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Yield of *Cupressus lusitanica* in Ethiopia

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TIIVISTELMÄ: CUPRESSUS LUSITANICAN TUOTOS ETIOPIASSA

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Yield of *Cupressus lusitanica* Mill. was modelled by predicting the diameter distribution of trees at given stand ages. The beta distribution was used as a theoretical distribution. The models used for the calculation of diameter distribution were based on 66 temporary sample plots with varying age, site and stand density. The growing sites of *Cupressus lusitanica* were divided into four classes on the basis of age and dominant height. Using the stand models developed in the study, the yield and profitability of different thinning schedules was evaluated by a simulation technique. In the simulated treatment regimes the mean annual increment varied from 6.6 m^3/ha in the poorest site class to 16.6 m^3/ha in the best class with rotation lengths ranging from 25 years (best sites) to 34 years (poorest sites). With typical planting densities (1600 trees/ha), thinnings increase the total harvest by a few percentage points and improve the profitability of plantation forestry.

Lusitaanian sypressin (*Cupressus lusitanica* Mill.) tuotos mallitettiin ennustamalla puuston läpimittajakauma halutuilla iänkohdilla. Teoreettisena läpimittajakaumana käytettiin betajakaumaa. Läpimittajakauman ennustamisessa käytetyt mallit perustuivat 66:een iältään, kasvupaikaltaan ja tiheydeltään vaihtelevaan koealaan. *Cupressus lusitanica*n kasvupaikat jaettiin neljään luokkaan iän ja valtapituuden perusteella. Laadituilla malleilla tutkittiin harvennuksen ja vaikutusta tuotokseen ja metsänkasvatuksen taloudellisuuteen. Tutkittujen harvennusohjelmien keskimääräinen vuotuinen kasvu vaihteli heikoimman kasvupaikkaluokan 6,6 m^3:stä/ha parhaan kasvupaikkaluokan 16,6 m^3:iin/ha 25–34 vuoden kiertoajalla. Tyypillisillä istutustiheyksillä (1600 puuta/ha) harvennukset lisäävät hiukan kokonaishakkuupoistumaa ja parantavat metsänviljelyn kannattavuutta.

Keywords: yields, models, yield tables, plantations, diameters, distribution, *Cupressus lusitanica*.
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1 Introduction

Cupressus lusitanica Mill. is the most widely planted conifer in Ethiopia. It was introduced in the country some 40–50 years ago. The oldest scattered trees, hedges and woodlots, planted on private farms and road sides, are found along the Ambo road, upto 50 km west of Addis Ababa. The first industrial plantations were established in the 1950s around the first sawmills, 200 km south of Addis Ababa, in the Munessa forest, along the eastern escarpments of the Rift Valley. Later, during the 1960s and beyond, a notable concentration of *Cupressus lusitanica* plantations were established in Munessa: 3100 ha in total by 1987 (Järvholm and Tivell 1987a).

In the 1970s and 1980s *Cupressus lusitanica* was – besides *Eucalyptus globulus* Labill. – a widely planted species in the soil conservation and community forestry programme in the Ethiopian highlands which was assisted by the FAO/WFP (World Food Programme 1986). *Cupressus lusitanica* was planted at an annual rate of over 1000 ha (Järvholm and Tivell 1987b). After the Sahelian drought of 1983–1985 the annual planting was reduced and *Cupressus lusitanica* was partly replaced by the more drought resistant indigenous conifer, *Juniperus procera* Hocht. ex Endl. By the end of the 1980s the established plantations of *Cupressus lusitanica* in Ethiopia totalled 10 000–15 000 ha.

A considerable part of the older plantations, especially in the Munessa forest, is already at thinning age, and some are approaching clear cutting. In the beginning of the 1990s the allowable cut from all the *Cupressus lusitanica* plantations in the country is estimated at 50 000 m^3/a (Järvholm and Tivell 1987b).

Proper management of Ethiopian *Cupressus lusitanica* plantations has been neglected partly due to lack of suitable growth models and yield tables. Without yield models there are no means to evaluate which rotation length or thinning schedule would give the most favourable yield of different timber assortments.

This study was in the first step aimed at modelling the growth of Ethiopian *Cupressus lusitanica* plantations. The target was to construct a set of ordinary yield tables for different Ethiopian growing sites of *Cupressus lusitanica*, and provide forest managers with a more flexible tool to examine different management options. This tool consisted of a number of models that facilitate the simulation of stand development along different treatment schedules. In the second step the models were used for simulating thinning schedules for different site productivity classes.

2 Material and methods

2.1 Material

Altogether 66 temporary sample plots of varying age, site and number of trees per hectare were measured inside planted stands of *Cupressus lusitanica* (Fig. 1, Table 1). The plots were situated in different parts of the central highland plateau of Ethiopia. The plot size varied between 200 and 2000 m^2, depending on the density and stage of development of the stand.

In each plot the number of trees in one- or two-centimetre diameter classes was counted. At least 10 sample trees per plot were measured by diameter (in mm) and height (in dm). They were selected as to uniformly cover the range of variation in diameter. Three smallest and three biggest trees were always selected as sample trees. The sample trees were used for determining the dependence of tree height on the breast height diameter for each particular stand. Näslund's (1936) formula was used as the height model:

$$h = 1.3 + d^2/(a + b \cdot d)^2 \qquad (1)$$

where h is tree height (m) and d is diameter at breast height (cm). Equation (1) was converted to a linear form when estimating parameters a and b.

