Kasetsart J. (Nat. Sci.) 32 : 495 - 510 (1998)

Ralating Environmental Factors to Growth of Some Australian Tree Species at Different Sites in Thailand

Sirirat Janmahasatien[1], Chingchai Viriyabuncha[1], Peter Snowdon[2], and Trevor H. Booth[2]

ABSTRACT

Height (Ht), diameter at breast height (DBH) and basal area (BA) growth of *Eucalyptus camaldulensis*, *Acacia mangium* and *Acacia auriculiformis* at three years of age were measured as well as climatic and soil conditions at over 180 plots at seven trial sites in Thailand. The results for Ht, DBH and BA showed highly significant differences among sites, but there were no significant differences among seedlots for all species. *E. camaldulensis* and *A. auriculiformis* showed generally high overall growth. *E. camaldulensis* grew particularly well at Si Sa Ket, whilst Sai Thong was the best site for *A. auriculiformis*. *A. mangium* grew poorly at all sites. Analysis of variance (ANOVA) was carried out for each year of planting with the growth of *E. camaldulensis* showing significant differences between years. Trees planted in 1987 grew more slowly than those planted in 1986 at both Sakaerat and Chanthaburi. Tree growth measurements were related to environmental factors using stepwise linear regression. The results of the statistical analyses showed that much of the variation in growth data could be explained by regression models including soil and climatic factors. The combined influence of all environmental factors in the models were shown by r^2 values. *E. camaldulensis* relationships produced high r^2 values of 0.70 or greater and similar r^2 values were obtained for most soil depths. *A. mangium* data produced highly variable r^2 values ranging between 0.26 and 0.85. *A. auriculiformis* data produced generally high r^2 values with values ranging between 0.65 and 0.91, with especially good relationships for Ht and DBH.

Key words : environmental factors, growth prediction, Australain tree species, Thailand

INTRODUCTION

Forestry plays an important role in the economy of Thailand. Its products are used domestically for housing materials, fuelwood and sawn wood and in addition forest cover prevents erosion in upland watersheds and contributes to stream flow regulation in downstream irrigation schemes. Natural forests in Thailand have been rapidly depleted for the past three decades through widespread tree cutting together with subsequent clearing for agricultural expansion. Realizing that the forests of the country are being destroyed at an alarming rate the Thai government sets up the National Economic and Social Development Plan to establish plantations at the rate of 1,000,000 rais or 160,000 hectares (6.25 rais = 1 hectare) per year. Extensive reforestation programmes are, therefore, emphasized by the Government as a means to alleviate land degradation and both rural people

1 Forest Research Office, Royal Forest Department, Chatuchak, Bangkok 10900, Thailand.
2 CSIRO Division of Forestry and Forest Product, PO Box 4008, Queen Victoria Terrace, Canberra, ACT, 2600, Australia.

and private companies are being encouraged to participate.

Some Australian tree species have been introduced and successfully established in plantations throughout Thailand. The Australian Centre for International Agricultural Research (ACIAR) Project 9127 is a joint project between the Royal Forest Department of Thailand and the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia. Its objectives are to develop methods to predict tree growth in Thailand and to aid the selection of appropriate tree species and provenances for particular areas, as well as indicating how well the trees can grow (Viriyabuncha *et al*.,1996). A previous paper has reported some of the project's early work in relating tree growth to soil properties (Janmahasatien *et al*., 1996). Information about environmental factors, such as soil and climate, must be considered to define the requirements of tree and is also important for predicting tree growth at other sites. This paper reports on work relating environmental factors to growth of three tree species introduced from Australia namely *Eucalyptus camaldulensis*, *Acacia mangium* and *Acacia auriculiformi*.

MATERIALS AND METHODS

Field data collection

Data were collected from experimental plots in the "Australian Tree Species Field Trials". These field trials were established with ACIAR support during 1985-1987 over seven trial sites selected to represent a range of climatic and geographic conditions in Thailand (Pinyopusarerk, 1989). Locations of the trial sites are shown in Figure 1, whilst geographic details are given in Table 1. Each experiment had a randomised complete block design consisting of three replications. In each plot 25 trees were arranged in a plot of 5×5 trees with spacing at 2×2 m interval. The planting spots were sprayed with herbicide (Round-up at 1:100 in water) 2-3 weeks prior to planting. One month after planting, 50 g of NPK fertilizer (15:15:15) was applied to each plant.

