Journal of Arid Environments (2003) **54**: 783–792
doi:10.1006/jare.2002.1067, available online at http://www.idealibrary.com on IDEAL®

Comparison of the growth and biomass production of six acacia species in Riyadh, Saudi Arabia after 4 years of irrigated cultivation

Ibrahim M. Aref*, L. I. El-Juhany & Said S. Hegazy

Plant Production Department, College of Agriculture, King Saud University, P. O. Box 2460, Riyadh 11451, Saudi Arabia

(Received 20 March 2002, accepted 1 July 2002)

The growth and biomass production of six acacia species were studied in the field for 4 years. The species used were *Acacia asak*, *A. negrii*, *A. seyal*, *A. karroo*, *A. ampliceps*, and *A. stenophylla*. The first three species are indigenous while the others are exotic. The results showed both A. ampliceps and A. asak with 100% survival while all *A. negrii* died. *Acacia ampliceps* attained the greatest height, diameter, relative growth rate and above-ground biomass while *A. asak* had the least. Height and diameter growth of acacia species decreased between warm and cold periods of the year.

Keywords: *Acacia ampliceps*; *Acacia asak*; *Acacia karroo*; *Acacia negrii*; *Acacia seyal*; *Acacia stenophylla*; tree biomass; relative growth rate (RGR)

Introduction

Acacia species are widely distributed through the drier tropical and subtropical regions, they have been called the most successful survivors in arid and semi-arid region, and possess most of the features required to withstand severe climatic conditions (El-Amin, 1976). In Saudi Arabia, the acacia communities represent the climax stage of xerophytic vegetation and generally have high cover and low species diversity (Shaltout & Mady, 1996). Most of acacia species are important sources of browse, fuel and pole timber; some are important commercial sources of gum and tannin. Some can be effectively utilized for shade, shelter, live fences, soil stabilization as well as street trees and ornamentals. Many are utilized by the rural populations in local medicines, for fiber, domestic utensils and handicrafts (Wickens, 1995). Recently, efforts have been directed to producing biomass through short-rotation forestry. The sustainability of short-rotation forest for biomass production is dependent upon such factors as biomass yield, biomass potential, tolerance of poor habitat, climatic condition, and biomass fuel value (Neenan, 1980). Maximizing the efficient production by means of optimizing the biomass growth of selected woody species is the goal of energy plantations (White & Gambles, 1988).

The objectives of the trial reported here were to evaluate the survival, growth, and biomass production of six acacia species grown in Riyadh region, Saudi Arabia.

*Corresponding author. fax: +966 1 467 5347.

0140-1963/03/040783 + 10 $30.00/0

Material and methods

Site characteristics

The site where the experiment was carried out has the following characters: 24°6′N, latitude; 46°5′E, longitude; 650-m altitude; temperature ranged between 10°C in winter and 37°C in summer (as an average of season); and 50-mm rainfall, annually. The soil of the site was sandy loam with average content of 61%, 23% and 15% for sand, silt and clay, respectively (Aref, 1987).

Plant material

Six acacia species were evaluated for their growth and biomass production in Riyadh region, Saudi Arabia. The acacia species used were *Acacia* asak (Forssk.) Willd., *A. negrii* Pichi- Sermoli, *A. seyal Del., A. karroo* Hayne, *A. ampliceps* Maslin, and *A. stenophylla* A. Cunn. The first three species are indigenous while the others are exotic. Seeds of both A. asak and A. *negrii* were brought from the south-west region of Saudi Arabia, while those of A. *seyal* were collected from the Riyadh region. Seeds of *Acacia karroo*, *A. ampliceps*, *A. salicina*, and *A. stenophylla* were brought from the north-west coast region of Egypt. Seeds of all species were subjected to water boiling pretreatment before sowing in wooden boxes in July 1996. Three months later the grown seedlings were transplanted in 15-cm polyethylene bags.

