# Growth, Stem Quality and age-age Correlations in a Teak Provenance Trial in Tanzania

By A. P. PEDERSEN[1)], J. K. HANSEN[2)], J. M. MTIKA[3)] and T. H. MSANGI[4)]

(Received 6th April 2006)


## Abstract

This study examines the growth and stem straightness variation between teak (*Tectona grandis* L. f.) provenances in a 30-year-old field trial in the coastal lowland of Tanzania. The results are compared with earlier results. The findings demonstrate that it is possible to find large height and yield differences between teak provenances. The best performing provenance grows some 10% (height) to 40% (volume) better than the average. The provenance Topslip, India, consistently proved to be outstanding in terms of growth and stem quality confirming earlier evaluations at age 5 and 17 years. Tanzanian land races also proved to be superior, especially as regards stem straightness.


*Key words: Tectona grandis*, land races, provenance variation

## Introduction

This study aimed at examining the variation of growth and stem straightness between teak (*Tectona grandis* L. f.) seed sources/provenances in a field trial 30 years after establishment and, to examine the correlation of the 30-year-results with earlier results from MADOFFE and MAGHEMBE (1988) and PERSSON (1971a). This paper uses the term provenance to define all types of seed sources irrespective of whether they were are domesticated or indigenous populations within the natural distribution area of Teak.

Teak, one of the most valued timber species in the world, is naturally distributed in India, Myanmar, Laos, and Thailand. It was introduced to Indonesia some 600 years ago (PANDEY and BROWN, 2000). Additional, plantings and domestication of teak have taken place through vast plantation established throughout Tropical Asia, Africa, Latin America and the Caribbean. Plantations are also established with the species in the Pacific region and Australia (PANDEY and BROWN, 2000).

Teak is relatively easy to establish in plantations where it generally shows high growth rates during the first twenty years. This is often followed by a substantial reduction in yield in subsequent decades (e.g. KADAMBI, 1972; KRISHNAPILLAY, 2000; PANDEY and BROWN, 2000). To achieve a high percentage of heartwood, the rotation age can be as high as 120 years. However, the rotation age is typically shorter, for example less than 40 to 60 years (KADAMBI, 1972; KRISHNAPILLAY, 2000; PANDEY and BROWN, 2000).

Earlier, the majority of teak wood came from natural forests. However, the areas with teak have rapidly diminished and this has led to a greater dependence of plantation-grown teak (PANDEY and BROWN, 2000). In spite of centuries of heavy and usually dysgenic exploitation, natural teak forests still offer valuable genetic sources. Nevertheless, clearing, illegal exploitation, deliberate burning and grazing continue at an increasing rate and put pressure on natural populations (e.g. HEDEGART, 1976; GRAUDAL et al., 1999). This emphasises the need to collect as much information as possible from existing field trials comparing different provenances of teak, in order to improve the choice of seed sources for teak plantations and teak breeding programs. In particular, older field trials are valuable since they are more reliable and may elucidate the possibility of making early selection.

Beside growth and health, stem straightness, fluting or buttressing of the stem, bark thickness, epicormics, branch size, and presence of protuberant buds, wood density, length of bole, heartwood percentage, and colour of heartwood are of importance (e.g KJAER et al., 1995; KRISHNAPILLAY, 2000). Several studies have shown differences between teak provenances in survival, growth, health and different stem quality parameters, such as stem straightness, branch size, epicormics, protuberant buds (e.g. PERSSON, 1971a; KEIDING, 1973; KEIDING et al., 1986; KJAER et al., 1995; KAOSA-ARD, 2000).

While some uncertainty remains on the exact origin of introduced material, it is accepted that the Germans introduced teak to Tanzania in the late 19th century. Some find it likely that the origin was in Myanmar and/or Java (KEIDING, 1989; PEDERSEN, 1995), while MADOFFE and MAGHEMBE (1988) refer to Calcutta, India. From 1905 to 1936 field trials were established in different parts of the country using seed sources from Burma, Java, India, and Thailand (WOOD, 1967). A good performance in these field trials led to the establishment of teak plantations in Eastern Tanzania (MADOFFE and MAGHEMBE, 1988).

## Material and Methods

The field trial evaluated in this study was established in December 1965 at the foothills of the East Usambara Mountains at Longuza, near Tanga (4°55' S, 38°40' E at 180 metres above sea level). According to the nearby weather station, Longuza Forest Plantation Office with its altitude of 168 meter (FAO, 2005) the mean maximum temperatures varies between 26–32 °C while mini-


[1)] Forest & Landscape Denmark, Hørsholm, Kongevej 11, DK-2970 Hørsholm. E-mail: anderspp@gmail.com.

[2)] Forest & Landscape Denmark Hørsholm Kongevej 11, DK-2970 Hørsholm. Telephone: +45-35281635, Fax: +45-35281517. E-mail: jkh@kvl.dk.

[3)] BSc., Head of Section at Tanzania Tree Seed Agency (TTSA).

[4)] Head, Tanzania Forestry Research Institute, P.O. Box 95, Lushoto, Tanzania.




