Profitability of establishing Eucalyptus globulus plantations in the Central Highlands of Ethiopia

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TIIVISTELMÄ: EUCALYPTUS GLOBULUS -VILJELMIEN PERUSTAMISEN KANNATTAVUUS ETIOPIAN KESKUSYLÄNGÖLLÄ

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The economic analysis is based on computer simulations which covered a seedling rotation and three successive coppice rotations. Calculations were carried out for the four site productivity classes of *Eucalyptus globulus* plantations. The rotation length that maximized the land expectation value is 12 . . . 20 years for seedling rotation and 8 . . . 16 years for coppice rotations with discounting rates 2 . . . 8%. The mean wood production is over 40 m³/ha/a in the best site class and about 10 m³/ha/a in the poorest class with rotation lengths ranging from 10 to over 20 years. Thinnings increase the wood production and land expectation value by a few percentage points. In areas suitable to *Eucalyptus globulus* growth, the land expectation value is considerably higher in forestry than in agriculture, except in very poor areas or with very high rate of interest.

Taloudelliset laskelmat perustuvat tietokonesimulointeihin, jotka kattoivat istutetun puusukupolven ja kolme seuraavaa vesasukupolvea. Laskelmat tehtiin kaikille neljälle *Eucalyptus globuluksen* pituusboniteettiluokalle. Suurin maan tuottoarvo saavutetaan, kun istutusmetsän kiertoaika on 12 . . . 20 vuotta ja vesametsän kiertoaika 8 . . . 16 vuotta käytettäessä laskentakorkokantoja 2 . . . 8 %. Keskimääräinen tuotos on parhaassa kasvupaikkaluokassa runsaat 40 m³/ha/v ja noin 10 m³/ha/v heikoimmassa luokassa, jos kiertoaika on vähintään 10 vuotta. Harvennus suurentaa jonkin verran puuntuotosta ja maan tuottoarvoa. *Eucalyptus globuluksen* kasvatukseen soveltuvilla alueilla maan tuottoarvo on yleensä huomattavasti suurempi metsätaloudessa kuin maataloudessa. Korkeaa laskentakorkokantaa käytettäessä kuitenkin maatalous on edullisempaa, etenkin huonoimmilla kasvupaikoilla.

Keywords: simulation of growth, economic analysis, reforestation, land use planning
ODC 651.72+176.1 *Eucalyptus globulus* + (63)

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1. Introduction

Fuelwood and pole plantations traditionally belong to Ethiopian forestry. *Eucalyptus globulus*, especially, is well known to people living in the central highlands of the country, in its plateaux and mountain areas above the altitude of 2 000 meters. For almost 100 years the small-sized eucalyptus wood has been highly appreciated by the rural and urban dwellers both as fuel and as light-scale construction poles.

Fuelwood or construction poles are, however, no more abundant for the people of Ethiopia. Natural forests once growing dense in the highlands have largely been cut, and the plantations established so far are too few to satisfy the wood demand. The annual planting of new forests (about 20 000 ha) can not cope with the annual destruction of the old forests (about 200 000 ha). New plantation projects are therefore initiated to alleviate the fuelwood shortage of the country (Establishment . . . 1982, 1985).

Carrying out cost-benefit analyses is nowadays a standard practice in planning development projects. By means of such an analysis the overall feasibility of a plantation project can be justified. In the preliminary cost-benefit analyses (Preliminary . . . 1985) the internal rate of return has been 18 . . . 20 %, which well justifies the production of fuelwood in *Eucalyptus globulus* plantations. Extension of the growing period beyond small fuelwood size has, however, not been studied.

The purpose of this study is to examine the profitability of different production alternatives in *Eucalyptus globulus* plantations.

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2. Plantation forestry and economic analysis

2.1. Development of plantation forestry in Ethiopia

Contrary to other Sudano-Sahelian countries Ethiopia has a long tradition and experience in plantation forestry. This dates back to the times of Emperor Menelik II, to the end of the 19th century. The existence of Addis Ababa as a capital was threatened by deepening fuelwood shortage, due to overcutting of the natural forests on the surrounding mountains. As a potential solution, eucalypts were introduced into the country in 1895 (Breitenbach 1961). The introduction was a success, and soon after the turn of the century planting of eucalypts for fuel was initiated in a large scale. The farmers around Addis Ababa adapted the new species for fuelwood and started planting their own woodlots, and also larger plantations.

The fuelwood plantation forestry around Addis Ababa, as well as around almost every Ethiopian major city, developed steadily until the revolution and land reform in 1974. Plantations, mainly with *Eucalyptus globulus*, were established altogether on more than 100 000 hectares (Forestry . . . 1981), out of which about 15 000 ha in the surroundings of Addis Ababa (Henry 1973, Persson 1975). Another type of plantation forestry started to develop in the 1950's, in Chilalo Awraja, 200 km south of Addis Ababa, in the escarpments of Munessa – Shashamane mountain range. Two saw mills had been established earlier in the area to exploit the existing natural forests. It was foreseen already in the mid-fifties that the natural forests around the saw-mills will vanish. The first plantations using exotic tree species (*Cupressus lusitanica* and *Eucalyptus* sp.) were established.

In the late 1960's and the early 1970's the Munessa – Shashamane forestry activities were included in a special development project (CADU). As a part of the project activities new potentially productive plantation species were introduced, and some of them (like *Eucalyptus regnans*) were planted in a large scale (Poulsen 1973). Altogether the Munessa – Shashamane plantation forests cover about 4 300 ha, out of which over 3 100 ha were planted with conifers and over 1 200 ha with eucalypts (Järvholm and Tivell 1987).

The total area under plantation forests in Ethiopia was about 310 000 ha in 1985 (Bowen 1985; Table 1). The figure is based on statistics about planted seedlings and on an estimated average survival rate in the plantations, and may therefore be an overestimate.