Statistical design, planting regime, and measurements

Seedlings were planted in the field in April 1997 using a randomized complete block design with three blocks. Each block had six experimental plots, representing six species of three seedlings each. The 18 seedlings were planted in one row at 4-m intervals. As the location of the experiment is an open area with the aforementioned climatic conditions, *A. salicina* Lindley seedlings of similar age were planted between the rows and as border lines around the whole experiment to provide protection to trees on the experiment. The seedlings were irrigated once a week. Total main stem height and diameter, at a previously marked point 10 cm above the base, were recorded every 3 months from October 1997 up to November 2000 (representing 13 periods of time).

Harvesting and sampling

In February 2001, two trees from each plot were randomly chosen and felled. Each tree was separated into stem, branches, and leaves. Fresh weights of these components were measured in the field and representative samples from each were taken for dry-weight determination. The samples of leaves were oven-dried at 70°C for 24 h, while those of stems and branches were dried at 102 ± 3°C. Total tree above-ground dry weight for each tree was calculated and biomass allocation percentage of each component was determined. Above-ground dry weight per hectare for each species was estimated as the average tree total above-ground dry biomass multiplied by 625 (based on $4 \times 4\,m^2$ spacing).

Survival and growth rate calculations

Survival percentage of each species was calculated as the number of trees surviving by the end of the experiment divided by initial tree number times 100. The relative growth rates (RGRs) for both height and diameter for each period (3 months) were calculated as the following:

$$\text{Height; RGR} = (\log H_2 - \log H_1)/t_2 - t_1 = \text{cm cm}^{-1}\,\text{month}^{-1}$$

$$\text{Diameter; RGR} = (\log D_2 - \log D_1)/t_2 - t_1 = \text{cm cm}^{-1}\,\text{month}^{-1}$$

where: H_1 and H_2 were the heights at times t_1 and t_2; D_1 and D_2 were the diameters at times t_1 and t_2; and t_1 and t_2 were the time at the beginning and the end of each period.

The obtained data were statistically analysed using SAS computer program.

Results

Survival data

Survival data of acacia species under the present investigation revealed that both *A. ampliceps* and *A. asak* had a 100% survival followed by *A. karroo* (77·8%), *A. seyal* (66·7%), and *A. stenophylla* (33·3%). While survival of *A. negrii* was 0%.

Biomass production

Table 1 shows the average values of total tree above-ground dry biomass and its components for the investigated acacia species apart from *A. negrii* as all its nine trees died by August 1999. *Acacia ampliceps* trees had the potential to accumulate more biomass than the other species ($p < 0{\cdot}0001$). They attained 12·3, 33·7, 17·5, and 63·5 kg tree^{-1} dry biomass for stem, branches, foliage, and total tree, respectively. Total above-ground dry biomass of *A. ampliceps* was estimated at about 39·7 ton ha^{-1}.

Allocation of dry biomass into different components as a percentage of the total above-ground dry biomass for each species is illustrated in Fig. 1. Dry biomass of branches of most acacia species accounted for about 50% of the total above-ground dry biomass, while stem allocation ranged between 19·4% and 36·7% for *A. ampliceps* and *A. seyal*, respectively. Foliage dry biomass allocation for *A. seyal* and *A. stenophylla* ranged between 11·9% and 40·5% of the total above-ground biomass, respectively.

Height and diameter growth

The analysis of variance of both height and diameter data recorded by the end of experiment revealed that there were highly significant differences between the acacia species ($p < 0{\cdot}0001$). *Acacia ampliceps* attained the highest mean values for both height and diameter; 5·00 m and 12·70 cm, respectively, while *A. asak* had the lowest values (1·9 m and 1·10 cm, respectively) (Table 2).

The periodical plotting curves for both height and diameter measurements recorded at 3 month intervals (from October 1997 up to November 2000) are shown in Figs 2 and 3. It is also noted that *A. ampliceps* had the highest curves for both height and diameter all over the mentioned period compared with the other species under this study.