DOI:10.1515/sg-2007-0022
edited by Thünen Institute of Forest Genetics

*Table 1.* – Seed Sources (provenances) of teak (*Tectona grandis* L. f.) tested in the field trial.

| | Seed source name | Province | State | Region | Origin | Lat. | Long. | Metres above sea leavel | Estimated precipitation (mm) |
|---|---|---|---|---|---|---|---|---|---|
| A | Kihuhwi, Longuza | Muheza, Tanga | Tanzania | East Africa | Unknown | 5°12' S | 38°39'E | 200 | 1550 |
| B | Mtibwa I | Morogoro | Tanzania | East Africa | Kihuhwi | 6°08' S | 37°38'E | 400 | 1200 |
| C | Mt. Harris | Trinidad | Trinidad & Tobago | S-America | Burma | 10° N | 61° W | n.a. | 1700 |
| D | Sudan | n. a. | Sudan | Sahel | Unknown | n.a. | n.a. | n.a. | n.a. |
| E | Saigon | Saigon | Vietnam | SE-Asia | Unknown | 11° N | 107° E | n.a. | 2270 |
| F | Mtibwa II | Morogoro | Tanzania | E-Africa | Kihuhwi | 6°08' S | 37°38'E | 400 | 1200 |
| G | Keravat | New Britain | Papua New Guinea | SE-Asia | Burma | 4° S | 52°E | n.a. | 2170 |
| H | Lembaga* | Central Java | Indonesia | SE-Asia | Unknown | 7° S | 110°E | n.a. | 2890 |
| I | East Region | Centr. Nigeria | Nigeria | Sahel | Unknown | 10° N | 8°E | n.a. | 1600 |
| J | Topslip | S. Coimbatore | Tamil Nadu (East) | India | Topslip | 11° N | 76°E | n.a. | 3280 |
| K | S. Chanda | Chandrapur | Maharashtra | India | Ballarshah | 20° N | 80° E | n.a. | 1346 |
| L | Hoshangabad | Hoshangabad | Madya Pradesh | India | Unknown | 22°30'N | 78° E | n.a. | 1280 |

n. a. Information not available, * Origin of this seed source/provenance is unknown, Lembaga refers to an Intitution in Indonesia.

mum temperatures range from 15–20 °C. The mean annual rainfall is 1548 mm with a dry spell between June and September.

The natural vegetation is moist-deciduous to evergreen lowland forest characterised by tree species like *Cephalosphaera usambarensis*, *Beilschmedia kweo*, *Newtonia buchananii*, *Melicia excelsa*, *Antiaris usambarensis* and *Khaya anthoteca* in the dominant canopy (PEDERSEN, 1995, personal observations). Prior to planting, timber was extracted from the site followed by clear cutting and slashing and burning of the remaining vegetation. The site is fertile and very suitable for teak, which now dominates the surrounding plantations.

The design was a randomised complete block (henceforth RCB). Thus, every block comprised of twelve plots, one for each provenance. The provenance Mtibwa replaced an unknown twelfth provenance that possibly never germinated. Thus, Mtibwa was represented twice in all four blocks. Each plot was established with ten by ten trees with a spacing of 1.83 x 1.83 m. Five rows of teak were planted around the whole experiment. Most provenances were landraces of different origin. Only the Asian provenances were of natural origin (*Table 1*). Three major seed sources in Tanzania are Kihuhwi, Mtibwa, and Bigwa, where the latter two are first and second generations of Kihuhwi, respectively which again originates from Tenasserim, Burma.

Survival, height, diameter, basal area per ha and straightness were evaluated by MADOFFE and MAGHEMBE (1988) 17 years after stand establishment. The trial was weeded biannually in the first third year, then it was slashed annually until canopy closure in 1971. Severe fires in the initial years influenced Block I and II and led to gaps and beeting up in these blocks. In 1980 a selective, plot-wise thinning operation removed up to 30% of the poorest trees (MADOFFE and MAGHEMBE, 1988).

Provenance means are available for height and survival 1, 2, 3, 4, 5, 10, 15, and 17 years after the establishment from MADOFFE and MAGHEMBE (1988). Further, 17 years provenance means for the diameter, stem straightness, basal area per ha ($m^2$/ha) and volume per ha ($m^3$/ha) are available from MADOFFE and MAGHEMBE (1988).

Thirty years after establishment, the field trial was re-identified. It seemed well protected, but had not been managed or measured in the 13 years since 1982. The trial was basically complete with some plots suffering from lack of thinning, while the stand density in other plots was low. Thus the number of trees varied from 7 to 35 within the plots. Diameter at breast height (DBH) were measured on all trees in all plots. Height was measured on 7 to 14 trees in each plot selected along the two diagonals to ensure coverage of the entire plot. A few trees were discarded in case of skew growth or broken tops. Diameter-height regressions were developed for each plot to estimate heights of remaining trees, based on their DBH. The linear regression model applied was

$$h_{ij} = a + b \times \ln(DBH_{ij}) + e_{ij} \qquad [1]$$

where $h_{ij}$ is the height of tree $i$ in plot $j$, $a$ is the intercept, $b$ the regression coefficient, $\ln(DBH_{ij})$ is the natural logarithmic of the DBH of tree $i$ in plot $j$ and is the residual.

