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# EVALUATION OF PROVENANCE VARIATION ON EARLY GROWTH AND SURVIVAL OF NEEM (*AZADIRACHTA INDICA*) IN BANGLADESH AND INDIA

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**KUNDU, S. K. 2000. Evaluation of provenance variation on early growth and survival of neem (*Azadirachta indica*) in Bangladesh and India.** Twenty provenances of neem (*Azadirachta indica* A. Juss.) were studied at three sites of the international provenance trials in Bangladesh and India after a growing period of about seven months in the field. Significant differences were observed between provenances in height and collar diameter. Mean plant heights, collar diameters and survival rates were 52.56 cm, 8.13 mm and 68.53% at site I; 42.19 cm, 6.72 mm and 89.02% at site II; and 36.07 cm, 4.78 mm and 45.50% at site III respectively. Variations in collar diameters and survival rates were detected at sites I and II and were associated with latitudinal clines. Positive correlations between heights and survival rates and between collar diameters and survival rates were detected at all three sites. Regression analyses indicated significant amounts of variation for collar diameter at sites I and II due to the effect of latitude. The data on height, collar diameter and survival rate of trees at the individual sites were subjected to principal component analysis (PCA). The first principal component accounted for 83% (site I), 86% (site II) and 72% (site III) of variation. The second principal component accounted for 16% (site I), 12% (site II) and 28% (site III) of variation. PCA revealed distinct population differentiation associated with variations in height and survival rate of neem populations at the three sites. Ecoclimatic attributes played an important role in the differentiation of neem populations and thereby affected their growth and survival during the early stages of establishment.

Key words: Clinal variation - growth - international provenance trials - survival

**KUNDU, S. K. 2000. Penilaian terhadap perubahan provenans bagi pertumbuhan awal dan kemandirian neem (*Azadirachta indica*) di Bangladesh dan India.** Dua puluh provenans neem (*Azadirachta indica* A. Juss.) dikaji di tiga tapak percubaan provenans antarabangsa di Bangladesh dan India selepas tempoh penanaman selama kira-kira tujuh bulan di ladang. Perbezaan bererti dalam ketinggian dan garis pusat kolar dicerap antara provenans. Purata ketinggian pokok, garis pusat kolar dan kadar kemandirian masing-masing ialah 52.56 cm, 8.13 mm dan 68.53% di tapak I; 42.19 cm, 6.72 mm dan 89.02% di tapak II; dan 36.07 cm, 4.78 mm dan 45.50% di tapak III. Perubahan dalam garis pusat kolar dan kadar kemandirian dikesan di tapak I dan II dan berasosiasi dengan klin latitud. Korelasi positif antara ketinggian dan kadar kemandirian dikesan di ketiga-tiga tapak. Analisis regresi menunjukkan jumlah perubahan yang bererti bagi garis pusat kolar di tapak I dan II akibat daripada pengaruh latitud. Data mengenai ketinggian, garis pusat kolar dan kadar kemandirian pokok di tapak individu bergantung kepada analisis komponen utama (PCA). Komponen utama yang pertama menjelaskan 83% (tapak I), 86% (tapak II) dan 72% (tapak III) daripada perubahan. PCA menjelaskan perbezaan populasi yang ketara yang berasosiasi dengan perubahan dalam ketinggian dan kadar kemandirian bagi populasi neem di ketiga-tiga tapak tersebut. Ciri-ciri ekoiklim memainkan peranan penting dalam pembezaan populasi neem dan dengan ini mempengaruhi pertumbuhan dan kemandirian pada tahap awal penubuhannya.

## Introduction

The neem tree (*Azadirachta indica* A. Juss.) (Meliaceae) is a multiple-use species (Radwanski & Wickens 1981, Koul *et al.* 1990, Maramorosch 1991, Ketkar & Ketkar 1995, Saxena 1995). *Azadirachta indica* possesses better medicinal and bioactive properties than its close relatives such as Thai neem (*A. siamensis*), sentang or marrango tree (*A. excelsa*) and the Persian lilac or Chinaberry tree (*Melia azedarach*) (Lauridsen *et al.* 1991). For fuelwood production, the neem tree has been identified as one of 233 species suitable for arid and semi-arid regions and one of 145 species suitable in the humid tropics (Pliske 1983). The natural range of the species covers Myanmar and the Indian subcontinent, although cultivation of neem by introduction was started long ago in many warmer parts of the world (Schmutterer 1995). In the natural range it is adapted to drier habitats but in introduction areas its acclimatisation is apparent in both drier and moist climate regimes (Arora 1993). Plant populations exhibit genetic variation on several ecogeographic levels and such variation exists along ecological gradients in latitude, altitude and humidity (Hill *et al.* 1998). Thus, many specialised populations have adapted to certain ecoclimatic conditions (Kundu & Tigerstedt 1997). It is important to recognise the genetic variation of the species and to identify the best seed sources adapted to different ecological regions and to breed them for efficient uses.