Relative growth rate

The analysis of variance of relative height and diameter growth rates for acacia species over a period of 37 months (13 intervals) showed highly significant differences ($p < 0{\cdot}0001$) either between species or intervals with significant interactions between both parameters ($p < 0{\cdot}0001$). The comparisons between the height and diameter RGR averages for species showed that *A. ampliceps* had the highest average height

Table 1. *Mean above-ground dry biomass of the whole- tree and its components (kg tree^{-1}) of five acacia species (*A. ampliceps, A. karroo, A. stenophylla, A. seyal, and A. asak*) and their total estimated above-ground biomass (ton ha^{-1}) based on $4 \times 4\,m^2$ spacing at age 4 years*

Species	Biomass production (kg tree^{-1})				Biomass production (ton ha^{-1})
	Stem	Branches	Foliage	Whole tree	
Acacia ampliceps	12·32a*	33·69a	17·49a	63·50a	39·69
A. karroo	1·35b	1·83b	0·63b	3·83b	2·39
A. stenophylla	0·21b	0·30b	0·35b	0·85b	0·53
A. seyal	0·16b	0·22b	0·05b	0·44b	0·27
A. asak	0·09b	0·16b	0·04b	0·29b	0·18

*Values followed by the same letters within each column are not significantly different at $p<0{\cdot}05$ according to Duncan's multiple range test.

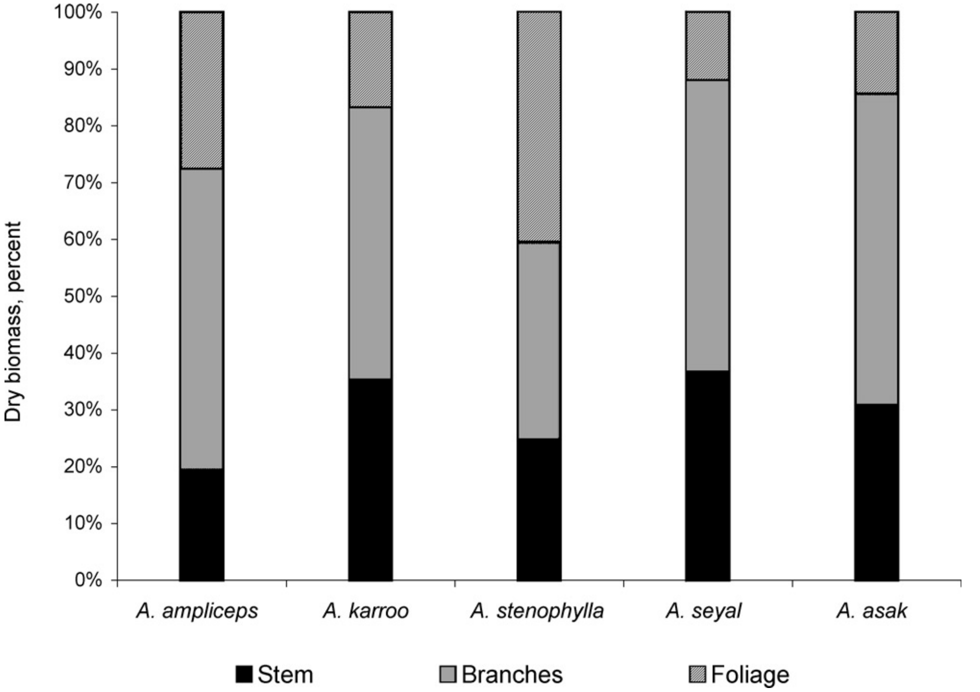

Figure 1. Allocation of above-ground dry biomass of *Acacia ampliceps, A. karroo, A. stenophylla, A. sayal* and *A. asak* into stem, branches, and foliage at age 4 years.