The "Australian Tree Species Field Trials" involved numerous species and provenances. Only three species, namely *E. camaldulensis*, *A. mangium* and *A. auriculiformis* were evaluated here as they were amongst the target species being examined in detail by Project 9127 and they also represend three important exotic species in Thailand. Growth data for *E. camaldulensis* (seedlot nos. 14537, 14106, 13692, and 14338), *A. mangium* (seedlot nos. 13846

Table 1 Environmental details of ACIAR Project trial sites (Source: Viriyabuncha and Pitpreecha 1989).

Location	Latitude (N)	Longitude (E)	Elevation (m)
1. Ban Hong Plantation, Lamphun (AC-1)	18° 20'	98° 55'	280
2. Huai Bong Experimental Station, Chiang Mai (AC-2)	18° 10'	98° 25'	800
3. Ratchaburi Experimental Station, Ratchaburi (AC-3)	13° 25'	99° 50'	35
4. Sai Thong Experimental Station, Prachuap Khiri Khan (AC-4)	10° 59'	99° 40'	50
5. Huai Tha Experimental Station, Si Sa Ket (AC-6)	14° 53'	104° 27'	130
6. Sakaerat Thai/Japan Project, Nakhon Ratchasima (AC-7)	14° 13'	101° 55'	420
7. Khao Soi Dao Seed Orchard, Chanthaburi (AC-8)	13° 00'	102° 15'	200