Here we use the term "provenance" in a broad sense, including all seed sources (natural and introduced) of neem from anywhere in the world. Provenance testing of a tree species is important because it defines the genetic and environmental components of phenotypic variation that are associated with geographic locations (Callaham 1964, Zobel & Talbert 1984). Provenance research assures good sources of seed that provide well-adapted, productive trees and allow selection and breeding of a species towards adaptation to particular localities. Furthermore, it provides the necessary scientific basis for selection of seed source, transfer of seeds and for the strategies of genetic improvement (Chang-Geng 1989).

*Azadirachta indica* possesses protandric bisexual flowers; both self and cross pollination have been reported by Gupta *et al.* (1996). However, due to its wide range, provenances have been shown to exhibit a high level of variability in growth and morphological characteristics (Gupta *et al.* 1996, Kundu & Tigerstedt 1997). The considerable variability suggests that attractive gains could be achieved through selection and breeding for desired traits. A tree improvement programme is a long-term process, hence an early selection strategy is preferred to accelerate the rate of genetic improvement (Lambeth *et al.* 1983).

The objectives of the International Neem Network are to examine genetic variation, adaptation and growth of neem provenances, and to assess the resulting genotype × environment (G × E) interactions over a range of environments (Hansen *et al.* 1997). The present study was based on the data from the provenance trials at three sites in Bangladesh and India. The aims of this study were 1) to examine the magnitude of provenance variation in growth (height and collar diameter) and survival at individual sites, 2) to investigate the relationships between growth and survival rate, and 3) to determine the relationships of the ecoclimatic factors (latitude, altitude and mean annual rainfall) with growth and with survival rate.

## Materials and methods

### *Nursery production and plantation establishment*

Open-pollinated bulked seeds were collected by the International Neem Network co-ordinated by the FAO. Common guidelines developed by the Network for nursery establishment of seedlings and experimental designs were followed (Thomsen & Souvannavong 1994). The hard-shelled seeds were germinated in open nursery beds containing loamy-sandy soils at the nurseries of the Bangladesh Forest Research Institute and Indian Arid Forest Research Institute. The sprouted seeds were then transferred into polybags, measuring 25.40 × 15.24 cm layflat, filled with topsoil and dry cowdung mixture (3:1). The nursery seedlings received supplementary watering whenever necessary until out-planting, 9 to 12 months later. The out-plantings were done between 28 and 30 July 1996 at Charaljani (site I), on 18 September 1996 at Charkhai (site II) and between 25 July and 5 August 1996 at Jodhpur (site III). The three sites include 20 provenances from Asia and Africa (Table 1). Provenances P1 to P6 were evaluated at the three sites, provenances P7 to P18 only at site III, provenance P19 at sites I and II, and provenance P20 only at site II.

### *Site conditions, experimental designs and silvicultural treatments*

The three test sites included in this study were Charaljani and Charkhai in Bangladesh, and Jodhpur in India (Table 2). The sites differed in edaphic and climatic conditions and were classified as optimum, intermediate and stress environments on the basis of mean annual rainfall (MAR), temperature (maximum and minimum) and soil conditions. Site I was characterised by a high MAR, moderate temperatures and clay loam soils and site III by low MAR and extreme temperatures with winter frost. The conditions at site II were intermediate. The experiments were designed as randomised complete block designs in four replicates. Each provenance was represented in each block by 25 seedlings per plot. The seedlings were planted in pits (30 × 30 × 30 cm) at 3 × 3 m. Periodic weedings were carried out at the three sites. Site II was hoed in December 1996 to enhance soil aeration.

### *Measurements*

Plant height (HT), collar diameter (CD) and survival rate (SV%) were recorded on 21 January 1997 (site III), 7 February 1997 (site I) and 24 February 1997 (site II) after a growing period of about seven months in the field. The measurements were made on all 25 plants in each plot. Border effect was ignored because of the early stage of plant growth. HT of the plant was measured as the distance between the soil surface and tip of the terminal bud and CD at the soil surface with a vernier calliper. SV% was calculated as number of survived plants divided by total plants planted and multiplied by 100.

### *Statistical analyses*

Prior to statistical analyses the data on survival rate were arcsin transformed in order to conform to a normal distribution (Fowler & Cohen 1990). Means and their

