ASSESSMENT OF PROVENANCE TRIALS WITH *AZADIRACHTA* SPECIES ON MULTIPLE SITES IN TANZANIA

Jan Svejgaard Jensen[1], John Mtika[2] & Peter Iversen[1]

[1)] Danish Forest and Landscape Research Institute, Hørsholm Kongevej 11, DK-2970 Hørsholm, Denmark
[2)] National Tree Seed Programme, P.O., Box 373, Morogoro, Tanzania
[3)] Forest Resources Division, FAO,Viale delle Terme di Caracalla, I-00100 Rome, Italy

Receicved June 16, 2003; accepted July 27, 2004

ABSTRACT

Four provenance trials with neem, *Azadirachta indica* A. Juss. and *A. siamensis* Val. were established in Tanzania in 1996. They comprised 21 provenances from 11 countries. Three provenances were from three countries in Africa originating from earlier introduced material. Six years after establishment in field, significant differences were found for survival and growth parameters (height and diameter). Large provenance variation was found for growth and flowering as well. The best growth performance was found for some provenances from Thailand and East India. High mortality rate was recorded for provenances from Western India, Pakistan and Thailand. The local seed source from Tanzania performed below average for growth and survival. The choice of provenance is discussed taking into consideration various criteria and specific provenances are recommended for Tanzania. The Thai provenances may be promising as timber producers, but a higher survival rate will first need to be secured.

Genotype by environment interaction (G × E) was found moderate for growth and high for plant mortality and flowering. The G × E is characteristic for specific provenances from Western India and Thailand. Higher gains in survival rate may be achieved by selecting specific provenances.

A considerable variation of mortality rate and growth was found. This emphasises the necessity for provenance trials when large scale planting programs with unknown genetic material are under consideration. Due to the large variability of responses between neem provenances, new trials are recommended comprising more provenances from suggested regions.

Keywords: *Azadirachta indica*, adaptive traits, genetic variation, provenance trials, Genotype by environment interaction.

INTRODUCTION

In recent years, attention has been drawn to breeding and improvement of agroforestry and multipurpose species, and especially tree species within the arid zone. Among those species, there has been a special interest for neem (*Azadiractha indica* A. Juss.). Neem can be utilized for a number of purposes such as production of timber and fuelwood, provision of shade, and for a number of medicinal purposes, as well as a biological insecticide. Oils, and especially azarachterin can be extracted from leaves, fruits and other plant tissues (TEWARI 1992). The products are used both locally, in small scales, by farmers and for household but also in large scale in industrial production (CIESLA 1993).

Three species of neem can be found, all naturally distributed in East Asia. The most common is *A. indica*, which is native to Northeast India and Myanmar (SCHMIDT & JØKER, 2000). Another species under the name of "Thai neem", *A. siamensis* Val., grows in Myanmar, Laos and Thailand. Its seeds and leaves are used as spices for different foods. Nevertheless the medicinal uses of *A. siamensis* in Thailand are very similar to *A. indica* in India. *A. siamensis* differs distinctly from the *A. indica* by being mostly single stemmed and having larger fruits and leaves. A third species of neem, *A. excelsa*, which is not commonly used, is native to Malaysia. Provenances of *A. indica* and *A. siamensis* are included in this investigation.

Neem species have been widely planted throughout the world´s tropical arid zone around the globe (ANONYMOUS 2004). A careful choice of provenance for neem planting is required for proper growth, for the breeding potential, and for maintaining the evolutionary potential. Genetically adapted seed sources can be identified through a systematic testing of provenances over the range of distribution. The first step in this process is to identify regimes of provenances with high adaptive properties like growth and survival. Secondly, to identify and select individuals carrying specific qualitative properties among the best provenances.