Based on the diameter distribution and diameter–height relationship the dominant height was calculated as the mean height of 100 thickest trees/ha. The stand volume was calculated using Örlander's (1986) stem volume equation for *Cupressus lusitanica*:

$$\ln(v) = -3.2161 + 1.8096 \cdot \ln(d) + 1.1492 \cdot \ln(h) \qquad (2)$$

where v is stem volume (dm^3) d is breast height diameter (cm) and h is height (m).

The other characteristics computed for each sample plot included the minimum, mean, maximum and variance of diameter, and the number of trees per hectare.

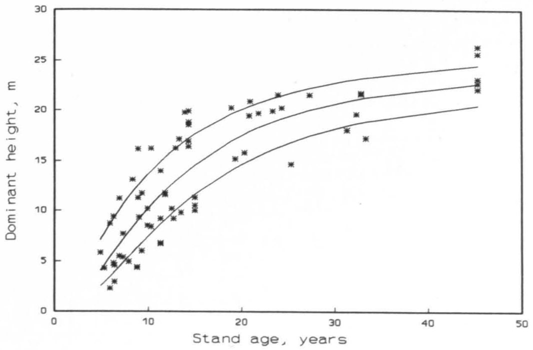

Fig. 1. Boundaries of site classes (lines) and the age-dominant height distribution of the study plots.

2.2 The site classification method

The site classification method was based on the stand age–dominant height relationship in the sample plot data (Pukkala and Pohjonen 1989, 1990). First, the plots were divided into two sets by fitting a dominant height development curve into the data. Sites better than average were above the curve and sites poorer than average below the curve. Both sets of plots were further divided into two parts in the same way (Fig. 1). As a result, the plots were grouped into four sets which were denoted as site class 1, 2, 3 and 4, respectively (Figs. 1 and 2).

The height development in each class was estimated separately from the plots belonging to the class. The following sigmoid curve was used to split the plot material and to express the development of dominant height along age:

$$H_{dom} = C/(1 + A \cdot T^B) \qquad (3)$$

where H_{dom} is dominant height (m) and T is stand age (a), calculated from seed sowing.

Table 1. Mean, standard deviation and range of stand characteristics among the 66 study plots.

Variable	Mean	Standard deviation	Minimum	Maximum	Unit
T	16.6	11.0	4.9	45.3	a
H(dom)	3.5	6.4	2.3	26.4	m
N	1351	1306	226	10544	trees/ha
H(n)	11.8	6.1	1.9	24.2	m
D(min)	7.3	6.1	0.5	30.0	cm
D(n)	14.5	7.7	1.1	36.8	cm
D(max)	23.9	11.4	2.5	48.0	cm
VAR	16.7	15.5	0.1	100.6	cm^2
V	140.2	129.6	0.2	552.6	m^3/ha

2.3 Yield model computation

The construction of yield models was based on the temporal change in the stem diameter distribution (Pikkarainen 1986, Pukkala and Pohjonen 1989, 1990, Pukkala et al. 1990). If the dependence of stem height on breast height diameter and the stem volume function are known, in addition to diameter distribution, all the stand characteristics of an ordinary yield table can be computed.

The diameter distribution was described with the beta distribution:

$$f(d) = c(d - D_{min})^{\alpha} \cdot (D_{max} - d)^{\gamma} \qquad (4)$$

where f(d) is frequency of diameter d (trees/ha), D_{min} is minimum diameter (cm), D_{max} is maximum diameter (cm), α and γ are parameters, and c is a scaling factor to obtain a specified total number of trees. Parameters α and γ can be calculated from the mean (denoted as D_n) and variance (VAR) of the distribution (Loetsch et al. 1970). Thus, the distribution is completely defined by the minimum, mean, maximum and variance of diameter and the total number of stems.

If the site class of the stand is specified, the dominant height at a particular age is known from the site classification system. In managed plantations it can be assumed that the number of stems is also known: it is the number of seedlings survived in the planting or left in a thinning treatment.

Thence, to be able to predict the diameter distribution at a given age, there should be models that express the minimum, mean, maximum and variance of diameter as a function of age, dominant height and number of stems per hectare.

The method to derive the stand characteristics has the following steps (Pukkala and Pohjonen 1988, p. 83):

(1) Divide the range in diameter variation into classes (in this study, 20 classes) and take the class-midpoint tree to represent each class.
(2) Calculate the number of trees in each diameter class.
(3) For each class-midpoint tree, calculate the tree height and stem volume.
(4) Calculate the stand characteristics from the tree characteristics.

3 Results

3.1 Yield models

3.1.1 Site classes

Parameters A, B and C of the sigmoid curves (Eqn 3) expressing the development of dominant height along age, were in different cases as follows:

	Parameter A	Parameter B	Parameter C	Number of plots
Site boundary				
1–2	30.0	–1.489	27	33
2–3	82.0	–1.752	25	66
3–4	154.3	–1.869	23	33
Site class				
1	30.7	–1.547	28	17
2	36.0	–1.494	26	17
3	109.9	–1.802	24	16
4	268.8	–2.014	22	16

Relative differences between site classes in dominant height are biggest in young stands (Fig. 2). After 20–25 years the absolute height differences remain constant, but the relative differences are decreasing.

3.1.2 Stand models

The following formula expresses how the number of trees per hectare (N) depended on stand age and dominant height:

$$\ln(N) = 8.4097 - 0.44938 \cdot \ln(T) - 0.09373 \cdot \ln(H_{dom}) \tag{5}$$

Equation (5) expresses how the average number of stems per hectare changed in the study material as a function of age and dominant height. It can not be used as a mortality model.

