SURVIVAL, GROWTH, YIELD AND WOOD DENSITY OF *PINUS PATULA* LAND RACES/PROVENANCES AT SAO HILL AND SHUME FOREST PROJECTS, TANZANIA

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NSHUBEMUKI, L., MUGASHA, A.G., CHAMSHAMA, S.A.O., MUGUNGA, C.P. & IDDI, S. 1996. Survival, growth, yield and wood density of *Pinus patula* land races/ provenances at Sao Hill and Shume Forest Projects, Tanzania. The performance of five *Pinus patula* land races at Kihanga Arboretum, Sao Hill (Sao Hill Forest Project) and two Mexican provenances and eight land races at Sungwi, Lushoto (Shume Forest Project), Tanzania were compared in terms of survival, growth, yield, stem form and wood basic density. Final assessment was done at Kihanga and Sungwi experiments at ages of 18.0 and 21.9 years respectively. The main results of the study were:

- The survival of all land races and/or provenances in the two sites was generally high (83.3 - 92.9%) but were not statistically significant ($p > 0.05$).
- At early ages: up to 5.3 years for the Kihanga experiment and up to 4.6 years for the Sungwi experiment, height growth revealed significant differences ($p < 0.05$).
- DBH growth showed significant differences ($p < 0.05$) at age 7.6 years for the Kihanga experiment and 4.6 and 9.9 years for the Sungwi experiment.
- There was no significant difference ($p > 0.05$) in stem form between the land races/ provenances at Sungwi.
- For the Kihanga experiment the two Sao Hill land races had significantly higher basal area and standing volume at early ages only. At Sungwi, there were significant differences between provenances in terms of basal area at ages 4.6 and 21.9 years and standing volume at ages of 4.6, 9.9 and 21.9 years. The two Rhodesian land races and two Mexican provenances had the highest yield.
- Basic density ranged from 372 km m^{-3} for one Sao Hill land race at Kihanga to 499 kg m^{-3} for the Kenya land race at Sungwi but there were no significant differences ($p > 0.05$) in wood basic density between land races/provenances at both sites.

Overall, the Rhodesian land races and Mexican provenances performed better than the rest. It is recommended therefore that these land races/provenances be used as seed source for afforestation programme at Shume. The Kigogo land race is already in use. However, as a way of broadening the genetic base, the other provenances can also be used as seed source for afforestation at the respective sites.

Key words: *Pinus patula* - provenance - land race - survival - growth - yield - wood density

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NSHUBEMUKI,L., MUGASHA, A.G., CHAMSHAMA, S.A.O. , MUGUNGA, C.P. & IDDI, S.1996. Kemandirian, pertumbuhan, hasil dan ketumpatan kayu ras tanah/ provenans *Pinus patula* di Projek Hutan Sao Hill dan Shume, Tanzania. Prestasi lima ras tanah *P.patula* di Arboretum Kihanga, Sao Hill dan dua provenans Mexico serta lapan ras tanah di Sungwi, Lushoro, Tanzania dibuat perbandingan dari segi kemandirian, pertumbuhan, hasil, bentuk batang dan ketumpatan asas kayu. Penilaian akhir dijalankan di eksperimen Kitanga dan Sungwi masing-masing pada umur 18.0 dan 21.9 tahun.

Keputusan-keputusan penting adalah:

- Kemandirian bagi semua ras tanah dan/atau provenans di dalam kedua-dua tapak pada umumnya adalah tinggi (83.3-92.9%) tetapi tidak ketara secara statistik ($p>0.05$).
- Pada usia yang rendah: sehingga 5.3 tahun bagi eksperimen Kihanga dan sehingga 4.6 tahun bagi Sungwi, pertumbuhan ketinggian menunjukkan perbezaan yang ketara ($p<0.05$).
- Pertumbuhan DBH menunjukkan perbezaan yang ketara ($P<0.05$) pada umur 7.6 tahun bagi eksperimen Kihanga serta 4.6 dan 9.9 tahun bagi eksperimen Sungwi.
- Tidak terdapat perbezaan yang ketara ($p>0.05$) di dalam bentuk batang di antara ras tanah/provenans di Sungwi.
- Bagi eksperimen Kihanga, kedua-dua ras tanah Sao Hill mempunyai luas pangkal dan isipadu dirian yang lebih tinggi pada usia yang rendah sahaja. Di Sungwi, terdapat perbezaan yang ketara di antara provenans-provenans dari segi luas pangkal pada umur 4.6 dan 21.9 tahun dan isipadu dirian pada umur 4.6, 9.9 dan 21.9 tahun. Kedua-dua ras tanah Rhodesia dan kedua-dua provenans Mexico mempunyai hasil tertinggi.
- Ketumpatan asas adalah di antara 372 kg m^{-3} bagi ras tanah Sao Hill di Kihanga hingga 499 kg m^{-3} bagi ras tanah Kenya di Sungwi tetapi tiada perbezaan yang ketara ($p>0.05$) di dalam ketumpatan asas kayu di antara ras tanah/provenans di kedua-dua tapak.

