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EARLY PERFORMANCE OF *AZADIRACHTA INDICA* PROVENANCES AT MKUNDI AND CHAMWINO, TANZANIA

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MUGASHA, A. G., CHAMSHAMA, S. A. O., SINGO, K. I. & MGANGAMUNDO, M. A. 2005. Early performance of *Azadirachta indica* provenances at Mkundi and Chamwino, Tanzania. Two trials to evaluate the performance of 20 provenances and one land race of *Azadirachta indica* A. Juss (neem) from 10 countries were established in January 1996 at two contrasting sites in Tanzania. Assessments were carried out at the ages of 17 and 53 months after field planting. Both assessments involved survival, root-collar diameter (RCD) and height while branch number, leaf mass, foliar nitrogen (N) and phosphorus (P) concentrations and contents were assessed at 17 months only. At all assessment occasions except for survival, significant ($p < 0.05$) variation among the provenances was detected for the tested parameters. Overall, the Ban Nong (Thailand), Vietianne (Vietnam), Ban Bo (Thailand), Ramanaguda (India) and Doi Tao (Thailand) were the best performing provenances for Chamwino site while for Mkundi site, the best performers were Doi Tao (Thailand), Ban Bo (Thailand), Ban Nong (Thailand), Ghaati (India) and Vietianne (Vietnam) provenances. These provenances should be used as seed sources and for the establishment of pilot plantations in the respective sites and other areas with similar environmental conditions.

Key words: Genetic variation – survival – root-collar diameter – nutrient content

MUGASHA, A. G., CHAMSHAMA, S. A. O., SINGO, K. I. & MGANGAMUNDO, M. A. 2005. Prestasi awal provenans *Azadirachta indica* di Mkundi dan Chamwino, Tanzania. Dua ujian untuk menilai prestasi 20 provenans dan satu ras daratan *Azadirachta indica* (semambu) daripada 10 negara diasaskan pada Januari 1996 di tapak berlainan di Tanzania. Penilaian dijalankan 17 bulan dan 53 bulan selepas penanaman. Kemandirian, diameter akar-kolar (RCD) dan ketinggian diambil pada umur 17 bulan dan 53 bulan. Bilangan dahan, jisim daun serta kepekatan dan kandungan nitrogen daun (N) dan fosforus daun (P) cuma dinilai pada umur 17 tahun sahaja. Variasi

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provenans adalah bererti ($p < 0.05$) untuk semua ciri yang dikaji kecuali kemandirian. Secara amnya, Ban Nong (negeri Thai), Vietianne (Vietnam), Ban Bo (negeri Thai), Ramanaguda (India) dan Doi Tao (negeri Thai) merupakan provenans terbaik bagi tapak Chamwino; Doi Tao (negeri Thai), Ban Bo (negeri Thai), Ban Nong (negeri Thai), Ghaati (India) dan Vietianne (Vietnam) merupakan provenans terbaik untuk tapak Mkundi. Provenans tersebut patut digunakan sebagai sumber biji benih dan untuk pembentukan ladang perintis di tapak kajian dan di kawasan lain yang mempunyai persekitaran yang sama.

Introduction

Tanzania's natural forest area covers about 38% of the total land area of 94.5 mill. ha. The rate of disappearance of closed forests and woodlands in Tanzania is estimated at about 400 000–500 000 ha per year (Tanzania Forest Policy 1998). The main cause of forest disappearance is rapid population increase, which results in increasing demand for agricultural land and forest products. Moreover, the growth of most naturally occurring trees in the country is very slow and many of them also develop crooked and gnarled stems which make them unfavourable for sawntimber and poles (Mugasha 1996).

To ameliorate the situation, fast-growing industrial exotic tree species such as *Pinus patula, Cupressus lusitanica* and *Eucalyptus* spp. were introduced in the country in the 1950s for trial purposes. Interest in community forestry in the 1970s led to the planting of *Azadirachta indica* A. Juss in woodlots for fuelwood and poles. *Azadirachta indica,* also called neem, is an evergreen (deciduous in drier areas) tree native to the Indian subcontinent but cultivated throughout Southeast Asia, Australia, Africa, Central and South America (Rawat 1995). However, it is in India that the tree is widely used (Anonymous 1992). The tree produces timber, fuelwood, fodder, oil, fertilizer, pesticide, mosquito repellent and even the products for manufacture of contraceptives (Biswas *et al.* 1995). Due to its evergreen nature and its ability to grow in even the most arid and nutrient deficient soils as well as its many commercially exploitable by-products and environmentally beneficial attributes, the species is recognized today as potentially one of the most valuable of all arid zone trees (Mohinder 1995, Nanang *et al.* 1997).

Despite its widespread uses, there had never been any serious effort by researchers to initiate genetic improvement work on *A. indica* (Mishira 1995). Thus data are lacking on survival, growth and yield of the different provenances and land races of *A. indica* (Nanang *et al.* 1997). As a result, the material currently exploited for various benefits is generally of a very narrow genetic base. There is therefore wide scope for improving the productivity of neem through selection of the best seed sources (provenances) for higher yield, quality and resistance to pests and diseases.

This study was thus carried out with the aim of examining the performance of 20 provenances and one land race of neem in terms of survival, height, root-collar diameter (RCD) and foliar nitrogen (N) and phosphorus (P) concentrations and contents at Mkundi and Chamwino sites in Morogoro and Dodoma regions respectively in Tanzania, as one of the steps towards broadening the genetic base of this tree species.

