond with the terms incoming payments and out payments. To calculate the NPV an interest factor or discount rate i is needed. i can be the rate of return required by an investor, the rate of return that can be achieved with an alternative capital asset, or it can be chosen as a target rate of return, including all influencing factors. In many cases *i* is chosen as the rate of return an alternative investment offers. Because of the controversial opinion regarding suitable interest rates for forest enterprises and forests, for calculating the NPV, interest rates between 0 and 15% have been used in this study.

Considering uncertainties and optimization

Uncertainty and sensitivity analysis

Damages to a forest stand which can result from insect outbreaks, volatile timber markets and other factors influence possible revenues. Also, it is impossible to forecast all relevant factors. For the paper at hand, the future risk situation in form of environmental circumstances or damages to the stand is deemed to be unknown by the decision maker. One way to factor these risks into the analysis is to perform a sensitivity analysis.

Within a sensitivity analysis, the marginal values of the results are elaborated. One or more parameters influencing the investment are changed (Heidingsfelder and Knoke 2004). It is tested at what point the target return values are affected (for example the NPV). By this approach, the sensitivity of the investment towards the change of influencing values like timber market development in form of timber prices, total increment, and others can be tested systematically. For this purpose, various input parameters were changed by posing a range of alternatives for the incoming payments.

Varying rotation lengths

The land expectation value (LEV) represents the present value of annuity of a perennial periodic annuity made up of the sum of the future felling value and all cash inflows compounded to the moment of final harvest, minus all compounded cash outflows for tending, material and other costs (Faustmann 1849). The sum is then diminished by the perennial annuity of administrative expenses. With the LEV it is possible to consider effects of different durations of investments, such as rotation, which is one of the most important control factors in forest management. Even for well investigated species, the optimal rotation length is still being discussed. For many tropical species a rotation period of 25 years is assumed to be ideal (Evans and Turnbull 2004). By investigating the development of LEVs under varying rotation lengths, production periods can be optimised. Furthermore the calculation of LEVs is necessary to assure that longer rotation periods are not estimated too optimistically, as well as to achieve comparability with other studies. Therefore the LEVs of all four investigated tree species were calculated for rotation periods between 10 and 30 years and a regression analysis was carried out with the ascertained values to smooth the curves relative to time.

Results

Results of the ranking methods

The description of the valuation results first goes into cash in- and outflows as well as felling values and other performance indicators. In a first step, a situation without uncertainty is implied.

Cash inflow and outflow

The observations made in sections "Income gained by timber sales" and "Yield projections" result in annual cash in- and outflows of varying amounts for *Tectona grandis* as shown in Fig. 3. The cash outflows are displayed as hanging columns because of their negative algebraic sign. The cash inflows from thinnings in year 8 and 10, as well as cash inflows from final harvest in year 25 are displayed as standing columns. In all other years, no cash inflows are being set.

The cash outflows for the tree species *H. alchorneoides, S. macrophylla* and *T. amazonia* only marginally differ from the cash outflows for *T. grandis* and are therefore not displayed in detail.

Net present value method

Considering the change of the NPV depending on the required rate of return, the criteria of relative profitability introduced in section "Net preent value method" is taken as basis. Figure 4 illustrates how the NPV for all four tree species changes depending on the discount rate used.

At a required discount rate of 0%, the NPV is equivalent to the total sum of all in- and outflows. The graph of the NPV always intersects with the axis of the discount rate at the internal rate of return. In the example displayed in Fig. 4, the tree species achieve internal rates of return of up to 15%. The internal rates of return for the investigated tree species appear in italics in Table 4.

Furthermore, the dependency of the required final stand value in year 25 and the internal rate of return can be displayed as in the following graph (Fig. 5).

The graph displays the felling value the investment must attain in year 25 to still reach a NPV of 0 and therefore to still be considered profitable. This graph can be used as a simple tool to assess the profitability of an investment, if a rough idea of the future felling values, that also holds true in practice, exists.

Because cash outflows are equivalent for all tree species, *H. alchorneoides, S. macrophylla* and *T. amazonia* follow as for the displayed species *T. grandis*.

For a required rate of return of 15% a felling value of around US $120.000/ha would be necessary to avoid a negative NPV. Therefore, such a high internal rate of return appears to be unlikely.