The plantation forestry in Ethiopia developed partly steered by market forces, partly on the basis of the plans of the government. In the pre-revolution times, when private forestry dominated, *Eucalyptus globulus* accompanied by *E. camaldulensis* was the most important species. In free pricing and market situation the main product was construction pole. Eucalypt poles were even exported from Ethiopia.

After the revolution and land reform more emphasis was given to exotic conifers, especially *Cupressus lusitanica*, which were believed to substitute the vanishing indigenous timber of *Juniperus procera* and *Podocarpus gracilior*. This hope was supported by research results in other East African countries, such as Kenya and Tanzania. Another justification for using longer-rotation conifers was soil conservation and erosion control. Such a programme has been going on in Ethiopia since 1980 (Rehabilitation . . . 1986).

Establishment of plantations with the main emphasis on fuelwood came into picture after the two global energy crises, in the early and late 1970's. In Ethiopia this happened in 1982-1985 when the government assisted by United Nations Sudano-Sahelian Office (UNSO), African Development Fund and World Bank initiated plantation projects (Establishment . . . 1982, 1985).

2.2 Need of fuelwood

In Ethiopia the biomass fuels used in households include fuelwood, charcoal, cow dung and crop residues. The annual amount of timber harvested for household fuels totals in 18.8 mill. m³ (Ethiopia . . . 1984, Pohjonen and Pukkala 1987). In sustained forestry the annual timber production of 18.8 mill. m³ corresponds to about one million hectares of well managed, highly productive eucalypt plantations, or to about 5 mill. ha of indigenous forests.

Burning of cow dung results in a loss of soil fertility and agricultural yields. Burning of crop residues has a similar effect. It also reduces the availability of feedstock to draught animals. The ultimate goal of energy forestry is to substitute all the currently burned cow dung and crop residues with fuelwood. This increases the need for additional fuelwood production with 24.7 mill. m³/a (Fig. 1).

Counting on full substitution of cow dung and crop residues with fuelwood, the annual demand in Ethiopia increases from 18.8 into 43.5 mill. m³/a (Booth 1985). The area requirement needed for new plantations is ab-

Table 1. Estimated area (ha) under plantation forestry in Ethiopia in 1985 (Bowen 1985).

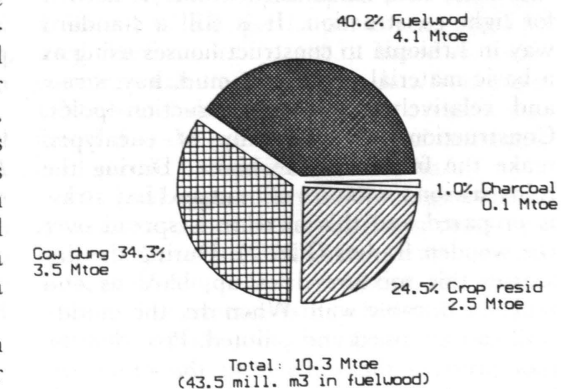|	
– Estimated area prior to 1979	98 200
– Area planted as state forests between 1979 and 1985	154 690
– Area planted as community forests between 1979 and 1985	45 480
– Miscellaneous, aid agencies, etc.	10 000
Total plantation area	308 370

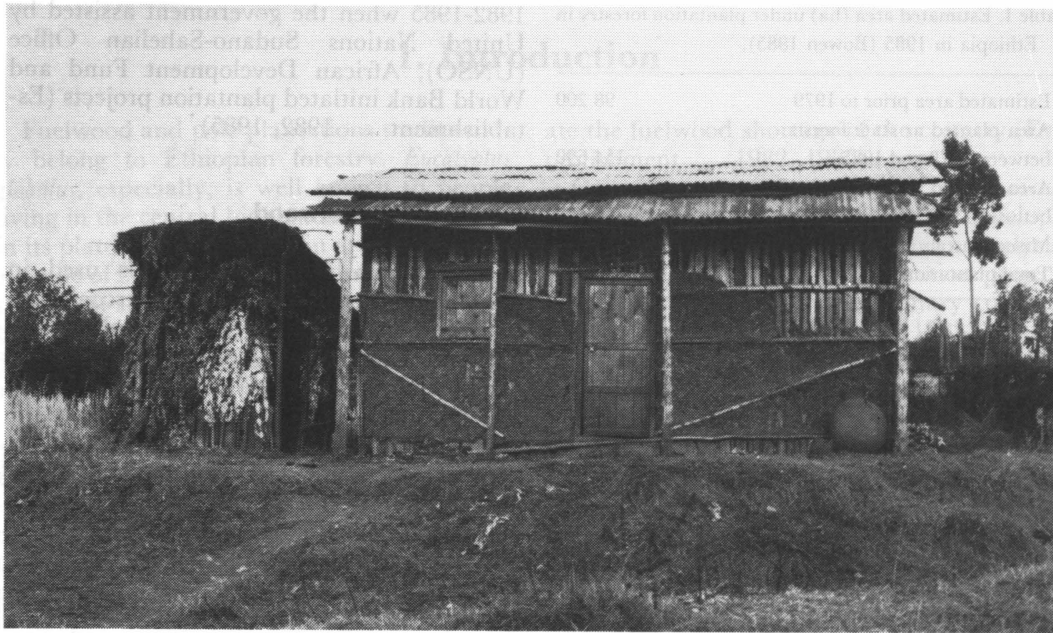Fig. 1. The sources of household fuel in Ethiopia in 1980.