RGR value for height (0·0291 cm cm^{-1} month^{-1}) followed by *A. asak*, *A. karroo*, *A. negrii*, *A. seyal*, and *A. stenophylla* (Table 2). The highest average diameter RGR was also attained by *A. ampliceps* (0·0358 cm^{-1} month^{-1}) followed by *A. asak*, *A. karroo*, *A. stenophylla, A. seyal*, and *A. negrii.*

The greatest height RGRs for *A. ampliceps*, *A. stenophylla*, and *A. asak* (0·0633, 0·037, and 0·147 cm cm^{-1} month^{-1}, respectively) were attained in the period from January to April 1999, followed by that from April to June 1999, while *A. karroo*,

Table 2. *Mean height, diameter and the RGRs of six acacia species (*Acacia ampliceps, A. karroo, A. stenophylla, A. seyal, A. asak*, and* A. negrii) at age 4 years

Species	Height (m)	Diameter (cm)	Height RGR ($cm\ cm^{-1}\ month^{-1}$)	Diameter RGR ($cm\ cm^{-1}\ month^{-1}$)
Acacia ampliceps	5·03a*	12·73a	0·02908a	0·03575a
A. karroo	3·22b	4·73b	0·02024ab	0·02437b
A. stenophylla	2·26bc	1·73c	0·00789c	0·01693c
A. seyal	2·60bc	1·67c	0·00995bc	0·02736b
A. asak	1·90c	1·08c	0·02691a	0·02736b
A. negrii	—	—	0·01116bc	0·01525c

*Values followed by the same letters within each column are not significantly different at $p < 0{\cdot}05$ level according to Duncan's multiple range test.

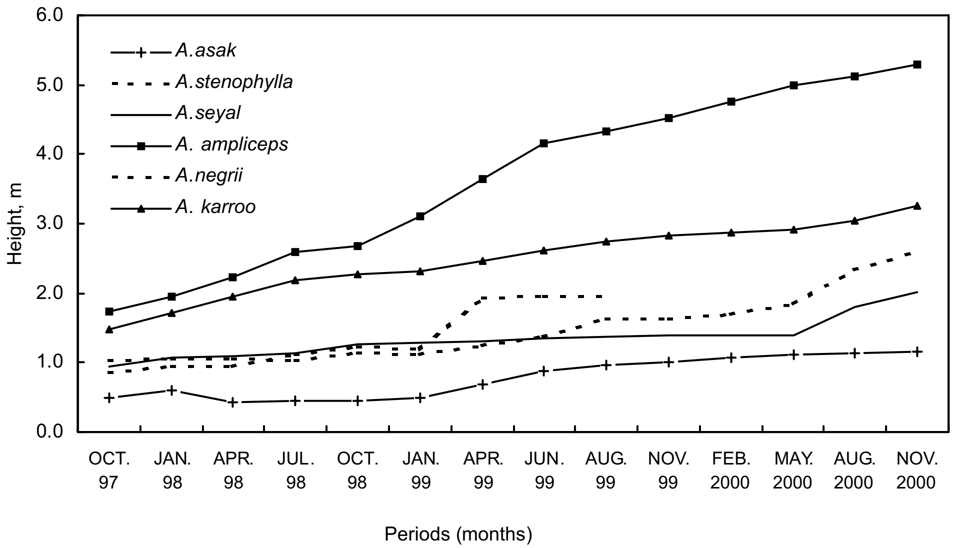

Figure 2. Growth of stem height (m) for *Acacia asak*, *A. stenophylla*, *A. seyal*, *A. ampliceps*, *A.negrii*, and *A. karroo* through sequential periods from October 1997 to November 2000.

A. seyal, and *A. negrii* had attained their greatest height RGRs (0·038, 0·033, and 0·019 $cm\ cm^{-}\ month^{-1}$, respectively, in the period from October 1997 to January 1998 (Table 3). On the other hand, the best diameter RGR values were attained in the period from October 1997 to January 1998 for all species followed by the period from January to April 1998 as the second favorite period for most species (Table 4).