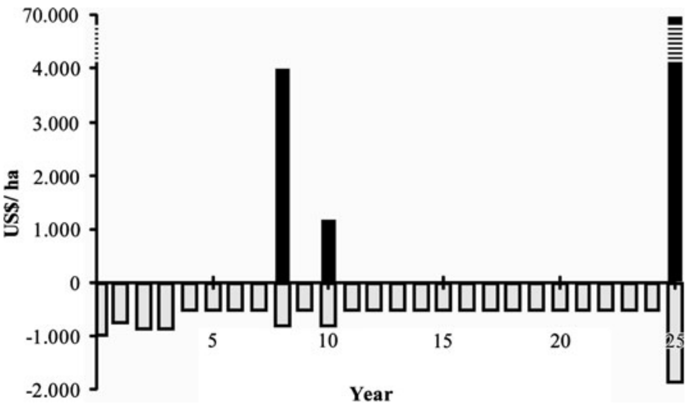

Fig. 3 Cash in- and out-flows *Tectona grandis*

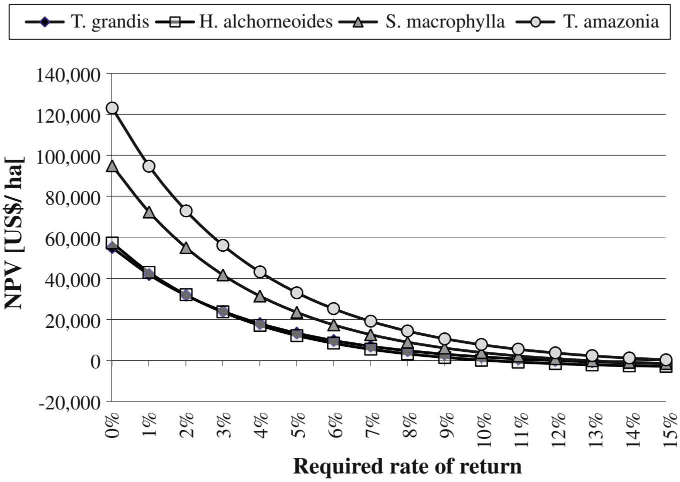

Fig. 4 Net present value function of all four tree species

Table 4 Net present values and internal rates of return

Internal rate of return (%)	Net present value (US $/ha)			
	T. grandis	*H. alchorneoides*	*S. macrophylla*	*T. amazonia*
0	55,023	57,340	94,921	123,139
1	41,860	43,016	72,335	94,809
2	31,738	32,049	54,980	72,975
3	23,940	23,642	41,622	56,113
4	17,920	17,192	31,324	43,062
5	13,267	12,240	23,375	32,942
6	9,663	8,438	17,233	25,079
7	6,868	5,520	12,483	18,960
8	4,698	3,282	8,807	14,191
9	3,013	1,568	5,963	10,468
10	1,702	*258*	3,763	7,559
11	*683*	*−739*	2,062	5,283
12	*−109*	−1,494	*750*	3,501
13	−725	−2,063	*−261*	2,106
14	−1,202	−2,487	−1,037	1,013
15	−1,572	−2,799	−1,629	*157*

Considering uncertainties: a sensitivity analysis of net present value and internal rate of return

The sensitivity analysis gives an overview of the reactions of the NPVs and internal rates of return on changes in the input variables.

Fig. 5 Felling value year 25 necessary for a NPV = 0

Varying initial cash outflow

A change in the initial cash outflow—meaning the costs of stand establishment—at the beginning of the period under consideration results in a parallel downwards shift of the NPV graph for all tree species. Any such change can for example evolve from rising costs for seedling or rising wages. If the initial cash outflow rises for a certain amount, the NPV declines by the same amount, irrespective of the used rate of return, and vice versa.

This effect is originated by using a discount rate $(1 + i)^0$ at the beginning of the period under consideration. The parallel shift furthermore results in a change of the point of intersection of the graph with the *X*-axis is moving to the left, which means that the internal rate of return declines as shown by the example of *T. grandis* in Fig. 6.

The changes in the payments made for stand establishment by US $2,500, and US $5,000, respectively, are deliberately chosen to be very high to clearly point out the parallel shift of the graph. For the sensitivity analysis itself, additional 25, 50, 75, and 100% are

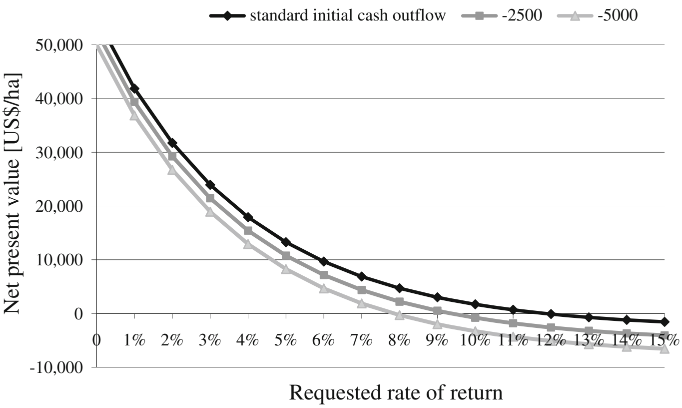

Fig. 6 Changes in the graph of the net present value function with rising initial cash outflows for stand establishment of *T. grandis*

charged for the initial cash outflow. A possible decline of the costs for stand establishment is not being considered, as an initial cash outflow of around US $1,000/ha including all plants is already set rather low. Detailed results for all four species investigated can be found in the appendix, Tables 10, 11, 12, and 13.

