A YIELD TABLE MODEL FOR THE GROWTH OF *PINUS PATULA* IN ETHIOPIA

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Received January 1996

MESFIN, D. & STERBA, H. 1996. A yield table model for the growth of *Pinus patula* in Ethiopia. Top height development of 8 permanent *Pinus patula* plots was used to show that the site index system for Uganda did suit well for Ethiopian stands. It also did not deviate much from the top height development found for South Africa. From 140 felled trees of *Pinus patula*, well distributed not only over the range of breast height diameters and heights but also over the agroclimatic zones of Ethiopia, a new stem form factor equation was calculated. From further 54 temporary plots in *Pinus patula* plantations in 10 plantation areas of Ethiopia the other necessary equations for a growth and yield model for unthinned *Pinus patula* stands were derived. Site index (top height at age 20) turned out to vary between 18 and 33 m, depending on elevation, soil type and initial spacing. Stem number development of these unthinned stands exhibited a much higher mortality at lower heights compared with the South African stands and much smaller mortality subsequently. Thus basal area per hectare developed more slowly over top height than in South African stands, exhibiting no maximum before a top height of 30 m, at this height reaching about the same level as the South African stands. Mean annual increment according to this growth model compares well with the best site class reported for northern Tanzania but is far below the mean annual increment of naturally regenerated stands of *Pinus patula* in Mexico at the same site index.

Key words: *Pinus patula* - growth model - unthinned stands - yield table -Ethiopia

MESFIN, D. & STERBA, H. 1996. Model jadual hasil pertumbuhan *Pinus patula* di Ethiopia. Pertumbuhan ketinggian dominan lapan plot kekal *Pinus patula* digunakan untuk menunjukkan bahawa sistem indeks tapak di Uganda sesuai bagi dirian Ethiopia. Ia juga tidak banyak berbeza daripada pertumbuhan ketinggian dominan untuk Afrika Selatan. Satu persamaan faktor bentuk batang baru telah dikira daripada 140 pokok *Pinus patula* yang ditebang yang tersebar dengan baik pada julat diameter aras dada dan ketinggian serta di zon agroiklim Ethiopia. Persamaan lain yang diperlukan bagi model pertumbuhan dan hasil dirian *Pinus patula* yang tidak dijarangkan telah diperolehi daripada 54 plot sementara di ladang *Pinus patula* di 10 kawasan ladang Ethiopia. Indeks tapak (ketinggian dominan pada umur 20 tahun) berkisar antara 18 dan 33 mm, bergantung kepada ketinggian, jenis tanah dan penjarakan awal. Pertumbuhan bilangan batang dirian-dirian yang tidak dijarangkan ini menunjukkan kematian yang jauh lebih tinggi pada ketinggian yang lebih rendah berbanding dengan dirian Afrika Selatan dan kematian menjadi semakin kurang selepas itu. Jadi luas pangkal sehektar berkembang lebih perlahan daripada ketinggian dominan jika dibandingkan dengan dirian Afrika Selatan, nilai maksimum tidak akan dicapai

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sebelum ketinggian dominan 30 m dan mencapai ketinggian yang hampir sama dengan dirian Afrika Selatan. Tambahan min tahunan berdasarkan model pertumbuhan ini adalah setanding dengan kelas tapak terbaik yang dilaporkan di Tanzania Utara tetapi jauh di bawah tambahan min tahunan dirian *Pinus patula* yang dipulihkan secara semulajadi di Mexico pada indeks tapak yang sama.

Introduction

Clearcutting for agricultural cultivation and unplanned exploitation of Ethiopia's forests are today among the most serious problems of the country. Erosion by wind and water, drought and decreasing soil productivity are the results of deforestation. For planning and control in regular forestry accurate yield data are of great importance. Yield tables or growth and yield models should provide accurate predictions for the whole rotation of forest stands and thus may assist the forest manager in his decisions on the background of sustainable yield. Yield tables play a part too in the objective comparison between two or more tree species. In particular, they assist the forest manager in making the following important decisions about a stand, namely, when to cut, what (how much) to cut and where to cut.

Pinus patula is one of the promising important exotic commercial timber species and sources of fuelwood in Ethiopia. It was vastly planted in different agroclimatic zones of the country, where elevations range from approximately 1500 to 3200 m.a.s.l. and mean annual precipitation lies between 700 and 1500 mm, depending on elevation and slope aspect.

So far no generally valid data have been obtained for most of the important tree species in Ethiopia. Yield figures used in forest planning have merely had the character of estimates based on results from more or less neighboring countries. The objective of this work was to collect yield data and compile them into yield tables for *Pinus patula* in Ethiopia.

The data

From several disks of felled *Pinus patula* trees it was seen that tree rings of this species in this region cannot be related each to one year, thus stem analysis turned out to be not a valid method for height growth reconstruction. Therefore, only the top height of 8 available permanent plots had to be used to compare with known site index systems in order to choose the most appropriate one.

In order to get appropriate stem volume equations, 140 trees–well distributed over the different agroclimatic regions and the whole range of breast height diameter and height–were felled. The diameters of these trees were determined in the midst of every 1 m section in order to calculate stem volume according to Huber (1828) and later on develop volume equations for *Pinus patula.*

To get data for stem number, basal area and volume per hectare, 54 sample plots were measured in 1995 in pure even-aged stands of *Pinus patula,* distributed over the most important agroclimatic regions of Ethiopia (Table 1).

Table 1. Distribution of sample plots

Plantation area	Name	Agroclimatic zone		Elevation of plots (m)	Number sample plots
		Climate	Mean annual prec. mm		
Wandre					10
Wandogenet		Semi-wet	1050	1800	5
Abaro	Munessa-Shashemane,	lowland	-	-	5
Hansawe	South Shao	and plateau	1250	2420	5
Leytelapis					7
Gambo					7
Holleta (Suba)	Suba Menagesha, Shoa	Semi-wet	1000-1150	2300-2450	3
Geresse		Semi-dry			3
Chencha	North Omo	and semi-	800	2000	7
Gardula		wet flat	-	-	
		and hilly	1100	2900	2
Total					54

The sample plots were purposely distributed over different elevations and soil groups in order to represent a large range of site conditions. The altitude of the stands ranges from 2000 to 3000 m, the soil types covered by the plots were clay, loam and silt. Plots which were not thinned were chosen because on thinned plots there was no information available about when and how they were thinned; nevertheless they varied in initial density and in actual stand density. The presented yield tables will only provide information on *Pinus patula* growth in unthinned stands.