The International Neem Network (INN) was established in 1993, and the network function has been described by THOMSEN & SIGAUD (1998). The Network members established a series of provenance trials with neem. The seed was collected in 1995 from 25 seed sources in 11 different countries (ANONYMOUS 1998). More than 30 trials were established from February to April 1996 on locations in tropical arid zones around the world (HANSEN *et al.* 2000). Four trials were established in Tanzania by the National Tree Seed Programme (NTSP). The collection, handling and distribution of seed for the trials was administrated by the Danida Forest Seed Centre, Denmark.

Important questions in this study are: which provenances are the best suited to a particular environment and a particular purpose? How is the performance of the local provenance compared to introduced material. Could better material improve the utilization of neem as a contribution to development?

MATERIAL

Four trials were established in Tanzania in spring 1996 with 21 provenances from 11 countries (see Table 1). Four provenances from Thailand and Laos belong to the species *A. siamensis* (Ban Bo, Doi Tao, Vientiane and Ban Nong). Three provenances of *Azadirachta indica* are from Africa: Suniyani (Ghana), Bandia (Senegal), Chamwino (Tanzania), originating from earlier introductions of unknown origin. According to CIESLA (1993), neem was introduced to West Africa between 1919 and 1927, but it is not known, whether this occured simultaneously in East Africa.

The trials were established at four locations: Kwalukonge, Mkundi, Ubena and Chamwino. All trial sites have been described and documented in details by the International Neem Network (Anonymous 1998). The trials were established as a randomized complete block design with 5–6 blocks and with 16 (4 x 4) trees per plot planted with a 3.5 x3.5m spacing. Three of the trials are established on old Miombo woodlands, and the Kwalukonge trial was established on a previous sisal plantation.

The climatic conditions for trials Kwalukonge, Mikundi, and Ubena are similar, whereas the Chamwino trial is situated at a dry location on a higher altitude (Table 2). No irrigation, fertilization or thinning

Table 1. Provenances in the international neem provenance trials in Tanzania (ANONYMOUS 1998). Basic information is given on latitude, longitude, precipitation and altitude (meter above sea level).

	Locality	Country	Latitude	Longitude	Precipitation mm/yr	Altitude m. a. s. l.
1	Yezin	Myanmar	19°51′ N	96°16′ E	1269	100
2	Ban Bo	Thailand	16°17′ N	103°35′ E	1400	150
3	Ban Nong	Thailand	14°05′ N	99°40′ E	1145	40
4	Doi Tao	Thailand	17°57′ N	98°41′ E	1250	300
5	Vientiane	Laos	18°00′ N	102°45′ E	1540	180
6	Chamwino	Tanzania	6°20′ S	35°50′ E	475	–
7	Chitradurga	India	14°02′ N	76°04′ E	417	615
8	Ghaati	India	13°22′ N	77°34′ E	741	950
9	Mandore	India	26°18′ N	73°01′ E	373	224
10	Allahabad	India	25°28′ N	81°54′ E	910	320
11	Annur	India	11°17′ N	77°07′ E	875	360
12	Sunyani	Ghana	07°21′ N	02°21′ W	1270–1400	950–1000
13	Ramannaguda	India	19°05′ N	83°49′ E	1100	250
14	Sagar	India	21°51′ N	78°45′ E	1405	527
15	Multan	Pakistan	30°11′ N	71°29′ E	276	>150
16	Geta	Nepal	28°46′ N	80°34′ E	1725	170
17	Lamahi	Nepal	27°52′ N	82°31′ E	1500	350–440
18	Balharshah	India	19°51′ N	79°25′ E	1000	250
19	Tibbi Laran	Pakistan	28°24′ N	70°18′ E	140	115
20	Kuliyapitiya	Sri Lanka	7°8′ N	80°00′ E	1397	–
21	Bandia	Senegal	14°30′ N	17°02′ W	436	50

Table 2. Geographical key data for the Tanzanian trials. Values are given for latitude, longitude, altitude (meter) and precipitation. Data was obtained from HANSEN *at al.* (2000).