Discussion

The presented study showed that the growth and biomass production potential of the exotic acacia species (i.e. *A. ampliceps*, *A. karroo*, and *A. stenophylla*) were greater than those of the indigenous ones (i.e. *seyal, A. asak*, and A. *negrii*). The outstanding

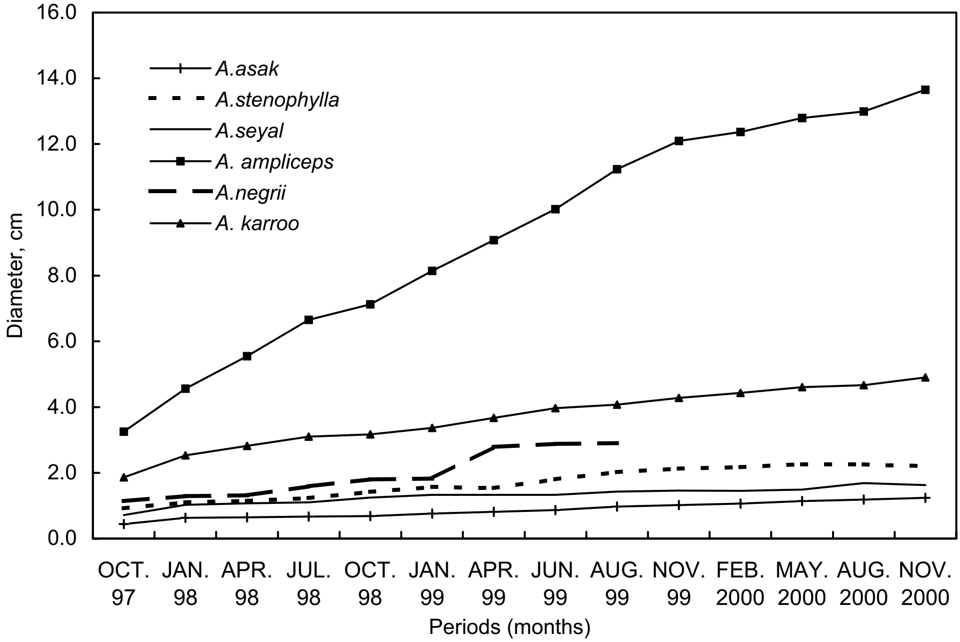

Figure 3. Growth of stem diameter (cm) for *Acacia asak*, *A. stenophylla*, *A. seyal*, *A. ampliceps*, *A. negrii*, and *A. karroo* through sequential periods from October 1997 to November 2000.

performance of *A. ampliceps* in terms of survival, crown health and density, height and diameter growth and biomass production potential would manifest it as one of the best candidate species for biomass production in short-rotation planting in the conditions prevailing in the area under study. *A. ampliceps* was reported to be the most promising species in the hot, dry subtropics and tropics with high salt tolerance and high coppicing ability (Thomson, 1987; McKinnell, 1990). It has also been reported that *A. ampliceps* had the best height growth and canopy spread in the Indian dry region (Neelam *et al.*, 1988). The total above-ground biomass attained by *A. ampliceps* in the present study (39·7 ton ha^{-1}) was higher than that mentioned by Banik & Bhosale (1999) which was 13·7 ton ha^{-1} at the age of 3·5 years.

From the morphology point of view, *A. ampliceps* is one of the species bearing phyllodic (broadened leaf petioles functioning like leaf blades), while the other acacia species in this study have pinnate leaves divided into small leaflets (Armstrong, 1999).