Materials and methods

Study areas

The trial was laid out in two sites located at Mkundi in Morogoro and Chamwino in Dodoma, Tanzania. These sites were chosen deliberately to subject provenances/land race to different ecoclimatical conditions.

Mkundi site

This site is located at Mkundi Fuel Wood Forest Reserve (6°40' S, 37°39' E; 475 m asl) about 20 km from Morogoro town along Morogoro–Dodoma highway. The area experiences two rainy seasons, i.e. long rains lasting from March to May followed by short rains which last from October to the end of December.

Table 1 Means of selected soil properties of *Azadirachta indica* provenances/land race trial sites at Mkundi and Chamwino, Tanzania

Soil depth (cm)	pH (H_2O)	E. conduct. (ms cm^{-1})	Total N (%)	Total P (%)	Available P (%)	Organic carbon (%)
Mkundi site						
0–10	6.81[1] (0.049)	0.12 (0.0054)	0.16 (0.013)	0.05 (0.002)	1.66 (0.062)	2.07 (0.066)
10–20	6.41 (0.061)	0.13 (0.0146)	0.24 (0.006)	0.04 (0.001)	1.03 (0.067)	1.46 (0.059)
20–30	6.46 (0.073)	0.08 (0.0103)	0.24 (0.0162	0.04 (0.001)	0.97 (0.062)	1.3 (0.029)
30–40	6.74 (0.057)	0.11 (0.0143)	0.19 (0.016)	0.03 (0.001)	0.71 (0.038)	1.3 (0.029)
40–70	6.53 (0.053)	0.13 (0.0191)	0.13 (0.011)	0.03 (0.001)	0.51 (0.026)	0.54 (0.023)
Chamwino site						
0–10	5.53 (0.036)	0.08 (0.002)	0.22 (0.009)	0.03 (0.001)	0.09 (0.006)	1.75 (0.071)
10–20	5.47 (0.068)	0.04 (0.002)	0.2 (0.008)	0.03 (0.000)	0.05 (0.005)	1.61 (0.066)
20–30	4.72 (0.018)	0.03 (0.001)	0.14 (0.007)	0.04 (0.000)	0.06 (0.004)	1.32 (0.062)
30–40	4.85 (0.025)	0.03 (0.001)	0.07 (0.003)	0.04 (0.001)	0.03 (0.002)	0.79 (0.032)
40–70	5.03 (0.053)	0.05 (0.003)	0.05 (0.002)	0.03 (0.001)	0.03 (0.001)	0.39 (0.015)

[1]Mean of four replicates. The values in parentheses are the standard errors of four replications.

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The mean annual rainfall is 800 mm. The coldest months of the year are June and July when the minimum temperature may range between 16 and 18 °C. The hottest period is October–December when the maximum temperature may reach 35 °C. Usually winds blow from the east or southeast throughout the year and are normally strong during the dry season.

Generally soils are of sandy loam, with varying amounts of clay characterized by acidic reaction (pH = 6.5). Pedon sample means (0 to 70 cm depth) of selected soil properties are presented in Table 1. The vegetation prior to site preparation was miombo woodland, which had been severely degraded by fuelwood collectors. Common species present are *Dalbergia melanoxylon, Balanites aegyaptiaca, Dichrostachys cinerea, Acacia* spp., *Albizia* spp. and *Sclerocarya birrea.*

Chamwino site

This site is located at about 35 km from Dodoma town (6°2' S, 34°49' E; 910 m asl). The area is characterized by one dry season lasting from May to November and one rainy season lasting from December to April (Kijoti & Chamshama 1990). The average annual rainfall is between 500 and 600 mm. Rainfall rarely falls evenly over a wide area but commonly occurs as scattered local showers or cloud bursts of short duration; therefore there are recurring dry spells within the rainy season. The highest monthly rainfall is recorded in January which generally receives 150 mm although monthly totals of over 400 mm have occurred (Kijoti & Chamshama 1990). Like rainfall, temperature shows both seasonal and diurnal variations although transitions are not sharply marked. The period of June to August is the coolest in the year. The hottest months are October and November. The mean monthly maximum temperature varies from 26.2 °C in January to 31.1 °C in November, and the mean monthly minimum temperature is from 13.3 °C in July to 18.2 °C in December (Kijoti & Chamshama 1990). Winds blow from the east or southeast throughout the year. Apart from seasonal variation, the wind speed varies according to the time of the day and topographic location. Strong winds of long duration are recorded mainly during the dry season.

Soils are dominated by sandy clay loam, with general acidic reaction (pH values range 4.7–5.5). Some selected soil properties are summarized in Table 1. The original vegetation was of miombo type characterized by *Brachystegia speciformis, Markhamia obtusifolia, Entandophragma bussei, Tamarindus indica, Adansonia digitata, Balanites aegyaptiaca, Ximenia abreviata* and *Cassia abreviata.* However, this area had been affected over time by heavy grazing, cultivation and fuelwood collection.

Source of provenances and nursery techniques

Seed sources of 21 provenances/land race of *A. indica* are shown in Table 2. These seeds were supplied by the United Nations Food and Agriculture Organization (FAO) in collaboration with the DANIDA Tree Seed Centre. Potted seedlings were raised at the National Tree Seed Centre, Morogoro, Tanzania, using standard cultural techniques (Forest Division 1982).