Fig. 2. Example of the use of *Eucalyptus globulus* poles in the construction of houses.

out 3 mill. ha. These figures apply to the population in Ethiopia of 42 mill. in 1985. Taking into account the population growth rate of 2.9 %, the overall demand for fuelwood will rise by year 2000 into 66.8 mill. m³/a and the needed plantation area into about 4.5 mill. ha, assuming the relative fuelwood consumption stays the same.

2.3 Need of construction poles

Besides fuel, small-sized timber is needed for light construction. It is still a standard way in Ethiopia to construct houses using as a basic material mixture of mud, hay, straw and relatively slender construction poles. Construction poles, usually of eucalypts, make the frame for the house. During the rainy season a mixture of mud and hay straw is prepared and this mixture is spread over the wooden frames (Fig. 2). During the dry season this mixture dries up, hardens and makes a durable wall. When dry the muddy wall can be limed and painted. Provided the roof protects the walls from the rains, the house is durable enough for Ethiopian conditions and will last over decades.

The total need of timber for light construction in Ethiopia is about one mill. m³/a (Palm 1983). Poles are also commonly used for supporting structures when erecting big town houses.

2.4 Need of transmission poles

The need of transmission line poles covers both high-voltage transmission, low-voltage distribution, and telecommunication lines. Although used widely in Ethiopia, *E. globulus* is not the best species for transmission line poles since it cracks, is often bended and does not impregnate well.

Better eucalypt species for transmission lines would be e.g. *E. cloeziana, E. paniculata, E. citriodora, E. pilularis, E. maidenii* and *E. saligna*. Since these species are not widely available in Ethiopian plantations, the more common *E. globulus* must be used. *E. globulus* outgrows all the other *Eucalyptus* species in Ethiopian highlands. Therefore, if the need for transmission poles is to be satisfied quickly, *E. globulus* has importance still for many years in Ethiopian transmission line construction.

At the moment the need for transmission line poles is small: about 1 000 m³/a for high-voltage, 5 000 m³/a for distribution lines and 5 000 m³/a for telecommunication poles (Ethiopian . . . 1988). The need for high-voltage transmission poles, especially, is rapidly increasing, due to the rigorous plan to electrify the country. As a mountainous country, Ethiopia has a high potential for hydropower. This energy source is to be utilized, besides for rural and urban areas of the country, by selling excess electricity abroad. There is a plan to connect Ethiopian and Sudanese networks in the near future. The most obvious transmission pole material would be timber, i.e. the eucalypts.

Besides fuelwood and poles there is some demand of eucalypts for mechanical wood industry. The overall annual use for sawmilling, particle board, fiber board and plywood is only 165 000 m³ including all tree species (Melaku Abegaz and Addis Tsehaye 1987).

2.5 Need for economic reasoning

Even if based on short rotations, the establishment of large scale plantations is a long-term investment, which should be based on careful preliminary studies. In a typical case the whole plantation project life will be 40 . . . 50 years including plantation establishment and intensive management over one seedling rotation and 3 . . . 5 coppice rotations.

Production of *Eucalyptus* plantations is always a combination of different outputs. The most urgent need today is for fuelwood, but construction poles and transmission line poles are also needed. Since it is feasible to produce all assortments in the same plantation, the management has an optimization problem: how to establish, grow, thin and harvest the plantations in a way that the total output from the forest is maximized. Since different outputs are priced differently, the economic output counts.

Economic reasoning is needed for deciding on the optimum management schedule. In addition, the funding organizations are interested in the economics of fuelwood plantations and how they compare with alternative projects.

3. Land opportunity cost

The land opportunity cost of tree plantations refers to the return produced by the best alternative production option. In Ethiopian highland conditions the alternative is usually grazing. The new alternative, forest plantation, must bring a higher return than grazing.

When selecting areas for plantation forests, agricultural fields are generally avoided in a densely populated, developing country like Ethiopia (Poluha 1985). However, in a minor scale some agricultural areas might be transformed into forest plantations. This could be the case for instance in intensive pole production for transmission lines in specified, rather small compartments along the transmission lines.

Agricultural lands which may come into question are slightly sloping fields, typically

under barley and beans, sometimes also wheat. As an average land opportunity cost in these cases 182 Ethiopian Birr (EB, one USD = 2.07 EB) per ha per annum could be used (Preliminary . . . 1985). Based on socio-economic calculations on the data from some UNSO-funded fuelwood project areas, it was found that the opportunity cost of cultivated land should be taken as 200 EB/ha/a.

The land opportunity cost for high-altitude grazing areas can be calculated in two ways: through the output of livestock or through the amount of hay which could be sold to the market. The average family livestock herd in the UNSO fuelwood project areas is 4 heads of cattle (cows and oxen), one horse, mule or donkey and 3 sheep or goats (Preliminary . . . 1985). The income from livestock comes

SEEDLING STAND

H (dom), m

Site class I

II

III

IV

Age, years

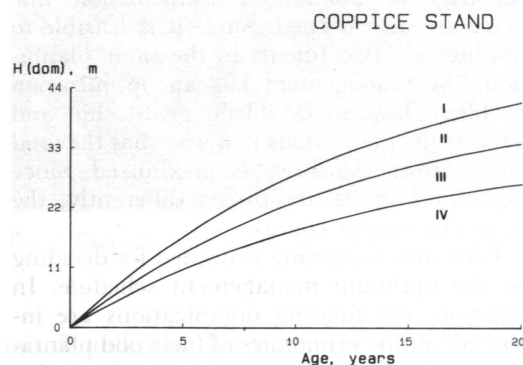COPPICE STAND
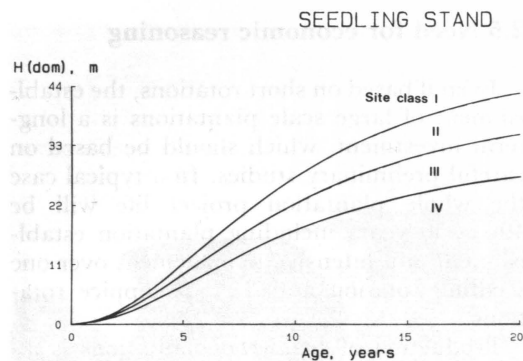
H (dom), m

I

II

III

IV

Age, years

Fig. 3. The site classes of *Eucalyptus globulus* in Ethiopia.

mainly from selling meat, milk and butter, hides, cow dung and young animals. In addition, the oxen and donkeys have an economic value for draught power and transportation.