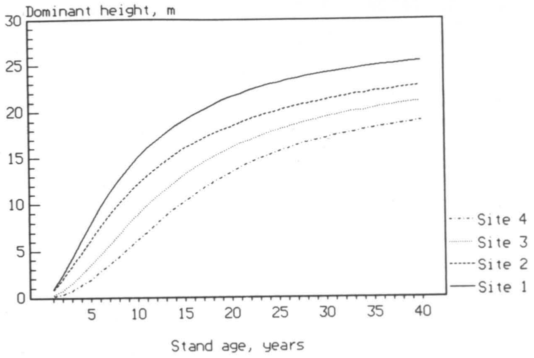

Fig. 2. Development of dominant height in different site classes.

The models for deriving the diameter distribution corresponding to a given age, dominant height and number of stems per hectare are as follows (a correction factor $sf^2/2$ has been added to each equation, due to the logarithm transformation):

$$\ln(D_{min}) = 1.4567 - 0.2908 \cdot \ln(T) + 1.9773 \cdot \ln(H_{dom}) - 0.5655 \cdot \ln(N) \tag{6}$$
$R^2 = 90.3\ \%$ $s_f = 0.400$ $s_e\% = 28.8$

$$\ln(D_n) = 0.5577 + 2.5587 \cdot \ln(H_{dom}) - 0.8767 \cdot \sqrt{(H_{dom})} - 0.1801 \cdot \ln(N) \tag{7}$$
$R^2 = 94.8\ \%$ $s_f = 0.176$ $s_e\% = 12.5$

$$\ln(D_{max}) = 1.0665 + 0.2094 \cdot \ln(T) + 2.4858 \cdot \ln(H_{dom}) - 1.0558 \cdot \sqrt{(H_{dom})} - 0.1274 \cdot \ln(N) \tag{8}$$
$R^2 = 95.4\ \%$ $s_f = 0.141$ $s_e\% = 10.0$

$$\ln(VAR) = -3.7163 + 1.7717 \cdot \ln(D_{max} - D_{min}) - 0.8337 \cdot \ln(H_{dom}) \tag{9}$$
$R^2 = 95.5\ \%$ $s_f = 0.260$ $s_e\% = 18.5$

The following models were made for computing the height curve (Eqn 1):

$$\ln(b) = -0.9288 + 0.0834 \cdot \ln(T) - 0.5404 \cdot \ln(H_{dom}) + 0.0961 \cdot \ln(N) \tag{10}$$
$R^2 = 90.9\ \%$ $sf = 0.098$ $se\% = 6.9$

$$\ln(a) = -0.6109 - 1.6236 \cdot \ln(H_{dom}) - 3.3637 \cdot \ln(b) \tag{11}$$
$R^2 = 77.8\ \%$ $s_f = 0.201$ $s_e\% = 14.3$

The model for H_n (height of a tree having diameter D_n) is:

$$\ln(H_n) = -0.3685 + 1.0858 \cdot \ln(H_{dom}) \tag{12}$$
$R^2 = 98.8\ \%$ $s_f = 0.068$ $s_e\% = 4.8$

H_n was used to adjust the height curve through the point defined by D_n and H_n (see Pukkala and Pohjonen 1989).

3.1.3 Yield tables

When producing yield tables, the number of stems was assumed to develop according to Equation (5). Therefore, the tables describe the *actual average stand conditions* in different site and age classes. The stand models facilitate, to some extent, the simulation of yield along other assumptions about the change in the number of stems.

Because the target of many *Cupressus lusitanica* plantations is to produce timber for sawmills, the volumes of saw logs and small-sized pole wood (or pulp wood) were included in the yield tables. In the absence of available taper curves for *Cupressus lusitanica*, the proportions of saw logs and pole wood were approximated using the taper curve model of another conifer, *Picea abies* (L.) Karst. (Laasasenaho 1982), using diameter at breast height and tree height as predictors. These proportions were multiplied by the stem volume function (Eqn 2) to obtain the volumes of timber assortments. The minimum top diameters were taken as applied by the State Forest Department in Ethiopia: 17 cm (with bark) for saw logs and 8 cm for pole wood. The allowed length of a saw log was 4–6 m and the minimum length of a piece of pole wood 2 m.

The simulated yield tables (Appendix 1) show that the growth culminates earlier in the best site classes (Fig. 3). The current annual increment of the remaining trees is at maximum at the age of 8 years in site class 1, and in site classes 2, 3 and 4 at the ages of 10, 14 and 17 years, respectively. The yield tables do not tell what is the mean annual increment and at which age it reaches the maximum value, because thinning removals and mortality were not included in the tables. It can be calculated, through simulations, that the mean annual increment usually reaches its maximum at the following ages: 10–15 a in class 1, 15–20 a in class 2, 20–25 a in class 3, and 25–30 a in class 4. If the aim is to produce saw log timber, the rotations should be somewhat longer than these figures suggest (Pikkarainen 1986). The stand begins to produce saw log timber at the age of 7 years in the best site class and at the following ages in the other classes: 10 a in class 2, 12 a in class 3 and 16 a in class 4.

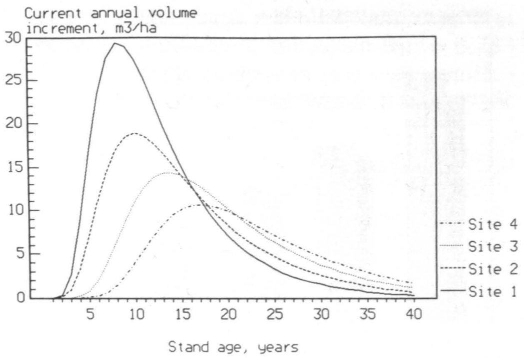

Fig. 3. Current annual increment in different site classes (growth of the remaining trees in the next year).