Secara keseluruhannya, ras tanah Rhodesia dan provenans-provenans Mexico menunjukkan prestasi yang lebih baik daripada yang lain. Adalah disyorkan supaya ras tanah/provenans-provenans ini digunakan sebagai sumber biji benih untuk program penghutanan di Shume. Ras tanah Kigogo telahpun digunakan. Bagaimanapun, sebagai satu cara untuk meluaskan asas genetik, provenans-provenans yang lain juga boleh digunakan sebagai sumber biji benih bagi penghutanan di tapak masing-masing.

Introduction

Tanzania's natural forests/woodlands cover about 42% of the total land area of 94.5 million ha. It was estimated that the rates of disapearance of these closed forests and woodlands in Tanzania at the end of 1980 were about 100 000 ha and 120 000 ha respectively (Troensegaard 1989). To reverse this trend, Tanzania, like many tropical countries, has embarked on an ambitious plantation forestry programme to meet the increasing demand for industrial wood, construction poles and fuelwood, as well as reducing exploitation pressure on indigenous forests (Mhando *et al.* 1993). As a result, the area under industrial plantation forestry has increased from 39 000 ha in 1976 to 80 000 in 1986 (Ahlback 1986). The main species planted are *Pinus patula, Pinus caribaea, Pinus elliottii, Cupressus lusitanica, Tectona grandis* and several *Eucalyptus* species. *Pinus patula* is a dominant softwood plantation species accounting for 60% and 72% of the total plantation and softwood plantation areas respectively (MLNRT 1989). In Sao Hill alone, the largest industrial plantation, *P. patula* accounts for 75% of the total area planted (Mbwana 1991).

Pinus patula was introduced into Tanzania by the Germans during their administration in early 1900. From this time, species trials were established in various mountain moist forest areas of Tanzania. As a result of relatively high productivity of *P. patula* trees obtained from these trials, large scale planting of the species was initiated in late 1950's. The species is planted mainly in the Northeastern Highlands (North and West Kilimanjaro and Mount Meru), West Usambara Mountains (Shume and Magamba) and the Southern Highlands (Sao Hill, Kiwira and Kawetire) (Nasser *et al.* 1993). The source of seed used for establishment of these plantations is not known.

Given the wide climatic variation over the species range, substantial provenance variations might be expected in such characteristics as tree survival, growth, stem form, yield and wood basic density. In order to evaluate the performance of different *P. patula* provenances and to broaden the genetic base and reduce risk of pests and diseases, provenance experiments were established in West Usambara Mountains (Lushoto and Shume), Meru and Sao Hill. The performance of *P. patula* provenances in Lushoto has been evaluated by Nasser *et al.* (1993). The survival, growth, yield and wood basic density of the three provenances of *P. patula* (ex Rhodesia, Kigogo in Mufindi at Sao Hill and Old Moshi in Moshi) revealed no significant differences between provenances (Nasser *et al.* 1993). The objective of the present paper is to compare the performance of *P. patula* provenances in terms of survival, growth, yield, stem form and wood basic density at Kihanga Arboretum (hereinafter referred to as Kihanga), Sao Hill and Sungwi, Lushoto, Tanzania. Two experiments, one with five land races and the second with two provenances and eight land races of *P. patula,* were established in 1972 and 1975 at Kihanga and Sungwi respectively.

Materials and methods

Study sites

Two experiments of *P. patula* were established, one at Kihanga Arboretum, Sao Hill (8° 26' S; 35° 13' E) (Sao Hill Forest Project) at an elevation of 1800 m a.s.l. and the other at Sungwi, Lushoto (4° 40' S; 38° 10' E) (Shume Forest Project) at 1900 m a.s.l., Tanzania.

Kihanga

The area receives mean annual rainfall of about 900 mm, most of it falling between November and April. A mean annual temperature of about 16 °C is experienced with some occasional frosts (Nykvist 1976). The soils are classified as dystric nitosol in association with orthic acrisols and some clay loams, acidic kaolinitic, with low base cation exchange capacity. The experimental area has a slope of approximately 2-3%. Selected soil properties are presented in Table 1. The pH in the pedon sampled to 70 cm depth ranged from 4.11 to 5.69. The original vegetation in the area was characterised by grassland with scattered short shallow rooted bushes dominated by *Brachystegia* and *Julbernardia* species.