*Table 2.* – Description of stem straightness scores.

| Score | Description |
|---|---|
| 1 | Straight stem |
| 2 | Almost straight, max. one minor discrepancy |
| 3 | More than one minor discrepancy from a straight line |
| 4 | One severe defects (plus possible one less severe or plus several minors) |
| 5 | Two or more crucial / severe stem form defects |



DOI:10.1515/sg-2007-0022
edited by Thünen Institute of Forest Genetics

The mean diameter corresponding to mean basal area ($D_g$) was estimated for each plot and the corresponding height ($H_g$) was estimated from $D_g$ using the respective plot-wise diameter-height regressions (equation 1 above). Tree volumes were estimated for each tree applying a gross form factor of $^1/_3$. V, the volume per ha was estimated for each plot based on individual tree volumes. Plot-wise mean heights and DBH of the 4 dominating trees in each plot were also estimated.

Clearly suppressed trees were not included due to their inconsistent form caused by their struggle to reach light. Inclusion of such trees would prevent an accurate evaluation for stem rich plots where thinning was overdue; such plots typically belonged to the leading provenances. Two of the authors, Pedersen and Mtika, arrived at a common agreement, scoring the stems on a 1-5-form scale (*Table 2*).

A linear one-way ANOVA model (with randomised blocks) was applied using plot means for the measured traits, or estimated volumes ($m^3$/ha) for the plots

$$Y_{ij} = \mu + b_i + P_j + \beta n_{ij} + e_{ij} \qquad [2]$$

Where $Y_{ij}$ is the dependent variable of a plot in block $i$ and with provenance $j$, $b_i$ is the random effect of replication $i$, $P_j$ is the fixed effect of provenance $j$, $n_{ij}$ is the number of trees in each plot (covariate), β is the regression coefficients for the covariate, and $e_{ij}$ is the residual. The covariate was removed from the model in case it proved non-significant ($P < 0.05$). Additionally, the dependent variable was plotted as function of the covariate to control the appropriateness of applying the covariate.

Plots with the provenances K and L were characterised by few trees and in two of the plots the number of trees was too limited to achieve crown coverage. The influence of plots with a low stand density on the results was examined making analysis of variance and estimating least square means for the provenances with- and without stand density as covariate.

The two replications of Mtibwa were analysed as two separate provenances to check provenance consistency.

Residuals were tested for normality (SHAPIRO and WILK, 1965) by applying the procedure UNIVARIATE of SAS (SAS INC., 1999). These tests were supplemented with normal distribution plots and frequency plots. Additionally, residuals were plotted as function of predicted values to reveal potential heteroscadicity. A square root transformation was used for the volumes V to remove an increasing residual variance with increasing volumes, i.e. variance heteroscadicity. The analysis of variance was made with the procedure GLM of SAS (SAS INC., 1999). Least square means were estimated using the procedure MIXED in SAS (SAS INC., 1999). Comparisons between provenance estimates were made using the Tukey-Kramer option in the procedure MIXED of SAS (SAS INC., 1999). Besides applying the least square means estimates for the provenances, a mixed model similar to model [2] considering provenance effects as random was applied. Thereupon, best linear predicted provenance values (e.g. HENDERSON,

*Table 3.* – Results from the analysis of variance.

| Trait | Source | DF | MS | F | Pr > F |
|---|---|---|---|---|---|
| Volume per ha ($m^3$/ha) - square root transformation | Prov | 11 | 14 | 7 | <.0001 |
| | Block | 3 | 1 | 0 | 0.8112 |
| | (N per ha)* | 1 | 64 | 32 | <.0001 |
| | Error | 32 | 2 | | |
| Volume per ha ($m^3$/ha) - square root transformation | Prov | 11 | 47.9 | 12.42 | <.0001 |
| | Block | 3 | 2.0 | 0.53 | 0.6666 |
| | Error | 33 | 3.9 | | |
| Average volume per tree ($m^3$) | Prov | 11 | 0.054 | 7.1 | <.0001 |
| | Block | 3 | 0.004 | 0.6 | 0.6394 |
| | (N per ha)* | 1 | 0.049 | 6.5 | 0.016 |
| | Error | 32 | 0.008 | | |
| Height of dominating trees | Prov | 11 | 1706 | 10 | <.0001 |
| | Block | 3 | 724 | 4 | 0.0122 |
| | Error | 33 | 171 | | |
| Diameter dominating trees | Prov | 11 | 79 | 6 | <.0001 |
| | Block | 3 | 13 | 1 | 0.4258 |
| | Error | 33 | 14 | | |
| Stems per ha | Prov | 11 | 51532 | 2.9 | 0.0092 |
| | Block | 3 | 6211 | 0.4 | 0.7915 |
| | Error | 33 | 17897 | | |
| Stem straightness average score | Prov | 11 | 0 | 4 | 0.0017 |
| | Block | 3 | 1 | 7 | 0.0006 |
| | Error | 33 | 0 | | |
| Stem straightness - percentage score 1-2 | Prov | 11 | 922 | 5 | 0.0001 |
| | Block | 3 | 1740 | 9 | 0.0001 |
| | Error | 33 | 183 | | |

* Number of trees per ha in the plots used as covariate.