The cash derived from livestock is about 16 EB/ha/a. Taking into account the non-cash economic value of the livestock (draught power, transportation, local use of cow dung) this is to be doubled into 32 EB/ha/a (Preliminary . . . 1985).

The highland pastures and grasslands yield approximately 700 kg/ha/a as hay (Furstenberg et al. 1984). The hay can be harvested by the cut and carry method and sold on town and village markets. The market

Table 2. Land opportunity cost for different site classes (for site classes, see Fig. 3).

Site class	Possible alternative crop or use	Opportunity cost EB/ha/a
1	Wheat	300
2	Barley	200
3	Beans, hay, good grazing	50
4	Poor grazing, barren land	10

value of dry hay is 3 . . . 15 Ethiopian cents per kg, and the value of hay production of the grassland thus 21 . . . 105 EB/ha/a, on average 63 EB/ha/a. Taking into account the reduction for harvesting and transport costs in the cut and carry method, this is in line with the UNSO opportunity cost of 32 EB/ha/a (Preliminary . . . 1985).

Barren lands (rangelands) have a poor production of hay. However, even if badly eroded, they are used for grazing. Some value must therefore be calculated for barren and badlands as well. The average productivity or carrying capacity for barren lands is on average about 0.28 livestock units per ha per annum (Furstenberg et al. 1984). At a take-off rate of 12 per cent, their productivity would be 7 . . . 10 EB/a, provided the livestock unit is valued at 200 . . . 300 EB.

The potential sites for *Eucalyptus globulus* plantations have been divided into four classes on the basis of age and dominant height. The classification is separate for seedling stands and coppice stands (Fig. 3). The land opportunity cost correlates, of course, with the site class (Table 2). The expected growth of the trees will be higher in areas with a higher land opportunity cost. The best sites may well be used for wheat production. The worst applicable site class is usually barren land.

In this study, the land opportunity costs presented in Table 2 were used for calculating the land expectation value in agriculture.

4. Plantation costs and benefits

4.1 Costs

The plantation establishment cost involves all the inputs needed to establish a fully-stocked stand. Part of the costs is due to the infrastructure, e.g. buildings and roads. Another part consists of recurrent costs like labour, nursery material and planting tools.

The plantation establishment cost in Ethiopia is estimated to be 2 000 EB/ha (National . . . 1983, Establishment . . . 1985). Lower prices than this have also been recorded, e.g. 1 500 EB/ha (Furstenberg et al. 1984) and 927 EB/ha (National . . . 1987). However, these lower figures do not always contain enough provision for weeding and guarding.

On the basis of existing information, an average plantation cost of 2 000 EB/ha will be used in this study. It was supposed to guarantee an *E. globulus* plantation at final stocking of 1 500 trees/ha (after 3 . . . 4 years of planting), properly weeded 3 or 4 times and guarded against feedstock.

After the establishment stage, there will be no later production costs if the trees are sold on stump, as assumed in this study.

4.2 Benefits

The immediate benefit from the plantation is to sell the timber it has produced. In Ethiopia, where fuelwood scarcity is acute, the tree has value as fuel from the very beginning. It is a common practice to use the whole biomass for cooking including stems,

Table 3. Minimum dimensions and prices of different assortments.

Assortment	Minimum top diameter	Minimum length	Price
Transmission line pole	14 cm	7 m	45 EB/m³
Construction pole	8 cm	2 m	18 EB/m³
Fuelwood, stem	–	–	15 EB/m³
Fuelwood, branches and leaves	–	–	27 EB/dry matter ton

branches, tops and even leaves. The dried leaves of *E. globulus*, especially, are regarded as excellent fuel in baking the national food, injera.

The smallest trees in the plantation fall into the category of fuelwood. This assortment has no minimum limit for diameter or height. The assortment of fuelwood is also cheapest by price. When the tree grows into the size of light construction pole, it exceeds the first value step: it is possible to utilize part of the tree for light construction. The top of the stem as well as branches and leaves can still be burned.

When the tree reaches larger dimensions, it is usable for transmission line poles. Depending on the tapering, the upper part of the stem can still yield one construction pole and fuelwood, or fuelwood only. In this study the cropped trees were divided into four assortments which were priced as presented in Table 3.

5. Simulations

5.1 Simulation of growth

The profitability of different reforestation and plantation management alternatives was studied by a simulation technique. The stand

growth was simulated by estimating the diameter distribution at desired age and calculating the stand characteristics from this distribution.

The beta distribution was used as a

theoretical diameter distribution. By using models on allometric relationships between stand characteristics the parameters needed for calculating the beta function were estimated from dominant height and stocking (Appendix 1). These parameters included the minimum, mean, maximum and the variance of the distribution (Loetsch et al. 1973).

During the seedling rotation and the first coppice rotation the development of dominant height followed the models made for the site classification system (Fig. 3, Appendix 1). In the second and subsequent coppice crops the development of dominant height was assumed to be 10 % slower than in the preceding crop. This was to allow for the deterioration of the growth rate in more frequently coppiced stands, and also for taking into account the impoverishment of the soil after years of monoculture.