3.2 Yield and profitability of thinning regimes

The effect of thinning treatment on the growth and economy of *Cupressus lusitanica* plantations was studied by simulating three alternative treatment schedules for each site class; one schedule without thinnings, another with one thinning and a third schedule with two thinnings. It is known that thinnings usually increase the total harvest since at least some trees of the removal would otherwise die.

The first thinnings of the Ethiopian *Cupressus lusitanica* plantations are often felt as a burden, since the price of pole-sized timber or pulp wood is low compared to that of saw logs (Järvholm and Tivell 1987). For this reason, the number of thinnings should be low. Thinning intensity should not, however, be more than 40 % of the

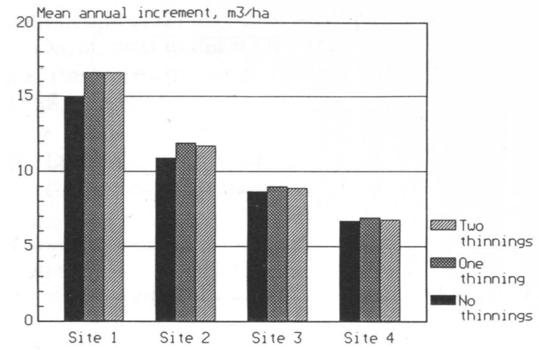

Fig. 4. Mean annual increment in the simulated thinning schedules.

Table 2. Rotation lengths and thinning years of the simulated treatment schedules.

Site class	Rotation, years	Thinning years: One thinning	Two thinnings: First	Two thinnings: Second
1	25	10	8	16
2	28	12	10	19
3	32	15	13	22
4	34	18	16	25

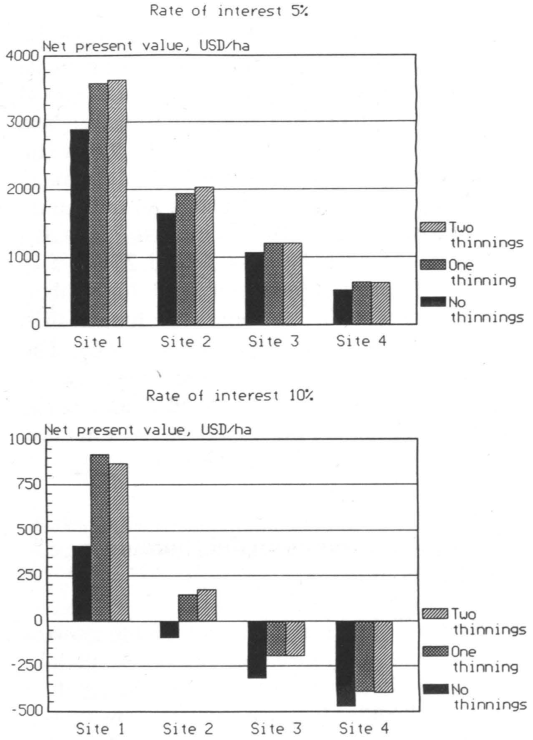

Fig. 5. Net present value of the simulated thinning schedules with 5 % (above) and 10 % (below) discounting rate.

Table 3. Harvested volume and net income of the simulated thinning schedules.

Variable	Unit	Number of thinnings: None	One	Two
Site class 1				
Total harvest	m^3/ha	374	415	415
Saw log harvest	m^3/ha	267	278	284
Pole harvest	m^3/ha	101	126	122
Net income	USD/ha	11566	12224	12459
Site class 2				
Total harvest	m^3/ha	306	333	327
Saw log harvest	m^3/ha	196	195	203
Pole harvest	m^3/ha	103	126	114
Net income	USD/ha	8502	8609	8848
Site class 3				
Total harvest	m^3/ha	275	287	281
Saw log harvest	m^3/ha	180	171	169
Pole harvest	m^3/ha	89	106	103
Net income	USD/ha	7685	7423	7304
Site class 4				
Total harvest	m^3/ha	224	232	225
Saw log harvest	m^3/ha	136	131	129
Pole harvest	m^3/ha	81	87	91
Net income	USD/ha	5746	5583	5464

stand basal area. Otherwise the yield begins to decline (Pikkarainen 1986).

In simulations, the thinning intensity was 40 % of the stand basal area, if there was only one thinning, and with two thinnings 25 % in both treatments. Thinnings were simulated in such a way that in each diameter class (except the smallest), the removal percentage was 95 % of that in the previous (smaller) class.

According to the experience gained in Tanzania, the first thinning should be done after about ten years of growing, earlier on good sites than on poorer sites (Pikkarainen 1986). This general rule was also followed in the simulations. With two thinnings the first thinning was done when the basal area median diameter exceeded 15 cm (at the age of 8–16 years), and with one thinning two years later. The second thinning was simulated in the middle between the first thinning and the final clear felling age (Table 2).

The rotation lengths of the simulated treatment schedules were selected on biological basis: the stand was clear felled just before the current annual increment fell below 3 m^3/ha (according to Appendix 1).

With thinnings the planting density was taken as 1600 trees/ha and the survival rate in planting as 90 %. After the planting year there was no more natural mortality. In the schedule without thinnings it was assumed that 900 out of the original 1600 trees per hectare will survive to the end of the rotation.