Experimental design

A randomized incomplete block design (RIBD) with five replications was used for Chamwino site as some provenances were not represented in some blocks. For the Mkundi site, a randomized complete block design (RCBD) with six replications was adopted.

Field procedures

Sites were prepared by manual clearing of all vegetation, burning residues, ploughing and harrowing by a tractor followed by staking and pitting. Planting was done in January and February 1996 for Chamwino and Mkundi sites respectively. For each provenance/land race (each plot), 4 x 4 trees were planted at 3.5 x 3.5 m spacing. All seedlings were planted in pits measuring 30 x 30 x 30 cm. In both sites, the experiments were having two guard rows made up of the land race. The distance between plots and blocks was the same (3.5 m). Weeding was done twice during the rainy season and once in the dry season.

Soil sampling and analysis for site characterization

Soil sampling was done at each study site in October 1997. Three soil pits were located at random and dug to 70 cm depth in each block. Within each soil pit, soil samples were taken at 0–10, 10–20, 20–30, 30–40 and 40–70 cm soil depths. Soil samples taken from the same depth within each block were composited and a subsample taken for laboratory analysis. In the laboratory, mineral soil particle size distribution was determined by the hydrometer method (Bouyoucos 1962). Soil pH was determined by means of hydrogen electrode pH meter at a distilled water:soil ratio of 2:1. Total N was determined by the micro-Kjeldhal procedure (Bremner & Mulvaney 1982) while total P was determined by the Bray-I method (Anderson & Ingram 1993). Carbon was estimated by the wet oxidation method (Bremner & Mulvaney 1982).

Data collection

Both experiments were assessed for survival, RCD (at 10 cm above ground) and height at 17 and 53 months after field planting. On the other hand, branch number was assessed at 17 months after field planting only. For each plot, all surviving trees were measured for RCD and height using microcalliper and calibrated wooden poles and recorded to the nearest 0.01 cm and 0.01 m respectively. For each surviving tree, primary branches were counted.

Plant foliage sampling was done at 17 months after field planting for determination of unit leaf mass (i.e. mass per leaf) and foliar P and N concentrations and contents. For each plot, mature unshaded leaf samples of all surviving trees were taken from the upper 1/3 of the crown. In the laboratory, oven-dry weights

Table 2 Seed sources for neem provenances/land race planted at Mkundi and Chamwino sites in Tanzania

Seed source number	Provenance	Country	Accession number	Latitude	Longitude	Altitude (m)	Mean annual rainfall (mm)	Dry season	Topography (Geomorphology)	Soil characteristics
03/IND/Man	Mandore	India	CIRAD 95/10300N	26° 18' N	73° 01' E	224	250	Sept–June	Medium sloping	Sandy loam
04/IND/Chl	Chitradunga	India	CIRAD 95/10301N	14° 02' N	76° 04' E	615	417	March–June	Gentle plain terrain	Black cotton, pH = 7.8
05/IND/All	Allhabad	India	CIRAD 95/10304N	25° 28' N	81° 54' E	320	950	March–June	Flat	Alluvial loam, well-drained
06/IND/Ano	Annur	India	CIRAD 95/10305N	11° 17' N	77° 07' E	360	875	March–June	Gentle undulating terrain	Gravelly sandy loam Alfisol
07/IND/Gha	Ghaati	India	CIRAD 95/10302N	13° 22' N	77° 34' E	950	741	March–June	Gentle plain terrain	Red sandy loam, pH = 6.5
08/IND/Sag	Chanatorin	India	CIRAD 95/10299N	21° 51' N	78° 45' E	527	1405	March–June	Gentle undulating terrain	Red sandy laterite (poor drainage)
09/IND/Bal	Balharshalt	India	CIRAD 95/10300N	19° 51' N	79° 25' E	250	1000	April–June	Gentle undulating terrain	Sandy loam (well-drained)
10/IND/Ram	Ramanaguda	India	CIRAD 95/10296N	19° 05' N	83° 49' E	250	1100	March–June	Gentle undulating terrain	Red sandy loam, pertlle urea
11/LAO/Vle	Vietianne	Vietnam	DFSC 01945/95	18° 00' N	102° 45' E	180	1540	Nov–March	Flat	Sandy loam (good drainage)
12/MYA/Yez	Yezin	Myanmar	DFSC 01954/95	19° 51' N	96° 16' E	100	1269	Nov–May	Gentle sloping	Gravelly sandy loam
14/NEP/Lam	Lamahal	Nepal	DFSC 01959/95	27° 52' N	82° 31' E	440	1500	Nov–May	Gentle and undulating	Sandy loam, pH = 6.9
15/NEP/Get	Geta	Nepal	DFSC 01961/95	28° 46' N	80° 34' E	170	1725	Nov–April	-	Sandy loam, pH = 6.3
16/PAK/Tib	Tibbi Laran	Pakistan	DFSC 01957/95	28° 24' N	70° 18' E	115	140	April–June	Slightly hilly	Sandy loam
17/PAK/Mul	Muttan	Pakistan	DFSC 01958/95	30° 11' N	71° 29' E	200	276	Oct–Feb	Flat	Sandy loam
18/SRL/Kul	Kuliyapitiya	Sri Lanka	DFSC 01962/95	7° 8' N	80° E	100	1397	July–Aug	-	Lateritic soil with good drainage
20/THA/Non	Ban Nong	Thailand	DFSC 01943/95	14° 05' N	99° 40' E	40	1145	Nov–March	-	Poor sandy podzolic soil
21/THA/Bo	Ban Bo	Thailand	DFSC 01942/95	16° 17' N	103° 35' E	150	1400	Oct–April	Flat	Sandy clay loam
22/THA/Doi	Doi Tao	Thailand	-	17° 57' N	98° 41' E	300	1250	Nov–April	Slightly undulating	Red podzolic with exposed laterite
23/GHA/Sun	Sunyani	Ghana	DFSC 01956/95	07° 21' N	02° 21' W	1000	1400	Dec–March	-	-
24/SEN/Ban	Bandia	Senegal	DFSC 01963/95	14° 30' N	17° 02' W	50	436	Oct–June	Flat	High clay content
25/TAN/Cha	Chamwino	Tanzania	DFSC 01941/95	06° 20' S	35° 50' E	1030	475	July–Oct	Gentle sloping	Sandy with good drainage