**Table 1.** Seed sources of *Azadirachta indica* used in the study

| Provenance code | Provenance/ seed source | Country of origin | Latitute | Longitude | Altitude (m) | Mean annual rainfall (mm) | Dry season |
|---|---|---|---|---|---|---|---|
| P1 | Tuang Luang | Thailand | 09°09´N | 99°07´E | 4 | 1755 | Jan–Apr |
| P2 | Ban Nong Rong | Thailand | 14°05´N | 99°40´E | 40 | 1145 | Nov–Mar |
| P3 | Doi Tao | Thailand | 17°57´N | 98°41´E | 300 | 1250 | Nov–Apr |
| P4 | Yezin | Myanmar | 19°51´N | 96°16´E | 100 | 1269 | Nov–May |
| P5 | Geta | Nepal | 28°46´N | 80°34´N | 70 | 1725 | Nov–Apr |
| P6 | Sunyani | Ghana | 7°21´N | 2°21´W | 950 | 1335 | Dec–Mar |
| P7 | Vientiane | Laos | 18°00´N | 102°45´E | 180 | 1540 | Nov–Mar |
| P8 | Chamwino | Tanzania | 6°20´S | 35°50´E | 1030 | 475 | June–Aug |
| P9 | Ramannaguda | India | 19°05´N | 83°49´E | 250 | 1100 | Mar–June |
| P10 | Kulapachra | India | 27°30´N | 75°25´E | 235 | 260 | Mar–June |
| P11 | Kalyani | India | 22°35´N | 88°20´E | 18 | 1500 | Oct–Apr |
| P12 | Balharshah | India | 19°51´N | 79°25´E | 250 | 1000 | Apr–June |
| P13 | Sagar | India | 21°51´N | 78°45´E | 527 | 1282 | Apr–June |
| P14 | Annur | India | 11°17´N | 77°07´E | 360 | 875 | Mar–June |
| P15 | Mandore | India | 26°18´N | 73°01´E | 224 | 373 | Mar–June |
| P16 | Alahabad | India | 25°28´N | 81°54´E | 320 | 900 | Mar–June |
| P17 | Ghatti | India | 13°22´N | 77°34´E | 950 | 741 | Mar–June |
| P18 | Lamahi Dang | Nepal | 27°52´N | 82°31´E | 350 | 1500 | Nov–Apr |
| P19 | Myene | Myanmar | 22°03´N | 95°13´E | 76 | 809 | Nov–Apr |
| P20 | Ban Bo | Thailand | 16°17´N | 103°35´E | 150 | 1400 | Oct–Apr |

Provenances P1 to P6 are common in the three sites; P7 to P18 occur only in site III; P19 occurs in sites I and II; P20 occurs only in site II.

**Table 2.** Description of sites of the international neem provenance trials in Bangladesh and India included in the study

| Site | Country | *Lat. | Long. | Alt. (m) | MAR (mm) | Dry season | MMRH (%) | Temperature (°C) | | Topography and soils | Original vegetation types |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Max | **Min | | |
| I Charaljani | Bangladesh | 24°43′N | 90°26′E | 19 | 2246 | Nov–Mar | 56–85 | 29.9 | 20.4 | Flat to very gentle sloping. Brown forest soils derived from Plio-Pleistocene sediments. Clay loam to clay, pH 5.0–5.5 | Moist deciduous *Shorea robusta* forests. Associates: *Adina, Albizia, Emblica, Syzigium, Terminalia* |
| II Charkhai | Bangladesh | 25°28′N | 88°58′E | 37 | 1695 | Nov–Apr | 46–83 | 30.8 | 19.7 | Flat to very gentle sloping. Brown forest soils derived from Plio-Pleistocene sediments. Clay loam and clay, pH 5.0–6.0 | Moist deciduous *Shorea robusta* forests. Associates: *Albizia, Anthocephalus, Bombax, Miliusa* |
| III Jodhpur | India | 24°40′N | 71°15′E | 224 | 250 | Mar–June | 55–63 | 46.0 | 02.0 | Flat to gentle sloping. Sandy loam, reddish-brown. Moderately acid soil, pH 5.5–6.5 | Dryland savanna forests, savanna dotted with xerophytes. Associates: *Prosopis, Acacia, Zizyphus* |

Note:
*Lat. = latitute, Long. = longitude, Alt. = altitude, MAR = mean annual rainfull, MMRH = mean monthly relative humidity; **minimum temperature prevails in the months of December, January and February.

standard errors (SE) were calculated on plot basis. Differences among provenances within each site were established with analyses of variance (ANOVA) using PROC GLM (SAS Institute Inc. Cary, NC) with type III estimation of sum of squares. Whenever the differences were significant in the ANOVA, the means were separated using Tukey's Honestly Significant Difference (HSD) at p=0.05. Data from the three sites were analysed separately using the statistical model as in equation 1. Block effect was considered to be fixed and all other effects were treated as random.

$$X_{ij} = \mu + G_i + E_j + \varepsilon_{ij} \qquad (1)$$

where $Xij$ = observed value of a given character for an individual measurement of the $i$th provenance at the $j$th replicate

$\mu$ = overall mean

$G_i$ = genotypic effect ($i$th provenance)

$E_j$ = environmental effect ($j$th replicate)

$\varepsilon_{ij}$ = random error

Pearson's product moment correlations and simple regressions among the studied traits and ecoclimatic attributes were computed using the provenance means from individual sites.

Principal component analyses (PCA) were performed on the measured traits. The STD option in PROC PRINCOMP was applied to standardise the data to minimise variation.

## Results

### *Variation among provenances*

In general, plant growth decreased from sites I to III (Table 3). Survival rate was highest (89.02%) at site II. Variations in plant height among the provenances were lower at site II than at site III. Individual site ANOVA (Table 4) indicated a significant provenance effect for all traits at the three sites, except at site II, where the effect on SV% was not statistically significant. Furthermore, there was a significant block effect for all studied traits at the stress site III.