When calculating the profitability of different alternatives the stand establishment cost was taken as 725 USD/ha (1 Ethiopian Birr = 0.483 USD). The stumpage price of saw logs was 43.5 USD/m^3 and that of pole wood 6.8 USD/m^3 (Järvholm and Tivell 1987).

The yield of the whole rotation ranged from 225 m^3/ha in the poorest site class to 415 m^3/ha in the best class (Table 3). Mean annual increment varied between 6.6 and 16.6 m^3/ha (Fig. 4). Thinnings increased the total utilizable harvest by 0–11 %, most in the best site classes (Table 3). The increase was mostly pole wood.

Because of the low stumpage price of small-sized timber, thinnings did not increase very much the total income. When the profitability of different treatment schedules was expressed in terms of net present value (discounted revenue minus plantation establishment cost), the effect of thinnings was clearer (Fig. 5). For example, with 10 percent discounting rate thinnings changed the net present value of site class 3 from the negative –84.5 USD/ha to 145–169 USD/ha.

4 Discussion

The presented tool to predict stand development has the advantage of being quick and reasonably easy to prepare. Based on temporary sample plots and stand models it provides tree-level information that enable a detailed description of the stand structure. The method has, however, some clear shortcomings.

The site classification presupposed that the site productivity distribution of the study material was more or less the same in every age class. If for example most of the young plots represented poor sites and the old ones good sites, the site classification system is certainly erroneous and the growth predictions biased. Test of the validity of the site classification and the development of dominant height is, however, difficult on the basis of temporary sample plots. The best check would be to remeasure selected sample plots after a few years of growing, and to check whether the dominant height did develop as indicated by the site class curves.

The possible error due to the description of the true diameter distribution by the beta distribution was examined by fitting the beta function to each of the 66 measured distributions, and comparing the stand volumes computed from the empirical distributions to those obtained from the beta distribution. The beta function was calculated from the measured minimum, mean, maximum and variance of diameter. The height curve was in both cases derived from the sample tree measurements. The theoretical diameter distributions described very well the empirical ones. The correlation between the stand volumes computed from the theoretical distribution and empirical distribution was 0.99999. The regression, which expresses the predicted volume as a function of the measured volume, shows that there are no systematic errors in the predictions:

$$V(\text{predicted}) = 0.0565 + 0.99974 \cdot V(\text{measured}) \quad (13)$$

The standard errors of Equations (6)–(12) are not estimates of the precision of the whole yield model because two models include predictors that are predicted with previous models, and therefore contain estimation errors. The combined precision of the stand models was tested in the same way as the possible error due to the use of beta distribution, but D_{min}, D_n, D_{max}, VAR and the height curve were predicted from the measured stand age, dominant height and

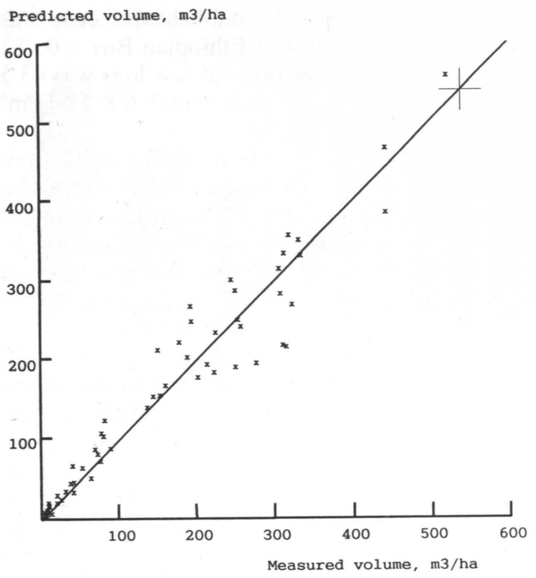

Fig. 6. Stand volume (m³/ha) of the 66 study plots calculated from the measured and predicted diameter distribution. The diameter distribution and the height curve are predicted from age, dominant height and number of stems per hectare.

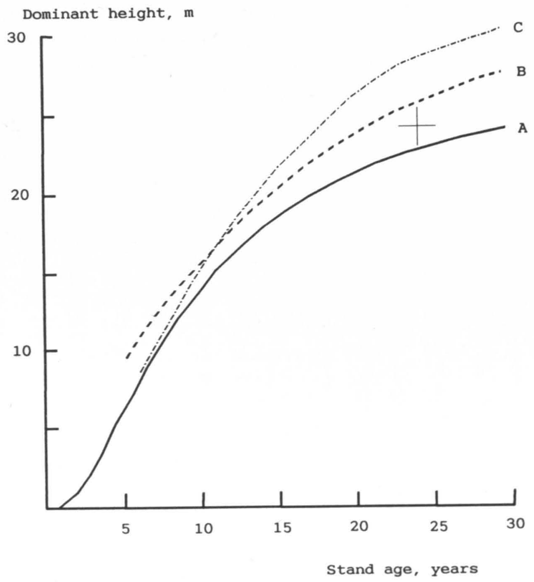

Fig. 7. Development of dominant height of *Cupressus lusitanica* stand according to different studies. A: present study, site class 1; B: Pikkarainen (1986), site class 1; C: Klitgaard and Mikkelsen (1976), site class 3.

number of stems per hectare. H_n, which was used to adjust the height curve, was predicted with Equation (12).

Now the correlation between the measured and predicted stand volumes is poorer: 0.9694 but still acceptable. The biggest absolute errors are in stands where the real volume is 200–400 m³/ha (Fig. 6). The regression between the measured and predicted volume was

$$V(\text{predicted}) = 3.2775 + 1.0044 \cdot V(\text{measured}) \quad (14)$$

which indicates that the stand models slightly overestimate the stand volume.