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(70 °C) of three subsamples each made up of ten (10) leaves from each provenance/land race were measured and recorded. The remaining plant samples were dried in the oven at 70 °C to constant weight, ground and analysed for N and P as described above.

Data analysis

Statistical analyses were carried out using SAS (Statistical Analysis Systems Institute, Inc. 1987). Each tree variable, percentage survival (%), RCD (cm), height (m), branch number, leaf mass (milligram/leaf), foliar N and P concentrations (%) and contents (µg N or P per leaf) were subjected to analysis of variance (ANOVA) using plot means. Prior to ANOVA arc-sine transformation was applied to percentage survival data to remove bias (Sokal & Rohlf 1969). Duncan's Multiple Range Test (Steel & Torrie 1980) was used to separate significantly different means.

To identify the best and the worst overall performing provenances, ordinal ranking was developed for each site. This was done as follows: for each plot and each statistically significant parameter, provenances were assigned ranks from the best (assigned 1 point) to the worst (assigned 21 points) performing provenances. Thereafter ranks were added, averaged and the overall score was taken as a basis of the overall provenance ranking.

Results and discussion

Survival

Survival of *A. indica* at the ages of 17 and 53 months in the two sites is shown in Table 3. Statistical analysis showed that for both sites, there were no significant ($p > 0.05$) differences in survival between provenances at all the assessment dates. Significant variations in survival between provenances of *A. indica* have been reported by Rajawat *et al.* (1994) in an Indian national provenance trial. At the age of 17 months the survival (transformed) of neem ranged from 73% for Mandore to 89% for Ghaati at Mkundi site, and from 69% for Vietianne and Chamwino to 90% for Annur, Kuliyapitiya and Bandia at Chamwino site. At the age of 53 months the range in survival was from 63% for Vietianne to 81% for Annur at Chamwino site, and from 67% for Mandore to 85% for Allhabad at Mkundi site (Table 3).

Generally there was a slight increase in mortality in successive assessment dates. This may be attributed to failure to withstand intense competition for growth resources. In general, the survival shown by *A. indica* in this trial was high. This may be due to the drought hardiness of most of the *A. indica* provenances used in this study. Another probable reason could be due to the fact that leaves and bark of *A. indica* contain several alkaloids which have pesticidal properties (Sidhu 1995). Methanol extract (10%), for example, is ovicidal to the eggs of mites (Schauer & Schmutterer 1980). Very high survival rates shown by these *A. indica* provenances are a good indication of the potential this species may have in the miombo woodlands where termites have caused considerable damage to other exotic tree species such as eucalypts and casuarina.

Table 3 Mean survival (%) trends of *A. indica* provenances/land race grown at Mkundi in Morogoro and Chamwino in Dodoma, Tanzania

Provenance	Transformed survival (%)				Untransformed survival (%)	
	Mkundi		Chamwino		Mkundi	Chamwino
Age (months)	17	53	17	53	53	17
Yezin	83	79	82	79	94	94
Ban Bo	80	76	76	72	91	86
Ban Nong	85	77	72	65	92	81
Doi Tao	88	81	73	71	95	86
Vietianne	76	76	69	63	92	75
Chamwino	79	78	69	67	90	84
Chitradunga	83	76	84	76	89	90
Ghaati	89	84	82	78	97	93
Mandore	73	67	81	72	82	91
Allhabad	87	85	87	78	98	91
Annur	80	70	90	81	84	96
Sunyani	80	73	89	78	86	93
Ramanaguda	80	76	78	74	91	90
Chanatorin	74	72	82	74	90	90
Tibbi Laran	82	75	85	70	90	88
Muttan	77	75	82	68	89	85
Geta	82	76	81	73	92	85
Lamahal	83	72	76	73	90	86
Balharshalt	75	70	85	78	82	93
Kuliyapitiya	74	71	90	73	89	90
Bandia	88	82	90	80	97	94
Pr > Fr[1]	0.727	0.559	0.059	0.332	-	-
RMSE	7.43	12.13	9.17	10.72	-	-
CV	7.86	16.04	9.98	14.58	-	-

[1]Pr > Fr = probability for greater F-ratio; RMSE = root mean square error; CV = coefficient of variation (%).