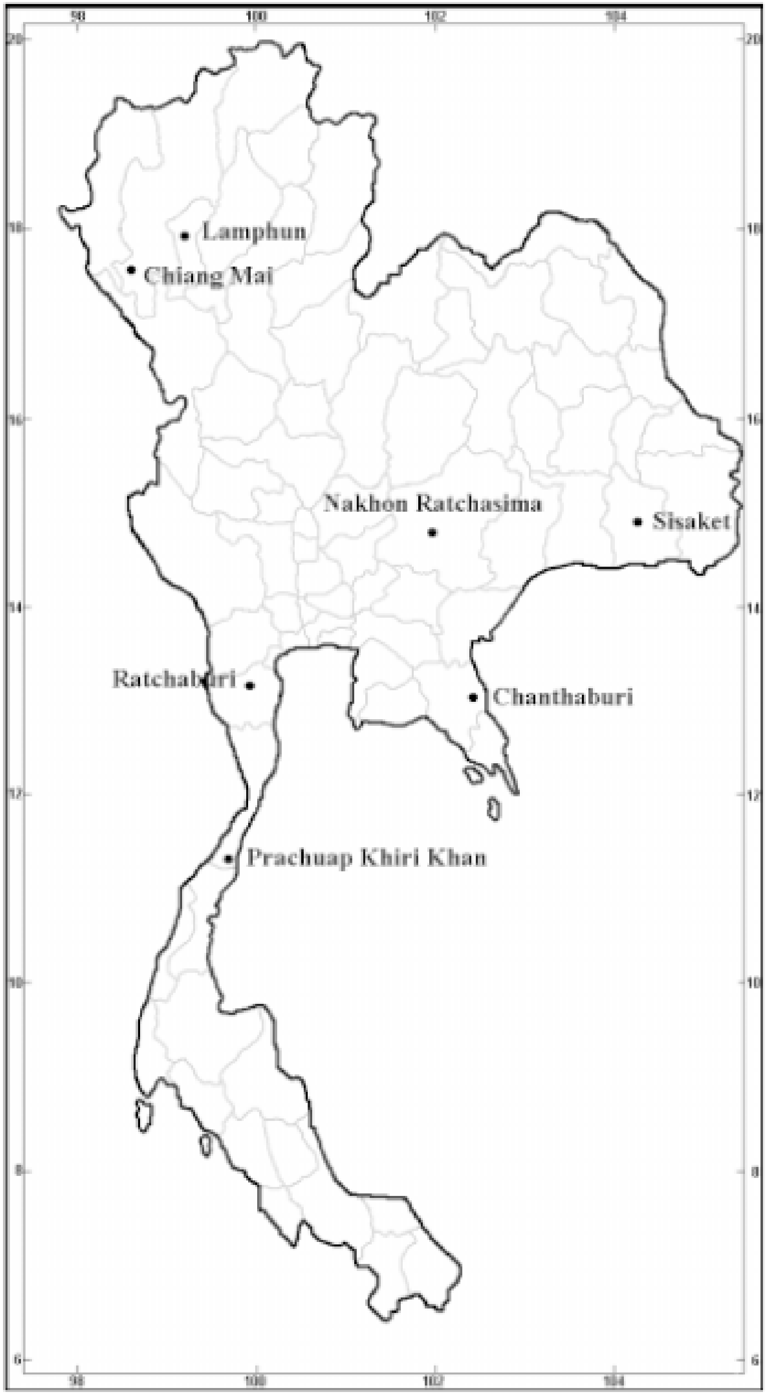

Figure 1 Location of trail sites used in the study.

and 13621) and *A. auriculiformis* (seedlot nos. 13854, 13861, 13684, 13686) were collected at three years of age by measuring height (Ht) in metres (m), diameter at breast height (DBH) in centimetres (cm) and basal area (BA) in square metres per hectare (m^2/ha). Details of the origins of these provenances are shown in Table 2.

Soil sampling methods

Soil samples were collected from plots at seven experimental sites in Thailand. Within each plot, samples were collected from three sample pits, then bulked and mixed prior to making a composite sample of about 500 g suitable for laboratory use. Samples were taken at depths of 0-20 cm, 20-50 cm and 50-70 cm. At each site a large walk-in pit was dug and a separate description of the soil profile was made. Additional soil samples were collected from each soil horizon in the profile.

The samples were analyzed according to methods described by Black (1965). Analyses were made for pH, soil conductivity (EC), available phosphorus (P), organic matter (OM), exchangeable cations; calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na), cation exchange capacity (CEC), and base saturation (BS). The soil classification and particle size distribution in profiles at each trial site are given in Table 3 (after Janmahasatien *et al*., 1996)

Statistical analyses

Analyses of variance were carried out to investigate differences in growth between sites, species and provenances. Stepwise linear regression was carried out using the GENSTAT statistical package (Payne *et al*. 1987) to determine relationships between growth and climatic and soil data at the seven trial sites.

Table 2 Provenance details.

Seedlot	Location	Latitude (S)	Longitude (E)	Elevation (m)
Acacia mangium				
13621	Piru Ceram, Indonesia	3° 4’	128° 12’	150
13846	7km SSE Mossman, N Qld	16° 31’	145° 24’	60
Acacia auriculiformis				
13684	Balamuk Prov, Papua New Guinea	8° 54’	141° 18’	18
13686	Iokwa Prov, Papua New Guinea	8° 41’	141° 29’	35
13854	Oenpelli Area, NT	12° 20’	133° 04’	50
Eucalyptus camaldulensis				
13692	Gilbert River, Qld	18° 12’	142° 53’	150
14106	Gilbert River, Qld	18° 00’	143° 00’	150
14338	E. of Petford, Qld	17° 17’	145° 03’	500
14537	Isdell River, WA	16° 25’	125° 35’	315

Note : Qld = Queensland, NT = Northern Territory, and WA = Western Australia

RESULTS

Soil characteristics

Soil texture varied from sand to sandy loam with the sand content of most horizons being more than 80% (Table 3). When there was less sand than this, silt content tended to be about 20%, for example, at Sakaerat (AC-7). Clay content was in the range of 4 to 13%. The soils were moderately well-drained except for the poorly drained soil at Chanthaburi (AC-8). However, most of the soils are seasonally waterlogged during the monsoon period and in some cases this has led to the development of mottles in the subsoil, for example, at Lamphun (AC-1), Ratchaburi (AC-4), and Si Sa Ket (AC-6). Prior to planting, the sites had experienced a variety of land use practices, some of which affected the properties of the surface soils. For example, the site at Sai Thong (AC-4) was eroded, whilst those at Si Sa Ket (AC-6) and Sakaerat (AC-7) were reduced fertility due to agricultural cropping.