The other two exotic species, *A. karroo* and *A. stenophylla* produced total above-ground biomass of 3·85 and 0·85 kg $tree^{-1}$, respectively. However, these values were much less than those reported by El-Osta & Megahed (1992) in the northern-west coast of Egypt (the source of seeds used in the present study), where they mentioned a range value of 22·98 – 28·23 kg $tree^{-1}$ for both species. The poor performance of *A. karroo* and *A. stenophylla* in biomass production and survival (77·8% and 33·3%, respectively) in this study may be a result of shade effect of *A. salicina* trees which were planted between rows for protection purposes and attained an average of 5·10 m height. However, *A. stenophylla* was reported to survive and grow well as an exotic species planted in the saline soil of Pakistan (Hussain *et al.*, 1991) and in hot, dry tropics and subtropics (Thomson, 1987).

The remarkable failure of the indigenous species for biomass production, and death (in case of *A. negrii*), might be explained as a response to the site condition of this study as well as tree-shade effect mentioned earlier. The natural distribution of some

Table 3. *Mean height RGRs (cm cm^{-1} month^{-1}) of six acacia species (*Acacia ampliceps, A. karroo, A. stenophylla, A. seyal, A. asak, and A. negrii*) through 13 sequential periods from October 1997 to November 2000*

No.	Period	*A. ampliceps*	*A. karroo*	*A. stenophylla*	*A. seyal*	*A. asak*	*A negrii*
1.	13 October 97 – January 98	0·0342cde*	0·0384a	0·0109abc	0·0333a	0·06100b	0·0193a
2.	January 98 – April 98	0·037bcd	0·0379a	−0·0081bc	0·0044cd	−0·1128dc	0·0031a
3.	April 98 – July 98	0·04111bc	0·0343a	−0·0170c	0·0059cd	0·01256c	0·0163a
4.	July 98 – October 98	0·0248def	0·0124bc	−0·0063bc	0·0103bcd	0·00622c	0·0127a
5.	October 98 – January 99	0·0396bcd	0·0080bc	−0·0077bc	0·0069cd	0·04467c	0·0045a
6.	January 99 – April 99	0·06333a	0·0276ab	0·03700a	0·0070cd	0·14700a	0·0050a
7.	April 99 – June 99	0·04978ab	0·0251abc	0·03540a	0·0066cd	0·10033ab	0·0050a
8.	June 99 – August 99	0·0203efg	0·0114bc	0·0145abc	0·0085bcd	0·02933c	0·0000a
9.	August 99 –November 99	0·01456fg	0·0095bc	0·0003abc	0·00163d	0·01644c	—
10.	November 99 – February 2000	0·01667fg	0·0069c	0·0100abc	0·0008d	0·02056c	—
11.	February 2000 – May 2000	0·0177fg	0·008bc	0·0190abc	−0·0051d	0·01667c	—
12.	May 2000 – August 2000	0·00778g	0·0143bc	0·04067a	0·0305ab	0·00278c	—
13.	August 2000 – November 2000	0·01122fg	0·020abc	0·02967ab	0·0262abc	0·0050c	—

*Values followed by the same letters within each column are not significantly different at $p<0.05$ level according to Duncan's multiple range test.

Table 4. *Mean relative diameter growth rates, RGR (cm cm^{-1} month^{-1}) of six acacia species (*Acacia ampliceps, A. karroo, A. stenophylla, A. seyal, A. asak and A. negrii*) through 13 sequential periods from October 1997 to November 2000*