Table 1. Means of selected soil properties of *Pinus patula* land races/provenances experimental sites at Kihanga arboretum, Sao Hill and Sungwi, Lushoto, Tanzania

Soil depth cm	$pH(H_2O)$[1]	Total N (%)	Available P ($ug\ g^{-1}$)
	Kihanga arboretum		
LFH			
0-10	5.23	0.12	238.7
10-20	4.96	0.11	277.1
20-40	5.23	0.09	143.8
40-70	5.11	0.05	198.8
	Sungwi		
LFH			
0-10	5.69	0.93	986.3
10-20	4.11	0.72	696.9
20-40	5.64	0.67	887.4
40-60	5.34	0.58	715.6
60-100	5.48	0.37	509.2

[1]Numbers of observations (n) per soil depth increment were 3 and 4 for Kihanga arboretum and Sungwi respectively.

Sungwi

The mean annual rainfall for 14 years (1958-1972) is 1090 mm, distributed in two main rain seasons, i. e. long rains from March to May, and short rains in November and December. The mean mininum and maximum temperatures are 7 °C and 27 °C respectively. The site is more or less flat with a slope of < 5%. The pH in the pedon sampled to 70 cm depth ranged from 4.96 to 5.23. The earlier vegetation of the site consisted of a 40-y-old cypress plantation before which the site was covered with a natural montane moist forest dominated by *Ocotea usambarensis* and *Podocarpus* species.

Provenances and land races in the experiments

The experiment at Kihanga is registered as Lushoto Silviculture Research Centre experiment No. 831 and has five land races as shown in Table 2. All land races were obtained locally in Tanzania. Evaluation of the performance of superior land races in Tanzania was necessary since the source of seed used for establishment of *P. patula* plantations (land races) is not known. The provenance/land race trial at Sungwi is registered as Lushoto Silviculture Research Centre experiment number No. 768 and has two provenances and eight land races as shown in Table 2.

Sources of seed and nursery techniques

Seed sources of *P. patula* provenances and/or land races planted at Kihanga and Sungwi are presented in Table 2. Seedlings of *P. patula* at Kihanga were raised at the Sao Hill Forest Project central nursery, while those for planting at Sungwi were raised at the Lushoto Silviculture Research Centre nursery. At both nurseries, seedlings were raised using standard cultural techniques (Forest Division 1982).

Table 2. Seed source location of *Pinus patula* land races/provenances planted at Kihanga arboretum, Sao Hill and Sungwi, Lushoto, Tanzania

Land race/ provenance[1]	Country of origin	Latitude	Longitude	Altitude (m a.s.l.)
		Kihanga arboretum		
Kawetire - K_1	Tanzania	8° 50'S	33° 22'E	2500
Kiwira - K_2	Tanzania	8° 50'S	33° 31'E	2000
Shume - K_3	Tanzania	4° 45'S	38 15' E	1500
Sao Hill - K_4	Tanzania	8° 26'S	35° 13'E	1800
Sao Hill - K_5	Tanzania	8° 26'S	35° 13'E	1800
		Sungwi		
Kawetire - S_1	Tanzania	8° 50'S	33° 30'E	2500
Kigogo - S_2	Tanzania	9° 0'S	33° 30'E	1800
N. Kilim. - S_3	Tanzania	2° 56'S	37° 28'E	2000
Kenya - S_4	Kenya	0° 40'N	35° 00'E	1850
Kenya - S_5	Kenya	0° 56'N	35° 04'E	1700
Manjakatonga - S_6	Madagascar	19° 22'S	47° 18'E	1700-1900
Rhodesia - S_7	Rhodesia	18° 02'S	32° 47'E	1935
Rhodesia - S_8	Rhodesia	19° 22'S	30° 39'E	1480
Oaxaca - S_9	Mexico	18° 10'N	96° 08'W	2072
Vera Cruz - S_{10}	Mexico	19° 33'N	96° 06'W	2760

[1]For abbreviations see text. N. Kilim. - North Kilimanjaro.

Experimental design and field procedures

For each site, a randomized complete block design was used. The Kihanga experiment consisted of three, while that of Sungwi four replications. For the respective experiments, each provenance or land race was represented once in each block.

Kihanga

For each land race (each plot) within each block 8 × 8 trees were planted at a spacing of 2.5 × 2.5 m. These 64 trees form a sample plot. In addition, two surrounding rows making up of a mixture of surplus stock were planted around the experiment.

Sungwi

Each provenance or land race within each block was made up of 9 x 9 trees planted at a spacing of 2.5 × 2.5 m. For each plot, there was one surrounding row. The inner 49 tree form a sample plot. The whole experiment has 2 surrounding rows made up of a mixture of surplus stock from the 10 provenances and/or land races .