	Latitude	Longitude	Altitude (m. a. s. l.)	Rain (mm/yr)
Kwalukonge	04°57′ S	38°42′ E	488	739
Mkundi	06°40′ S	37°39′ E	475	793
Ubena	06°36′ S	38°09′ E	305	842
Chamwino	06°02′ S	34°39′ E	910	570

took place). There has been no noteworthy replacement plantings, and the trials are almost complete. Weeding (slashing) has taken place periodically in all trials. Competition between the three crowns has not occured until recently in a small part of the Mikundi trial.

METHODS

In October 2001, six years after planting, measurements were carried out. At this time the growth was apparently slow as the crown leaf mass was low or even null. Land preparation by slashing of grass was done before the quantitative characteristics were measured.

The characters 'tree height', 'diameter at breast height (DBH)', 'number of stems' originating from under 1.3 m and 'straightness' of the main stem(s) were measured on all trees in the trials.

In the Mkundi trial, the height measurements were made electronically due to the taller trees, and in the remaining trials, heights were recorded by measuring rod. The diameter (DBH) of all stems larger than 1 cm in diameter was measured. Some of the trees were bush shaped and it was technically difficult to distinguish between branches and stems, but We assume that the measured diameters are adequate to estimate an index for biomass production for the specific provenances.

Flowering and fruiting were recorded using a categorical scale: 0 for no observed flowering/fruiting, 1 for observed flowering/fruiting.

Branching was measured at the Mkundi trial from 1.3 m and to the top of the tree. The number of branches, that were not likely to be naturally self pruned, was counted. Since this assessment is based on the relative size of the branches compared to the stem it should be possible to compare large and small trees on the same scale. Branching is mainly used to determine the shape of the tree and the crown size, and can be used for estimating the ability for producing shade and as an indicator of biomass production. Measurement of branching is expected to be highly subjective and difficult to carry out in a standardized way.

Apparent health status was recorded as a remark for each observation. The relative amount of leaves and their vitality could normally be used as a health indicator, but the trees were measured in the dry season, when many trees had dropped their leaves by natural causes.

The most frequent damage on trees was top dying which appeared occasionally in all trials and most often in Chamwino. Several trees at the Kwalukonge trial were seriously attacked by termites.

Statistical methods

A general linear model using the SAS statistical software was applied for data analysis of each trial (ANONYMOUS 1985), and all calculations were based on plot means.

Least-square means estimates were produced for the overall analysis. The statistical univariate analysis proved that all quantitative data was normally distributed, and there were no significant deviations caused by missing data. Plots with less than 5 living trees were discarded from the analysis. Only a few plots from the Ubena trial and Chamwino trials were discarded because of low survival rate, mainly due to flooding.

Genotype by environment interaction (G × E) was estimated in an overall model. The principles of 2-way analysis of variance, univariate test of normality and test for outliers are described in details by HANSEN (2000).

Genotype by environment interaction has been studied by applying different linear methods. These various methods have been described and compared by LIN *et al.* (1986) and SKRØPPA (1983). Part of the genotype by environment interaction is explained by provenance variance and increases the standardized variance (CV). Within the statistical linear model, the total G × E sums of squares can be distributed to the single genotypes (and environments), referred to as "ecovalence" (WRICKE 1962). Change of rank between provenances on different locations are referred to as true G × E interaction and can be indicated by correlation of provenance performance between trials. A linear regression for genotypes over average field performance per test site can be interpreted as a stability parameter (FINLAY & WILKINSON 1963). A steep regression line (the slope "beta") indicates a provenance with high adaptive plasticity.

MUIR *et al.* (1992) developed a mathematical approach to split G × E interaction in two components, a part mainly due to heterogeneous variance SS(HV) and the second one due to rank change (imperfect correlation) SS(IC). KUNDU *et al.* (1998) tested the d_i^2 parameter on specific neem provenances within the INN network. This parameter was proposed by EBERHARDT & RUSSEL (1966) and is closely related to the heterogeneous variance, SS(HV).