No.	Period	*A. amplicep*	*A. karroo*	*A. stenophylla*	*A. seyal*	*A. asak*	*A negrii*
1.	October 97–January 98	0·09878a*	0·09100a	0·04822a	0·0960a	0.11822a	0.0388a
2.	January 98 –April 98	0·05667b	0·03111b	0·00822b	0·0087bc	0.0090c	0.0040a
3.	April 98 – July 98	0·04978bc	0·0263bc	0·0030b	0·0073bc	0.0096c	0.0055a
4.	July 98 – October 98	0·02678ed	0·0094ed	0·0082b	0·01738bc	0.0108c	0.0077a
5.	October 98 – January 99	0·0426bcd	0·0216bcd	0·0298ab	0·01388bc	0.0385bc	0.0090a
6.	January 99 – April 99	0·0416bcd	0·03656b	0·0160b	0·0031bc	0.0254bc	0.0130a
7.	April 99 – June 99	0·0373bcd	0·03267b	0·0160b	0·0030bc	0.0259bc	0.0030a
8.	June 99 – August 99	0·0380bcd	0·0145abc	0·0270ab	0·02438b	0.04456b	—
9.	August 99 – November 99	0·0298cde	0·00563e	0·0175b	0·0071bc	0.0191bc	—
10.	November 99 – February 2000	0·0092ef	0·0124ef	0·0075b	0·0067bc	0.0120c	—
11.	February 2000 – May 2000	0·0124ef	0·0141cde	0·0145b	0·0061bc	0.0223bc	—
12.	May 2000 – August 2000	0·0051f	0·0044e	0·0000b	0·0000bc	0.0096c	—
13.	August 2000 – November 2000	0·0167ef	0·0041e	0·0000b	0·0012bc	0.0107c	—

*Values followed by the same letters within each column are not significantly different at $p < 0{\cdot}05$ level according to Duncan's multiple range test.

acacia species along the altitudinal gradient between the Red Sea and Asir mountains at the south-western region of Saudi Arabia was reported by Abdullah & Abulfatih (1995). They found that the approximate range of distribution of *A. asak* is between 250 and 1750 m a.s.l. and *A. seyal* is between 0 and 1500 m. At these elevations, the highest mean monthly temperature is 38°C and the lowest mean monthly one is 20°C with an average annual rainfall of about 65 mm. On the other hand, *A. negrii* occupied the high mountains (1750–2500 m) that were characterized by cold winter and mild summer temperatures. The highest mean monthly temperature is 32°C and the lowest is 10°C with an average rainfall of about 500 mm (Ministry of Agriculture and Water, 1988).

Acacia seyal was reported to produce a wood volume of $3{\cdot}13\ m^3\ ha^{-1}$ in the first year under irrigation with a planting density of 625 trees ha^{-1} on the dryland of Sudan clay plain (Mustafa, 1997). Masutha *et al.* (1997) also stated that *A. seyal* is considered a suitable species for agroforestry in South Africa. Others reported that it was the best species well adapted to cope with harsh droughts (e.g. Sanchez & King, 1994). Regarding the data of RGR, it would suggest that the preferred temperature for height growth of *A. ampliceps*, *A. stenophylla*, and *A. asak* would be the moderate warm seasons whereas the preferred temperature for *A. karroo*, *A. seyal* and *A. negrii* would be the cold seasons. On the other hand, the preferred temperature for diameter growth for all the studied acacias would be in the cold season and the beginning of warm season. Bisht & Toky (1993) reported that the growing period of 6-year-old *A. nilotica* trees growing in the dry monsoonic climate of north-western India was 301 days. They mentioned that both *A. nilotica* and *A. catechu* had a long period of growth which began in the dry season, but most shoot extension was completed during the rainy season that followed. Fogarty & Facelli (1999) also reported that the native species of both *A. verniciflua* and *A. myrtifolia* in South Australia had their highest RGR during spring. The growth pattern of *A. karroo* also was studied by Teague & Walker (1988) and they reported that leaf and shoot growth at the beginning of the season took place only if there was sufficient moisture available, and if the minimum temperature rose above a threshold value. They concluded that the growth in *A. karroo* was dominated by the current growing conditions rather than those of the previous seasons, and it was able to make opportunistic growth at any time.

References

Abdullah, M.A.R. & Abulfatih, H.A. (1995). Predation of acacia seeds by bruchid beetles and its relation to altitudinal gradient in southwestern Saudi Arabia. *Journal of Arid Environments*, **29**: 99–105.

Aref, I.M. (1987). Provenance trail of *Casuarina* sp. in Riyadh region of Saudi Arabian Kingdom. M.Sc. thesis, King Saud University, Riyadh, Saudi Arabia.