### *Interdependence among the characters*

The Pearson's product moment correlation coefficient (r) and significant probabilities among the studied traits and ecoclimatic data are summarised in Table 5. A high positive linear correlation (r= 0.81***) between CD and HT was recorded at site III. Positive linear correlations (r=0.65, 0.47 and 0.39) between HT and SV%, and negative correlations (r= –0.76*, –0.85** and –0.07) between latitude and CD and between latitude and SV% (r= –0.60, –0.67 and –0.04) were also detected at sites I, II and III respectively. However, a general inspection of Table 5 shows very few significant correlations. This is probably due to the early trial measurements still affected by planting effects. The coefficients of determination ($r^2$%) resulted from regression analyses between measured variate and seed origin are listed in Table 6. The relationships between latitude and CD and between latitude and SV% of the provenances of the sites I and II are illustrated in Figures 1 and 2 respectively. There were no significant regressions at site III.

*Principal component analyses*

The first three eigenvectors extracted from the individual sites by PCA are presented in Table 7. Survival rate (SV%) and height (HT) were indicated as having the largest absolute loading values in the first and second principal components at sites I and II respectively. Conversely, HT and SV% had the largest absolute loading values in the first and second principal components at sites II and III respectively. The first principal component accounted for 83% (site I), 87% (site II) and 72% (site III) and the second for 16% (site I), 12% (site II) and 28% (site III) of the variations respectively. A plot of the first and the second principal components for the three sites revealed (Figures 3, 4 and 5) three groups of populations. In Figure 3, provenances P1 and P6 formed two separate groups exhibiting intermediate and high survival rates, and provenances P2, P3, P4, P5 and P19 clustered into a large group indicated low survival rates at site I respectively. In Figure 4, provenances P3 and P5 constituted two separate groups based on their intermediate and low survival rates, and P1, P2, P4, P6, P19 and P20 formed a third group representing high survival rates at site II respectively. Likewise, in Figure 5, provenances P1, P2, P3, P4, P5, P6, P7, P9, P10, P11, P12, P13, P14, P16, and P17 constituted a large group indicating their low survival rates, while P8 and P18 formed two separate groups exhibiting intermediate and high survival rates at site III respectively.

## Discussion

Generally, provenance means of the plant height, collar diameter and survival rate at the individual sites decreased with increasing altitude and decreasing rainfall and temperature of the sites. The highest variation on plant height and survival rate among the provenances at site III indicated a stress environment. This was manifested in the significant block effect. On the other hand, sites I and II exhibited lower variation in all studied traits. The significant variation among neem provenances in growth and survival rates at the three sites observed in this study was probably genetic in origin and indicated a potential for choosing the best provenances for a site. In an earlier study involving six provenances that were common to all three sites, significant genotype × environment interactions were found for height (Kundu *et al.* 1998). Similar variations have been reported in other species adapted to arid and semi-arid conditions such as *Acacia albida* (Sniezko & Stewart 1989), *Eucalyptus* spp. and *Casuarina* spp. (Toky & Bisht 1991) and *Prosopis cineraria* (Arya *et al.* 1995).

The results from this study showed that ecoclimatic attributes affect growth and survival rate of neem. In the present study, correlations between the latitude of origin and CD and between latitude and SV% at sites I and II suggested a clinal variation in neem. Clinal variations in morphological characters have been reported in many forest species such as *Eucalyptus* spp. (Pinyopusarek *et al.* 1993) and *Racosperma auriculiformis* and *R. mangium* (Khasa *et al.* 1995). Kundu and Tigerstedt (1997) reported clinal