The reduction of stocking (self-thinning, natural die-back) was assumed to depend on dominant height according to the functions determined by Pohjonen and Pukkala (1987) (Appendix 1). If the stocking was under this curve, due to thinning, all the trees were assumed to stay alive.

Using the estimated beta distribution, the number of stems per hectare was calculated for 20 diameter classes. In the calculations, each class was represented by a tree whose diameter equalled the class-midpoint. The height, stem volume and the dry masses of stem, branches and leaves were calculated for each class-midpoint-tree by using models of Pohjonen and Pukkala (1987). The stand characteristics were computed as means or sums of the tree characteristics.

5.2 Simulation of treatments

The only simulated treatments were thinning and clear cutting (coppicing). The principle was to thin from below in a way that in each diameter class, except the first, the removal percentage was 95 % of that in the preceding (smaller) class. The thinning was calculated as of basal area (not of stocking).

Clear cutting and thinning were done on a 10-cm stump. After cutting the stand was let to coppice. No silvicultural treatments (fertilization etc.) were done before the first thinning.

For each cropped tree the amounts of the following assortments were computed:

- transmission line pole volume
- construction pole volume
- volume of fuelwood from stem
- dry mass of branches and leaves

Since taper curve equations for *E. globulus* were not available, the taper curve equation of *Betula pendula* (Laasasenaho 1980) was used for calculating the proportions of transmission-line-polewood, construction wood and fuelwood for each stem. Diameter and height were used as predictors. The proportions were converted into volumes by multiplying them with the stem volume which was calculated by the volume equation of *E. globulus*. The income obtained from the harvest was computed by multiplying the total amounts of different assortments by their unit prices.

5.3 Land expectation value

The profitability of different scenarios was studied in terms of the mean annual production and in terms of the land expectation value. For the land expectation value the costs and income associated with a particular scenario were discounted to the beginning of the simulation and then summed. The result was the net present value of the first four rotations. It was assumed that after four rotations the stand will be re-established by planting, and similar four-rotation income and costs would apply indefinitely. The land expectation value was the sum of the net present value of the simulated four-rotation scenario, and the net present value of the later similar scenarios.

For comparing the profitability of the tree plantation with agriculture, the land opportunity cost, i.e. the annual net return in agriculture, was converted into the land expectation value.

All the economic computations were carried out by using discounting rates ranging from 2 to 8 %.

5.4 Simulated scenarios

The simulations always started with the plantation establishment. They covered a seedling rotation and three subsequent coppice rotations. The stand was re-established by planting after the fourth rotation (third coppice crop).

In all simulations the rotation time was 4 years shorter for the coppice crops than for the seedling crop because of the slow initial growth of a seedling stand; the rotation that maximizes the mean annual increment is about 4 years longer in seedling stand than in coppice stand (Pohjonen and Pukkala 1987). All the studied rotations (8 . . . 30 years) were simulated with and without thinnings. If the scenario involved thinnings, they were simulated according to the following rules:

Seedling stand
- 30 % thinning, calculated from basal area, executed when the basal area median diameter exceeds 12 cm (at the age of 6 . . .10 years).

- If the clear cutting is to be done within 2 years (site classes 1 and 2) or 3 years (site classes 3 and 4), the thinning is not executed.

Coppice stand
- First thinning, 30 % of basal area, at the age of 2 years (site classes 1 and 2) or at the age of 3 years (site classes 3 and 4).
- Second thinning, 30 % of basal area, executed when the basal area median diameter exceeds 12 cm (6 . . .22 years after coppicing).
- If the clear cutting is to be done within 2 years (site classes 1 and 2) or 3 years (site classes 3 and 4), the thinning is not executed.

The purpose of the first thinning in the coppice stand was to harvest for fuel those small stems which would in any case die as a result of natural thinning. The purpose of thinnings at mean diameter of 12 cm was to harvest construction poles and fuelwood as well as to leave ample growing space for the remaining trees to grow on.

6. Results

6.1 Optimum rotation

The optimum rotation of *E. globulus* plantations is depicted with the help of the land expectation value. In all cases, should thinnings be practiced or not, the optimum rotation is between 10 and 20 years (Figs. 4 and 5). The discounting rate has a clear effect on the optimum rotation: the higher the rate, the shorter the rotation. The land expectation value is not very sensitive to the rotation length. If the discounting rate is 4 . . . 8 %, the optimum rotation varies between 10 . . . 14 years for coppice rotations (and 4 years more for the first rotation).

Thinnings have no clear effect on the optimum rotation, but they increase slightly the land expectation value. The site class affects very little the length of the optimum rotation; on the poorest sites the optimum rotation is 1 . . . 5 years longer than in the best class, depending on the discounting rate.

The site class affects very strongly the land expectation value; it is about 9 times as high in the best site class as in the poorest site class when the discounting rate is 2 %. With increasing rate the relative differences between the site classes increase. In site class 4 the land expectation value is never positive at the rate of 8 %.