In each of these 54 stands one plot was established such that at least 30 trees fell into a circle with a fixed radius thus depending on stand density. The plot size was determined by first estimating actual stem number per hectare using tree distance measurements. Then the plot size was calculated such that about 30 trees fell into the plot. The radius, *r*, on the slope was then calculated from the angle of the slope, α, and the plot size *A* as

$$r = \sqrt{\frac{A}{\pi . \cos(\alpha)}}$$

On each plot the following site information was recorded: elevation, aspect, slope, position on the slope, soil type, thickness of the humus layer. To further characterise the stand, its age, ranging from 4 to 38 years, and the initial spacing (1200 to 2500 trees per hectare) were recorded and supplied by a rough estimate of site quality (good, medium or poor). Within every plot from every tree the dbh was recorded to the nearest mm using a tape, and the height to the top as well as to the base of the live crown was measured using a SUUNTO-hypsometer.

From the site information of every plot the following distribution of site characteristics can be given (Table 2).

Table 2. Site characteristics of the investigated stands

	Minimum	Maximum	Average
Elevation (m)	2100	2900	2431
Slope (degree)	2	21	8.6
Thickness of humus layer (mm)	5	28	11.3

Further site information is given by the distribution of relief-types, soil-types and aspect groups in Figure 1.

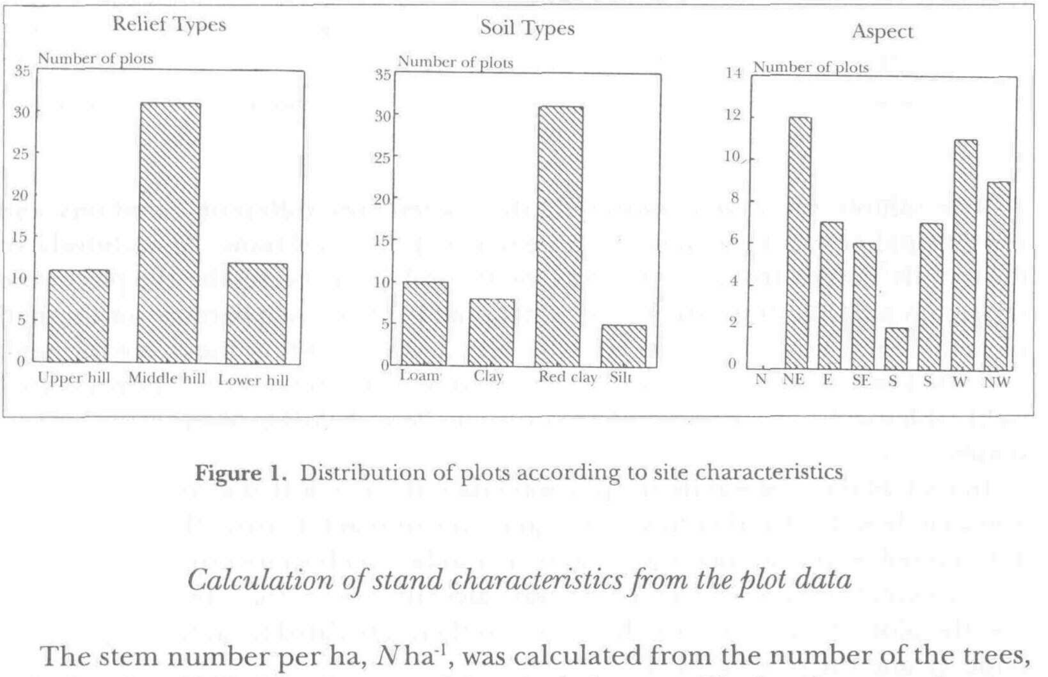

Figure 1. Distribution of plots according to site characteristics

Calculation of stand characteristics from the plot data

The stem number per ha, $N\,ha^{-1}$, was calculated from the number of the trees, n, in the plot, divided by the area of the plot in hectare. The basal area per hectare was calculated from

$$BA_{m^2 ha^{-1}} = \frac{\sum_{i=1}^{n} dbh_i^2 \cdot \frac{\pi}{4}}{A}$$

with A, the area of the plot, and dbh the breast height diameter of the n trees in the plot. The quadratic mean diameter, dg, was calculated from

$$dg = \sqrt{\frac{\sum_{i=1}^{n} dbh_i^2}{n}}$$

For this figure the following equations are valid too:

$$\overline{ba} = \frac{BA}{N}\ ; \quad dg = \sqrt{\overline{ba}\ .\ \frac{4}{\pi}}$$

Lorey's mean height, h_L, was calculated from $h_L = \dfrac{\sum_{i=1}^{n} h_i\ .\ ba_i}{\sum_{i=1}^{n} ba_i}$ with h_i and ba_i the height and the basal area respectively for the *i*th tree. For top height the definition of Assmann (1970) was followed, i.e. the height belonging to the quadratic mean diameter of the 100 largest trees per hectare. In order to find this height, in every plot the coefficients *a* and *b* of the height curve

$$h = \left[\frac{1}{a + \dfrac{b}{dbh}}\right]^2 + 1.3$$

were estimated by linear regression using the transformation

$$\frac{1}{\sqrt{h - 1.3}} = a + b\ .\frac{1}{dbh}\ .$$

Then the quadratic mean diameter of the 100 largest stems per hectare of this plot was inserted into this equation thus gaining the top height according to Assmann. The volume per hectare was calculated using the stem form factor equation defined later,

$$V_{m^3ha^{-1}} = \frac{\frac{\pi}{4}\sum_{i=1}^{n} dbh_i^2\ .\ h_i\ .\ f(dbh_i\ ,\ h_i)}{A}$$

with $f(dbh_i, h_i)$, the form factor, calculated from the breast height diameter and the height of the *i*th tree.

Results

Site index curves

In order to find an appropriate site index system the development of top height on eight permanently observed plots was compared with the site index system for *Pinus patula* in Uganda (Alder 1980) and in Tanzania (Klitgaard & Mikkelsen 1976). The data of these permanent plots were made available by the Ethiopian Forest Research Center and by the Wandogenet Forest College. Because both these site index systems were given only graphically they were smoothed using Richard's (1959) model,

$$h = SI \cdot \left[\frac{1 - e^{-k \cdot age}}{1 - e^{-k \cdot 20}}\right]^r \qquad (1)$$

thus defining site index as the top height at age 20 and estimating k and r by nonlinear regression from the values for top height and age taken from the figures in Klitgaard and Mikkelsen (1976) and Alder (1980) respectively. The estimated coefficients are given in Table 3.