DOI:10.1515/sg-2007-0022
edited by Thünen Institute of Forest Genetics

1984) were estimated to account for provenance repeatability. Effects showing a significance level below 0.05 were considered statistically significant.

## Results

The mean volume was 337 $m^3$ per ha, but varied between 73 and 674 $m^3$/ha reflecting the large differences in stand density and average tree size between plots. The overall mean volume per tree was 0.56 $m^3$. Overall mean DBH corresponding to the mean basal area per tree ($D_g$) in the plots and the corresponding height ($H_g$) was estimated to be 27.9 cm and 27.4 metres, respectively. Height ($H_{dom}$) and DBH of the four dominating trees in each plot ($D_{dom}$) was 29.7 metres and 38.4 centimetres, respectively. On average, 20% of the original trees remained in the plots, with values ranging from 7% to 35%. Thirteen years earlier the percentage of remaining trees ranged from 48–61% after a selective thinning (MADOFFE and MAGHEMBE, 1988).

There was a significant difference in stand density among the provenances (*Table 3*), explained mainly by four plots with only; 7, 8, 10 and 11 trees each., All were of provenance K or L (*Fig. 1*). When these two provenances were discarded, there were no significant differences between the provenances in stand density ($Pr < 0.3159$).

Provenance significantly affected V (volume per ha), $V_m$ (average volume per tree in the plots), $H_{dom}$ and $D_{dom}$. Stand density was a significant as covariate for volume per ha (*Table 3*), but not for $D_{dom}$. The average volume per tree decreased with increased stand density, except for the provenances K and L (*Fig. 2*).

Thus, the estimates of volume per ha, using stand density in the plots as a covariate, were probably overestimated for provenances K and L. This is indicated by their lack of growth in response to increased space where $D_{dom}$ and volume per tree seem stagnant. Estimates for volume per ha for provenances showed much

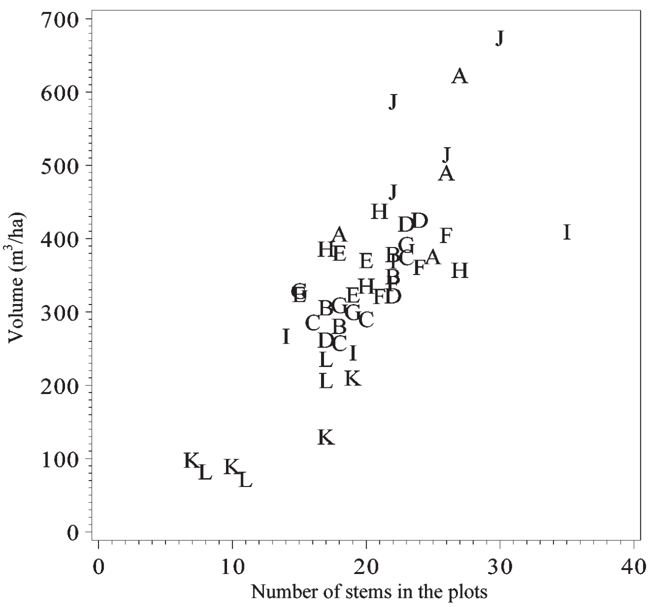


*Figure 1.* – Volume per ha in different plots in the field trial. The letters refers to provenances.

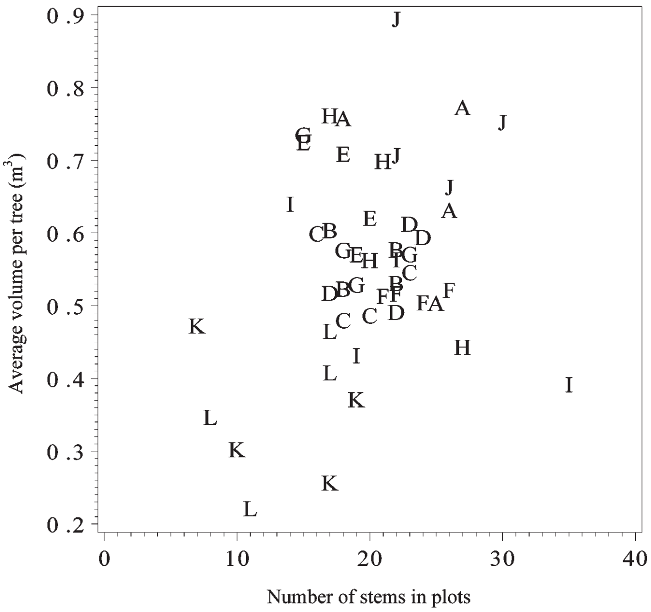


*Figure 2.* – Average volume per tree in different plots in the field trial. The letters refers to provenances.

larger variation when based on a model without stand density as a covariate. However, using or not using stand density in the plots as a covariate only marginally changed the rank of the provenances (*Table 4*).