The presented stand models provide a far more flexible tool to study alternative ways to manage the stand, than a set of yield tables. However, the models have some limitations, which are partly related to the properties of the study material. Almost all of the sample plots represented more or less normal planting densities and thinning practices; there were only a few exceptionally dense or sparse stands in the study material. This means that the presented stand models give unreliable prediction for the diameter distribution if the number of stems per hectare deviates considerably from the values given by Equation (5).

The time since thinning was not taken directly into account when constructing the stand models, although it is likely that the relationship between the number of stems and diameter distribution is affected by thinnings. Therefore, the models should not be used to analyze the immediate effect of thinning on the diameter distribution.

When simulating the yield of different thinning methods, it was assumed that there is no mortality after the stand establishment stage. This is a realistic assumption because suppressed and unhealthy individuals are usually removed in thinnings. A reliable simulation of the yield of unthinned stand would require a mortality model or a survivor function showing the highest possible stand density with given site and stand age.

Another drawback in the simulation was that the share of different timber assortments was computed with a model for another tree species. Accordingly, the predictions for saw log and pole volumes are unreliable. Note, however, that only proportions, and not volumes, of saw log and pole wood were computed with the taper curve of another species. In addition, there are no commonly accepted definitions, not even a common practice, for the quality and other requirements of timber assortments in Ethiopia. This means that the predicted quantities of saw logs and pole wood would be unreliable even with a proper taper curve model.

According to the presented models the growth of *Cupressus lusitanica* is considerably lower in Ethiopia than in Tanzania (Fig. 7). The dominant height of site class 1 remains clearly below the best site class of Pikkarainen (1986). In the system of Klitgaard and Mikkelsen (1976), even site class 3 is above site class 1 of the present study. The general shape of our dominant height curve is between those of Pikkarainen (1986) and Klitgaard and Mikkelsen (1976) (Fig. 7). The poor growth of the Ethiopian plantations could be explained by higher altitude and lower precipitation. In Tanzania, the rainfall is distributed more evenly over the year than in Ethiopia, which also creates growth differences between the two countries.

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Total of 14 references

Appendix 1. Yield tables for *Cupressus lusitanica*. H_{dom} = dominant height (m), DgM = basal area median diameter (cm), HgM = basal area median height (m), N = number os stems per hectare, G = stand basal area (m^2/ha), V = stand volume (m^3/ha), Log = saw log volume (m^3/ha), Pulp = pulp wood volume (m^3/ha), CAI = current annual increment (m^3/ha), Min = minimum diameter (cm), Max = maximum diameter (cm).

Site class 1

Age	H_{dom}	DgM	HgM	N	G	V	Log	Pulp	CAI	Min	Max
1	.9	.0	.0	3000	.0	0	0	0	.0	0	0
2	2.4	1.4	2.0	3000	.3	0	0	0	.3	0	2
3	4.2	3.6	3.7	2394	1.7	3	0	0	2.7	1	5
4	6.1	6.4	5.5	2033	4.8	12	0	0	8.8	1	9
5	7.9	9.3	7.2	1795	9.1	28	0	14	16.6	2	13
6	9.6	12.0	8.8	1624	13.8	52	0	38	23.4	3	16
7	11.2	14.2	10.2	1494	18.3	80	0	66	27.7	4	19
8	12.6	16.1	11.5	1391	22.3	109	14	83	29.4	5	22
9	13.8	17.7	12.7	1308	25.6	138	34	93	29.0	7	23
10	15.0	18.9	13.8	1238	28.3	165	64	92	27.4	8	25
11	16.0	20.0	14.7	1179	30.5	191	81	101	25.1	9	26
12	16.9	20.8	15.6	1128	32.2	213	97	108	22.5	10	28
13	17.7	21.5	16.3	1083	33.5	233	116	109	19.8	11	29
14	18.5	22.1	17.0	1044	34.5	250	137	107	17.4	12	30
15	19.1	22.6	17.6	1009	35.2	265	155	103	15.1	13	30
16	19.7	23.0	18.2	977	35.7	278	165	106	13.0	13	31
17	20.2	23.4	18.7	948	36.1	290	182	100	11.3	14	32
18	20.7	23.7	19.1	922	36.4	299	195	98	9.7	15	32
19	21.2	24.0	19.5	898	36.6	308	200	101	8.3	15	33
20	21.6	24.2	19.9	876	36.7	315	209	100	7.1	16	33
21	21.9	24.4	20.2	856	36.7	321	223	92	6.1	16	34
22	22.3	24.6	20.5	837	36.7	326	231	89	5.2	17	34
23	22.6	24.8	20.8	819	36.7	331	239	85	4.5	17	34
24	22.9	24.9	21.1	803	36.6	334	244	85	3.9	18	35
25	23.1	25.1	21.3	787	36.5	338	252	80	3.3	18	35
26	23.4	25.2	21.5	773	36.4	341	254	81	2.8	18	36
27	23.6	25.4	21.7	759	36.3	343	261	77	2.4	19	36
28	23.8	25.5	21.9	746	36.2	345	263	78	2.1	19	36
29	24.0	25.6	22.1	734	36.1	347	269	73	1.8	19	37
30	24.2	25.7	22.2	723	35.9	348	276	68	1.6	20	37
31	24.3	25.8	22.4	712	35.8	350	276	69	1.3	20	37
32	24.5	25.9	22.5	701	35.7	351	285	62	1.2	20	37
33	24.6	26.0	22.7	691	35.5	352	285	62	1.0	20	38
34	24.8	26.1	22.8	681	35.4	353	285	64	.9	21	38
35	24.9	26.2	22.9	672	35.3	354	285	64	.7	21	38
36	25.0	26.3	23.0	664	35.2	354	287	63	.6	21	39
37	25.1	26.3	23.1	655	35.1	355	289	62	.5	21	39
38	25.2	26.4	23.2	647	34.9	355	289	63	.4	21	39
39	25.3	26.5	23.3	639	34.8	355	289	63	.4	21	39
40	25.4	26.6	23.4	632	34.7	356	292	60	.3	22	40