Table 3. Coefficients of the site index systems "Uganda" and "Tanzania". R^2, the coefficient of determination and s_e, the standard error of estimate for the top height are given to characterise the accuracy of the site index system

	k	r	R^2	s_e(m)
Uganda	- 0.0866	1.35	0.960	± 0.042
Tanzania	- 0.1157	1.96	0.997	± 0.012

Then from the data of eight permanent plots in Ethiopia for every age of observation, the site index was calculated from the above two equations and plotted over the age. An appropriate site index system should exhibit no trend between age and estimated site index. As seen from Figure 2, the site index system of Uganda clearly fitted better to the data of the Ethiopian permanent plots. The site index system of Tanzania exhibited unbelievably high site indices in the young stands, quickly decreasing with age. Therefore, the Uganda site index system will be used further on in this study.

Site index and site

In the permanent plots as well as in the 54 plots, observed only once, there was no significant relationship between site index and age. This first again supports the decision to use the site index system of Uganda (Alder 1980) and second, allows to relate the site index to site factors directly without any corrections for age. Slope, and azimuth did not significantly affect site index. Only elevation, soil type and initial spacing had a significant influence on site index. Table 4 indicates that site index improves with the amount of clay in the soil.

Table 4. The average site indices (SI) by soil types

Soil type	Silt	Loam	Clay	Red clay
Average site index (m)	26.5	27.8	28.6	30.6
Standard deviation (m)	3.27	1.55	2.41	1.76
Number of plots	31	10	8	5

Figure 3 reveals that the plots with an initial spacing of less than 2.25 m, i.e. initially more than 2000 tress per hectare, have been observed only in the highest elevation, thus for this spacing no relationship between site index and elevation could be investigated. For the higher spacings (less dense initial planting), the site index decreases expectedly with increasing elevation, but the regression lines differ significantly for different spacings. For the very wide spacings, the decrease in site index is faster than for the denser spacings. Thus it seems that wider spacing increases height growth (and thus site index) in low elevations and decreases height growth in high altitudes. For an altitude of 2000 m, site index is 28.9 m for high initial densities and 35.6 m at lower initial densities. For an elevation of 2400 m, it is the other way around; high density exhibits a site index of 27.6 m and low density one of only 22.4 m. With this result it seems reasonable that in the very high altitudes (> 2700 m) the lowest spacing, thus the highest initial planting density, was chosen.

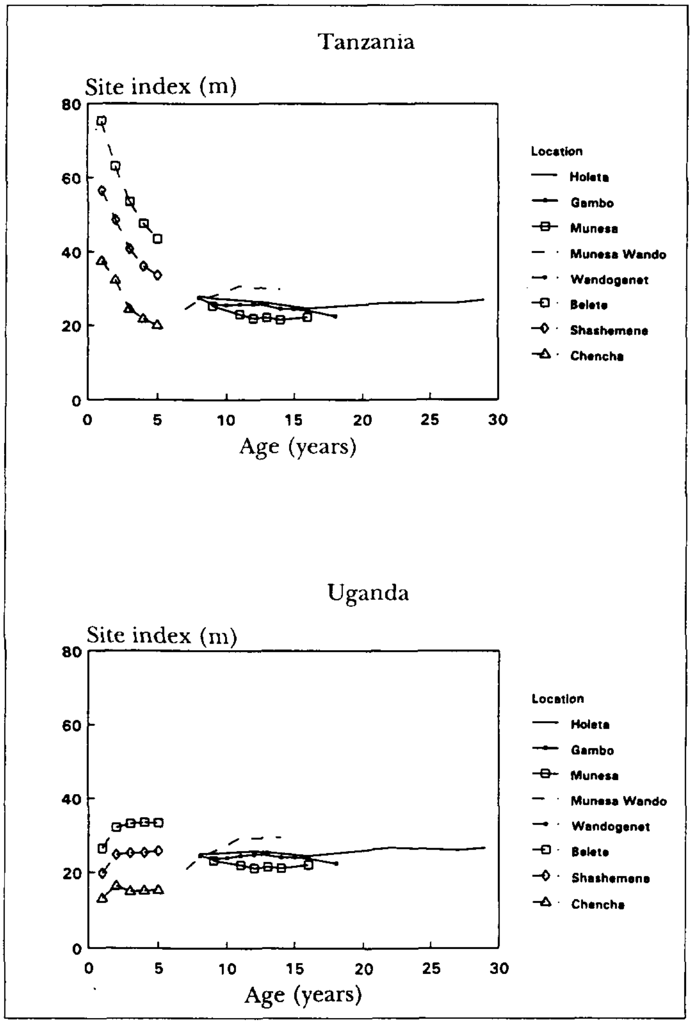

Figure 2. Site indices of Ethiopian stands when determined with Tanzania (Klitgaard & Mikkelsen 1976), and Uganda (Alder 1980) site index systems

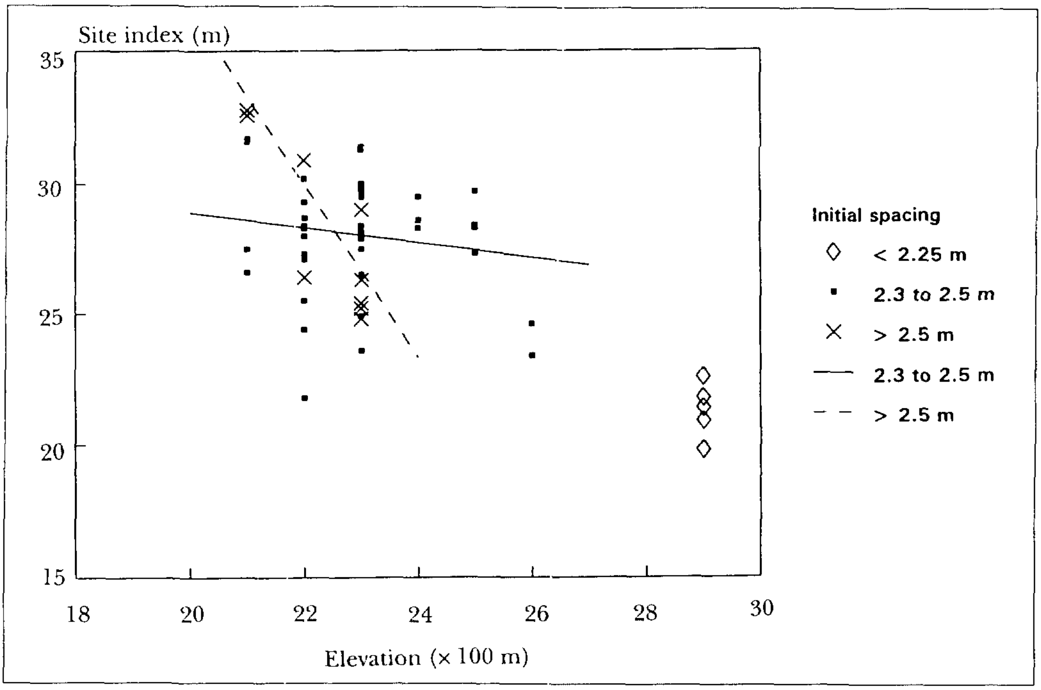

Figure 3. Site index, elevation and initial spacing

Stem volume equations

In order to check the volume equation, developed by Örlander (1986) for *Pinus patula* in Ethiopia, 140 trees were felled and the volume of it determined by 1 m sections. At first the form factors of these trees were compared to those calculated from Örlander's allometric volume equation:

$$\ln v_{[dm^3]} = -3.0332 + 1.7308 \cdot \ln dbh_{[cm]} + 1.1806 \cdot \ln h_{[m]}$$