For volume and height of dominating trees, two provenances, Topslip and Kihuhwi, were superior, while a group of three provenances, East Nigeria, Hoshangabad and S. Chanda were poor (*Table 4*). Some discrepancy was noticed between $H_{dom}$ and V. Mtibwa II had low volume per ha but tall dominant trees, and Saigon had high volumes per ha but relatively short dominant trees (*Table 4*).

The mean stem form was 2.8. On average 40% of the trees scored 1 and 2. Provenances were highly significant different for this trait (*Table 3*) and they were divided into a superior group with 56–57% of the trees with score 1 or 2: Mt. Harris, Topslip, and the second generation Tanzanian provenance Mtibwa (I and II); an intermediate group with 30–47% of the trees scoring 1 or 2: Kihuwi, Saigon, Keravat, and Lembaga; and a third group with less than 22% of the trees scoring 1 or 2: S. Chanda, and Hoshangabad, (*Table 4*). Only 8% fo the trees had completely straight stems and provenances were not significantly different in this regard ($Pr < 0.14$).

Despite some discrepancy between dominant heights ($H_{dom}$) and volumes (V, $m^3$/ha) the overall correlation of 0.93 between provenance estimates for volume per ha and height of dominant trees (*Table 5*) further supports earlier evidence of large differences in growth between the provenances. Uneven stand density in the plots possibly explains some of the discrepancies between height and volume estimates. This discrepancy may also reflect that differences in volume in older stands are less related to differences in height.

Provenance estimates for basal area and volume after 17 years (MADOFFE and MAGHEMBE, 1988) were significantly correlated with the estimates for height and vol-



DOI:10.1515/sg-2007-0022
edited by Thünen Institute of Forest Genetics

*Table 4.* – Provenance least square means estimates (LSM) and predicted values (PRED) estimated as the deviation from the mean in the case of volume, height and diameter in percentage points, otherwise as absolute values. Least square estimates with same letter are not significantly (Pr < 0.05) different from each other.

| | | Stand density in plots | | Volume per ha | | Volume per ha[#] | | Average volume per tree | | Height dominating trees | | Diameter at breast height dominating trees | | Average stem straightness | | Percentage of trees with straightness score of 1 or 2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average | | 597 trees/ha | | 337 $m^3$/ha | | 337 $m^3$/ha | | 0.56 $m^3$/ tree | | 27.4 m | | 27.9 cm | | 2.8 (score) | | 40% | |
| Provenance | ID | LSM | PRED (%) | LSM | PRED (%) | LSM | PRED (%) | LSM | PRED (%) | LSM | PRED (%) | LSM | PRED (%) | LSM | PRED | LSM | PRED |
| Kihuhwi, Longuza | A | 717 ab | 14 | 470 ab | 41 | 417 ab | 23 | 0.67 ab | 17 | 30.7 ab | 4 | 42.1 ab | 8 | 2.9 ab | 0.0 | 41 ab | 2 |
| Mtibwa I | B | 590 ab | -1 | 328 b | 1 | 327 b | 1 | 0.56 abc | 0 | 29.9 bc | 1 | 38.5 abc | 0 | 2.5 a | -0.3 | 55 a | 13 |
| Mt. Harris | C | 575 ab | -2 | 301 b | -6 | 306 bc | -5 | 0.53 bc | -4 | 30.1 abc | 2 | 37.6 abc | -2 | 2.5 a | -0.2 | 59 a | 16 |
| Sudan | D | 642 ab | 5 | 355 b | 9 | 335 b | 2 | 0.55 abc | 0 | 29.0 bc | -1 | 39.2 abc | 2 | 2.8 ab | 0.0 | 33 ab | -4 |
| Saigon | E | 537 ab | -7 | 350 b | 7 | 370 ab | 13 | 0.66 ab | 15 | 29.2 bc | -1 | 41.8 ab | 7 | 2.8 ab | 0.0 | 47 ab | 6 |
| Mtibwa II | F | 694 ab | 11 | 357 ab | 9 | 318 bc | -3 | 0.52 bc | -6 | 30.2 abc | 2 | 38.1 abc | -1 | 2.5 a | -0.2 | 55 a | 13 |
| Keravat | G | 560 ab | -4 | 332 b | 2 | 343 b | 6 | 0.60 ab | 7 | 30.3 abc | 3 | 40.8 abc | 5 | 2.8 ab | 0.0 | 30 ab | -7 |
| Lembaga | H | 635 ab | 4 | 379 ab | 16 | 362 ab | 9 | 0.62 ab | 9 | 30.3 abc | 3 | 40.4 abc | 4 | 3.0 ab | 0.2 | 33 ab | -5 |
| East Region | I | 672 ab | 8 | 320 b | -1 | 296 bc | -8 | 0.51 bc | -7 | 28.8 bcd | -2 | 35.6 bc | -6 | 3.1 ab | 0.2 | 21 b | -14 |
| Topslip | J | 747 a | 17 | 558 a | 66 | 488 a | 40 | 0.75 a | 30 | 33.2 a | 11 | 45.5 a | 15 | 2.5 a | -0.2 | 55 a | 13 |
| S. Chanda | K | 396 b | -23 | 129 c | -57 | 188 c | -34 | 0.35 c | -31 | 25.0 d | -13 | 30.5 c | -17 | 3.5 b | 0.5 | 17 b | -17 |
| Hoshangabad | L | 396 b | -23 | 141 c | -53 | 200 c | -31 | 0.36 c | -30 | 26.6 cd | -8 | 30.6 bc | -17 | 3.1 ab | 0.2 | 19 b | -16 |

[#] Stand density in plots used as covariate.