Field procedures

Both sites were prepared by complete clearing of all vegetation followed by staking and pitting. Pit size was 30 × 30 cm at both sites. Planting was done in March 1975 at Kihanga and January 1972 at Sungwi.

Pruning was carried out once to half height in March 1979 at Kihanga and in August 1976 at Sungwi. The Kihanga experiment has never been thinned. The Sungwi experiment was thinned (selective thinning) in 1988 (age 15 years) by removing 30 trees from each plot. According to the Tanzania Forest Division Technical Order No. 24 of 1970, thinning of *P. patula* plantations is done at ages 9, 13, 17, and 21 years (Forest Division 1982).

Data collection

Previous assessments

Data on previous assessments of tree survival, breast height diameter (DBH), and height for Kihanga were obtained from the Tanzania Forestry Research Institute Southern Research Centre, Sao Hill and those for Sungwi were obtained from the Silviculture Research Centre in Lushoto. The Kihanga experiment was assessed at ages 1.3, 2.3, 3.6, 5.3 and 7.6 years. The Sungwi experiment was assessed at ages 1.2, 2.2. 4.6, 9.9 and 16.9 years.

Final assessments

In December 1993 when the final assessment was done, the Kihanga experiment was 18.0 years old, while that of Sungwi was 21.9 years old. Both experiments were assessed for DBH, height, and wood basic density. For each plot, all surviving inner plot trees were measured for DBH using a diameter tape to the nearest 0.1 cm. The DBH tally also gave the tree survival or stand stocking data. For height, two fattest trees in each plot were measured to obtain dominant height. In order to get average height, four other trees (two representing small and two medium sized trees) were measured from each plot to make a total of six measured trees. Height was measured using a suunto hypsometer. Since all trees at Kihanga showed very good stem form there was no assessment of stem form. Stem quality was assessed for the Sungwi experiment only. This was done for all surviving inner plot trees in each plot. The stem quality was categorised as follows:

- straight
- stem with slight bend
- crooked stem

For determination of wood basic density, six defect-free trees with straight boles and representative of the diameter ranges of each plot were sampled. Wood cores were then taken from selected trees using an increment borer. Wood cores were taken at DBH point. Each core was inserted in the trough of a fluting paper and immediately air dried to prevent fungal growth. In the laboratory, each core was divided into three equal portions representing inner, middle and outer wood. The cores were saturated in distilled water for at least 24 hrs in order to regain green condition after which their volumes were measured by water displacement. The cores were then oven-dried at 103 ± 2 °C to constant weight and cooled over silica gel before determining oven dry weight. Basic density for each core was calculated as its oven dry weight divided by green volume.

Soil sampling and analysis for characterization of study sites

Soil sampling was done at each study site in December 1993. Four soil pits were located at random and dug to 70 cm depth in each block. Within each soil pit, soil samples were taken at the following depth intervals: LFH-layer, 0-10, 10-20, 20-40, and 40-70 cm. Soil samples taken from the same depth within the same block were composited and a sub-sample taken for laboratory analysis. In the laboratory, soil samples were air dried and ground to pass a 2-mesh sieve. Mineral soil particle size distribution was then determined by the hydrometer method. Soil pH was determined by means of hydrogen electrode pH meter at distilled water:soil ratio of 2:1. A sub-sample of 2-mesh sieved soil was ground to pass a 100-mesh sieve and analysed for N, P and C. Total N was determined by the Kjeldahl method. For total P, soil sub-samples were ashed in the muffle furnace at 550 °C for 1-2 h. P was then extracted by placing the ash in sulphuric acid followed by shaking for 24 h. Total P in the filtrate was estimated by the ascorbic acid method. Carbon was estimated by loss on ignition method.

Data analysis

Statistical analyses were carried out using SAS-PC (SAS Inst. Inc. 1987). For each experiment and for each tree, survival percentage, DBH (cm), height (m), wood basic density (kg m^{-3}) and stem form, and stand [(basal area (m^2 ha^{-1}) and volume (m^3 ha^{-1})] attributes were subjected to analysis of variance (ANOVA) of plot means. Volume of individual trees at Kihanga and Sungwi was obtained using individual tree volume equation developed previously for *P. patula* at Sao Hill (Malimbwi 1987) and Northeast Tanzania (Maatta & Paivinen 1987).

Prior to ANOVA, score and count data were transformed to force normality and equal variance. Arcsine transformation was applied to percentage survival data and a square root transformation to stem form (Sokal & Rohlf 1969, Kilinganire & Hall 1993). For significant treatments, the Duncan's Multiple Range Test was used for grouping of means (Steel & Torrie 1980).