RESULTS

Site variation

There are distinct differences in growth parameters (height and diameter growth) between the trials (Table 3). Mikundi has the highest growth rate. The highest mortality rate (missing trees) is found in the second and third best growing trial (Kwalukonge and Ubena, respectively), whereas the typically dry location of Chamwino has a low mortality. Percentage of missing trees and flowering frequency seems to be negatively correlated.

Provenance performance

Provenance means based on all four Tanzanian provenance trials are presented in Table 4. The two provenances from Thailand, Ban Bo and Ban Nong, have the highest growth rate. The Thai and the Lao provenances in most instances one-stemmed and with straighter stem form compared to other provenances, and appear better suited for timber production. This is significantly unlike the other provenances.

Among the *A. indica* provenances, Ghaati and Rammanaguda have overall good growth, high survival and an intermediate number of stems and could possibly be utilized for many purposes.

The provenances of Multan, Tibbi Laran and Mandore, all from the dry region around the Thar Desert (Pakistan and India), have produced the least growth. With the exception of the Multan provenance they also have a high mortality. In particular Mandore is failing in all trials but one, Chamwino, where it has a good survival. Also the provenances Geta, Sagar, Kuliyapitiya, Lamahi, Doi Tao and Vientiane are having a poor growth or survival rate.

The local Tanzanian provenance Chamwino is performing below average on survival and growth rate. High biomass is yielded by the multistem Sunyani and Yezin provenances, but the height is only intermediate. The provenances are robust and shady multistem with large crowns, but they do not produce large stems suitable for timber.

Genotype × environment interaction (G × E)

Five different measures of G × E have been calculated and listed for all genotypes (Table 5). Large variation between provenances are found for height, flowering and mortality (missing trees). G × E interaction is limited for height, but larger for flowering and missing tree frequency.

For height growth, the provenance Doi Tao has high ecovalence along with Mandore and Sagar. It is typical for the most extreme provenances to exhibit relatively high G × E interaction.

Most of the G × E for the provenance Doi Tao is caused by heterogeneous variance (HV) and a high plasticity in the Finlay & Wilkinson regression. The relative high values for imperfect correlation for Mandore and Sagar indicate true rank change.

Most of the G × E interaction is caused by large variation in growth in different sites. Some provenances react with a moderate or a flat regression slope (beta), like the slow growing provenances Mandore and Tibbi Laran (Data not shown). The Rammannaguda and Ghaati provenances react positively on better sites.

Moderate genotype by environment interaction has been found for flowering. Mandore and Tibbi Laran are

Table 3. Average tree parameters (arithmetic mean) for 4 neem provenance trials. Heights, diameter, stemform (1–9), average stem number per tree, percentage missing trees, percentage flowering trees (based on average plot values).

Trial	Height m	Diameter cm	Stem form 1–9	Stem numbers	Missing trees %	Flowering trees %
Kwalukonge	4.6	7.3	5.8	1.9	30	2
Mkundi	6.2	10.6	6.1	2.1	11	29
Ubena	3.6	6.6	6.1	1.6	28	8
Chamwino	3.1	5.4	6.1	2.8	11	14

Table 4. Provenance mean data for 4 Tanzanian provenance trials. Deviations from average mean is presented. The overall mean and the statistics for the overall analysis of variance are presented below (Overall mean, standard deviation, R^2, F-values for provenances and G x E interaction). Deviations (dev) in percent from mean values are presented for each value.