The grand mean exhibited no significant difference between the form factors resulting from this equation and those measured from the 140 stems $\bar{\Delta} = f_{Örlander} - f_{observed} = -0.00260$, and standard error $s_{\bar{\Delta}} = \pm 0.00442$.

A check for relationships between difference in form factor and tree dimensions resulted in a highly significant relationship between this difference and the height-diameter ratio of the tree ($r^2 = 0.261$). Thus the form factor would have been overestimated in trees with high height-diameter ratios (suppressed trees) and underestimated in trees with low height-diameter ratios (predominant trees).

From this it was decided to estimate an own form factor equation following the concept of Pollanschütz (1974)

$$f_2 = b_0 + b_1 . \ln^2 dbh + \frac{b_2}{h} + \frac{b_3}{dbh} + \frac{b_4}{dbh^2} + \frac{b_5}{dbh \, . \, h} + \frac{b_6}{dbh^2 . \, h}$$

Using the form factors of the 140 felled trees and their dimensions *dbh* and height in the above transformation in a stepwise linear regression showed that only the last term of the above equation was significant, thus resulting in a new form factor equation

$$f_2 = 0.4504 + \frac{5.21}{dbh^2 . \, h}$$

with *dbh* and *h* given in decimeters with $r^2 = 0.254$. This equation now did not any more exhibit any bias related with *dbh*, height or height-diameter ratio.

Although further tests with Pollanschütz's (1965) equation, which included the diameter at three tenths of the height expectedly gave a much better R^2 ($R^2 = 0.569$) than the above equation, it was decided not to use this equation because usually the upper diameter is hard to measure and needs at least a mirror relascope to be used.

With this form factor equation the volume of every tree in the plots was calculated and added thus giving the stand volume, *V*, of every plot. The stand form factor, *F*, then was calculated as

$$F = \frac{V}{BA \, . \, h_{Lorey}}$$

with *BA* the plot's basal area and h_{Lorey}, Lorey's mean height of the plot. This stand form factor was depicted as a function of quadratic mean diameter and Lorey's mean height as

$$F = 0.454 - \frac{0.181}{dg} + \frac{2.6324}{dg^2} + \frac{43.747}{dg^2 . \, h_L} \qquad (2)$$

with *dg*, the quadratic mean diameter in cm, and h_L, Lorey's mean height in m, by linear regression with the data of the 54 plots, resulting in an $R^2 = 0.998$.

Further relationships needed to calculate the yield table

From the site index system for any site index within the range of data, the development of the top height over age can be calculated. Getting the mean height needed in the stand form factor equation followed Schmidt (1971) and Moser (1991) who state that for a stem number of N ha^{-1} = 100, the top height of Assmann

(1970) must equal Lorey's mean height, and for a top height of 1.3 m , which is breast height, again mean height must equal top height. This results in an equation

$$\Delta H = TH - h_{Lorey} = a \,.\, \ln(TH/1.3) \,.\, \ln(N/100) \qquad (3)$$

with *TH*, Assmann's top height and *N*, the stem number per hectare. The coefficient *a* was estimated from our 50 plots with $a = 0.2420$ by linear regression with intercept zero.

Quadratic mean diameter, *dg*, was hypothesised to depend on stand density and top height according to Sterba(1987):

$$dg = \frac{1}{a_0 \,.\, TH^{a_1} \,.\, N + b_0 \,.\, TH^{b_1}}$$

with *TH* and *N* as above. This model with four parameters was compared with another one using only three parameters, the last one being substituted by the assumption of Reineke's (1933) slope of the maximum stem number-diameter relationship of $E = -1.605$ (see Sterba 1987). Using nonlinear regression for the 54 plots exhibited that Reineke's assumption could not be rejected on the $\alpha = 5\%$ level and thus the following equation was finally to be used:

$$dg_{[cm]} = \frac{1}{0.000001285 \,.\, TH_{[m]}^{\;0.6978} \,.\, N/\mathrm{ha} \;+ 1.20 \,.\, TH_{[m]}^{\;-1.153}} \qquad (4)$$

The standard error of estimate for the quadratic mean diameter, *dg*, was ± 2.28 cm, and $R^2 = 0.908$.

Thus only the development of stem number over age was needed. Using Assmann's idea of one general yield level for all stands, which was already the necessary assumption for using one and only one equation like (4), it was decided to relate stem number to top height rather than to age, thus using the compensation effect of top height between age and site quality. Therefore Gadow's (1983) equation was modified to describe stem number development over top height rather then over age. The coefficients were determined by nonlinear regression, thus gaining

$$N = N_{init} \,.\, \left(1 - 0.4916\, e^{\left(\frac{e^{6.00 - 0.452 \,.\, \ln(N_{init})}}{TH}\right)^2}\right) \qquad (5)$$

with an R^2=0.992 and a standard error of estimate of ± 105 trees per hectare.

Figure 4 shows that this relationship describes well the development of stem number as it depends on initial stem number.