Even for changes of up to 100%, the internal rate of return for all tree species only varies in a range of less than 1%. Even a considerable increase of the costs for stand establishment has only very little influence on the NPVs. Furthermore it is to be tested how the NPV changes over all requested rates of return if the cash inflow earned by final harvest varies.

Varying cash inflow from final harvest

Varying earnings from final harvest can for example be caused by declining timber prices. Also, lower increments—for example caused by changing environmental conditions—that lead to lower dimensions in the produced timber and lower standing volumes, can influence the earnings gained during final harvest. Vice versa, timber prices, saw wood proportions and many other factors can also change in a positive way. To asses financial consequences of all possible future developments, the cash inflow by final harvest in year 25 for the four tree species considered was varied from −50% through +50%, resulting in a change of the NPVs. The possible range of the NPV at higher, and lower incomes gained by final harvest is shown for *T. grandis* in Fig. 7.

The NPV at lower cash inflows from final harvest is below the NPV of the standard scenario. Likewise, the NPV gained with a higher final cash inflow as a basis are above the standard scenario. However, in both cases the difference between the standard scenario and the other scenarios becomes smaller and approaches zero with rising discount rate. This is due to the fact that the discount factor used for the cash inflow after final harvest ($(1 + i)^{-25}$) quickly becomes very small due to rising interest rates and the discounting period of 25 years,.

Pessimistic and optimistic combinations

Within a framework of pessimistic and optimistic combinations, the paper at hand investigates the fluctuation margin of the NPVs for the investigated tree species, if rising

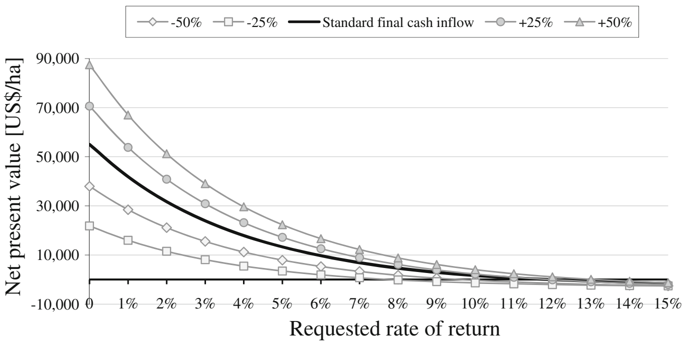

Fig. 7 Changes in the graph of the net present value function with rising and declining cash inflows from final harvest, *T. grandis*

cash outflows for stand establishment occur along with sinking cash inflows after final harvest and vice versa. To consider a pessimistic development of the NPV, initial cash outflows are increased by 50% whilst simultaneously decreasing the cash inflow after final harvest by 50%. To consider an optimistic development of the NPV, decreased cash outflows for stand establishment by 50% are combined with 50% higher cash inflows gained by final harvest. The results for all four tree species can be seen in Table 5.

If the internal rate of return is considered, the following ranking results: If a pessimistic development occurs, *T. amazonia* still reaches the highest internal rates of return. Already at a slight increase of the cash inflows, *T. amazonia* can compete with the results of the other three species in the situation of an optimistic development.

T. grandis turns out to be least susceptible to the alternative scenarios, whilst *H. alchorneoides* in a pessimistic case scores lowest and is therefore rather susceptible towards changes.

Varying rotation lengths

By calculating LEVs under varying rotation lengths, production periods can be optimized. Therefore the LEVs of all four investigated tree species are calculated for rotation periods between 10 and 30 years and a regression analysis was carried out with the ascertained values.

The development of the LEV of *T. grandis* is exemplary displayed in Fig. 8, the graphs for the three native species can be found in the appendix (Figs. 9, 10, and 11). Whereas the smoothed curve is pictured as a bold line, the "real" values are pictured as a dashed line.