Seedlot	Seedno (TZ)	Height	Dev.	Diameter	Dev.	Stem form	Dev.	Stem numbers	Dev.	Branches score	Dev.	Missing trees	Dev.	Flowering trees	Dev.
		m	%	cm	%	"1–9"	%	No.	%	"1–9"	%	%	%	%	%
Allahabad / India	1	4.5	–3	7.8	1	6.0	–2	2.8	32	3.3	–10	10	–28	15	30
Annur/India	2	4.8	4	8.7	13	5.5	–11	2.7	24	4.7	29	7	–49	13	9
Balharshah/India	3	4.7	0	8.0	4	5.8	–5	2.4	12	4.2	14	6	–55	19	63
Ban Bo/Thailand	4	5.2	12	8.9	16	6.6	8	1.3	–38	2.9	–22	14	3	23	95
Ban Nong/Thailand	5	5.7	22	8.8	15	7.2	18	1.2	–43	2.5	–32	13	–8	11	–7
Bandia/Senegal	6	4.9	5	7.8	1	5.9	–4	2.0	–6	4.4	18	16	14	–1	–109
Chamwino/Tanzania	7	4.4	–5	7.5	–2	5.8	–6	2.5	15	3.8	4	18	32	12	–1
Chitradurga/India	8	4.9	7	7.6	–1	5.8	–6	2.0	–7	3.9	7	10	–24	9	–22
Doi Tao/Thailand	9	5.4	16	7.8	1	7.3	19	1.2	–45	2.0	–46	18	30	15	29
Geta/Nepal	10	4.0	–14	6.1	–20	6.2	1	2.1	–3	3.5	–4	15	9	6	–48
Ghaati/India	11	5.5	19	9.1	18	5.5	–10	2.2	0	3.9	6	9	–34	15	26
Kuliyapitiya/Sri Lanka	12	5.0	8	8.5	10	5.7	–6	2.0	–10	4.1	12	18	31	2	–82
Lamahi/Nepal	13	4.4	–5	7.7	0	5.9	–3	2.5	13	3.7	1	17	25	11	–10
Mandore/India	14	3.2	–31	4.6	–40	6.5	7	1.9	–13	3.8	3	33	140	2	–80
Multan/Pakistan	15	3.6	–23	5.7	–26	6.3	2	2.0	–9	3.8	3	21	56	1	–91
Ramannaguda/India	16	4.9	6	8.8	14	5.6	–9	2.5	14	4.5	23	9	–37	21	75
Sagar/India	17	4.5	–3	6.8	–12	6.4	4	1.8	–19	3.9	7	11	–16	17	43
Sunyani/Ghana	18	4.7	2	9.0	17	5.6	–8	3.4	56	4.4	20	5	–64	7	–39
Tibbi Laran/Pakistan	19	3.6	–23	6.2	–20	6.4	4	2.3	7	3.5	–4	9	–33	5	–58
Vientiane/Laos	20	4.7	1	7.5	–3	6.6	8	1.2	–44	2.3	–36	23	67	27	129
Yezin/Myanmar	21	4.8	4	8.9	16	5.9	–4	3.5	63	3.9	7	5	–61	17	47
Mean		4.6		7.7		6.1		2.2		3.7		14		12	
Standard deviance		0.65		1.4		0.38		0.47		0.48		0.13		0.13	
R^2		0.91		0.87		0.78		0.82		0.77		0.7		0.73	
$F_{PROVENANCE}$		15.5		12.6		32.4		33.8		13.3		6.2		5.6	
Significance		***		***		***		***		***		***		***	
F_{GxE}		1.79		1.59		1.28		1.59		1 site		2.93		2.83	
Significance		**		**		NS.		NS.		1 site		***		***	

***Significance on P>0.001 level, ** Significance on P>0.01 and P<0.5, NS. Non-significant.

Table 5. Parameters indicating genotype by environment interaction for each neem provenances. Summary of stability statistics. Coefficient of variance (CV, pct.), ecovalence (Eco, pct.), Muir`s statistic: imperfect correlation (IC) and heterogeneous variance (HV) and Finlay & Wilkinsson`s regression slope (beta).