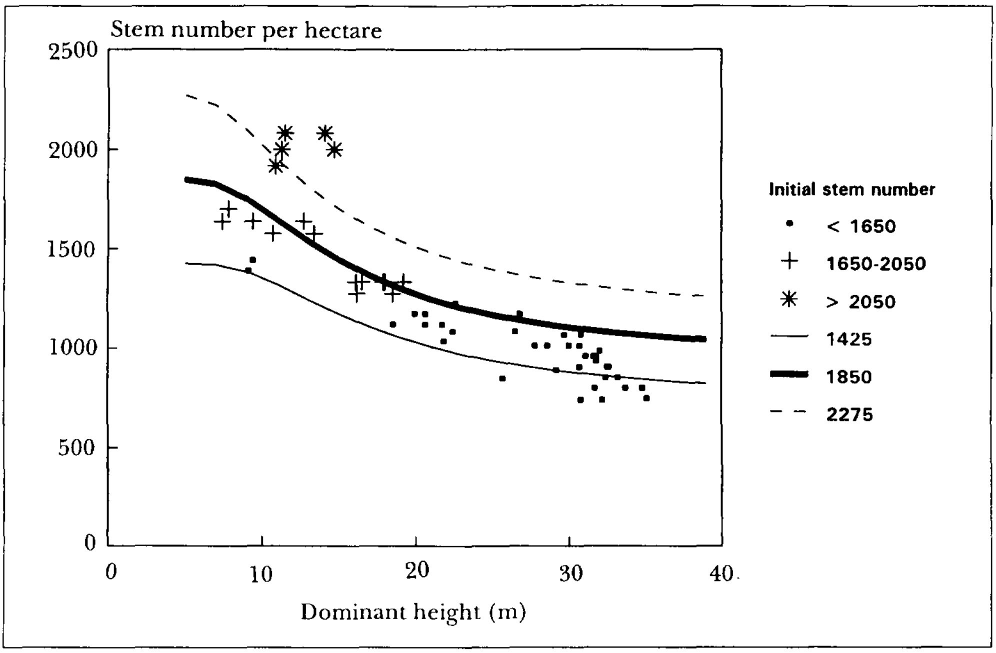

Figure 4. Stem number over dominant height depending on initial stem number

The final yield table

With the above equations the final yield table can be calculated depending on site index and initial stem number. From equation (1) with the coefficients for Uganda (Table 3) the development of top height over age is calculated. The stem number is then calculated using equation (5). Inserting the stem number and the top height into (3) results in the difference between top height and Lorey's mean height. Stem number and top height, inserted into equation (4), gives the quadratic mean diameter. Equation (2) with mean diameter and Lorey's mean height give the stand form factor. Basal area is then calculated from mean diameter and stem number, and volume results from the product of basal area, Lorey's mean height and the stand form factor. Mean annual increment results from dividing volume by age, and current volume increment by dividing the difference between the volumes at different ages.

The yield tables for site indices 22 and 32 m, and each with initial stem numbers of 1600 and 2400 ha^{-1}, are given in the Appendix. The development of mean annual increment is given in Figure 5. It increases with increasing initial stem number. Its maximum is found between ages 18 and 22 y, the later the lower are the site index and initial stem number. For the highest site index (32.4 m) found in the data, the maximum mean annual increment was thus high at 38 $m^3\ ha^{-1}\ y^{1}$.

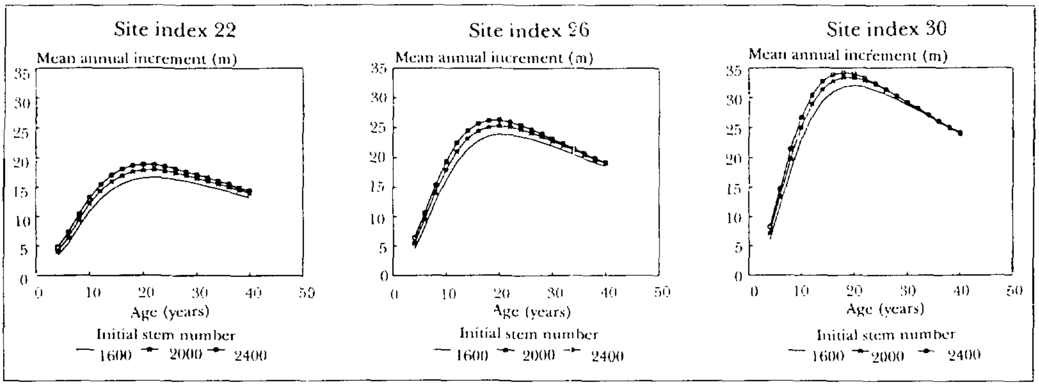

Figure 5. Mean annual increment according to the growth model for unthinned *Pinus patula* stands, depending on site index and initial stem number

Discussion

Other studies on thinned stands of *Pinus patula* have already been done by Klitgaard and Mikkelsen (1976) for northern Tanzania, for unthinned stands by Gadow (1983) and Villiers and van Laar (1986) in South Africa, and by Aguirre and Winter (1994) in naturally regenerated unthinned stands of Mexico.

Figure 6 depicts the height developments as they are given by Gadow (1983) and by Villiers and van Laar (1986) as they compare with the "Uganda"-site index system, recalculated in our study. While Villiers and van Laar (1986) give top height development, Gadow (1983) and Aguirre and Winter (1994) only give mean height development. Therefore for Figure 6 their mean heights had been increased by the difference between top height and mean height as it has been calculated from our data in equation (3). The stem number needed in the equation is calculated from the basal area and the mean diameter development as they are given in Aguirre and Winter (1994), and from Gadow's stem number development respectively. Starting from about age 10, the shapes of all these top height developments do not differ too much. The site index of Gadow's (1983) height growth curve is about the same as that of Villiers and van Laar (1986), namely 21 m in reference age 20. The site index of the Mexican study turns out to be about 2 m less. What is important to note is that the maximum site indices found in the Ethiopian study much exceeded those of the other studies , the highest site index found on the plots of this study being 32.8 m.