Height and root-collar diameter growth

Height growth of plants varied significantly ($p < 0.05$) among provenances/land race and also between ages at 17 and 53 months after field planting (Tables 4 and 5). Significant differences in height growth between provenances of *A. indica* have also been reported by Rajawat *et al.* (1994) in an Indian national provenance trial. In this study, fast-growing provenances at 17 months stage did not maintain their ranking at 53 months. For example, at the age of 17 months, mean height ranged from 1.42 m for Vietianne to 2.52 m for Allhabad at Mkundi site, and from 0.92 m for Doi Tao to 1.68 m for Sunyani at Chamwino site. At the age of 53 months the range in mean height was from 2.50 m (Tibbi Laran and Geta) to 3.94 m (Lamahal) at Chamwino site, and from 3.96 m (Mandore) to 6.95 m (Doi Tao) at

Mkundi site (Table 4). These results also show that tree height growth was better at Mkundi site as compared with Chamwino site. This is probably due to the fact that the Mkundi site receives much more rainfall than Chamwino site.

Statistical analysis showed that there were significant ($p < 0.05$) differences between provenances/land race in RCD at all the assessment dates for the Chamwino site. However, for the Mkundi site significant ($p < 0.05$) differences in RCD were detected only at age 53 months (Table 5). At the age of 17 months mean RCD ranged from 1.54 cm for Bandia to 3.98 cm for Sunyani at Chamwino site, and from 2.48 cm for Mandore to 4.92 cm for Sunyani at Mkundi site. Provenance ranking in respect of RCD changed by 53 months of field growth (Table 5). At the age of 53 months, mean RCD ranged from 4.96 cm for Geta to 7.42 cm for Chitradunga at Chamwino site, and from 7.08 cm for Mandore to 13.82 cm for Doi Tao at Mkundi site.

Table 4 Mean height (m) development of *A. indica* provenances/land race grown at Mkundi and Chamwino, Tanzania

Serial No.	Provenance/ land race	Mean height (m)			
		Mkundi		Chamwino	
	Age (months)	17	53	17	53
1	Yezin	1.97	5.05	1.29	3.06
2	Ban Bo	2.02	6.01	1.19	3.36
3	Ban Nong	1.78	5.69	1.28	3.40
4	Doi Tao	2.21	6.95	0.92	3.04
5	Vietianne	1.42	5.52	1.11	3.24
6	Chamwino	1.83	5.04	1.11	2.96
7	Chitradunga	2.04	6.77	1.46	3.44
8	Ghaati	2.21	6.18	1.52	3.38
9	Mandore	1.76	3.96	1.00	2.85
10	Allhabad	2.52	5.76	1.03	2.93
11	Annur	2.25	5.22	1.32	2.80
12	Sunyani	2.35	5.40	1.68	3.76
13	Ramanaguda	1.97	5.40	1.17	2.92
14	Chanatorin	1.65	4.68	1.01	2.74
15	Tibbi Laran	1.55	4.00	0.96	2.50
16	Muttan	2.26	5.32	0.98	2.62
17	Geta	2.04	5.41	1.02	2.50
18	Lamahal	1.89	5.32	1.20	3.94
19	Balharshalt	1.95	5.10	1.43	2.84
20	Kuliyapitiya	1.80	5.12	1.12	2.86
21	Bandia	1.71	4.99	0.98	2.78
Pr > Fr[1]		0.046	0.001	0.040	0.001
RMSE		0.504	0.872	0.320	0.683
CV(%)		25.62	16.23	26.77	22.27

[1]Pr > F-ratio = probability for greater F-ratio; RMSE = root mean square error; CV = coefficient of variation.

Wide variations in growth among provenances and in between the growth stages were also reported in *Albizia falcataria* and *Leucaena leucocephala* (Palit 1980), pine (Ghosh *et al.* 1987) and *Sesbania macrantha* (Magangamundo *et al.* 1999). Tree height and root-collar growth are the most important parameters as far as tree biomass production is concerned. The statistically significant variations among provenances of *A. indica* in height and RCD growth provide strong grounds to establish a wide range of provenance trials of this species, to exploit the genetic variation among the provenances which is reflected in this study.

Table 5 Mean root-collar diameter (cm) development of *A. indica* provenances/ land races grown at Mkundi and Chamwino, Tanzania

Serial No.	Provenance/ land race	Mean root collar diameter (cm)			
		Mkundi		Chamwino	
	Age (months)	17	53	17	53
1	Yezin	3.67	9.64	2.78	6.10
2	Ban Bo	3.92	12.52	2.06	6.28
3	Ban Nong	3.37	10.90	2.33	6.56
4	Doi Tao	4.10	13.82	1.64	5.27
5	Vietianne	2.88	10.60	2.39	6.46
6	Chamwino	3.24	9.87	1.92	6.06
7	Chitradunga	3.53	11.08	2.67	7.42
8	Ghaati	4.15	11.58	2.60	7.06
9	Mandore	2.48	7.08	1.99	5.30
10	Allhabad	4.20	10.12	2.00	5.93
11	Annur	4.15	11.15	2.37	6.26
12	Sunyani	4.92	11.13	3.98	7.18
13	Ramanaguda	3.79	10.98	2.31	6.58
14	Chanatorin	3.42	9.15	1.76	5.22
15	Tibbi Laran	2.73	7.87	1.92	5.55
16	Muttan	4.01	9.72	1.61	5.10
17	Geta	3.94	10.53	2.09	4.96
18	Lamahal	3.82	10.37	2.37	7.28
19	Balharshalt	3.74	10.06	2.31	6.04
20	Kuliyapitiya	3.63	11.02	1.90	5.68
21	Bandia	3.49	10.25	1.54	5.28
Pr > Fr[1]		0.248	0.001	0.017	0.001
RMSE		1.200	1.520	0.809	1.009
CV(%)		32.55	14.54	36.19	16.51

[1]Pr > F-ratio = probability for greater F-ratio; RMSE = root mean square error; CV = coefficient of variation.