**Table 3.** Statistical parameters of neem provenances studied at the three sites

| | | Site I Charaljani | | | Site II Charkhai | | | Site III Jodhpur | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Prov. code | Stat. param. | HT (cm) | CD (mm) | SV% (arcsin) | HT (cm) | CD (mm) | SV% (arcsin) | HT (cm) | CD (mm) | SV% (arcsin) |
| P1 | Mean | 65.12$^{a}$ | 9.00$^{a}$ | 76.31$^{ab}$ | 40.72$^{ab}$ | 8.09$^{a}$ | 90.00$^{a}$ | 40.27$^{bc}$ | 4.89$^{abc}$ | 49.03$^{ab}$ |
| | SE | 1.72 | 0.46 | 6.40 | 3.99 | 0.77 | 0.01 | 4.10 | 0.36 | 8.31 |
| P2 | Mean | 49.51$^{bc}$ | 9.27$^{a}$ | 66.87$^{ab}$ | 42.89$^{ab}$ | 7.83$^{a}$ | 90.00$^{a}$ | 30.43$^{bc}$ | 5.24$^{ab}$ | 34.22$^{ab}$ |
| | SE | 2.74 | 0.53 | 2.83 | 1.12 | 0.21 | 0.01 | 3.95 | 0.39 | 4.28 |
| P3 | Mean | 41.10$^{c}$ | 8.62$^{ab}$ | 57.32$^{b}$ | 33.30$^{b}$ | 6.74$^{ab}$ | 87.13$^{a}$ | 29.51$^{bc}$ | 4.47$^{bc}$ | 51.96$^{ab}$ |
| | SE | 2.77 | 0.37 | 3.42 | 3.92 | 0.94 | 2.87 | 2.43 | 0.15 | 4.60 |
| P4 | Mean | 54.16$^{b}$ | 8.25$^{ab}$ | 58.90$^{b}$ | 50.15$^{a}$ | 6.37$^{ab}$ | 90.00$^{a}$ | 39.64$^{bc}$ | 4.47$^{bc}$ | 33.10$^{ab}$ |
| | SE | 1.92 | 0.52 | 7.12 | 3.28 | 2.18 | 0.01 | 1.82 | 0.22 | 2.08 |
| P5 | Mean | 51.14$^{bc}$ | 6.72$^{b}$ | 68.35$^{ab}$ | 41.40$^{ab}$ | 5.34$^{b}$ | 85.01$^{a}$ | 34.91$^{bc}$ | 5.37$^{ab}$ | 51.86$^{ab}$ |
| | SE | 2.49 | 0.40 | 5.51 | 1.47 | 0.14 | 4.98 | 3.44 | 0.30 | 7.57 |
| P6 | Mean | 55.57$^{ab}$ | 8.32$^{ab}$ | 84.23$^{a}$ | 45.38$^{ab}$ | 7.03$^{ab}$ | 90.00$^{a}$ | 40.71$^{bc}$ | 4.46$^{bc}$ | 52.96$^{ab}$ |
| | SE | 0.72 | 0.18 | 4.00 | 0.34 | 0.20 | 0.01 | 2.64 | 0.36 | 11.36 |
| P7 | Mean | – | – | – | – | – | – | 43.20$^{abc}$ | 5.48$^{ab}$ | 43.80$^{ab}$ |
| | SE | | | | | | | 3.83 | 0.10 | 6.2 |
| P8 | Mean | – | – | – | – | – | – | 67.35$^{a}$ | 6.49$^{a}$ | 55.38$^{ab}$ |
| | SE | | | | | | | 14.40 | 0.80 | 5.96 |
| P9 | Mean | – | – | – | – | – | – | 29.03$^{bc}$ | 4.11b$^{c}$ | 45.55$^{ab}$ |
| | SE | | | | | | | 4.32 | 0.38 | 7.61 |
| P10 | Mean | – | – | – | – | – | – | 42.24$^{bc}$ | 5.53$^{ab}$ | 52.96$^{ab}$ |
| | SE | | | | | | | 7.71 | 0.35 | 6.68 |
| P11 | Mean | – | – | – | – | – | – | 18.33$^{c}$ | 3.57$^{c}$ | 40.95$^{ab}$ |
| | SE | | | | | | | 0.49 | 0.33 | 4.15 |
| P12 | Mean | – | – | – | – | – | – | 33.52$^{bc}$ | 4.38$^{bc}$ | 44.97$^{ab}$ |
| | SE | | | | | | | 6.17 | 0.20 | 8.57 |
| P13 | Mean | – | – | – | – | – | – | 49.54$^{ab}$ | 5.13$^{abc}$ | 48.52$^{ab}$ |
| | SE | | | | | | | 6.86 | 0.59 | 3.44 |
| P14 | Mean | – | – | – | – | – | – | 35.13$^{bc}$ | 4.74$^{bc}$ | 45.13$^{ab}$ |
| | SE | | | | | | | 4.99 | 0.2 | 9.45 |
| P15 | Mean | – | – | – | – | – | – | 37.33$^{bc}$ | 5.42$^{ab}$ | 38.30$^{ab}$ |
| | SE | | | | | | | 6.65 | 0.38 | 11.38 |
| P16 | Mean | – | – | – | – | – | – | 26.90$^{bc}$ | 3.96$^{bc}$ | 36.20$^{ab}$ |
| | SE | | | | | | | 1.49 | 0.30 | 1.49 |
| P17 | Mean | – | – | – | – | – | – | 22.26$^{c}$ | 3.57$^{c}$ | 30.40$^{b}$ |
| | SE | | | | | | | 1.35 | 0.07 | 5.2 |
| P18 | Mean | – | – | – | – | – | – | 28.92$^{bc}$ | 4.79$^{bc}$ | 63.68$^{a}$ |
| | SE | | | | | | | 1.42 | 0.11 | 9.33 |
| P19 | Mean | 51.32$^{bc}$ | 6.72$^{b}$ | 67.74$^{ab}$ | 41.94$^{ab}$ | 6.03$^{ab}$ | 90.00$^{a}$ | – | – | – |
| | SE | 2.64 | 0.40 | 5.88 | 2.15 | 0.36 | 0.01 | | | |
| P20 | Mean | – | – | – | 41.74$^{ab}$ | 6.38$^{ab}$ | 90.00$^{a}$ | – | – | – |
| | SE | | | | 2.55 | 0.27 | 0.01 | | | |
| All prov. | Mean | 52.56 | 8.13 | 68.53 | 42.19 | 6.72 | 89.02 | 36.07 | 4.78 | 45.50 |
| | SE | 1.49 | 0.23 | 0.23 | 1.15 | 0.21 | 0.71 | 1.69 | 0.11 | 1.77 |

Means with the same superscript letters are not significantly different at p=0.05 (Tukey's HSD test); Stat. param, statistical parameter; SE, standard error; HT, height; CD, collar diameter; SV%, survival rate.