Results

Survival

The survival of the different provenances and/or land races is shown in Table 3. For both experiments, there was no significant difference (p>0.05) in survival between provenances and/or land races of *P. patula*. During the final assessment of the Kihanga experiment at the age of 18 years, tree survival ranged between 83.3 and 88%. For the Sungwi experiment, just before it was thinned at the age of 16.9 years, the tree survival ranged from 86.2 to 92.2%.

Table 3. Survival (%) trends and stocking[1] (%) after thinning of *Pinus patula* land races/provenances at Kihanga arboretum in Sao Hill and Sungwi in Lushoto, Tanzania

Land race/ provenance[2]	Age (y)	Kihanga arboretum					
		1.3	2.3	3.6	5.3	7.6	18.0
Kawetire - K_1		94.3	91.7	89.1	87.5	85.8	84.9
Kiwira - K_2		98.9	97.9	97.9	97.4	97.4	88.0
Shume - K_3		97.9	98.4	98.4	97.9	97.4	83.8
Sao Hill - K_4		99.5	98.9	98.9	98.4	97.4	83.3
Sao Hill - K_5		98.9	97.9	97.9	96.9	93.8	85.4
		Sungwi					
	Age (y)	1.2	2.2	4.6	9.9	16.9	21.9[2]
Kawetire - S_1		99.5	99.5	99.0	98.0	88.5	60.7
Kigogo - S_2		98.5	98.5	98.5	98.0	92.2	63.3
N. Kilim. - S_3		100.0	99.5	99.5	98.5	87.2	62.3
Kenya - S_4		99.0	99.0	98.5	96.9	86.7	61.8
Kenya - S_5		99.5	99.5	99.5	96.9	86.7	58.8
Manjakatonga - S_6		99.5	98.5	98.5	97.5	89.3	64.8
Rhodesia - S_7		100.0	99.5	99.5	99.0	91.8	64.8
Rhodesia - S_8		100.0	99.5	99.0	98.0	88.8	62.3
Oaxaca - S_9		100.0	99.5	99.5	96.4	86.2	59.7
Vera Cruz - S_{10}		100.0	100.0	100.0	98.5	87.8	61.7

[1]Stocking percentage after thinning. For Sungwi, stocking is presented for age 21.9 years since the stand was thinned at the age of 17 years.
[2]N. Kilim. - North Kilimanjaro.

Height growth

For the five land races of *P. patula* at Kihanga, ANOVA revealed significant differences (p< 0.05) in height growth at the ages of 2.3, 3.6 and 5.3 years (Table 4). In general, Sao Hill land races showed superior height growth when compared to the other land races. At Sungwi, the 10 provenances and land races of *P. patula* showed significant differences ($p < 0.05$) at the ages of 2.2 and 4.6 years. The Laventa provenance showed least height growth.

Table 4. Mean height growth of *Pinus patula* land races/provenances at Kihanga arboretum in Sao Hill and Sungwi in Lushoto, Tanzania

Land race/ provenance[1]	Age (y)	Kihanga arboretum					
		1.3	2.3	3.6	5.3	7.6	18.0
Kawetire - K_1		0.9	1.8c[2]	3.5b	13.6b	18.8	23.5
Kiwira - K_2		0.9	1.9c	3.7b	13.5b	18.8	21.9
Shume - K_3		0.9	1.9bc	3.7b	14.6ab	19.6	22.2
Sao Hill - K_4		1.0	2.2a	4.1a	15.3a	19.3	22.5
Sao Hill - K_5		0.9	2.1ab	4.0a	15.7a	20.9	23.0
		Sungwi					
	Age (y)	1.2	2.2	4.6	9.9	16.9	21.9
Kawetire - S_1		1.6	3.1bc[2]	6.5bcd	15.1	20.0	21.4
Kigogo - S_2		1.8	3.1abc	6.7bcd	15.4	26.4	23.9
N. Kilim. - S_3		1.8	2.3ab	6.9abc	15.6	22.8	23.5
Kenya - S_4		1.8	3.2abc	6.8abc	14.4	21.8	23.9
Kenya - S_5		1.8	3.2abc	6.7abc	14.7	22.1	23.6
Manjakatonga - S_6		1.9	3.0c	6.4cd	15.2	21.1	22.9
Rhodesia - S_7		1.8	3.4ab	7.0a	16.1	21.9	23.9
Rhodesia - S_8		1.8	3.4ab	6.9a	15.1	24.0	24.3
Oaxaca - S_9		1.8	3.2a	7.0ab	15.2	22.2	23.2
Vera Cruz - S_{16}		1.8	3.0c	6.2d	13.2	21.7	22.7

[1]N. Kilim. - North Kilimanjaro.
[2]For each site, values with the same letter(s) within the same column do not differ significantly at $p < 0.05$.