Branch number and unit leaf mass

For both sites, the number of tree branches was significantly ($p < 0.05$) different between provenances/land race (Table 6). Mean branch number ranged from 3 for Doi Tao and Vietianne to 12 for Yezin and Annur at Chamwino site, and from 4 for Vietianne to 22 for Ghaati at Mkundi site (Table 6). Overall, there was development of more branches per tree at Mkundi site than at Chamwino site.

Data analysis of unit leaf mass indicated that there were significant ($p < 0.05$) differences between provenances/land race studied at both sites. Leaf biomass is the major contributor to the photosynthetic biomass and it ranged from 46.3 mg per leaf for Kuliyapitiya to 184.2 mg per leaf for Ban Nong at Mkundi site, and for Chamwino site the range was from 76.9 mg per leaf for Bandia to 210.1mg per leaf for Doi Tao (Table 7). Generally, Chamwino site produced heavier leaves than Mkundi site. This could be due to the adaptability of the tested provenances/land race to drought.

Table 6 Mean branch number of 17-month-old *A. indica* provenances/ land race grown at Mkundi and Chamwino, Tanzania

Serial No.	Provenance/land race	Site	
		Mkundi	Chamwino
1	Yezin	15	12
2	Ban Bo	8	5
3	Ban Nong	7	4
4	Doi Tao	5	3
5	Vietianne	4	3
6	Chamwino	16	9
7	Chitradunga	18	11
8	Ghaati	22	11
9	Mandore	11	8
10	Allhabad	16	7
11	Annur	18	12
12	Sunyani	20	10
13	Ramanaguda	19	9
14	Chanatorin	14	8
15	Tibbi Laran	14	8
16	Muttan	17	6
17	Geta	16	7
18	Lamahal	15	10
19	Balharshalt	16	10
20	Kuliyapitiya	14	6
21	Bandia	12	6
Pr > F-ratio[1]		0.0001	0.0001
RMSE		4.837	2.9741
CV(%)		33.98	37.875

[1]As defined in Table 3.

Table 7 Unit leaf mass (mg per leaf) of 17-month-old *A. indica* provenances/land race grown at Mkundi and Chamwino, Tanzania

Serial No.	Provenance/land race	Site	
		Mkundi	Chamwino
1	Yezin	88.08	85.05
2	Ban Bo	132.80	148.35
3	Ban Nong	184.20	196.76
4	Doi Tao	129.02	210.10
5	Vietianne	152.00	179.67
6	Chamwino	79.82	82.00
7	Chitradunga	66.74	84.25
8	Ghaati	87.64	84.80
9	Mandore	80.60	90.60
10	Allhabad	77.35	102.05
11	Annur	71.48	84.23
12	Sunyani	95.12	86.30
13	Ramanaguda	98.30	107.12
14	Chanatorin	72.72	94.98
15	Tibbi Laran	81.70	88.50
16	Muttan	78.44	90.02
17	Geta	83.70	94.55
18	Lamahal	62.96	84.53
19	Balharshalt	74.20	92.40
20	Kuliyapitiya	46.34	85.77
21	Bandia	60.68	76.85
Pr > F-ratio[1]		0.0001	0.0001
RMSE		23.9910	32.0080
CV(%)		22.5240	35.0080

[1]As defined in Table 3.

Variations in *A. indica* provenances in respect of branch number and unit leaf mass could be due to the fact that this tree species grows over a wide range of altitude, rainfall, topography and soil type in India and other countries (Table 2). Considerable variations in the performance of provenances of this species should thus be expected when exposed to different environmental conditions. Such variations in relation to habitat have also been reported in *Albizia lebbek* (Kumar & Toky 1993). The wider distribution of *A. indica* and its growth under a variety of climates are indicative of the presence of high genetic diversity, the selective use of which can be made for yield improvement of this species.

Foliar nitrogen and phosphorus concentration and content

Foliar N concentration was not significantly ($p > 0.05$) different between provenances/land race in both sites (Table 8). However, due to the large observed differences in leaf mass, foliar N content was significantly ($p < 0.05$) different between provenances/land race for Mkundi site although no significant ($p > 0.05$) differences

Table 8 Foliar nitrogen concentration (%) and content (µg per leaf) of 17-month-old *A. indica* provenances/land race grown at Mkundi and Chamwino, Tanzania