Table 5 Pessimistic and optimistic net present values in US $/ha at varying interest rates

Internal rate of return (%)	*T. grandis*		*H. alchorneoides*		*S. macrophylla*		*T. amazonia*	
	Pessimum	Optimum	Pessimum	Optimum	Pessimum	Optimum	Pessimum	Optimum
0	21,358	88,688	20,190	94,489	39,031	150,811	54,840	191,439
1	15,502	68,218	13,941	72,091	28,647	116,023	41,444	148,174
2	11,028	52,448	9,215	54,882	20,723	89,236	31,155	114,796
3	7,607	40,272	5,645	41,639	14,674	68,569	23,238	88,987
4	4,988	30,853	2,952	31,431	10,055	52,593	17,138	68,987
5	2,982	23,551	*927*	23,553	6,528	40,223	12,430	53,454
6	1,445	17,880	*−591*	17,467	3,837	30,629	8,792	41,366
7	*268*	13,468	−1,722	12,762	1,788	23,178	5,979	31,942
8	*−633*	10,030	−2,559	9,122	*231*	17,384	3,802	24,580
9	−1,322	7,347	−3,171	6,306	*−949*	12,875	2,117	18,819
10	−1,847	5,251	−3,613	4,129	−1,837	9,363	*813*	14,304
11	−2,246	3,612	−3,924	2,447	−2,503	6,627	*−196*	10,761
12	−2,548	2,329	−4,138	1,149	−2,996	4,495	−975	7,977
13	−2,774	1,325	−4,277	*151*	−3,358	2,835	−1,575	5,786
14	−2,943	*538*	−4,359	*−615*	−3,617	1,544	−2,037	4,062
15	−3,067	*−77*	−4,400	−1,199	−3,799	*541*	−2,390	*2,704*

Italic values indicate the range of max. internal rate of return that can be gained for each species applying optimistic and pessimistic scenarios

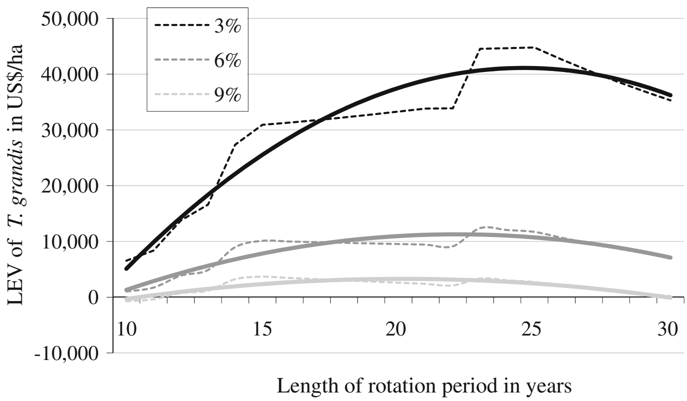

Fig. 8 LEV development for *T. grandis* under varying rotation lengths

The partially remarkable leaps of the LEV graphs originate from the variation in incomes from timber due sales due to increasing log sizes.

For all four species a rotation period of 25 years turns out to be ideal at a discount rate of 3%. At discount rates larger than 3%, the ideal rotation decreases, but the differences of the LEVs with age however are comparatively low. Overall, the trend line added to Fig. 8 clearly shows the bell-shaped development which is typical for corresponding graphs, whereas the assumed optimal rotation length of 25 years is close to the maximum value at all times. The explicit increase of the LEVs between a 22 year and a 23 year rotation length rests on the rising incoming payments for timber sales due to larger dimensions. Furthermore, the flat run of the graph that occurs in all four species points out a wide range of management options regarding ideal market situations for harvesting operations.

Discussion

Reassessing the hypothesis

Calculating the net present values (NPV) for a standard scenario at a rotation length of 25 years led to the result that *T. grandis* reaches internal rates of return of approximately 11–12%. The natural forest species *H. alchorneoides* reaches values of 10–11%, *S. macrophylla* reaches internal rates of return of approximately 12–13% and the third natural forest species *T. amazonia* even reaches internal rates of return of >15%. The calculations of the NPVs were carried out for the standard scenario without considering the costs for purchase of land, costs for maintaining an administration, taxes or a distribution system. If all these costs are considered, the results will shift towards the results of the pessimistic development scenario. For plantations growing selected indigenous tree species, Cubbage et al. (2007) calculated rates of return between 5 and 13%. An equivalent result is aimed for at the research site mixing the four species *T. grandis, H. alchorneoides, S. macrophylla* and *T. amazonia*.

The rates of return calculated here do turn out to be comparatively low. As predictions regarding timber markets at the rotation age are difficult to make, it has to be mentioned that with increasing volumes of wood becoming available from maturing plantations (Clark 2001), price expectations may not necessarily be realized, even though a market premium for certified logs may be fetched in the future (Kollert and Lagan 2006). The pessimistic scenarios considered here however, display future performances at price declines of up to 50%.

Furthermore there exist large uncertainties regarding the survival probability for the natural forest species. As mentioned before, especially for *S. macrophylla* there are indications that a rotation period of 25 years in a plantation cannot be assumed offhand. One of the largest known problems with *S. macrophylla* in plantations are calamities of the insect pest *Hypsipyla* spp. which can be found in all of Central America (Mayhew and Newton 1998). An infestation results in a damage of the main shoot and therefore forked trees and a considerable decrease of increments. At the research site, single appearances of *H. grandella* were observed during inventories.