Prov No.	Internat. Name	Height					Flower					Missing				
		CV	Eco	IC	HV	Finlay	CV	Eco	IC	HV	Finlay	CV	Eco	IC	HV	Finlay
1	Yezin	20	1.9	1.15	1.06	0.91	15	1.9	447	515	0.76	11	3.4	282	987	0.27
2	Ban Bo	21	6.8	1.43	2.36	1.31	18	21.7	1204	2536	2.17	12	3.1	851	373	1.11
3	Ban Nong	18	3.6	1.81	0.94	1.03	20	0.6	308	482	0.89	10	3.4	557	705	0.38
4	Doi Tao	24	33.1	1.37	10.83	1.81	23	3.7	480	737	1.56	10	9.5	1775	411	0.15
5	Vientiane	20	4.3	1.96	1.01	0.90	13	9.7	779	1280	1.81	9	2.1	701	374	1.20
6	Chamwino	19	4.5	1.35	1.70	0.77	20	0.7	343	450	1.15	12	1.3	560	386	1.34
7	Chitradurga	19	0.9	0.94	0.94	0.97	21	1.6	422	506	0.79	15	3.7	861	446	0.58
8	Ghaati	18	2.0	1.12	1.11	1.12	23	5.2	590	843	1.61	17	0.2	294	495	0.81
9	Mandore	25	16.1	3.24	3.52	0.52	47	9.1	971	1001	0.05	11	24.9	1169	3332	3.00
10	Allah	22	0.4	0.78	0.94	1.06	21	3.0	500	624	1.44	15	2.6	758	388	1.23
11	Annur	20	0.3	0.77	0.94	0.98	22	1.3	400	490	1.27	21	6.9	1324	469	0.27
12	Sunya	19	0.1	0.66	0.98	0.95	23	0.5	286	484	0.89	18	4.4	1000	421	0.56
13	Ramannaguda	20	1.2	0.97	1.03	1.10	15	4.3	574	730	1.52	15	3.4	500	763	0.35
14	Sagar	19	10.8	3.09	1.98	0.68	12	2.9	406	707	0.53	12	1.0	322	576	0.67
16	Multan	29	5.4	1.93	0.40	1.16	33	6.7	613	1033	0.18	13	11.5	1381	1102	1.77
17	Geta	23	0.5	0.85	0.91	1.01	29	0.5	229	540	0.81	12	0.7	487	366	1.27
18	Lamahi	20	3.1	1.17	1.43	0.82	20	3.7	769	453	0.80	13	3.1	810	414	1.28
19	Balharshah	20	1.9	0.77	1.44	0.83	17	5.8	484	1025	1.78	12	5.4	684	890	0.12
20	Kuliyapitiya	21	2.2	1.21	1.08	1.11	192	8.5	131	1756	0.00	13	3.0	662	547	1.63
21	Bandia	20	0.8	0.88	0.99	0.95	122	8.6	329	1573	0.00	15	6.4	740	975	2.04

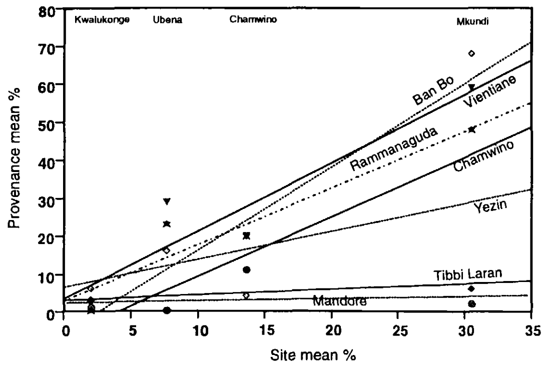

Figure 1. Finlay & Wilkinson regression slopes on "flowering frequency" for a subset of neem provenances included in the Tanzanian INN neem trial. The regression is shown as a regression of the population mean related to site means, which is indicated abowe the slopes.