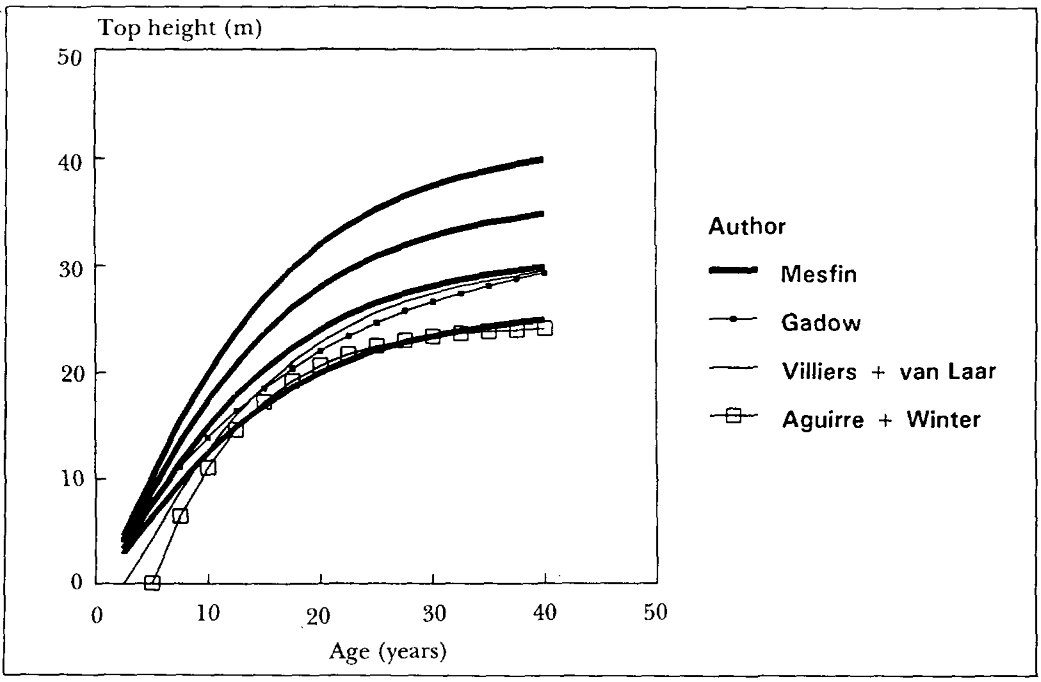

Figure 6. Top height development of *Pinus patula* according to Gadow (1983), Villiers and van Laar (1986) and Agurre and Winter (1994) drawn in the site index system recommended for Ethiopian stands (Mesfin)

Figure 7 (left) compares the stem number development as it can be calculated from Gadow (1983) at two of his experimental sites (Nelshoogte and MacMac) for an initial stem number of 2000 ha^{-1} and that of our study for the same initial stem number. The stem numbers as they change over age from the Aguirre and Winter (1994) study are those from naturally regenerated stands with initial stem numbers given by the authors as exceeding 25 000 stems per hectare. The figure reveals that in our plots early mortality must have been much higher than in both regions, the South African study areas of Gadow (1983) and, expectedly, the naturally regenerated stands of Aguirre and Winter (1994) in Mexico. Between ages 20 and 30 y, the mortality of the Ethiopian stands seems to approach nearly zero and therefore our stands at these heights have higher stem numbers than all those compared with. The resulting basal areas are depicted in the same figure, right. Because higher stem numbers result in smaller mean diameters and vice versa, the differences in basal area per hectare are much smaller than those in stem number. Gadow's stands seem to have higher basal areas at an age of about 20 y, culminating at that time, and then decreasing until they reach below our basal areas near an age of 40 y. Both studies, the Ethiopian as well as the Mexican, do not yet exhibit a maximum of basal area.

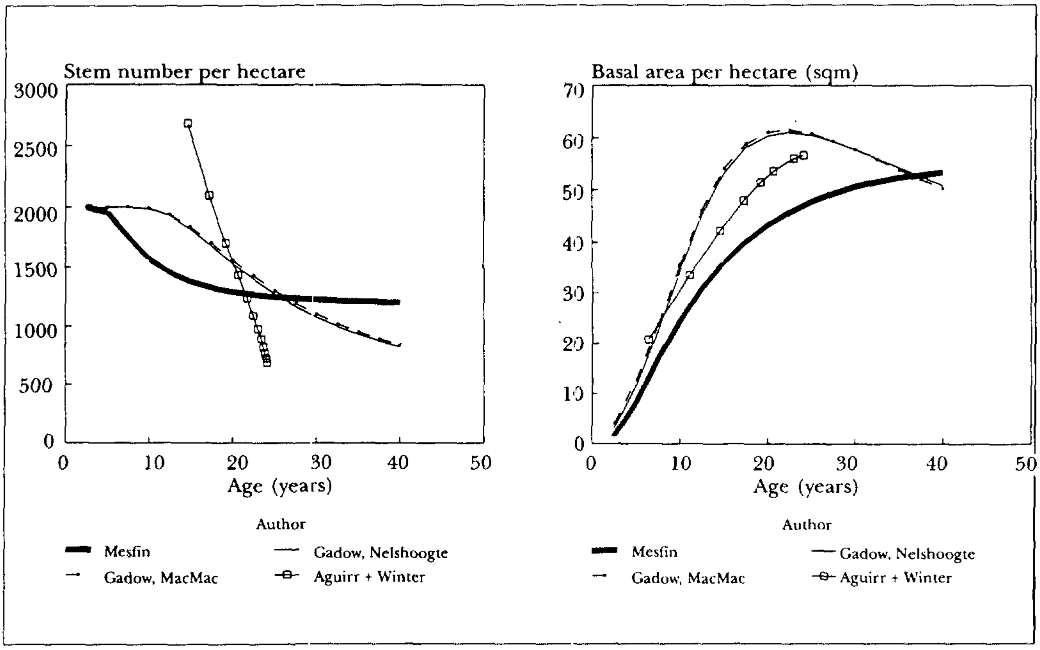

Figure 7. Stem number and basal area development according to the growth model for Ethiopian stands (Mesfin), compared with the respective developments in South African (Gadow) and Mexican (Aguirre and Winter) stands

In order to compare what Assmann (1970) calls yield level, describing the site dependent variation of potential density o f stands with the same site index and the same stand treatment, the diameter development for a site index of 21 m, an initial stem number of 2000 ha^{-1} and a stem number development as it was found in the Ethiopian stands [equation (5), Figure 7, bold line] was calculated from our equation (4) and from the equations of Gadow (1983) and Villiers and van Laar (1986). These different developments are depicted in Figure 8. Up to an age of 20 y both sites would have about the same quadratic mean diameter if the stem numbers are equal. Only later on diameter increment is less in our Ethiopian stands than in the South African ones–which could be the reason for the lower mortality in our stands.

Finally the mean annual volume increments as they are derived from our model are compared with those calculated from Aguirre and Winter (1994) and by Klitgaard and Mikkelsen (1976) (Figure 9). For the comparison with the mean annual increments of Aguirre and Winter (1994), our yield table model was calculated for a site index of 18.6 m (the site index reported by Aguirre and Winter) and with the highest initial stem number in our data, 2500 ha^{-1}. Stem number development and mean annual increment under these assumptions are depicted together with those, given by Aguirre and Winter in Figure 9. At the culmination of the m.a.i. at about age 20 y, the increment of the Mexican stands is much higher then ours, thus indicating that in these site indices in Mexican *Pinus patula* stands, the volume, and thus yield level *sensu* Assmann (1970) are distinctly higher than in the Ethiopian stands, although in higher ages the development of the mean annual increments approaches each other. Therefore rotations in these site classes should be longer in Ethiopia than in Mexico. The comparison with Klitgaard and Mikkelsen's (1976) best site class was calculated with our equations, the site index of 33.8 m, and an initial stem number of 1600 ha^{-1}, which are the site index and the initial stem number given by Klitgaard and Mikkelsen (1976). Although the thinning regime of these authors is very different to our unthinned stands, the mean annual increments do not differ, whether in magnitude nor in the shape of its development over age. For several species, Assmann (1970) has already described that volume increment does not change much as long as a certain degree of stocking (observed basal area per hectare in percent of maximum basal area of unthinned stands) does not fall below a critical value. For those species which he investigated, this critical stocking degree lies between 60 and 80%. Thus thinning within this range would well affect mean diameter but not so much total volume increment.