*Table 5.* – Correlation coefficient between provenance means for different traits measured at different ages. Mean values for measurements up to 17 years from MADOFFE and MAGHEMBE (1988), but only the traits with significant provenance differences. H1–H17: mean height 1,2, 5,15 and 17 years after establishment; H_dom30: mean height of dominating trees after 30 years; BA17: basal area after 17 years; V17: volume per ha after 17; V30*: Volume per ha after 30 years estimated from a model with the stem number in the plots as covariate. V30: Volume per ha, V30m: Average volume per tree; STR17: stem straightness after 17; STR30: stem straightness (percentage of trees with score 1 and 2) after 30 years; STRSC30: stem straightness score after 30 years. Significant correlations are shown with bold figures.

| | H1 | H2 | H5 | H15 | H17 | BA17 | V17 | H_dom30 | V30* | V30 | $V30_m$ | STR17# | STR30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H2 | 0.17 | | | | | | | | | | | | |
| H5 | 0.22 | 0.27 | | | | | | | | | | | |
| H15 | -0.05 | 0.23 | 0.44 | | | | | | | | | | |
| H17 | 0.03 | -0.23 | 0.49 | 0.27 | | | | | | | | | |
| BA17 | -0.17 | 0.52 | **0.77** | 0.57 | 0.23 | | | | | | | | |
| V17 | -0.14 | 0.49 | **0.78** | 0.55 | 0.20 | **0.99** | | | | | | | |
| H_dom30 | 0.13 | 0.53 | **0.85** | 0.48 | 0.27 | **0.85** | **0.86** | | | | | | |
| V30* | 0.16 | **0.60** | **0.80** | 0.43 | 0.15 | **0.82** | **0.86** | **0.93** | | | | | |
| V30 | 0.15 | **0.59** | **0.86** | 0.41 | 0.23 | **0.87** | **0.89** | **0.93** | **0.98** | | | | |
| $V30_m$ | 0.17 | 0.50 | **0.81** | 0.35 | 0.15 | **0.75** | **0.80** | **0.89** | **0.98** | **0.94** | | | |
| STR17# | -0.25 | 0.18 | 0.57 | **0.58** | 0.36 | **0.68** | **0.64** | **0.64** | 0.54 | **0.59** | 0.44 | | |
| STR30 | -0.16 | 0.28 | **0.66** | **0.69** | 0.31 | **0.80** | **0.80** | **0.74** | **0.61** | **0.60** | **0.58** | 0.48 | |
| STRSC30 | 0.11 | -0.23 | **-0.63** | -0.55 | -0.31 | **-0.76** | **-0.77** | **-0.80** | **-0.63** | **-0.61** | **-0.58** | **-0.62** | **-0.92** |

[#] stem straightness after 17 years was scored on a scale from 1–5, but where the score 1 was given to very crooked trees (MADOFFE and MAGHEMBE, 1986), while the score 1 after 30 years was given to trees with a straight stem.

ume after 30 years (*Table 5*). Provenance heights after 1, 2, 3, 4, 5, 10, 15 and 17 in MADOFFE and MAGHEMBE (1988) were, with exception of the height after 5 years, not significantly correlated with height or volume after 30 years. However, the correlations between provenance estimates for height in different years in MADOFFE and MAGHEMBE (1988) were also surprisingly low (*Table 5*).

The latest ranking between provenances in this study concerning stem straightness was very similar to the one at five years, where especially the two Mtibwa samples and Mt. Harris already showed superior stem straightness and the two central Indian provenances, Hoshangabad and S. Chanda, showed poor stem straightness (PERSSON, 1971a). The correlation between provenance means for stem straightness scores in PERSSON (1971a) and stem straightness scores in this study was 0.87 (P < 0.0003). Provenance estimates for stem straightness scores after 17- (from MADOFFE and MAGHEMBE, 1988) and 30 years were significantly correlated (*Table 5*), although the superior rank of Mt. Harris as found in this study, and after 5 years by Persson (1971a), was not found by MADOFFE and MAGHEMBE (1988).



DOI:10.1515/sg-2007-0022
edited by Thünen Institute of Forest Genetics

## Discussion

The study showed that it was possible to find more than 10% differences in height between the best provenance and intermediate provenances, and 40% differences in volume per ha. Furthermore there were large and significant differences in the percentage of straight trees. As demonstrated by previous investigations (KEIDING, 1986; KJAER et al., 1995), it is possible to find fast growing provenances with high percentages of straight or semi-straight trees.