6.2 Production of different assortments

When there are no thinnings the wood production is maximized with the rotations 18 + 3 × 14 years (18 years for the seedling crop and 14 years for the subsequent coppice rotations), which are slightly more than the most economical rotations with discounting rates of 4 . . . 8 %. With thinnings the optimum rotation is usually the same. It is noteworthy that many rotations give almost the same mean wood production (Figs. 6 and 7).
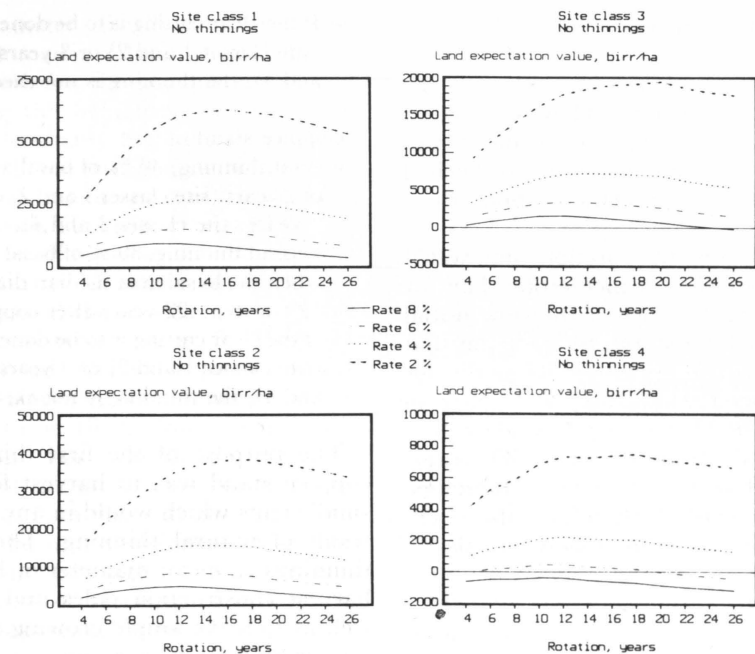
Fig. 4. The dependence of land expectation value on rotation length when thinnings are not applied. The x-axis shows the rotation length of the coppice rotations. For the seedling stand the rotation is always four years longer.
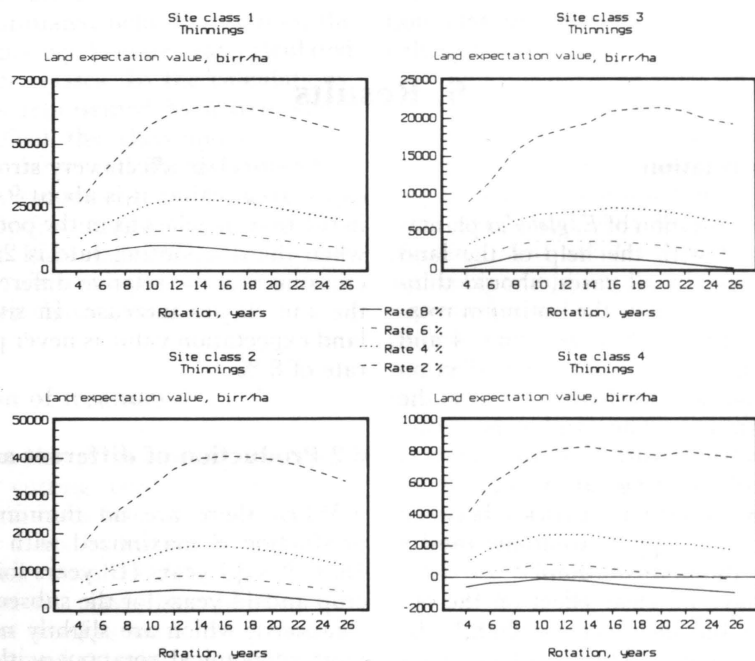

Fig. 5. The dependence of land expectation value on rotation length when thinnings are applied. The x-axis shows the rotation length of the coppice rotations. For the seedling stand the rotation is always four years longer.
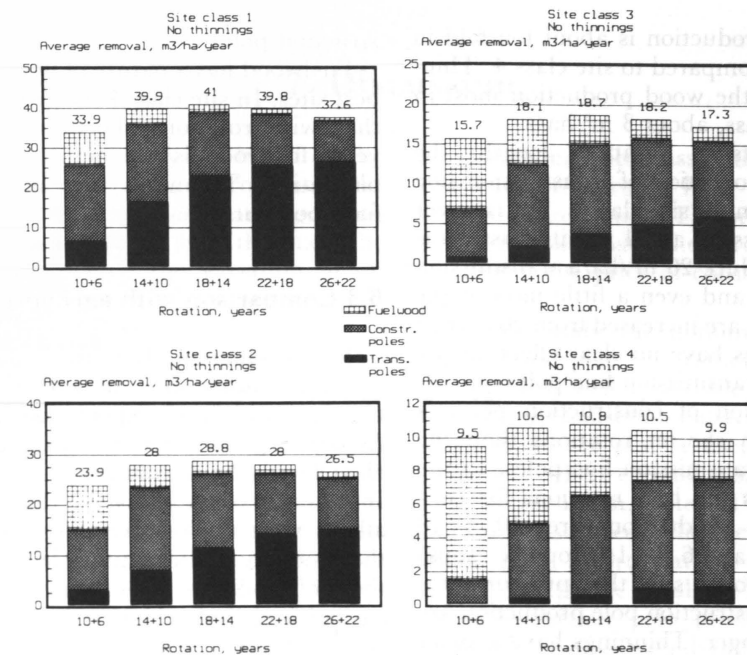

Fig. 6. The mean annual production of different wood assortments in relation to rotation length if thinnings are not applied. The first number below the bar indicates the rotation length of seedling stand and the second number that of coppice stand.
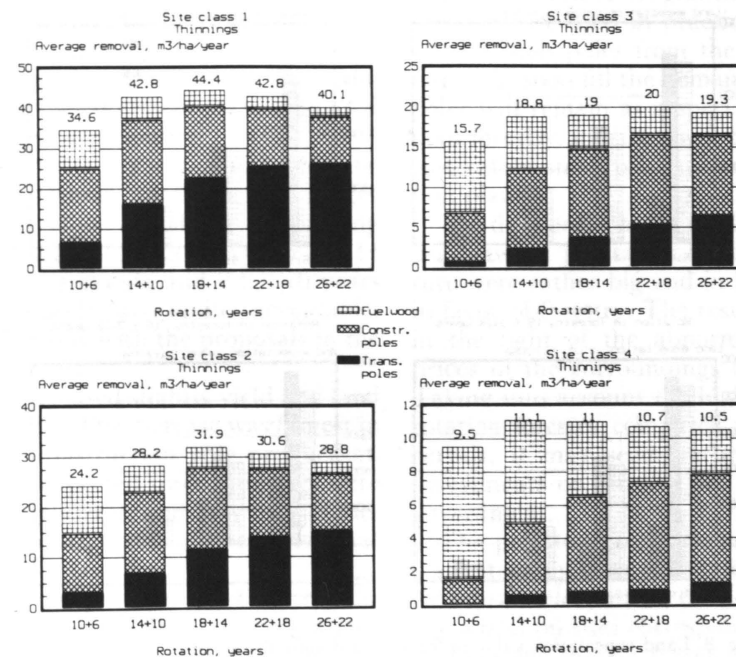