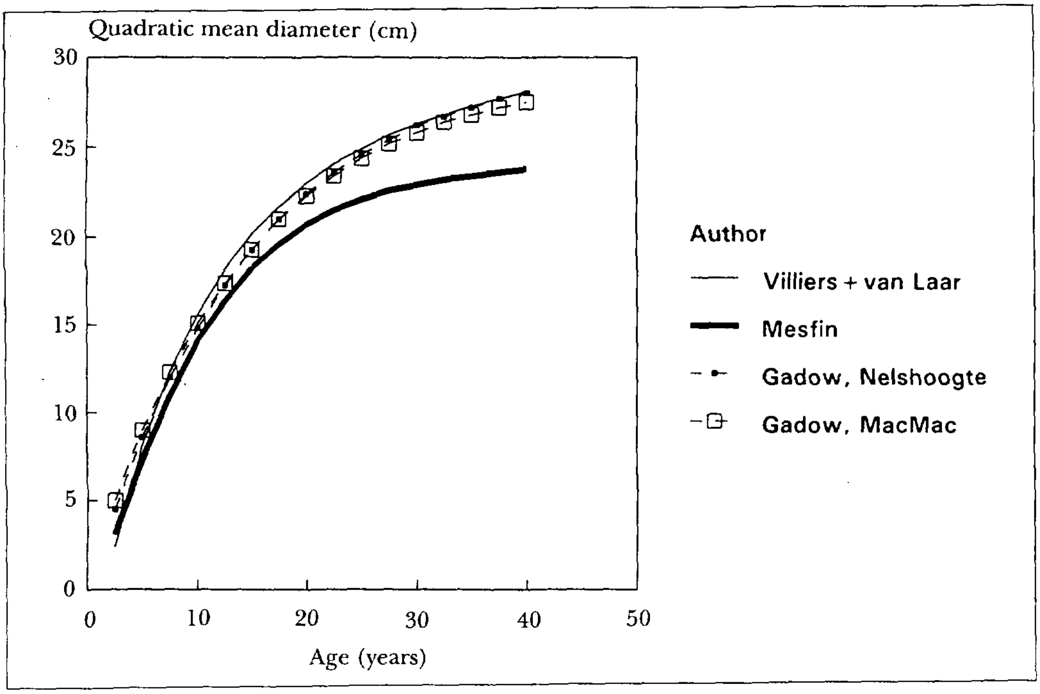

Figure 8. Quadratic mean diameter development for given stem number and site index according to the Ethiopian growth model (Mesfin) and the South African models (Gadow, and Villiers & van Laar)

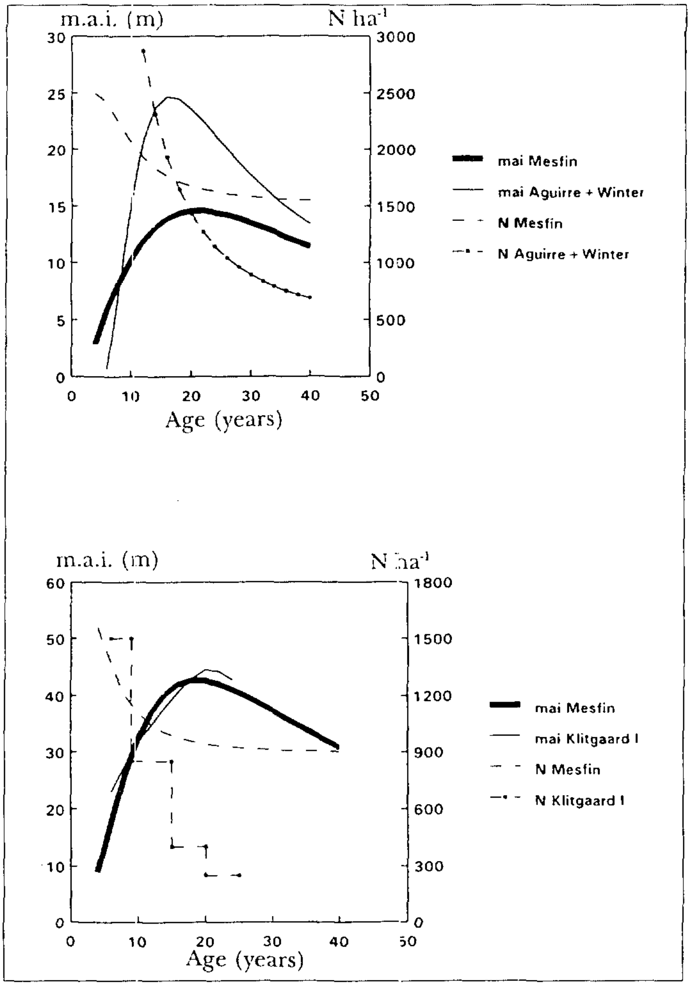

Figure 9. Mean annual volume increment (m.a.i.) according to the Ethiopian growth model (Mesfin) compared with the figures given by Aguirre and Winter (1994) for Mexican stands and by Klitgaard and Mikkelsen (1976) for Tanzania for comparable site indices

Acknowledgements

The authors are highly obliged to the Austrian Academic Exchange Service (ÖAD) for providing D. Mesfin with a scholarship and necessary funds for data collection and carrying out the research project. They are also grateful to the head of the Ethiopian Forest Research Center, Ato Mebrate, and to the researchers, Ato Amsalu and Ato Nega, for their cooperation during data collection in Ethiopia. Finally they want to thank the anonymous reviewer for his useful comments.