Serial No.	Provenance/land race	Mkundi		Chamwino	
		N conc.	N cont.	N conc.	N cont.
1	Yezin	12.78	2020	2.47	1870
2	Ban Bo	2.31	3638	2.23	3033
3	Ban Nong	2.47	4828	2.78	6261
4	Doi Tao	2.38	4839	2.65	3413
5	Vietianne	2.28	3608	2.68	3894
6	Chamwino	2.75	2039	2.80	2069
7	Chitradunga	2.94	2400	2.92	2143
8	Ghaati	2.64	2327	2.66	1938
9	Mandore	2.54	1933	3.02	2394
10	Allhabad	2.73	2745	2.70	1899
11	Annur	2.61	1975	2.48	1643
12	Sunyani	2.54	2116	2.82	1629
13	Ramanaguda	2.38	2432	3.09	2643
14	Chanatorin	2.45	1513	2.90	2145
15	Tibbi Laran	2.66	2300	2.94	2699
16	Muttan	2.80	2362	3.58	2716
17	Geta	2.51	2152	2.91	2426
18	Lamahal	2.57	2017	2.82	1550
19	Balharshalt	2.43	2913	2.81	1982
20	Kuliyapitiya	2.45	2026	2.80	1233
21	Bandia	2.84	2172	3.08	1691
Pr > F-ratio[1]		0.202	0.0001	0.651	0.172
RMSE		0.270	765.9	0.514	1557.4
CV(%)		10.49	30.08	18.30	63.35

[1]As defined in Table 3.

were observed between provenances/land race at Chamwino site (Table 8). At the former site Doi Tao was outstanding in respect of N content with 4.839 mg per leaf. This was followed by Ban Nong (4.828 mg per leaf) and Ban Bo with 3.638 mg per leaf. The Chanatorin provenance attained the least N content of 1.513 mg per leaf.

Provenances/land race differed significantly ($p < 0.05$) from each other in foliar P concentration and content at Mkundi site (Table 9). At this site, the Bandia provenance had the highest foliar P concentration of 0.096% followed by Balharshalt (0.091%), Kuliyapitiya (0.090%) and Tibbi Laran (0.089%). The Yezin provenance had the least foliar P concentration of 0.042%. The Ban Nong provenance attained the highest mean P content of 108 µg per leaf at this age while the least P content of 31 µg per leaf was attained by the Yezin provenance at Mkundi site. For Chamwino site, significant ($p < 0.05$) differences between

Table 9 Foliar phosphorus concentration (%) and content (µg per leaf) of 17 month-old *A. indica* provenances/land race grown at Mkundi and Chamwino, Tanzania

Serial No.	Provenance/land race	Mkundi site		Chamwino site	
		P conc.	P cont.	P conc.	P cont.
1	Yezin	0.042	30.52	0.076	58.17
2	Ban Bo	0.049	74.08	0.088	114.2
3	Ban Nong	0.056	107.9	0.087	183.5
4	Doi Tao	0.053	105.2	0.086	109.9
5	Vietianne	0.069	106.5	0.096	137.4
6	Chamwino	0.080	56.79	0.094	71.17
7	Chitradunga	0.083	69.79	0.092	67.77
8	Ghaati	0.085	75.10	0.091	65.53
9	Mandore	0.069	53.19	0.103	81.18
10	Allhabad	0.084	85.40	0.106	73.09
11	Annur	0.060	44.86	0.090	58.09
12	Sunyani	0.087	72.47	0.085	49.62
13	Ramanaguda	0.071	71.63	0.101	86.58
14	Chanatorin	0.072	43.43	0.101	76.38
15	Tibbi Laran	0.089	76.08	0.076	69.54
16	Muttan	0.066	54.58	0.086	59.85
17	Geta	0.081	72.12	0.119	99.37
18	Lamahal	0.081	63.92	0.093	51.72
19	Balharshalt	0.091	75.86	0.115	82.47
20	Kuliyapitiya	0.090	73.20	0.105	46.93
21	Bandia	0.096	73.14	0.074	38.42
Pr > F-ratio[1]		0.0057	0.0237	0.0721	0.0200
RMSE		0.0165	24.006	0.0144	38.961
CV(%)		22.25	33.93	15.29	47.97

[1]As defined in Table 3.

provenances/land race were observed only in foliar P content but not for foliar P concentration (Table 9). The highest foliar P content was attained by Ban Nong (184 µg per leaf), followed by Vietianne which had 137 µg per leaf. The least foliar P content value was shown by Bandia which attained 38 µg per leaf.

The values of foliar N and P concentrations and contents observed in this study indicate that *A. indica* can provide fodder of good quality. Biswas *et al.* 1995 reported that neem tree happens to be one of the most palatable species for cattle. The leaves make good fodder for camels, goats and bullocks. *Azadirachta indica* leaves are regularly fed to the cattle/goats to increase milk production immediately after pasturation.

The spread of genetic variability in a population is reflected to some extent in the morphology and/or chemical constituents of the population (Veerendra 1995). From the above observations, it can be clearly seen that large genetic variability exists in the various tested parameters from height and RCD to foliar N and P concentrations and contents. The study of biological parameters of natural

population is often a useful step in the study of genetic variability (Veerendra 1995). The morphological characters such as tree height and other crown characters are known to be strongly inherited. Therefore tree height may be considered one of the most useful characters for early selection of superior provenances. However, selection of seed lots on the basis of one character alone may not give the desired level of superiority as the Sunyani and Allhabad provenances showed greatest mean height at 17 months in Chamwino and Mkundi sites respectively, but mean N and P contents were low.