On our assumtions, native species appear competitive with *T. grandis* in this area. The comparison of the NPVs shows that the profitability of growing *T. grandis* is below the profitability of *T. amazonia* as well as *S. macrophylla* and only slightly higher than the profitability of growing *H. alchorneoides* if the standard scenario is used. However, for *S. macrophylla* high uncertainties regarding future outcomes have to be considered, leading to the assumption that results will strongly tend towards the pessimistic scenario if the stands of this species are able to reach the rotation age. Furthermore, the timber may turn out to be mainly sapwood, unless a much longer rotation is used. These uncertainties also raise the question if *S. macrophylla* should be planted at all. If trees of this species are planted in small groups or as single tree admixtures the risk of insect losses can be minimized. If the trees of *S. macrophylla* should then fail to reach rotation age, surrounding trees of other species will be able to fill in the gaps. We therefore recommend understanding the admixture of *S. macrophylla* as an investment that offers certain chances at a high risk and should therefore be planted in proportions smaller than 5% only.

For *H. alchorneoides* it is likely that the revenues from timber sales will in reality turn out to be higher than the revenues used in the paper at hand, as according to Piotto et al. (2003), an increasing demand for saw timber of this species is to be expected. In this case, the small advantage of *T. grandis* towards *H. alchorneoides* would wear off in the occurrence of an according scenario. Our hypothesis—*the profitability of Teak plantations cannot be equalled by planting native tree species*—is therefore refuted, provided that all assumptions turn out to be true in the future.

Conclusions

This paper was able to show how the investigated species behave regarding their financial performance. To our knowledge it is the first paper delivering actual data for financial comparison of the three investigated native species with *Tectona grandis*, as so far very little is known about the financial competitiveness of natives. Regarding the NPV of all four tree species, the profitability of *T. grandis* drops below the profitability of *T. amazonia* and *S. macrophylla* applying the standard scenario already and lies only slightly above the profitability calculated for *H. alchorneoides*. This result clearly indicates that the investigated native tree species are comparable with *T. grandis* regarding their economic profitability assuming that in the future the wood can be sold at comparable prices. Besides its ecological impact (Evans and Turnbull 2004; Hartley 2002) growing native tree species now also obtains economic legitimacy and should therefore be considered to be used alongside *Tectona grandis* in plantation establishments. Reconciliation between ecology and economics is made possible as the only obstacle so far was the lack of knowledge existing in this field of research.

An increase in the revenues from final harvest in year 25 has a great influence on the total profitability of the investment. Alongside the timber prices, which cannot be influenced by small enterprises, especially quality and dimension of the grown stem wood plays an important role for increasing revenues. Special attention should therefore be paid to the tending of such timber.

The information provided here makes a substantial contribution to the acceptance of native tree species within commercial forestry in Central America. The information regarding their profitability and growth also provides a basis for further calculations. However, it has to be noted that the extrapolation of growth from year 10 to 25 is very long and therefore holds uncertainties. For more reliable results, future evaluation of the profitability and economy of the investigated species to ages beyond age 10 has to be carried out. By integrating risk, as done for by Heidingsfelder and Knoke (2004) in a comparable study, the insecurity of an investment decision can be quantified. Such risk integration can for example consider the uncertainty regarding the future revenues gained by future timber sales. Furthermore, the tendency to risk taking by the decision maker can be integrated into evaluating the profitability of the investment. The relevance of integrating risks was determined by Knoke and Wurm (2006). Assessments of the diversification that results by growing the four different tree species would be reasonable as well. Diversification effects were first described by Markowitz (1952) in his Portfolio-Theory. An investment made up of a combination of different capital assets can—compared to a single investment—lower the risk at equivalent rates of return. Also, the rate of return can be positively influenced by combining different capital assets. Knoke et al. (2005) devolved this approach on forest economics, determining mixed species plantations to be equivalent to a mixed portfolio. They observed that the ecologic concept of “mixed forests” leads to considerable economic benefits. To assess the diversification effects for the four tree species investigated would further advance the clarification of the economy and productivity of *T. grandis, H. alchorneoides, S. macrophylla* and *T. amazonia*. To increase the accuracy of assessing such forest investments there is also further need for information about tree species interaction in mixed stands, according to the research carried out by Petit and Montagnini (2006).

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Appendix

See Tables 6, 7, 8, 9, 10, 11, 12, and 13; Figs. 9, 10, and 11.