Table 3 Soil classification and particle size distribution in profiles at each trial site(after Janmahasatien *et al*., 1996).

Site	US Soil Taxonomy	Horizon	Particle size distribution (%) sand	silt	clay	Texture (USDA)	Fertility rating
AC-1 Lamphun (Ban Hong)	Ustic Quartzipsamments	A	90.39	2.27	7.33	sand	Moderate
		B	84.67	9.50	5.83	loamy sand	
AC-2 Chiang Mai (Huai Bong)	Typic Ustipsammentes	A	86.17	1.67	12.17	loamy sand	Low to moderate
		B1	83.79	3.83	12.38	loamy sand	
		B2	73.00	19.79	7.21	sandy loam	
AC-3 Ratchaburi	Typic Quartzipsamments	A	88.67	6.56	4.77	sand	Low to moderate
		B1	86.05	6.45	7.50	loamy sand	
		B2	81.70	8.00	10.30	loamy sand	
AC-4 Prachuap Khiri Khan (Sai Thong)	Typic Quartzipsamments	A	85.85	9.05	4.65	loamy sand	Low
		AB	85.08	9.45	5.47	loamy sand	
		B	81.85	8.17	9.98	loamy sand	
AC-6 Si Sa Ket (Huai Tha)	Ustic Dystropepts	A	82.52	12.83	4.64	loamy sand	Low to moderate
		AB	80.38	9.37	13.33	sandy loam	
		B	79.67	11.11	9.17	sandy loam	
AC-7 Nakhon Ratchasima (Sakaerat)	Ustic Dystropepts	AB	69.60	20.60	9.80	sandy loam	Moderate
		B2	69.20	20.40	10.40	sandy loam	
		B3	65.67	25.40	8.92	sandy loam	
AC-8 Chanthaburi	Typic Troporthents	A	69.67	20.52	9.80	sandy loam	Low to moderate
		B	85.64	8.85	5.50	loamy sand	

Soil pH was highly correlated with exchangeable Ca and base saturation (Table 7). In the 0-20 cm samples, the soils from Lamphun (AC-1) and Chanthaburi (AC-8) were only slightly acid and had high base saturation. Soils at Ratchaburi (AC-3) and Sai Thong (AC-4) were very acid and had low base saturation, while those from the other sites had intermediate properties. Exchangeable Na, K, Ca and Mg values were low in all surface soils except for Lamphum (AC-1) where K and Mg had medium values, and at Chanthaburi (AC-8) where Ca and Mg had medium values. Organic matter was low at all sites but was positively correlated with cation exchange capacity (Table 7). P was low at all sites except Chiang Mai (AC-2) and was particularly low at Lamphun (AC-1) (Janmahasatien, *et al*., 1996)

Growth analysis

Analysis of variance for height, diameter at breast height (DBH) and basal area (BA) across sites showed highly significant differences among sites. Growth differed significantly among species, but there were no significantly differences in growth among seedlots within any of the species. *E. camaldulensis* and *A. auriculiformis* showed generally high overall growth (Table 4, Figure 2). *E. camaldulensis* grew particularly well at Si Sa Ket (AC-6), whilst Sai Thong (AC-4) was the best site for *A. auriculiformis*. *A. mangium* grew poorly at all sites.

Analysis of variance indicated that there were significantly differences in growth of *E. camaldulensis* between different years of planting (see Figure 3). Trees planted in 1987 grew more slowly than those planted in 1986 at Sakaerat (AC-7) and Chanthaburi (AC-8). The plots planted in each year were in different locations and growth was affected by differences in soil conditions.