Fig. 7. The mean annual production of different wood assortments in relation to rotation length if thinnings are applied. The first number below the bar indicates the rotation length of seedling stand and the second number that of coppice stand.

The wood production is about fourfold in site class 1 as compared to site class 4. Thinnings increase the wood production most in the best site class, about 3 m³/ha/a.

With increasing rotation length the amount and proportion of transmission line poles increase in all site classes, but is never very high in classes 3 and 4. In site class 1 it is possible to produce 26 m³/ha/a transmission line pole wood and even a little more if the rotation lengths are increased from 26 and 22 years. Thinnings have no clear effect on the production of transmission line poles.

The production of construction poles is maximized with shorter rotations than the production of transmission line poles. In the best site classes the best rotations for construction pole production are 10 ... 18 (seedling crop) and 6 ... 14 (coppice crops) years. In the poorest sites the optimum rotations for the construction pole production are considerably longer. Thinnings have a small increasing effect on the production of con-

struction poles.

Fuelwood has a nature of byproduct on the best sites. In site class 4 the growth is so slow that with rotations shorter than 10 ... 15 years fuelwood is the main product of the plantation. Thinnings increase slightly the fuelwood cut.

6.3 Comparison with agriculture

The production alternatives of agriculture (with a suitable crop or with grazing) give clearly lower land expectation values than *Eucalyptus globulus* plantations, except in site class 4 with the discounting rate 8 % (Fig. 8). In this worst site class the discounting rate affects most the relative differences between the production alternatives. In all site classes the profitability of forestry, as compared with agriculture, is the higher the lower the discounting rate.
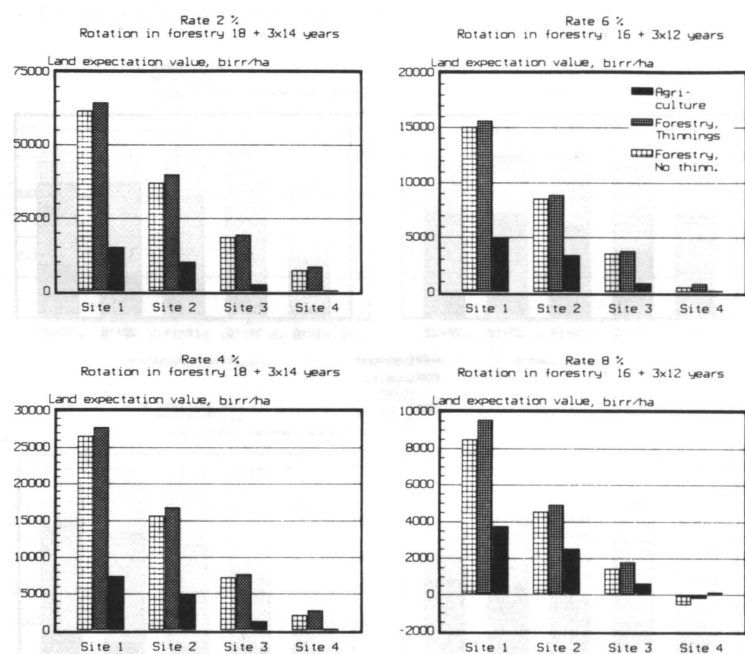

Fig. 8. Land expectation value in forestry and agriculture with different discounting rates.

7. Discussion

The results of this study are based on the sample plot measurements of Pohjonen and Pukkala (1987) for *E. globulus* stands growing in the central highlands of Ethiopia. The measurements covered the variation in altitude, age and density of the existing forests. The sample plot material contains only a few plots older than 15 years, because practical forestry does not apply long rotations.

Another limitation of the yield estimation is that the stand models are based on temporary plots and the site classification system is derived from the same plots as the rest of the models. Thus, if the distribution of sample plots into different sites is not the same in different age classes, the estimates on the growth of dominant height and on the stand development may be biased.

One of the main results of the earlier studies is that the rotation that maximizes the mean annual increment of *E. globulus* in Ethiopia is clearly higher than expected in the planning phase of the plantation projects (Establishment ... 1982, Establishment ... 1985). The mean annual increment reaches its maximum at the age of 14 ... 18 years, whereas the fuelwood project plans are based on about 10-year rotations.

According to the present study, also the economically optimal rotations are longer than 10 years. However, if the discounting rate is more than 5 %, rotations of 12 ... 14 years for seedling stands and 8 ... 10 years for coppice stands are quite acceptable, which is well in line with the proposals in the project documents.

Thinnings increased slightly yield and land expectation value. The increase was largest in fuelwood and construction pole production. This was to be expected since thinnings were simulated at early ages, and they had a function of capturing those small-sized trees that otherwise would have died.

During the times of private forestry, the most desired product of *Eucalyptus* plantations was construction poles which were also exported to the Arab countries. The applied rotation was usually less than 10 years. The practice is partly justified by the present study. On sites reasonably fertile for *Eucalyp-*

tus growth, e.g. site class 2, the production of construction poles is high already with a 6 ... 10-year rotation. The production of construction poles with these rotations is well-justified if the price of construction poles is high.