Table 6 Yield projection for *Tectona grandis* at the study site

Tectona grandis (Teak)							
Age	N	Intensity of thinning (%)	d_g (cm)	h_g (m)	Remaining vol. (m^3/ha)	Harvested vol. (m^3/ha)	TI (m^3 o.b./ha)
2	714	0	4.3	5.5	3	0	3
3	714	0	8.3	8.8	15	0	15
4	714	0	11.0	11.8	36	0	36
5	714	0	12.4	11.4	44	0	44
6	714	0	12.8	12.2	50	0	50
7	714	0	13.7	13.1	62	0	62
8	420	41	15.9	15.8	59	42	115
9	420	0	17.1	16.5	66	0	122
10	362	14	18.3	17.1	73	12	127
11	360	0	20.2	17.7	92	0	145
12	358	0	22.1	18.3	114	0	167
13	357	0	24.1	18.9	138	0	191
14	355	0	26.0	19.5	165	0	218
15	353	0	27.9	20.1	195	0	248
16	351	0	28.9	20.7	214	0	267
17	350	0	29.8	21.2	233	0	286
18	348	0	30.8	21.8	254	0	307
19	346	0	31.8	22.3	275	0	328
20	344	0	32.7	22.9	298	0	351
21	343	0	33.7	23.4	322	0	375
22	341	0	34.5	23.9	343	0	396
23	339	0	35.4	24.4	365	0	419
24	337	0	36.2	24.9	389	0	442
25	336	100	37.0	25.4	413	413	467

N Number of trees/ha, *Intensity of thinning* in percent of number of standing trees, d_g diameter of mean basal area tree, h_g height of mean basal area tree, *TI* total increment

Table 7 Yield projection for *Hieronyma alchorneoides* at the study site

Hieronyma alchorneoides (Zapatero)							
Age	N	Intensity of thinning (%)	d_g (cm)	h_g (m)	Remaining vol. (m^3/ha)	Harvestes vol. (m^3/ha)	TI (m^3 o.b./ha)
2	400	0	1.7	2.5	0	0	0
3	400	0	3	4.05	1	0	1
4	400	0	4.65	5.35	2	0	2
5	400	0	6.6	7.05	4	0	4
6	400	0	7.6	8.7	7	0	7
7	400	0	9.3	9.9	12	0	12
8	321	22	10.7	11.7	15	4	16
9	321	0	12.6	13.4	24	0	28

Table 7 continued

Hieronyma alchorneoides (Zapatero)							
Age	N	Intensity of thinning (%)	d_g (cm)	h_g (m)	Remaining vol. (m^3/ha)	Harvestes vol. (m^3/ha)	TI (m^3 o.b./ha)
10	299	4	13.4	15.3	29	1	34
11	298	0	14.80	17.00	39	0	44
12	296	0	16.20	18.70	51	0	56
13	295	0	17.60	20.40	66	0	71
14	293	0	19.00	22.10	83	0	87
15	292	0	20.40	23.80	102	0	107
16	290	0	21.80	25.50	124	0	129
17	289	0	23.20	27.20	149	0	154
18	287	0	24.60	28.90	178	0	182
19	286	0	26.00	30.60	209	0	214
20	284	0	27.40	32.30	244	0	249
21	283	0	28.80	34.00	282	0	287
22	282	0	30.20	35.70	324	0	329
23	280	0	31.60	37.40	370	0	375
24	279	0	32.86	38.93	414	0	419
25	277	100	33.98	40.29	456	456	461

N Number of trees/ha, *Intensity of thinning* in percent of number of standing trees, d_g diameter of mean basal area tree, h_g height of mean basal area tree, *TI* total increment

Table 8 Yield projection for *Swietenia macrophylla* at the study site

Swietenia macrophylla (Caoba)							
Age	N	Intensity of thinning (%)	d_g (cm)	h_g (m)	Remaining vol. (m^3/ha)	Harvested vol. (m^3/ha)	TI (m^3 o.b./ha)
2	400	0	2.1	3	0	0	0
3	400	0	3.8	4.7	1	0	1
4	400	0	6.1	6.2	5	0	5
5	400	0	9.3	9.6	17	0	17
6	400	0	12.3	13	40	0	40
7	400	0	13.2	14.3	51	0	51
8	375	6	14.9	16.1	68	5	73
9	375	0	17.1	17.8	100	0	104
10	368	2	18.8	19.5	129	1	135
11	366	0	20.52	20.24	159	0	165
12	364	0	22.24	20.98	193	0	199
13	363	0	23.96	21.72	231	0	237
14	361	0	25.68	22.46	273	0	279
15	359	0	27.4	23.2	319	0	325
16	357	0	28.62	23.86	356	0	362
17	355	0	29.84	24.52	396	0	402
18	354	0	31.06	25.18	438	0	444