**Table 4.** Individual site analyses of variance on height (HT), collar diameter (CD) and survival rate (SV%) of neem provenances tested at the three sites

| Site | Trait | Source of variation | d.f. | Mean square | F-value |
|---|---|---|---|---|---|
| I Charaljani, Bangladesh *Optimal environment* | HT | Block | 3 | 14.18 | $0.66^{ns}$ |
| | | Provenance | 6 | 209.13 | 9.79*** |
| | | Error | 18 | 21.36 | |
| | | Total | 27 | | |
| | CD | Block | 3 | 0.16 | $0.19^{ns}$ |
| | | Provenance | 6 | 4.20 | 5.17*** |
| | | Error | 18 | 0.81 | |
| | | Total | 27 | | |
| | SV% | Block | 3 | 20.75 | $0.21^{ns}$ |
| | | Provenance | 6 | 352.66 | 3.51* |
| | | Error | 18 | 100.37 | |
| | | Total | 27 | | |
| II Charkhai, Bangladesh *Intermediate environment* | HT | Block | 3 | 12.66 | $0.41^{ns}$ |
| | | Provenance | 7 | 89.24 | 2.91* |
| | | Error | 21 | 30.69 | |
| | | Total | 31 | | |
| | CD | Block | 3 | 0.72 | $0.76^{ns}$ |
| | | Provenance | 7 | 3.33 | 3.51** |
| | | Error | 21 | 0.95 | |
| | | Total | 31 | | |
| | SV% | Block | 3 | 30.87 | $2.13^{ns}$ |
| | | Provenance | 7 | 14.51 | $1.00^{ns}$ |
| | | Error | 21 | 14.51 | |
| | | Total | 31 | | |
| III Jodhpur, India *Stress environment* | HT | Block | 3 | 500.68 | 5.37** |
| | | Provenance | 17 | 488.47 | 5.24*** |
| | | Error | 51 | 93.22 | |
| | | Total | 71 | | |
| | CD | Block | 3 | 2.47 | 6.42*** |
| | | Provenance | 17 | 2.26 | 5.87*** |
| | | Error | 51 | 0.38 | |
| | | Total | 71 | | |
| | SV% | Block | 3 | 1341.34 | 9.89*** |
| | | Provenance | 17 | 309.27 | 2.28** |
| | | Error | 51 | 135.62 | |
| | | Total | 71 | | |

$^{ns}$, not significant; *, significant at $p < 0.05$; **, significant at $p < 0.01$; ***, significant at $p < 0.001$.

**Table 5.** Pearson's product-moment correlation coefficients among the studied traits and geoclimatic data of neem provenances at the three individual sites. Provenance means of each site have been used in the analyses.

| | Site I | | | Site II | | | Site III | | |
|---|---|---|---|---|---|---|---|---|---|
| Traits | HT | CD | SV% | HT | CD | SV% | HT | CD | SV% |
| CD | 0.14 | | | –0.05 | | | 0.81*** | | |
| SV% | 0.65 | 0.05 | | 0.47 | 0.57 | | 0.39 | 0.43 | |
| Latitude | –0.46 | –0.76* | –0.60 | –0.08 | –0.85** | –0.67 | –0.35 | –0.07 | –0.04 |
| Altitude | –0.05 | 0.09 | 0.55 | 0.06 | 0.05 | 0.11 | 0.38 | 0.07 | 0.17 |
| MAR | 0.48 | 0.14 | 0.30 | –0.40 | 0.10 | –0.41 | –0.24 | –0.24 | 0.18 |

*, significant at $p < 0.05$; **, significant at $p < 0.01$; ***, significant at $p < 0.001$.

**Table 6.** Coefficent of determination ($r^2$ %) obtained from simple regression analyses of height, collar diameter and survival percentage with geoclimatic variables of provenance origin (latitude, longitude, altitude and MAR) for neem at the three sites

| | Site I | | | Site II | | | Site III | | |
|---|---|---|---|---|---|---|---|---|---|
| Independent variable | HT | CD | SV% | HT | CD | SV% | HT | CD | SV% |
| Latitude | 20.78 | 57.27* | 35.72 | 0.57 | 71.52** | 44.86 | 12.52 | 0.57 | 0.19 |
| Longitude | 2.86 | 0.36 | 54.53 | 7.84 | 0.00 | 0.23 | 17.43 | 2.94 | 11.82 |
| Altitude | 0.22 | 0.80 | 30.73 | 1.02 | 0.29 | 1.17 | 14.77 | 0.51 | 2.84 |
| MAR | 0.22 | 2.05 | 8.81 | 0.51 | 0.89 | 17.19 | 5.95 | 5.50 | 3.22 |

* significant at $p < 0.05$; **, $p < 0.01$.