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Appendix

Yield tables for *Pinus patula* in Ethiopia for selected site indices and initial stem numbers

Site index = 22 m Initial stem number = 1600 ha^{-1}

Age	*TH*	*HL*	*DG*	*N*	*BA*	*F**1000	*V*	c.a.i .	m.a.i.
4	5.4	4.5	5.5	1599	3.8	800	14		3.4
								11.6	
6	8.5	7.2	8.7	1556	9.3	548	37		6.1
								18.5	
8	11.2	9.8	11.6	1448	15.3	491	74		9.2
								22.9	
10	13.7	12.2	14.0	1338	20.7	473	119		11.9
								25.0	
12	15.9	14.3	16.1	1254	25.4	465	170		14.1
								25.4	
14	17.8	16.2	17.8	1191	29.5	461	220		15.7
								24.5	
16	19.4	17.8	19.2	1146	33.0	458	269		16.8
								22.9	
18	20.8	19.2	20.3	1112	35.9	457	315		17.5
								20.8	
20	22.0	20.4	21.2	1087	38.4	456	357		17.8
								18.5	
22	23.0	21.4	22.0	1067	40.4	455	394		17.9
								16.3	
24	23.9	22.2	22.6	1052	42.2	455	426		17.8
								14.2	
26	24.6	23.0	23.1	1040	43.6	455	455		17.5
								12.3	
28	25.2	23.6	23.5	1031	44.8	454	480		17.1
								10.6	
30	25.8	24.1	23.9	1024	45.8	454	501		16.7
								9.1	
32	26.2	24.5	24.1	1018	46.6	454	519		16.2
								7.8	
34	26.6	24.9	24.4	1013	47.3	454	534		15.7
								6.6	
36	26.9	25.2	24.6	1009	47.8	454	548		15.2
								5.6	
38	27.2	25.5	24.7	1005	48.3	454	559		14.7
								4.7	
40	27.4	25.7	24.9	1002	48.7	454	568		14.2

Site index = 32 m						Initial stem number = 1600 ha^{-1}			
Age	*TH*	*HL*	*DG*	*N*	*BA*	*P**1000	*V*	c.a.i.	m.a.i.
4	7.9	6.7	8.2	1571	8.2	569	31		7.9
								30.3	
6	12.3	10.9	12.7	1399	17.6	481	92		15.3
								44.5	
8	16.3	14.8	19.6	1238	26.4	464	181		22.6
								52.5	
10	19.9	18.3	19.6	1133	34.1	458	286		28.6
								55.1	
12	23.1	21.4	22.0	1066	40.6	455	396		33.0
								53.6	
14	25.8	24.2	23.9	1023	45.9	454	503		36.0
								49.6	
16	28.2	26.5	25.3	993	50.1	454	603		37.7
								44.5	
18	30.3	28.5	26.5	972	53.5	453	692		38.4
								39.0	
20	32.0	30.2	27.3	957	56.2	453	770		38.5
								33.8	
22	33.5	31.7	28.0	946	58.3	453	837		38.1
								29.0	
24	34.7	33.0	28.6	937	60.0	452	895		37.3
								24.7	
26	35.8	34.0	29.0	930	61.3	452	944		36.3
								20.9	
28	36.7	34.9	29.3	925	62.4	452	986		35.2
								17.7	
30	37.5	35.7	29.6	921	63.3	452	1022		34.1
								14.9	
32	38.1	36.3	29.8	918	64.0	452	1051		32.9
								12.6	
34	38.7	36.9	30.0	915	64.6	452	1077		31.7
								10.6	
36	39.2	37.3	30.1	913	65.0	452	1098		30.5
								8.9	
38	39.5	37.7	30.2	911	65.4	452	1116		29.4
								7.5	
40	39.9	38.0	30.3	909	65.7	452	1131		28.3

Site index = 22 m					Initial stem number = 2400 ha^{-1}				
Age	*TH*	*HL*	*DG*	*N*	*BA*	*F**1000*	*V*	c.a.i.	m.a.i.
4	5.4	4.3	5.4	2390	5.5	800	19		4.8
								15.1	
6	8.5	7.0	8.4	2241	12.5	557	49		8.2
								22.0	
8	11.2	9.7	11.1	2022	19.5	496	93		11.7
								26.6	
10	13.7	12.0	13.3	1850	25.6	476	147		14.7
								28.6	
12	15.9	14.1	15.1	1732	30.8	467	204		17.0
								28.4	
14	17.8	16.0	16.5	1650	35.2	463	261		18.6
								26.9	
16	19.4	17.6	17.6	1593	38.8	460	314		19.6
								24.6	
18	20.8	19.0	18.5	1553	41.8	459	364		20.2
								22.0	
20	22.0	20.1	19.2	1522	44.2	458	408		20.4
								19.3	
22	23.0	21.1	19.8	1499	46.2	457	446		20.3
								16.8	
24	23.9	22.0	20.3	1482	47.8	456	480		20.0
								14.5	
26	24.6	22.7	20.6	1468	49.1	456	509		19.6
								12.4	
28	25.2	23.3	20.9	1457	50.2	456	534		19.1
								10.6	
30	25.8	23.8	21.2	1449	51.1	455	555		18.5
								9.0	
32	26.2	24.3	21.4	1442	51.8	455	573		17.9
								7.6	
34	26.6	24.7	21.6	1436	52.4	455	588		17.3
								6.5	
36	26.9	25.0	21.7	1432	52.9	455	601		16.7
								5.5	
38	27.2	25.2	21.8	1428	53.3	455	612		16.1
								4.6	
40	27.4	25.5	21.9	1425	53.7	455	621		15.5

Site index = 32 m Initial stem number = 2400 ha^{-1}

Age	*TH*	*HL*	*DG*	*N*	*BA*	*F**1000	*V*	c.a.i.	m.a.i.
4	7.9	6.6	7.9	2279	11.2	579	43		10.7
								36.1	
6	12.3	10.7	12.0	1942	22.1	485	115		19.1
								50.9	
8	16.3	14.6	15.4	1711	31.9	466	217		27.1
								57.9	
10	19.9	18.1	18.0	1577	40.0	460	323		33.2
								58.2	
12	23.1	21.2	19.8	1498	46.3	457	449		37.4
								54.3	
14	25.8	23.9	21.2	1448	51.2	455	557		39.8
								48.3	
16	28.2	26.2	22.2	1414	54.8	455	654		40.9
								41.8	
18	30.3	28.3	22.9	1391	57.5	454	738		41.0
								35.6	
20	32.0	30.0	23.5	1374	59.5	454	809		40.4
								30.0	
22	33.5	31.4	23.9	1362	61.0	453	869		39.5
								25.2	
24	34.7	32.7	24.2	1352	62.1	453	919		38.3
								21.0	
26	35.8	33.7	24.4	1345	62.9	453	961		37.0
								17.6	
28	36.7	34.6	24.6	1339	63.5	453	997		35.6
								14.7	
30	37.5	35.4	24.7	1334	64.0	453	1026		34.2
								12.2	
32	38.1	36.0	24.8	1331	64.4	453	1050		32.8
								10.2	
34	38.7	36.6	24.9	1328	64.7	453	1071		31.5
								8.5	
36	39.2	37.0	25.0	1325	64.9	453	1088		30.2
								7.1	
38	39.5	37.4	25.0	1323	65.1	453	1102		29.0
								6.0	
40	39.9	37.7	25.1	1322	65.2	453	1114		27.9