Table 8 continued

Swietenia macrophylla (Caoba)							
Age	N	Intensity of thinning (%)	d_g (cm)	h_g (m)	Remaining vol. (m^3/ha)	Harvested vol. (m^3/ha)	TI (m^3 o.b./ha)
19	352	0	32.28	25.84	484	0	489
20	350	0	33.5	26.5	531	0	537
21	348	0	34.16	27.04	561	0	567
22	347	0	34.82	27.58	592	0	597
23	345	0	35.48	28.12	623	0	629
24	343	0	36.14	28.66	656	0	661
25	341	100	36.8	29.2	689	689	695

N number of trees/ha, *Intensity of thinning* in percent of number of standing trees, d_g diameter of mean basal area tree, h_g height of mean basal area tree, *TI* total increment

Table 9 Yield projection for *Terminalia amazonia* at the study site

Terminalia amazonia (Amarillo)							
Age	N	Intensity of thinning (%)	d_g (cm)	h_g (m)	Remaining vol. (m^3/ha)	Harvested vol. (m^3/ha)	TI (m^3 o.b./ha)
2	625	0	1.6	2.7	0	0	0
3	625	0	3.1	4.1	1	0	1
4	625	0	5.7	6.2	4	0	4
5	625	0	7.6	7.9	10	0	10
6	625	0	10.3	11.2	26	0	26
7	625	0	12.2	13.6	45	0	45
8	378	40	14.8	15.6	46	30	75
9	378	0	16.2	17.8	62	0	92
10	284	25	18.8	20	71	11	112
11	283	0	20.50	21.60	91	0	132
12	281	0	22.20	23.20	114	0	155
13	280	0	23.90	24.80	140	0	181
14	278	0	25.60	26.40	170	0	211
15	277	0	27.30	28.00	204	0	245
16	276	0	29.00	29.60	242	0	284
17	274	0	30.70	31.20	285	0	326
18	273	0	32.40	32.80	332	0	373
19	271	0	34.10	34.40	384	0	425
20	270	0	35.80	36.00	440	0	482
21	269	0	37.50	37.60	502	0	543
22	267	0	39.20	39.20	569	0	611
23	266	0	40.90	40.80	642	0	683
24	265	0	42.43	42.08	709	0	750
25	263	100	43.79	43.36	774	774	815

N number of trees/ha, *Intensity of thinning* in percent of number of standing trees, d_g diameter of mean basal area tree, h_g height of mean basal area tree, *TI* total increment

Table 10 Changes in the NPV of *T. grandis* with rising initial cash outflows

Internal rate of return (%)	NPV *T. grandis* (US $/ha) Standard initial cash outflow	Increase of initial cash outflow			
		25%	50%	75%	100%
0	55,023	54,780	54,537	54,293	54,050
1	41,860	41,616	41,373	41,129	40,886
2	31,738	31,494	31,251	31,008	30,764
3	23,940	23,696	23,453	23,209	22,966
4	17,920	17,677	17,434	17,190	16,947
5	13,267	13,023	12,780	12,536	12,293
6	9,663	9,419	9,176	8,932	8,689
7	6,868	6,625	6,381	6,138	5,894
8	4,698	4,455	4,212	3,968	3,725
9	3,013	2,769	2,526	2,282	2,039
10	1,702	1,459	1,215	972	728
11	683	440	196	−47	−291
12	−109	−353	−596	−840	−1,083
13	−725	−968	−1,212	−1,455	−1,699
14	−1,202	−1,446	−1,689	−1,933	−2,176
15	−1,572	−1,815	−2,059	−2,302	−2,546

Table 11 Changes in the NPV of *H. alchorneoides* with rising initial cash outflows

Internal rate of return (%)	NPV *H. alchorneoides* (US $/ha) Standard initial cash outflow	Increase of initial cash outflow			
		25%	50%	75%	100%
0	57,340	57,096	56,853	56,609	56,366
1	43,016	42,772	42,529	42,285	42,042
2	32,049	31,805	31,562	31,318	31,075
3	23,642	23,398	23,155	22,912	22,668
4	17,192	16,948	16,705	16,461	16,218
5	12,240	11,997	11,753	11,510	11,266
6	8,438	8,195	7,951	7,708	7,464
7	5,520	5,276	5,033	4,790	4,546
8	3,282	3,038	2,795	2,551	2,308
9	1,568	1,324	1,081	837	594
10	258	15	−229	−472	−716
11	−739	−982	−1,226	−1,469	−1,713
12	−1,494	−1,738	−1,981	−2,225	−2,468
13	−2,063	−2,306	−2,550	−2,793	−3,037
14	−2,487	−2,730	−2,974	−3,217	−3,461
15	−2,799	−3,043	−3,286	−3,529	−3,773

Table 12 Changes in the NPV of *S. macrophylla* with rising initial cash outflows