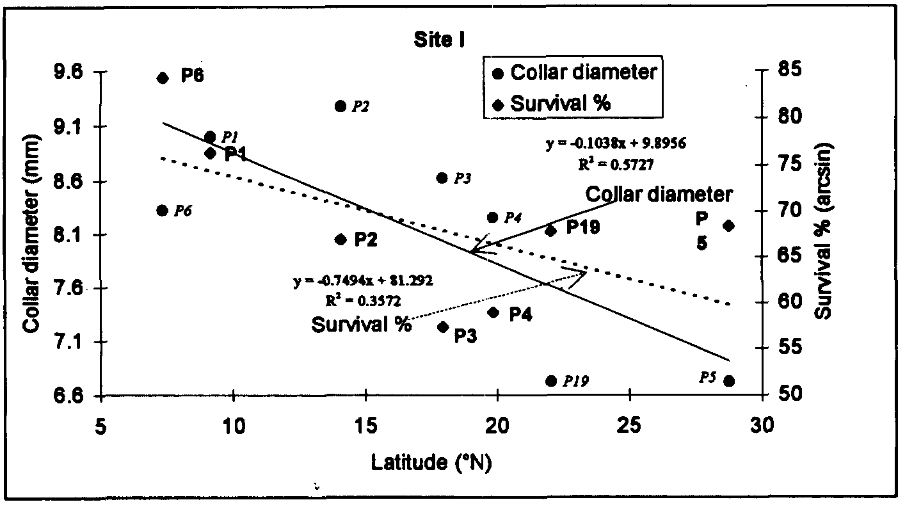


**Figure 1.** Plot of CD and SV% for the seven neem provenances against the latitude of origin with corresponding regression lines at Charaljani site in Bangladesh. Provenances values for the CD and SV% are represented as italics and bold letters respectively.

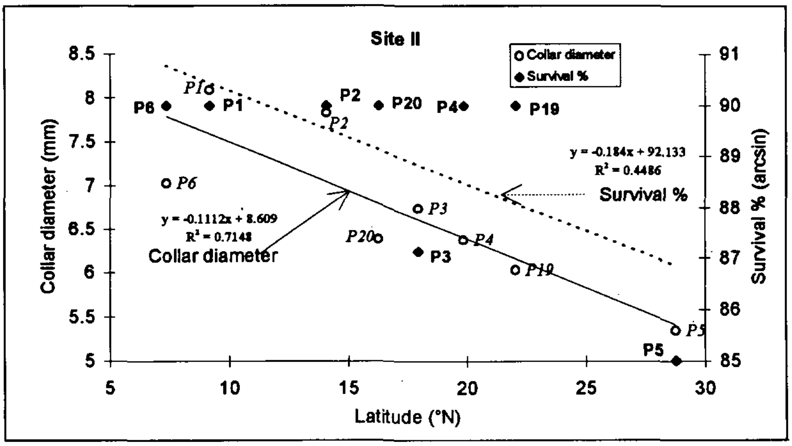


**Figure 2.** Relationship between latitude and collar diameter on the one hand and latitude and survival % on the other hand of the eight neem provenances at Charkhai site in Bangladesh. Provenances values for the CD and SV% are represented as italics and bold letters respectively.

**Table 7.** Eigenvectors extracted from the data by principal component analysis (PCA) at the three sites

| | Site I | | | Site II | | | Site III | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | PRIN1 | PRIN2 | PRIN3 | PRIN1 | PRIN2 | PRIN3 | PRIN1 | PRIN2 | PRIN3 |
| HT | 0.558 | <u>0.829</u> | -0.029 | <u>0.977</u> | -0.192 | 0.085 | <u>0.868</u> | -0.492 | -0.053 |
| CD | 0.008 | 0.029 | <u>0.999</u> | -0.002 | 0.398 | <u>0.917</u> | 0.051 | -0.016 | <u>0.998</u> |
| SV% | <u>0.829</u> | 0.017 | -0.463 | 0.210 | <u>0.897</u> | -0.388 | 0.493 | <u>0.869</u> | -0.011 |

* significant at $p < 0.05$; **, $p < 0.01$.

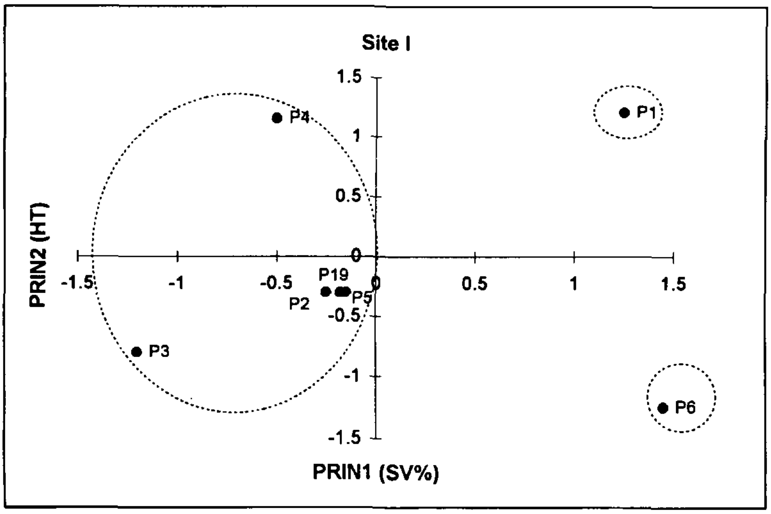


**Figure 3.** Relationships between the first and second principal components showing the three distinct groups of populations on the basis of PCA at Charaljani (Bangladesh). HT, CD and SV% attributes were used in the analysis.