Breast height diameter growth

The DBH growth of the five land races of *P. patula* at Kihanga was significantly different ($p < 0.05$) at the age of 7.6 years (Table 5). Breast height diameter growth for the two Sao Hill land races was significantly higher than the other three land races. For the Sungwi experiment, the 10 provenances and land races of *P. patula* showed significant differences ($p < 0.05$) in DBH growth at the ages of 4.6 and 9.9 years.

Stem form and yield

For the Sungwi experiment, there was no significant difference ($p > 0.05$) between the 10 provenances and land races of *P. patula* (Table 6).

Basal area and standing volume

For Kihanga experiment at age of 5.3 years, the two Sao Hill land races showed significantly ($p < 0.05$) higher basal area and standing volume. Assessments in later years showed no significant differences ($p > 0.05$) although the Kawetire land race had higher basal area and standing volume. At Sungwi, statistical analysis showed that there were significant differences between provenances and land races in terms of basal area at 4.6 and 21.9 years and standing volume at the ages of 4.6, 9.9 and 21.9 years. At the age of 21.9 years the Rhodesian land race had the highest basal area and standing volume.

Table 5. Mean breast height diameter growth of *Pinus patula* land races/provenances at Kihanga arboretum in Sao Hill and Sungwi in Lushoto, Tanzania

Land race/provenance[1]		Kihanga arboretum		
Age (y)	5.3	7.6	18.0	-
Kawetire - K_1	9.3	13.0a[2]	20.9	-
Kiwira - K_2	8.8	13.4abc	19.7	-
Shume - K_3	9.8	13.2bc	19.7	-
Sao Hill - K_4	10.7	14.4ab	20.1	-
Sao Hill - K_5	10.5	14.6a	20.4	-
		Sungwi		
Age (y)	4.6	9.9	16.9	2.19
Kawetire - S_1	11.5abc[2]	17.4abc	22.3	24.0
Kigogo - S_2	11.5abc	17.9bc	21.1	24.1
N. Kilim. - S_3	12.0ab	18.0bc	21.3	23.8
Kenya - S_4	11.8ab	18.5ab	21.8	25.2
Kenya - S_5	11.6abc	17.8bc	21.3	24.5
Manjakatonga - S_6	10.8c	17.5c	21.0	23.7
Rhodesia - S_7	12.2a	18.5ab	22.1	25.8
Rhodesia - S_8	11.9ab	18.4abc	22.1	25.6
Oaxaca - S_9	12.2a	18.9a	23.2	28.7
Vera Cruz - S_{10}	11.1bc	17.3bc	21.1	24.2

[1]N. Kilim. - North Kilimanjaro.
[2]For each site, values with the same letter(s) within the same column do not differ significantly at $p < 0.05$.

Wood basic density

At the age of 18.0 years at Kihanga and 21.9 years at Sungwi, wood basic density assessments indicated that there were no significant differences between provenances and land races ($p > 0.05$; Table 6). However, at Kihanga one Sao Hill land race (K_5) had the lowest value of 372 kg m^{-3} while Kiwira land race (K_2) had the highest value of 421 kg m^{-3}. At Sungwi, the Kigogo land race had the lowest basic density of 471 kg m^{-3} while the two Kenya land races had the highest value of 499 kg m^{-3}.

Table 6. Mean standing total basal area and standing volume production, wood basic density and stem form of *Pinus patula* land races/provenances at Kihanga arboretum in Sao Hill and Sungwi in Lushoto, Tanzania