In this study the minimum diameter of construction pole was rather large, 8 cm at the top. It is well applicable in the construction of town houses and apartment buildings, where poles are mainly used for supporting structures when erecting concrete walls. In light construction, poles of smaller dimensions are also used. The inclusion of such a small pole assortment in the calculation would change the results a little in favor of the construction pole production, but the economic results would remain almost unchanged, since the unit prices of fuelwood and construction poles are almost equal.

In view of timber assortment demand and location of markets the role of transmission line poles is rather insignificant. If the longest rotations are used in practice, the output of transmission poles from the present plantations will soon fill the demand. Transmission poles will remain as a special case in Ethiopian forestry and they will be grown in special, rather small plantations near impregnation plants.

The differences in the land expectation values between plantation forestry and agriculture were rather big and in best sites always in favor of forestry. The results are expected in the light of the abnormally high wood prices in the surroundings of Addis Ababa. Taking into account the high return of short rotation forestry compared to cultivation of cereals, it may seem surprising why more investments on forestry are not done by the government.

The private forestry around Addis Ababa was established on undulating hills and agricultural fields, and it often replaced cereals like wheat on sites corresponding to site class 2. Thus the market forces directed the land use towards forestry. Because the prices of forest products have risen much more than the prices of agricultural crops after those times, it would now be very profitable to start

plantation forestry e.g. near Addis Ababa.

The economically favorable position of eucalypt plantations does not apply to all sites. The best agricultural sites do not necessarily belong to site class one. In flat areas the soil has a waterlogging problem and the eucalypts will not grow on such a soil. Even if these areas are productive in teff and wheat production, they are unproductive in wood production. The best sites for forestry are slightly undulating slopes with a reasonably deep soil layer and favorable rainfall. Because such sites are not predominant in agriculture, the present results do not mean that, for economic reasons, most agricultural fields near Addis Ababa should be converted into forests.

Anyway, the good economic prospects of fuelwood plantation forestry in the central highlands of Ethiopia have now been realized by the government and international organi-

zations. Fuelwood projects have been initiated, not only with grant money like in UNSO fuelwood projects, but also with soft loans from the African Development Fund (Addis Ababa ... 1981) and World Bank.

Besides fuelwood and other timber the *Eucalyptus* plantations have also other benefits: the forest products support foreign exchange balance and the plantations protect soil against erosion. An indirect benefit of a plantation project is in creating employment.

In the altitudes of about 3 000 m above sea level, where a considerable proportion of the fuelwood plantations grow, most sites belong to class 4 or are even poorer than that. In these areas the plantations cannot be justified by economic reasons if the interest rate is more than 6%. But if the other beneficial effects of reforestation are taken into consideration, also these high altitude plantations are justified.

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Appendix 1. Models used for estimating the diameter distribution at given age and the heights of trees sampled from the distribution.

The dominant height (H_{dom}, m) is calculated by the guide curve equations of the site classification system.

Seedling stand
$$H_{dom} = 48/(1+92.65\,T^{-1.990}) \quad (A.1)$$

Coppice stand
$$H_{dom} = 48/[1-\exp(-0.07956\,T)] \quad (A.2)$$

where T is the age of the stand (a). The guide curve value is multiplied by 1.2, 1.0, 0.8 and 0.6 in site classes 1, 2, 3 and 4, respectively.

If the number of stems per hectare (N) is greater than the estimate of the following model, the model estimate is taken as stand density.

Seedling stand
$$N = 1437 - 10.30\,H_{dom} \quad (A.3)$$

Coppice stand
$$N = 347300\,H_{dom}^{-1.484} \quad (A.4)$$

The minimum (D_{min}, cm), mean (D_n, cm), maximum (D_{max}, cm) and variance (VAR) of the diameter distribution are calculated by the following models (H_n is mean height, m).

$$\ln(H_n) = 0.2056 + 1.096\ln(H_{dom}) - 0.1064\ln(N) \quad (A.5)$$
$$F(2, 200) = 2773, R^2 = 98\,\%, S_e = 0.17$$

$$\ln(Dn) = 2.305 + 0.6943\ln(H_n-1.3) - 0.2326\ln(N) \quad (A.6)$$
$$F(2, 61) = 613, R^2 = 95\,\%, S_e = 0.16$$

$$\ln(D_{max}) = 1.916 + 0.8056\ln(H_{dom}) - 0.1744\ln(N) \quad (A.7)$$
$$F(2, 61) = 264, R^2 = 89\,\%, s_e = 0.19$$

$$\ln(D_{min}) = -0.2525 + 2.283\ln(D_n) - 1.293\ln(D_{max}) \quad (A.8)$$
$$F(2, 61) = 140, R^2 = 82\,\%, S_e = 0.46$$

$$VAR = 1.785 + 0.04854(D_{max}-D_{min})^2 \quad (A.9)$$
$$F(2, 62) = 1659, R^2 = 96\,\%, S_e = 7.4$$

Parameters α and γ of the beta distribution are calculated from D_n and VAR (Loetsch et al. 1973)

The height curve, $h=1.3+d^2/(a+bd)^2$, corresponding to the actual dominant height is estimated by

$$b = 0.7912\,H_{dom}^{-0.4972} \quad (A.10)$$
$$F(2, 62) = 350, R^2 = 85\,\%, S_e = 0.028$$

$$a = 0.3312\,b^{-0.6106} \quad (A.11)$$
$$F(2, 62) = 40, R^2 = 39\,\%, S_e = 0.236$$

The height estimates of trees sampled from the diameter distribution are multiplied by the ratio

$$H_n / [1.3+D_n^2/(a+bD_n)^2]$$