The volumes are associated with some uncertainty due to different survival and/or inconsistent felling. This is particularly pronounced for the two slow growing provenances K and L with a systematic low stand density in the plots. Unfortunately, we cannot conclude to what extend the differences in stand density are due to different felling regimes, or solely due to different mortality. The differences between provenances were not present after 15 years (MADOFFE and MAGHEMBE, 1988). Thus, it seems most likely that the differences in stand density after 30 years are due to differences in mortality rather than a systematically felling only in plots containing provenance K and L.

Differences in growth and stem straightness have also been found in other provenance test series including a large range of natural provenances (KEIDING et al., 1986; KUMARAVELU, 1993; KJAER et al., 1995; KUANG et al., 1996). However, a provenance by site interaction was found for growth, but not for stem straightness (KJAER et al., 1995). Thus, the results of this study concerning growth are probably only valid for similar areas.

Nevertheless, Topslip was also superior in an Indian provenance trial (KUMARAVELU, 1993). Topslip is located 23 km West of Varagalaiar, 80 km South of Coimbatore in Tamil Nadu. It is part of the Malabar bioregion in the Anamalai Hills of the Western Ghats of the states Tamil Nadu and the adjacent state Kerala, India (MUTHURAMKUMAR and PARTHASARATHY, 2000). The vegetation in the region is characterised as tropical evergreen forests and the climate is strongly influenced by the south-west monsoon (June–August/September) and north east monsoon (October–December) with a distinct dry season from January to April/May (MUTHURAMKUMAR and PARTHASARATHY, 2000). From this area a number of Malabarian provenances have shown outstanding growth and stem straightness in several tests elsewhere in the world, also at sites with less precipitation than observed in the region of Malabar (KEIDING et al., 1986, KJAER et al., 1995; SUHAENDI, 1998). The precipitation at the trial site evaluated in this study is less than for the Malabar region (*Table 1*). However, this is probably compensated by frequent mists at the rainy side east of the Usambaras and mountain streams that provide a continuous water supply and a high water table.

A similar rank between Kihuwi and Mtibwa concerning growth and stem straightness was indicated in a five year progeny trial with open pollinated families from the provenances Kihuwi, Mtibwa and Bigwa (PERSSON, 1971b). The comparable high proportion of well formed trees for Tanzanian landraces was also reported in field trials in Ivory Coast and Mexico (KEIDING et al., 1986). Although comparisons among trials are difficult without the same provenance represented, it supports the hypothesis that the interaction between genotype and environment for stem straightness in teak is modest.

This study showed good opportunities to make selections for growth after 17 years based on basal area and volume estimates. Early provenance estimates for height (up to 17 years after establishment) were with the exception of height after 5 years poorly correlated with volume after 30 years. The correlation coefficient at the provenance mean level between 7- and 17-year basal areas was respectively 0.77 and 0.67 in two Central American field trials and the 9-17-year correlation was 0.93 in a Brazilian field trial (KJAER et al., 1995).

The opportunity for early selection for stem straightness is indicated by the high and significant correlation with the 5 years results from PERSSON (1971a). The contradicting results after 5, 17 and 30 years for Mt. Harris are disturbing in this respect, but it is possible that they are due to an early flowering causing forks as found by (PERSSON, 1971a), combined with selective thinning that have removed the worst performing trees in this provenance after the evaluation of MADOFFE and MAGHEMBE (1988). In KJAER et al. (1995), correlations between estimates of provenance means for stem form at age 9 and 17 years varied between 0.35 and 0.76 in different trials.

## Conclusion

In this study, the provenance Topslip emerged as the single, outstanding provenance for both growth and stem straightness confirming that the Annamalai Hills in the states of Kerala and Tamil Nadu contains well performing provenances. Beside this provenance, the Tanzanian landrace Kihuhwi proved superior growth and stem straightness.

## References


FAO: New_LocClim. Local Climate Estimator (2005): ESA Newsletter No 26 2004, 1–5 pp.

GRAUDAL, L., E. D. KJAER, V. SUANGTHO, P. SAARDAVUT and A. KAOSA (1999): Conservation of genetic resources of teak (*Tectona grandis*) in Thailand. Technical Note, DANIDA Forest Seed Centre No. 52, 39 pp.

HEDEGART, T. (1976): Breeding systems, variation and genetic improvement of teak *(Tectona grandis* L.f.). *In:* BURLEY, J. and STYLES, B. T. (Eds). Tropical trees: variation, breeding and conservation. Linn. Soc. Symp. Ser. No. 2. Academic Press, London.

HENDERSON, C. R. (1984): Applications of linear models in animal breeding. University of Guelph, Canada, 462 pp.

KADAMBI, K. (1972): Silviculture and management of teak. Bulletin No. 24. Scholl of Forestry, Stephen F. Austin State University, Nacogdoches, Texas, 137 pp.

KAOSA-ARD, A. (2000): Gains from provenance selection. *In:* T. ENTERS and C. T. S. NAIR (eds.). Site, Technology and Productivity of Teak Plantations. Proceedings, Bangkok, 2000. FORSPA publication No. 24/2000. Teaknet Publication No. 3. p. 191–207.

KEIDING, H. (1973): Forest Genetic resources information. FAO Forestry Occasional Paper 1, 38 pp.