Site class 2

Age	H_{dom}	DgM	HgM	N	G	V	Log	Pulp	CAI	Min	Max
1	.7	.0	.0	3000	.0	0	0	0	.0	0	0
2	1.9	1.0	1.5	3000	.1	0	0	0	.1	0	1
3	3.3	2.3	2.8	2453	.7	1	0	0	.9	0	4
4	4.7	4.4	4.2	2084	2.2	4	0	0	3.3	1	7
5	6.1	6.7	5.5	1839	4.6	11	0	0	7.0	1	10
6	7.5	8.9	6.8	1662	7.6	22	0	10	11.1	2	13
7	8.8	11.1	8.0	1528	10.8	37	0	24	14.6	3	16
8	10.0	13.0	9.1	1422	13.9	54	0	42	17.1	3	18
9	11.1	14.6	10.1	1336	16.9	73	0	61	18.5	4	20
10	12.1	16.1	11.1	1263	19.6	91	10	71	18.9	5	22
11	13.0	17.3	12.0	1202	21.9	110	25	75	18.6	6	24
12	13.8	18.4	12.7	1149	23.8	128	36	83	17.8	7	25
13	14.6	19.3	13.5	1103	25.5	144	48	89	16.7	7	27
14	15.3	20.1	14.1	1062	26.9	160	67	85	15.4	8	28
15	16.0	20.8	14.7	1026	28.1	174	79	87	14.1	9	29
16	16.5	21.4	15.3	993	29.0	187	92	88	12.8	9	30
17	17.1	21.9	15.8	964	29.8	198	110	82	11.6	10	30
18	17.6	22.3	16.2	937	30.4	209	111	91	10.4	10	31
19	18.0	22.8	16.7	912	31.0	218	125	87	9.3	11	32
20	18.4	23.1	17.1	889	31.4	226	131	90	8.3	12	32
21	18.8	23.5	17.4	868	31.7	234	146	82	7.4	12	33
22	19.2	23.8	17.7	849	32.0	240	152	83	6.6	12	34
23	19.5	24.0	18.1	831	32.2	246	160	81	5.9	13	34
24	19.8	24.3	18.3	814	32.3	252	161	86	5.3	13	35
25	20.1	24.5	18.6	798	32.4	256	165	85	4.7	14	35
26	20.4	24.7	18.8	783	32.5	260	172	83	4.2	14	35
27	20.6	24.9	19.1	769	32.6	264	176	83	3.7	14	36
28	20.8	25.1	19.3	756	32.6	267	180	82	3.3	15	36
29	21.0	25.3	19.5	743	32.6	270	188	78	2.9	15	37
30	21.2	25.4	19.7	731	32.6	273	188	80	2.6	15	37
31	21.4	25.6	19.8	720	32.5	275	192	78	2.3	15	37
32	21.6	25.7	20.0	709	32.5	277	193	79	2.0	16	38
33	21.8	25.8	20.2	699	32.4	279	200	74	1.8	16	38
34	21.9	26.0	20.3	689	32.4	281	202	74	1.6	16	38
35	22.1	26.1	20.5	680	32.3	282	203	75	1.4	16	39
36	22.2	26.2	20.6	671	32.2	283	208	71	1.2	16	39
37	22.3	26.3	20.7	662	32.1	284	207	73	1.0	17	39
38	22.5	26.4	20.8	654	32.0	285	218	62	.9	17	39
39	22.6	26.5	20.9	646	31.9	286	218	63	.8	17	40
40	22.7	26.6	21.0	639	31.9	286	217	65	.6	17	40