Internal rate of return (%)	NPV *S. macrophylla* (US $/ha) Standard initial cash outflow	Increase of initial cash outflow			
		25%	50%	75%	100%
0	94,921	94,678	94,434	94,191	93,947
1	72,335	72,091	71,848	71,605	71,361
2	54,980	54,736	54,493	54,250	54,006
3	41,622	41,378	41,135	40,891	40,648
4	31,324	31,081	30,837	30,594	30,350
5	23,375	23,132	22,888	22,645	22,402
6	17,233	16,990	16,746	16,503	16,259
7	12,483	12,239	11,996	11,753	11,509
8	8,807	8,564	8,321	8,077	7,834
9	5,963	5,720	5,476	5,233	4,989
10	3,763	3,519	3,276	3,033	2,789
11	2,062	1,819	1,575	1,332	1,088
12	750	506	263	19	−224
13	−261	−505	−748	−991	−1,235
14	−1,037	−1,280	−1,524	−1,767	−2,010
15	−1,629	−1,873	−2,116	−2,359	−2,603

Table 13 Changes in the NPV of *T. amazonia* with rising initial cash outflows

Internal rate of return (%)	NPV *T. amazonia* (US $/ha) Standard initial cash outflow	Increase of initial cash outflow			
		25%	50%	75%	100%
0	123,139	122,896	122,653	122,409	122,166
1	94,809	94,565	94,322	94,078	93,835
2	72,975	72,732	72,489	72,245	72,002
3	56,113	55,869	55,626	55,383	55,139
4	43,062	42,819	42,575	42,332	42,089
5	32,942	32,699	32,455	32,212	31,968
6	25,079	24,836	24,593	24,349	24,106
7	18,960	18,717	18,474	18,230	17,987
8	14,191	13,947	13,704	13,461	13,217
9	10,468	10,225	9,981	9,738	9,494
10	7,559	7,315	7,072	6,828	6,585
11	5,283	5,039	4,796	4,552	4,309
12	3,501	3,258	3,014	2,771	2,527
13	2,106	1,862	1,619	1,375	1,132
14	1,013	769	526	282	39
15	157	−86	−330	−573	−817

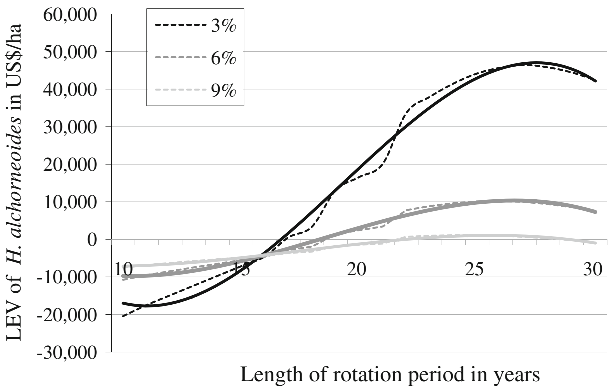

Fig. 9 LEV development for *H. alchorneoides* under varying rotation lengths

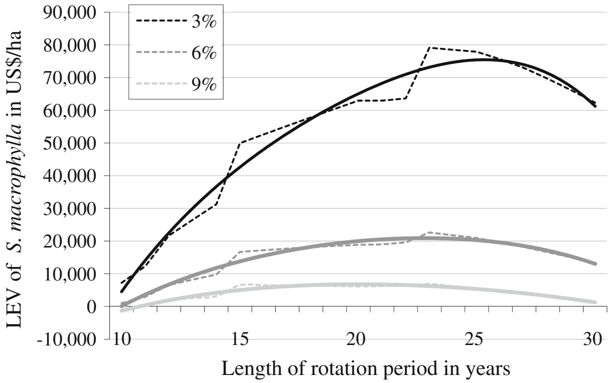

Fig. 10 LEV development for *S. macrophylla* under varying rotation lengths

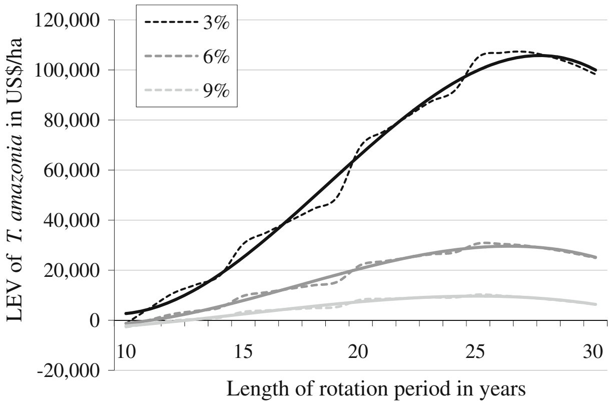

Fig. 11 LEV development for *T. amazonia* under varying rotation lengths

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