KEIDING, H., H. WELLENDORF and E. B. LAURIDSEN (1986): Evaluation of an international series of teak provenance trials. Danida Forest Seed Centre (Danish Centre for Forest, Landscape and Planning), Denmark, 81 pp.




DOI:10.1515/sg-2007-0022
edited by Thünen Institute of Forest Genetics

KEIDING, H. (1989): Seed collection from teak plantations at Mtibwa and Longuza, Tanzania. Report/note 7 p. Danida Forest Seed Centre, Denmark.
KJAER, E. D., E. B. LAURIDSEN and H. WELLENDORF (1995): Second evaluation of an international series of teak provenance trials. Danida Forest Seed Centre (Danish Centre for Forest, Landscape and Planning), Denmark, 118 pp.
KRISHNAPILLAY, B. (2000): Silviculture and management of teak plantations. Unasylva **51**: 14–21.
KUANG, B., S. ZHEN, M. LUO and M. LIN (1996): Evaluation of aggregate genetic value of main characters of provenances of teak. Forest Research **9**: 7–14.
KUMARAVELU, G. (1993): Teak in India. *In:* H. WOOD (ed.) Teak in Asia, FORSPA Publication No. 4, Bangkok, pp. 27–34.
MADOFFE, S. S. and J. A. MAGHEMBE (1988): Performance of teak (*Tectona grandis*) provenances seventeen years after planting at Longuza, Tanzania. Silvae Genetica **37**: 175–178.
MUTHURAMKUMAR, S. and N. PARTHASARATHY (2000): Alpha diversity of lianas in a tropical evergreen forest in the Anamalais, Western Ghats, India. Diversity and Distributions **6**: 1–14.
PANDEY, D. and C. BROWN (2000): Teak: a global overview. Unasylva **51**: 3–13.
PEDERSEN, A. P. (1995): IUFRO Symposium on Innovations in Tropical Tree Seed Technology. Post Symposium Tour Guide, pp. 27–33.
PERSSON, A. (1971a): Observations from a provenance trial of Tectona grandis Linn. F. at Longuza, Tanga Region. Tanzania Silviculture Res. Note 22. Lushoto. 13 p.
PERSSON, A. (1971b): Observations from a progeny trial of *Tectona grandis* Linn. F. at Longuza, Tanga Region. Tanzania Silviculture Res. Note 24. Lushoto. 11 p.
SAS INST. INC. (1999): SAS OnlineDoc_ version eight, SAS Institute Inc., Cary, NC, USA, http://v8doc.sas.com/sashtml.
SHAPIRO, S. S. and M. B. WILK (1965): An analysis of variance test for normality (complete samples). Biometrika **52**, 591–611.
SUHAENDI, H. (1998): Teak improvement in Indonesia. *In:* Teak for the Future – Proceedings of Second Regional Seminar on Teak. Myanmar 1995. Edited by: MASAKAZU KASHIO and KEVIN WHITE, FAO Regional Office for Asia and the Pacific.
WOOD, P. J. (1967): Teak planting in Tanzania. Proc. FAO World Symp. Man-made forests. Document 3: Canberra, A.C.T., pp. 1631–1644.

# Swiss Stone Pine Provenance Experiment in Romania: II Variation in Growth and Branching Traits to Age 14

By I. BLADA*) and F. POPESCU

Forest Research and Management Institute, Sos. Stefanesti, 128, Sector 2, Bucharest 11, Romania

(Received 10th April 2006)

## Summary

After the nursery testing, twelve Swiss stone pine (*Pinus cembra* L.) provenances from the Alps and Carpathian Mountains were planted out at two sites located at high elevation in the Southern and Northern Carpathians. Total height growth (H), annual height growth (h), root collar diameter (RCD), branches per whorl (BW) and survival (SV) were measured and analyzed. Analysis of variance showed highly significant ($p < 0.01$; $p < 0.001$) differences between provenances for all traits, except survival, suggesting that selection at the provenance level could be possible. Also, over locations analysis revealed significant genotype x environment interaction, demonstrating that some provenances react differently to environmental conditions and, selection should take this into account. The phenotypic coefficient of variation was moderate for growth and high for number of branches per whorl suggesting that selection within provenance can also be applied.

Finding of significant and highly significant age-age and trait-trait phenotypic correlations indicated that early and indirect selection in Swiss stone pine species is possible. According to DUNCAN's multiple range test the best performing provenances of the two mountain ranges were selected for operational planting and breeding programmes. The results of this study validate that a very slow growing species, such as Swiss stone pine may still possess very high genetic variation in growth rate; consequently, this trait can be improved. Finally, an attempt has been made to develop a seed transfer guidelines for the species by using the pattern of geographic variation as a basis.

*Key words: Pinus cembra*, Swiss stone pine, provenance trial, genetic variation, growth traits, branching, age-age correlation, early selection, indirect selection.

## Introduction

The Swiss stone pine is a glacial age relict naturally distributed at high elevations in the Alps and Carpathi-

*) Corresponding author: I. BLADA. E-mail: ioan_blada@yahoo.com



DOI:10.1515/sg-2007-0023
edited by Thünen Institute of Forest Genetics