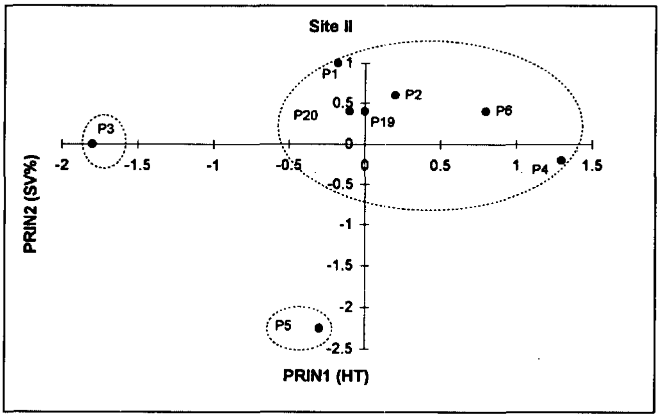


**Figure 4.** Relationships between the first and second principal components showing the three distinct groups of populations on the basis of PCA at Charkhai (Bangladesh). HT, CD and SV% attributes were used in the analysis.

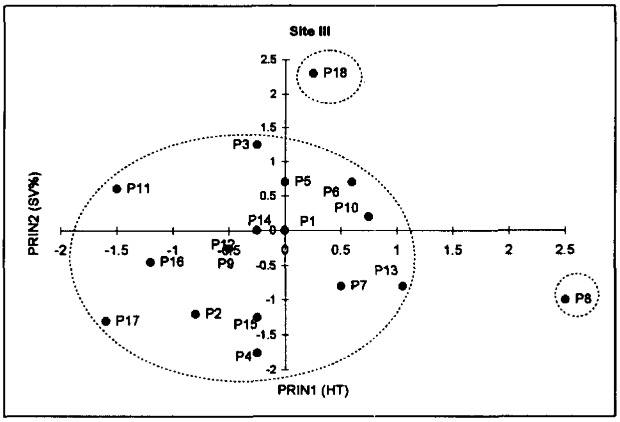


**Figure 5.** Relationship between the first and second principal components showing the three distinct groups of populations on the basis of PCA at Jodhpur (India). HT, CD and SV% attributes were used in the analysis.

variation in leaflet ratio for *A. indica*. The clinal variations could be useful for selection of seed sources for transfer as well as plant introduction.

Height and collar diameter are used to determine quality classes of seedlings and are generally related to survival and growth after planting (Bhagat *et al.* 1990, Eler *et al.* 1993, Tosun *et al.* 1993). There are indications of relationships between HT and SV% and between CD and SV% in the present study suggesting that there is a scope for determining the quality classes of seedlings prior to planting. Similar results were also suggested by Dhuria (1995) in 10 broad-leaved multipurpose tree species and by Bisht and Toky (1991) on 12 different forest species.

Vegetational differences are often expected to correlate with the environmental differences and could be determined by quantitative measurements (Greig-Smith 1957). The correlations as well as regressions of seedling growth and survival at least with latitude suggest a selective environmental pressure with increasing aridity (Kundu & Tigerstedt 1997). Furthermore, drought is an important factor involved in natural selection and survival of plant species (Blake & Hill 1996). The present results are in agreement with the study of Kundu and Tigerstedt (1997) which was carried out in the growth chamber. The regression models could provide a good prediction of growth traits (such as collar diameter) and survival rate for further breeding and cultivation programmes. This information would rather save time and costs, and promote the genetic gain.

In this study, PCA revealed three groups of populations mainly based on their survival rates at the three sites. Height and survival rate represented distinguishing characters for differentiating the provenances. Variation in survival rates observed in this study was probably mainly due to the environmental factors (Khasa *et al.* 1995). Provenances with high survival rates could be an important selection criterion for early establishment of plantations.

For early establishment of a plantation, provenances of *A. indica* that show high survival rate and fast growth may be the best choice. In the long term, for utilisation as timber, provenances that have a straight stem and more promising intraspecific hybrids could be among the selection criteria. Multiple stems that produce high biomass, high wood density, and large quantities of fruit having high limnoid and oil contents should be the criteria for selecting provenances for fuelwood production, charcoal, pharmaceuticals and pesticide industries. Stability analyses for selecting provenances for high alkaloid and oil contents across environments are recommended. For population differentiation, a number of morphometric traits (Kundu & Tigerstedt 1997) including alkaloid and oil content data are suggested for analysis in the future. A comprehensive genecological and physiological study to screen desired provenances would provide more insight into the potential for neem improvement.

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