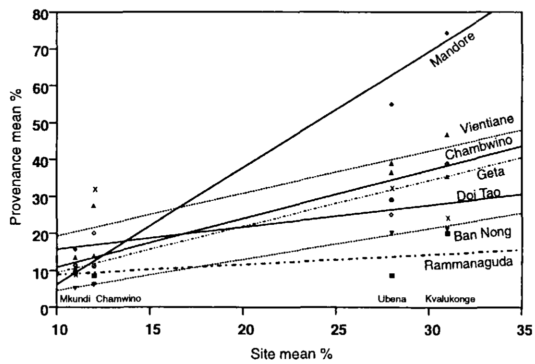

Figure 2. Finlay & Wilkinson regression slopes on "mortality in pct" for a subset of neem provenances included in the Tanzanian INN neem trial. The regression is shown as a regression of the population mean related to site means, which is indicated below the slopes.

generally not flowering at all. The provenances Doi Tao, Ban Bo and Vientiane are more responsive, with a steeper regression slope (beta) than the other provenances. A subset of the provenances shows distinct variation (Figure 1). The provenances Tibbi Laran (data not shown), Mandore, Kuliyapitya and Bandia flower scarcely in all trials.

Large G × E interaction has been revealed for frequency of missing trees, (Table 5). The regression lines can be divided into two groups – one with slight change in mortality over site range (flat slope) and a group with greater change in mortality (steeper slope) (Figure 2). (The provenance Mandore has an extremely high mortality rate). The two main groups have a distinct difference in mortality (from 17 % to 35 % on average). Most provenances shows moderate mortality, but a few have serious mortality on the driest locations (high response) (Mandore, Multan, Bandia and Kuliyapitiya). The provenances Balharshah, Ramannaguda, Yezin, Annur, Chitradurga, show a stable and low (5–10 %) mortality. The frequency of missing tree for the Thai provenances, Doi Tao and Ban Bo are stable and high (22 %). The provenances Multan and Doi Tao have high imperfect correlation and following true rank changes.

DISCUSSION

Comparison with other provenance studies

Only a few field provenance tests with neem have been reported in literature so far. Large variation in growth between provenances has been revealed in a 6 year old trial with *A. siamensis* provenances in Thailand (HONGTHONG 2002). A provenance from Doi Tao was included in this trial and performed a significantly poor growth compared to other Thai provenances. As opposite the Doi Tao provenances are performing quite well in the Tanzanian trials. This could be due to different seed material or to the different climatic conditions between the Tanzanian and the Thai sites.

Provenance trials with *A. indica* have been established in India. A few results have been published by EDWARDS and NAITHANI (1999) and excellent provenances for multipurpose use were identified, however none were common to the provenances in this paper.

A subset of provenances from the Network collection was included in a method study placed in the nursery. This showed genetic variation and genotype by environment interaction (KUNDU *et al.* 1998; KUNDU 2000). KUNDU and TIGERSTEDT (1997) also demonstrated genetic variation on adaptive traits as water-use-efficiency. Studies of genetic variation in neem provenances using AFLP markers have been carried out by SINGH *et al.* (1999). They found distinctive difference between Thai and Indian provenances. The genetic variation within the Indian region was broad, whereas the four Thai provenances formed a relatively narrow genetic base.

Provenance performance in the Tanzanian trials

Our analysis shows extensive growth and phenological variation between the provenances included in the trials. However the provenance rankingwithin this study should be cautiously interpreted since the number of trees (64) per provenance per trial is restricted. Anyway the trials have produced statistically significant results.

Provenances from central and eastern India seem to be superior, as they are growing well and have low mortality rate. They perform better than the South

Indian provenances, the Nepalese provenances and especially the provenances originating from very arid conditions in Western India and Pakistan.

These results also indicate that provenances from the very arid regions of Western India and Western Pakistan cannot be recommended for the sites tested in Tanzania.

The local seed source from Chamwino would be expected to be very well adapted to the climate in Eastern Africa. It seems well adapted at the Chamwino site where it has been collected, but its performance in general for the four trials is no more than average in respect of growth and vigour. In this case the local seed source is not the best, and this emphasises the importance of choosing good genetic material and the importance of provenance testing.