Land race/ provenance[1]	Standing basal rea (m^2 ha^{-1})			Standing volume (m^2 ha^{-1})			Wood density (kg ha^{-1})	Stem form
				Kihanga arboretum				
Age (years)	5.3	9.9	18.0	5.3	7.6	18.0	18.0	
Kawetire K_1	9.5b[2]	-	47.0	78.1c	192.1	546.6	388	-
Kiwira K_2	9.7b	-	43.0	78.4c	229.9	475.0	421	-
Shume K_3	11.9ab	-	41.1	103.1b	234.0	458.8	386	-
Sao Hill K_4	14.1a	-	42.5	126.1a	267.6	478.9	408	-
Sao Hill K_5	13.3ab	-	43.0	124.1a	287.0	515.5	372	-
				Sungwi				
Age (years)	4.6	9.9	21.9	4.6	9.9	21.9	21.9	21.9
Kawetire - S1	16.4abc[2]	39.9abc	51.2	58.9ab	288.9	450.1c	484	1.3
Kigogo - S2	16.4abc	39.5abc	48.7b	60.5ab	309.9	530.9abc	470	1.3
N. Kilim. S3	18.0ab	40.0abc	47.0ab	67.8a	318.7	502.3c	471	1.2
Kenya - S_4	17.1ab	41.5ab	51.0ab	64.2ab	302.3	550.1bc	499	1.2
Kenya - S_5	16.8abc	38.6bc	48.2b	62.0ab	288.9	500.7c	499	1.2
Manjakatonga - S_6	14.4c	37.4c	48.6b	51.7b	292.3	504.8c	496	1.2
Rhodesia - S_7	18.5a	43.1a	56.6ab	70.9a	347.1	588.0ab	483	1.2
Rhodesia - S_8	17.6ab	40.5abc	54.5ab	66.9a	318.3	590.3ab	491	1.2
Oaxaca - S_9	18.4a	43.3a	58.8ab	70.9a	330.3	656.8abc	482	1.2
Vera Cruz - S_{10}	15.5bc	39.5abc	49.3ab	53.2b	247.7	493.8bc	492	1.3

[1]For abbreviations see text. N. Kilim. - North Kilimanjaro.
[2]For each site, values with the same letter(s) within the same column do not differ significantly at $p < 0.05$.

Discussion

The survival of all the provenances in the two sites was generally high (83.3 - 92.2%). The local land races, the Rhodesian and Madagascar land races, showed survival values comparable with the imported Mexican sources. The provenances and land races were planted at high elevation sites receiving adequate rainfall. *Pinus patula* has been shown to perform well at such sites (Wormald 1975, Zobel *et al.* 1987).

The provenances and land races tested at both sites showed significant differences both in diameter and height growth at early ages and insignificant differences at later ages. This indicates a poor juvenile-mature correlation. Zobel and Talbert (1984), while discussing juvenile-mature correlations, cautioned that mistakes can be made by premature provenance selection. They concluded that about one half-rotation age is required to obtain reasonably safe juvenile-mature correlations (especially for characteristics related to growth) for use in large scale operational planting.

As for survival, diameter and height growth, the land races compared favourably with the recently introduced provenances. While heights are comparable to values indicated in the yield tables for the species (Adegbehin & Philip 1979), diameters are lower. This is due to competition arising from absence of thinning or fewer thinnings.

While standing basal areas and volumes of land races at Kihanga are not significantly different at final assessment, total basal areas and volume of provenances and land races at Sungwi differed significantly with the two Rhodesian land races and Mexican provenance having the highest yields. The yields for the provenances and land races at Sungwi are higher than the values in yield tables (Adegbehin & Phillip 1979), indicating that the site is very suitable for growing *P. patula.* The yields for the provenances and land races at Sungwi were not significantly different at 9.9 years but were significantly different at 21.9 years. The segregation of trees into varying diameter classes due to competition and death of some individuals (which may differ between provenances) may partly account for the observed differences in total volume production at 21.9 years of age. This segregation of trees into varying diameter classes may also be a response to thinning carried out at age of 15 years.

Basic density values obtained in this study were within the ranges reported in the literature for the species in its natural range and when grown as an exotic (Wormald 1975, Lema *et al.* 1978, Ringo & Klem 1980, Banda & Ringo 1984, Zobel *et al.* 1987, Nasser *et al.* 1993). The wood density of the land races grown at Kihanga Arboretum was lower (372 - 421 kg m^{-3}) than that of provenances and land races grown at Sungwi (470 - 499 kg m^{-3}). The lower densities of land races at Kihanga could be due to the younger age of the land races (18 years) compared to the Sungwi provenances and land races which were 21.9 years at the time of assessment. It has been shown for conifers that, because of the lesser amount of juvenile wood, the wood density of older trees is usually higher than that of young trees (Zobel *et al.* 1987). Also, wood density can be greatly affected by environment other than age. Differences in environment between the two sites may have partly contributed to the observed wood density differences.

All provenances and/or land races had generally good stem form indicating that the initial selection for straightness was not negatively affected by the environments of the two sites.

It is recommended therefore that on the basis of their high basal area and volume yields, the two Rhodesian land races and the two Mexican provenances be used as seed source for afforestation programme at Sungwi and similar sites. The Kigogo land race is already in use. However, as a way of broadening the genetic base, the other provenances can also be used as seed source for afforestation at the respective sites.

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References

ADEGBEHIN, J.O. & PHILLIP, M.S. 1979. *Studies of Dominant Height Development and Yield of Pinus patula at Sao Hill Forest Project, Southern Tanzania.* Division of Forestry, Faculty of Agriculture, Forestry and Veterinary Science, University of Dar es Salaam, Tanzania. Record No. 6. 21 pp.