Site class 3

Age	H_{dom}	DgM	HgM	N	G	V	Log	Pulp	CAI	Min	Max
1	.2	.0	.0	3000	.0	0	0	0	.0	0	0
2	.7	.0	.0	3000	.0	0	0	0	.0	0	0
3	1.5	.0	.0	2641	.0	0	0	0	.0	0	0
4	2.4	1.4	2.0	2220	.2	0	0	0	.2	0	2
5	3.4	2.7	2.9	1942	.7	1	0	0	.8	0	4
6	4.5	4.3	4.0	1744	1.7	3	0	0	2.1	1	7
7	5.6	6.2	5.0	1594	3.3	7	0	0	4.1	1	10
8	6.7	8.1	6.1	1476	5.2	14	0	3	6.5	2	12
9	7.8	9.9	7.1	1381	7.5	23	0	13	8.9	2	15
10	8.8	11.7	8.0	1302	9.9	34	0	24	11.1	3	17
11	9.8	13.3	8.9	1235	12.3	47	0	36	12.7	3	19
12	10.7	14.7	9.8	1177	14.6	60	1	50	13.8	4	21
13	11.5	16.0	10.6	1128	16.8	75	7	59	14.3	5	23
14	12.3	17.2	11.4	1084	18.7	89	18	62	14.4	5	25
15	13.1	18.2	12.1	1045	20.5	103	28	66	14.1	6	26
16	13.8	19.1	12.7	1010	22.0	117	38	70	13.5	6	27
17	14.4	19.8	13.3	979	23.3	130	48	74	12.8	7	28
18	15.0	20.5	13.9	951	24.4	142	64	70	12.0	8	29
19	15.5	21.1	14.4	925	25.4	153	78	68	11.1	8	30
20	16.0	21.7	14.8	901	26.3	163	82	75	10.2	9	31
21	16.5	22.1	15.3	879	27.0	172	93	73	9.4	9	32
22	16.9	22.6	15.7	859	27.6	181	99	76	8.5	10	33
23	17.3	23.0	16.0	840	28.1	189	113	70	7.8	10	33
24	17.7	23.3	16.4	823	28.5	196	115	75	7.0	11	34
25	18.0	23.6	16.7	806	28.8	202	120	76	6.4	11	34
26	18.3	23.9	17.0	791	29.1	208	128	74	5.7	11	35
27	18.6	24.2	17.3	776	29.4	213	130	78	5.2	12	35
28	18.9	24.4	17.5	763	29.5	218	138	75	4.6	12	36
29	19.1	24.6	17.7	750	29.7	222	148	69	4.2	12	36
30	19.4	24.9	18.0	738	29.8	225	149	71	3.7	13	37
31	19.6	25.0	18.2	726	29.9	229	150	74	3.4	13	37
32	19.8	25.2	18.4	715	30.0	232	157	70	3.0	13	37
33	20.0	25.4	18.5	705	30.0	235	161	69	2.7	13	38
34	20.1	25.6	18.7	695	30.0	237	161	71	2.4	14	38
35	20.3	25.7	18.9	685	30.1	239	162	72	2.1	14	38
36	20.5	25.9	19.0	676	30.1	241	163	73	1.9	14	39
37	20.6	26.0	19.1	667	30.0	243	166	72	1.7	14	39
38	20.8	26.1	19.3	659	30.0	244	172	67	1.5	14	39
39	20.9	26.3	19.4	651	30.0	245	173	68	1.3	14	40
40	21.0	26.4	19.5	643	29.9	247	176	66	1.2	15	40

Site class 4

Age	H_{dom}	DgM	HgM	N	G	V	Log	Pulp	CAI	Min	Max
1	.1	.0	.0	3000	.0	0	0	0	.0	0	0
2	.3	.0	.0	3000	.0	0	0	0	.0	0	0
3	.7	.0	.0	2825	.0	0	0	0	.0	0	0
4	1.3	.0	.0	2357	.0	0	0	0	.0	0	0
5	1.9	1.1	1.6	2051	.1	0	0	0	.1	0	2
6	2.7	1.8	2.2	1832	.3	0	0	0	.2	0	3
7	3.5	2.9	3.0	1667	.7	1	0	0	.7	0	5
8	4.3	4.3	3.9	1538	1.4	3	0	0	1.5	1	7
9	5.2	5.8	4.7	1433	2.5	5	0	0	2.7	1	9
10	6.1	7.4	5.5	1347	3.8	9	0	1	4.1	1	12
11	7.0	9.0	6.4	1274	5.4	15	0	5	5.6	2	14
12	7.8	10.5	7.2	1212	7.2	22	0	13	7.1	2	16
13	8.7	12.0	8.0	1158	9.0	30	0	21	8.3	3	18
14	9.5	13.4	8.7	1111	10.9	40	0	31	9.4	3	20
15	10.2	14.6	9.4	1069	12.7	50	0	41	10.1	4	22
16	10.9	15.8	10.1	1032	14.3	60	5	46	10.5	4	24
17	11.6	16.8	10.7	999	15.9	71	9	53	10.6	5	25
18	12.2	17.7	11.3	969	17.3	81	20	53	10.5	5	26
19	12.8	18.5	11.8	941	18.6	92	28	55	10.3	6	27
20	13.4	19.3	12.4	916	19.8	102	38	57	9.9	6	29
21	13.9	19.9	12.8	893	20.8	111	47	57	9.4	6	29
22	14.4	20.5	13.3	872	21.7	120	50	64	8.9	7	30
23	14.8	21.1	13.7	853	22.5	128	58	64	8.3	7	31
24	15.2	21.6	14.1	834	23.2	136	66	63	7.7	8	32
25	15.6	22.0	14.4	817	23.9	143	77	60	7.2	8	33
26	15.9	22.4	14.8	801	24.4	150	83	61	6.6	8	33
27	16.3	22.8	15.1	786	24.8	156	86	64	6.1	9	34
28	16.6	23.1	15.4	772	25.2	161	94	62	5.6	9	34
29	16.9	23.4	15.6	759	25.6	166	97	64	5.1	9	35
30	17.1	23.7	15.9	746	25.9	171	101	64	4.7	10	35
31	17.4	24.0	16.1	734	26.1	175	107	64	4.2	10	36
32	17.6	24.2	16.3	723	26.3	179	113	61	3.9	10	36
33	17.8	24.5	16.6	712	26.5	183	117	61	3.5	11	37
34	18.0	24.7	16.7	702	26.7	186	118	63	3.2	11	37
35	18.2	24.9	16.9	692	26.8	189	119	65	2.9	11	38
36	18.4	25.1	17.1	683	26.9	191	125	62	2.6	11	38
37	18.5	25.2	17.2	674	27.0	194	129	60	2.4	11	38
38	18.7	25.4	17.4	666	27.1	196	129	62	2.1	12	39
39	18.8	25.6	17.5	657	27.1	198	130	64	1.9	12	39
40	19.0	25.7	17.7	650	27.1	200	131	64	1.7	12	39