Armstrong, W.I.P.E. (1999). The unforgettable Acacias. *Zoonooz*, **71**: 28–31.

Banik, S. & Bhosale, L. J. (1999). Productivity and energy content of four exotic acacia species at young age. *Journal of Environmental Pollution*, **6**: 289–293.

Bisht, R.P. & Toky, O.P. (1993). Growth pattern and architectural analysis of nine important multipurpose trees in an arid region of India. *Canadian Journal of Forest Research*, **23**: 722–730.

El-Amin, H.M. (1976). Geographical distribution of Sudan acacias. Kartoum, Sudan. *Sudan forestry administration Bulletin for Research Institute*, 2; 22 14 ref.

El-Osta, M.L.M. & Megahed, M.M. (1992). Characterization of biomass of some species introduced to Egypt. *Alexandria Journal of Agricultural Research*, **37**: 85–105.

Fogarty, G. & Facelli, J.M. (1999). Growth and competition of *Cytisus scoparius*, an invasive shrub and Australian native shrubs. *Plant-Ecology*, **144**: 27–35.

Hussain, A., Pazir G., Hussain, A. & Gul, P. (1991). Selection of suitable tree species for saline and waterlogged areas. *Pakistan Journal of Forestry*, **41**: 34–43.

Masutha, T.H., Muofhe, M.L. & Dakora, F.D. (1997). Evaluation of N_2 fixation and agroforestry potential in selected tree legumes for sustainable use in South Africa. *Soil Biology and Biochemistry*, **29**: 993–998.

McKinnell, F. (1990). Species trail on alkaline soils in Indonesia. *Forestry Newsletter*, **10**: 1, 3. Australian Center for International Agricultural Research, Canberra, Australia.

Ministry of Agriculture and Water (1988). *Climatic Atlas of Saudi Arabia*. Riyadh, Saudi Arabia, 118 pp.

Mustafa, A.F. (1997). Regeneration of Acacia seyal forests on dry land of Sudan clay plain. Tropical Forestry Reports, Department of Forest Ecology, University of Helsinki, No. **15**, 103 pp.

Neelam, B., Chopra, D.P. & Bhatnagar, N. (1988). Germination and establishment of exotic Australian acacias in the Indian arid region. *Nitrogen Fixing Tree Research Reports*, Vol. **6**: 28 pp.

Neenan, M. (1980). Ecological basis for selection for species. In: *Production of Energy from Short Rotation Forestry.* An Foras Tauntais. 19, Sandymount Ave., Dublin, Ireland.

Sanchez, B.F. & King, G.W. (1994). Ecological factors affecting the early development of seedlings of three acacia species from Ethiopia. *South African Journal of Plant and Soil*, **11**: 147–148.

Shaltout, K.H. & Mady, M.A. (1996). Analysis of raudas vegetation in central Sudi Arabia. *Journal of Arid Environments*, **34**: 441–454.

Teague, W.R. & Walker, B.H. (1988). Growth patterns and annual growth cycle of Acacia karroo Hayne in relation to water stress.I. Leaf and shoot growth. *Journal of the Grassland Society of Southern Africa*, **5**: 85–95.

Thomson, L.A.J. (1987). Australian acacias for saline, alkaline soil in the hot, dry subtropics and tropics. ACIAR-Proceeding, Australian Center for International Agricultural Research, No. 16: 66-69. In: Turnbull, J.W. (Ed.), Australian Acacias in Developing Countries. *Proceedings of an International Workshop*, Gympi, Qld., Australia, 4–7 August 1986.

White, H.W. & Gambles, R.L. (1988). Experiences with willow as wood biomass species. *Biojoule*, **10**: 4–7.

Wickens, G.E. (1995). Role of Acacia species in rural economy of dry Africa and the Near East. *FAO Conservation Guide*, Vol. 27, 176 pp, 185 ref.