AHLBACK, A.J. 1986. *Industrial Plantation Forestry in Tanzania - Facts, Problems, Challenges.* Planning Division/Forest and Beekeeping Division, Ministry of Natural Resources and Tourism, Dar es Salaam, Tanzania. 197 pp.

BANDA, C.A. & RINGO, W.N. 1984. *Wood Basic Density Variations in Pinus patula grown in Bunduki Forest Reserve, Tanzania.* Record No. 33. Faculty of Forestry, Sokoine University of Agriculture, Morogoro, Tanzania. 12 pp.

FOREST, DIVISION. 1982. *Management Practices in Coniferous Plantations in Tanzania. Notes on Forestry Operations.* Forest Division, Dar es Salaam, Tanzania. 68 pp.

KILINGANIRE, P.Y. & HALL, J.B. 1993. Growth and biomass production of young *Grevillea robusta provenances* in Rwanda. *Forest Ecology and Management* 62 : 73 - 84.

LEMA, C.N., KITALI, M.M. & KLEM, G.S. 1978. *Basic Density and Its Variation within and between Trees of Pine (Pinus patula) and Cypress (Cupressus lusitanica) in the Meru Forest Project.* Record No. 3. Division of Forestry, University of Dar es Salaam, Morogoro, Tanzania. 11 pp.

MAATTA, M. & PAIVINEN, R. 1987. *Stand Volume Tables for Cupressus lusitanica and Pinus patula in North-eastern Tanzanian Softwood Plantations.* Department of Forest Mensuration and Management, University of Helsinki, Helsinki, Finland, and Forest Division, Ministry of Tourism Natural Resources and Environment, Dar es Salaam, Tanzania.

MBWANA, S.B. 1991. Tree species for industrial forestry in Tanzania: Experiences and future recommendation. Pp. 99 - 104 in *Proceedings of a Workshop on Priority Species for Tree Planting and Afforestation in Tanzania.* Morogoro, 14-18 May 1990. Ministry of Tourism, Natural Resources and Environment, Dar es Salaam,Tanzania.

MALIMBWI, R.E. 1987. A growth and yield model for *Pinus patula* at Sao Hill, Southern Tanzania. Ph.D. thesis, University of Arberdeen.

MHANDO, M.L., S.M. MALIONDO, S.M. & MUGASHA, A.G. 1993. Early response of *Eucalyptus saligna* to site preparation and fertilization at Sao Hill, Tanzania. *Forest Ecology and Management* 62 : 303 - 311.

MNLRT. 1989. *Tanzania Action Plan (TFAP): 1990/91 - 2007/08.* Forestry and Beekeeping Division, Dar es Salaam, Tanzania. 128 pp.

NASSER, S.M., CHAMSHAMA, S.A.O. & IDDI, S. 1993. Survival, growth, yield and wood quality of three *Pinus patula* provenances at Lushoto, Tanzania. *Journal of Tropical Forest Science* 5(3): 353 - 360.

NYKVIST, N. 1976. *Meteorological Data for Sao-Hill Mufindi Area.* Tanzania Silviculture Technical Note (New Series) No. 26. 25 pp.

RINGO, W.N. & KLEM, G.S. 1980. *Basic Density and Heartwood Content in the Wood of Pinus patula from Sao Hill.* Record No. 3. Division of Forestry, University of Dar es Salaam, Morogoro, Tanzania. 11 pp.

SAS Institute Inc., 1987. *Stat Guide to Personal Computers.* 6th edition. Cary, NC, USA.

SOKAL, R.R. & ROHLF, F.J. 1969. *Biometry.* W.H. Freeman and Co., New York, USA.

TROENSEGAARD, J. 1989. Natural forest management and development. Pp. 278 - 289 in *Report on the Workshop on the Management and Development of Indigenous Forests in the SADC Region.* 19-25 October 1987. Prepared for the Government of the Republic of Malawi : 278 - 289.

STEEL, R.C.D. & TORRIE, J.H. 1980. *Principles and Procedures of Statistics: A Biotic Approach.* McGraw-Hill Inc., Toronto, Canada. 633 pp.

WORMALD, T.J. 1975. *Pinus patula.* Tropical Forestry Paper No. 7. Commonwealth Forestry Institute, Oxford. U.K. 172 pp.

ZOBEL, B.J. & TALBERT, J. 1984. *Applied Tree Improvement.* Wiley, New York. 521 pp.

ZOBEL, B.J., VAN WYK, G. & STAHL, P. 1987. *Growing Exotic Forests.* Wiley, New York : 95 - 140.