Even though the 4–5 East Indian provenances of *A. indica* indicate positive properties, it is still too early to be sure that the later growth, health and quality will still be good. Rather than recommending a single provenance of choice, it would be preferable to indicate a group of provenances if they appear in a similar way – preferably a region of provenance. This would increase the degrees of freedom for choice of provenances, and in this specific case the eastern Indian zone seems interesting concerning *A. indica*.

These trials also demonstrate large differences in provenance vitality. In particular *A. siamensis* provenances, which show good productivity and stem quality, have high mortality rate, especially in the Kwalukonge trial. This demonstrates the potential risk of choosing well growing provenances based on too few years of testing.

The results and conclusions from this provenance trial have disqualified a number of the tested provenances for use in Tanzania because of low fitness. The actual ranking of provenances is valuable reference for the East African region, but it could not be applied to other regions.

Most important is probably the finding that the local Tanzanian provenance, Chamwino, shows below average performance and may indicate that there could be some gains in introducing new genetic material. For further refinement it would be interesting to test provenances from promising seed zones like Eastern India and establish new provenance trials.

Influence by the environment

In forest species, genotype by environment interaction is often observed, but this can result in high heterogeneous variance without relevant rank change (SKRØPPA 1983). As opposite, in our neem trials, remarkable rank changes were observed for survival at different sites, despite of their similar environmental conditions. The reason is probably the extremely heterogeneous performance of introduced provenances in Eastern Africa from very different geographic origins (for example the Thar desert and the humid zones of Thailand and Laos). In this specific case, the trials should be evaluated independently from each other, and specific recommendations should be made for each location.

The methods applied in this investigation are based on linear statistical models, which are feasible for performance forest field trials, though they may not reflect the true situation in the case of non-linear response of genotype to the environment (NAMKOONG *et al.* 1988).

The growth and survival of the various provenances has also been related to geographic data of provenance origin (latitude, longitude, altitude and precipitation) (WESTFALL 1992). A preliminary multivariate statistical analysis between geographic variables and growth variables was carried out.

A relation would be expected between precipitation on site of origin and drought resistance. This is actually seen for *A. siamensis* provenances which originate from semi-humid sites and show high growth potential but also sensitivity to drought. Similarly, the Pakistan and Mandore provenances of *A. indica* are all slow growing in the Tanzanian trials, coherently with their desert origin (140-373 mm precipitation/year). However no general relationship can be found between site origin and growth/vigour for the other provenances of *A. indica*. It should be noted that several of the provenances for such species used in our trials are domesticated (*i.e.* not native) since a limited number of years, and have probably not yet adapted as landraces. As mentioned by THOMSEN & SIGAUD (1998), one explanation for slow growth could be narrow selection and subsequent inbreeding of local provenances or landraces. At this time, this hypothesis cannot be rejected. Further studies with genetic markers may indicate the plant history, and possible inbreeding of introduced neem seed sources.

CONCLUSIONS

This study underscores the importance of provenance trials as a basis for the domestication of tree species like neem in Western Africa. Specific regions can be recommended (Eastern and Central India) and imports from the semi-arid desert areas should be avoided. Application of plant material from Thailand in Tanzania should include risk evaluation that the trees could possibly suffer severe dieback. A general evaluation on all international neem trials in the International Neem Network would be relevant, and a similar analysis should be carried out with a larger number of sites (and provenances) when such data are available.

This study only include a few basic growth and qualitative characters, and as neem is a species of many purposes, it will be very useful to study other properties like flowering, seed production and oil content within various provenances of neem. Experiments show that substantial provenance variation can be found in leaf extracts of Azarachterin from neem in eastern Asia (SMUTTERE & DOLL 1993).

ACKNOWLEDGEMENTS

These investigations were supported by Danida Forest Seed Centre and FAO within the framework of the International Neem Network and the FAO-Netherlands Partnership Program. Thanks to Anders Pedersen, Daniela Salvini and Søren Hald for valuable comments and assistance. The work has been organised by the National Tree Seed Programme in Morogoro, and we wish to thank Komba Singo, Kombo Siva, Ester Willifred and Mr. Moshe for valuable assistance.

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