Ordinal ranking of provenances

The ordinal ranking to identify the best and the worst performing provenances for a given growth parameter was developed and the results are shown in Tables 10 and 11. For Mkundi site, the best performing provenances were Doi Tao, Ban Bo, Ban Nong, Ghaati and Vietianne. These provenances have shown promising growth throughout the study period, indicating their suitability to the locality. On the

Table 10 Ordinal ranking of *A. indica* provenances/land race grown at Mkundi, Tanzania

Provenance/land race	Parameter and ordinal ranking							
	Mean height	Mean RCD	Branch number	Leaf mass	Foliar N cont.	Foliar P cont.	Mean	Overall rank
Doi Tao	1	1	13	4	1	3	3.8	1
Ban Bo	4	2	11	3	3	8	5.2	2
Ban Nong	6	9	12	1	2	1	5.2	2
Ghaati	3	3	1	8	10	7	5.3	3
Vietianne	7	10	14	2	4	2	6.5	4
Ramanaguda	9	8	3	5	7	13	7.5	5
Sunyani	9	5	2	6	15	11	8.0	6
Allhabad	5	14	6	14	6	4	8.2	7
Chitradunga	2	6	4	18	8	14	8.7	8
Geta	8	11	6	9	13	12	9.8	9
Balharshalt	13	15	6	15	5	6	10.0	10
Muttan	10	17	5	13	9	17	11.8	11
Tibbi Laran	17	20	8	10	11	5	11.8	11
Annur	11	4	4	17	19	19	12.3	12
Kuliyapitiya	12	7	8	21	17	9	12.3	12
Lamahal	10	12	7	19	14	15	12.8	13
Chamwino	15	16	6	12	15	16	13.3	14
Bandia	16	13	9	20	12	10	13.3	14
Yezin	14	18	7	7	18	21	14.2	15
Mandore	18	21	10	11	19	18	16.2	16
Chanatorin	15	19	8	16	20	20	16.3	17

Rankings for mean height and mean root-collar diameter were done for measurements taken at 53 months after field planting while the rest of the parameters were obtained at 17 months after field planting.

other hand, while some provenances like the Ramanaguda, Sunyani, Allhabad, Chitradunga and Geta showed average performance, the Bandia, Yezin, Mandore and Chanatorin provenances failed to put on promising growth at Mkundi site.

For the Chamwino site, overall best performers were the Ban Nong, Vietianne, Ban Bo, Ramanaguda and Doi Tao provenances. Chitradunga, Ghaati, Balharshalt, Lamahal and Allhabad had average performance while Muttan, Annur, Kuliyapitiya and Bandia were the worst performers. The Doi Tao, Ban Bo, Ban Nong and Vietianne provenances have shown great growth stability as they were consistently suitable in both sites, a chararacter which is highly needed for better provenances.

Table 11 Ordinal ranking of *A. indica* provenances/land race grown at Chamwino, Tanzania

Provenance/land race	Parameter and ordinal ranking							
	Mean height	Mean RCD	Branch number	Leaf mass	Foliar N cont.	Foliar P cont.	Mean	Overall rank
Ban Nong	4	6	10	2	1	1	4.0	1
Vietianne	7	7	11	3	2	2	5.3	2
Ban Bo	6	8	9	4	4	3	5.7	3
Ramanaguda	12	5	4	5	7	6	6.5	4
Doi Tao	9	18	11	1	3	4	7.7	5
Chitradunga	3	1	2	17	11	13	7.8	6
Ghaati	5	4	2	15	14	14	9.0	7
Balharshalt	15	12	3	9	13	7	9.8	8
Lamahal	1	2	3	16	20	18	10.0	9
Allhabad	11	13	6	6	15	10	10.2	10
Mandore	14	16	5	10	9	8	10.3	11
Sunyani	2	3	3	18	19	19	10.7	12
Yezin	8	10	1	14	16	16	10.8	13
Geta	20	21	6	8	8	5	11.3	14
Chanatorin	18	19	5	7	10	9	11.3	14
Tibbi Laran	20	15	5	12	6	12	11.7	15
Chamwino	12	11	4	20	12	11	11.7	15
Muttan	19	20	8	11	5	15	13.0	16
Annur	16	9	1	19	18	17	13.3	17
Kuliyapitiya	13	14	8	12	21	20	14.8	18
Bandia	17	17	8	21	17	21	16.8	19

Rankings for mean height and mean root-collar diameter were done for measurements taken at 53 months after field planting while the rest of the parameters were obtained at 17 months after field planting.

Conclusions

The results of this trial indicate opportunities for selection of the suitable provenances to increase growth in height and RCD, and N and P contents. Based on the results of this trial, suitable provenances for pilot planting at Mkundi site and other areas with similar environmental conditions are Doi Tao, Ban Bo, Ban Nong, Ghaati and Vietianne while for the Chamwino site and other areas with similar environmental conditions the suitable provenances are Ban Nong, Vietianne, Ban Bo, Ramanaguda and Doi Tao in that order of priority. These provenances will be able to cope with the edaphic and climatological conditions of the two sites.

Since these trees are normally grown for production of fuelwood and poles, more research is needed on neem trees for wood biomass, volume production and calorific value. As a further step in the utilization of genetic diversity of this species, research geared at selection of superior clones (plus trees) out of plantations raised using seed from the superior provenances and establishment of clonal banks is also recommended. This can be followed by mass multiplication of the tested clones and raising of clonal plantations using tested superior quality clones.

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