Growth relationships with environmental factors

Data were available for 90 plots of *E. camaldulensis*, 33 plots of *A. Acacia mangium*, and 60 plots of *A. Acacia auriculiformis* at three years of age (Table 4). Climatic data for each site consisted of mean maximum temperature (Max), mean minimum temperature (Min) and mean annual rainfall (Rain) (Table 5) together with data for elevation above mean sea level (MSL). The soil data were the values of pH, EC, OM, P, K, Ca, Mg, Na, CEC and BS for each plot. Averages of these for each site are given in Table 6. Tree growth (i.e. Ht, DBH and BA) measurements were related to environmental factors by stepwise linear regression and the results are summarised in Table 8. Blank spaces indicate that a particular factor was not significant in the stepwise regression. Adjusted r^2 values are shown in the rightmost column. This is a measure of the amount of variation in growth explained by the regression model. If the relationship of the model has a high r^2 value (e.g. greater than 0.70) this suggests the model may be useful for prediction of the trend of tree growth at other sites with similar soil and climatic conditions. There was not sufficient space here to present correlation matrices between growth and environmental factors for all species at all soil depths. To indicate some of the general trends the correlation matrix for the upper level (0-20cm) for *E. camaldulensis* is shown in Table 7. Correlation coefficients greater than 0.70 are shown in bold text. With these, half or more of the variance in one variable would be explained by a linear regression upon the others. The results the stepwise regressions should be treated cautiously because there may be a number of different regression models which explain closely similar amounts of variation. This is likely to be the case with these data because there were strong correlations amongst the climatic variables and amongst the exchange characteristics.

Table 4 Mean height, DBH and basal area at three years of age in each of the trial sites.

Code	Site	Year	Species	Height (m)	DBH (cm)	Basal area (m^2/ha)
AC-1	Lamphun	1985	*E.camaldulensis*	*	*	*
			A. auriculiformis	*	*	*
			A. mangium	*	*	*
		1986	*E.camaldulensis*	6.15	4.74	4.26
			A. auriculiformis	*	*	*
			A. mangium	*	*	*
		1987	*E.camaldulensis*	*	*	*
			A. auriculiformis	*	*	*
			A. mangium	*	*	*
AC-2	Chiang Mai	1985	*E.camaldulensis*	5.53	4.96	5.07
			A. auriculiformis	4.69	4.82	4.89
			A. mangium	1.03	0.77	0.01
		1986	*E.camaldulensis*	6.77	5.41	6.35
			A. auriculiformis	*	*	*
			A. mangium	*	*	*
		1987	*E.camaldulensis*	*	*	*
			A. auriculiformis	*	*	*
			A. mangium	*	*	*
AC-3	Ratchaburi	1985	*E.camaldulensis*	10.30	7.85	12.74
			A. auriculiformis	6.64	6.39	8.30
			A. mangium	6.69	6.98	6.39
		1986	*E.camaldulensis*	9.90	7.92	13.23
			A. auriculiformis	*	*	*
			A. mangium	*	*	*
		1987	*E.camaldulensis*	9.66	7.72	10.79
			A. auriculiformis	*	*	*
			A. mangium	*	*	*
AC-4	Sai Thong	1985	*E.camaldulensis*	10.70	7.89	12.41
			A. auriculiformis	11.99	10.32	20.71
			A. mangium	7.95	7.08	9.95
		1986	*E.camaldulensis*	11.91	8.14	13.36
			A. auriculiformis	*	*	*
			A. mangium	*	*	*
		1987	*E.camaldulensis*	9.21	7.59	12.10
			A. auriculiformis	*	*	*
			A. mangium	*	*	*

Table 4 Continued.

Code	Site	Year	Species	Height (m)	DBH (cm)	Basal area (m^2/ha)
AC-6	Si Sa Ket	1985	*E.camaldulensis*	11.25	9.61	19.16
			A. auriculiformis	8.98	8.28	14.08
			A. mangium	6.07	5.32	5.97
		1986	*E.camaldulensis*	12.07	9.87	20.13
			A. auriculiformis	*	*	*
			A. mangium	*	*	*
		1987	*E.camaldulensis*	*	*	*
			A. auriculiformis	*	*	*
			A. mangium	*	*	*
AC-7	Sakaerat	1985	*E.camaldulensis*	8.53	6.69	9.08
			A. auriculiformis	8.15	7.68	12.05
			A. mangium	4.65	4.23	4.05
		1986	*E.camaldulensis*	9.08	7.02	10.52
			A. auriculiformis	*	*	*
			A. mangium	*	*	*
		1987	*E.camaldulensis*	6.84	5.04	5.49
			A. auriculiformis	*	*	*
			A. mangium	*	*	*
AC-8	Chanthaburi	1985	*E.camaldulensis*	8.57	6.74	9.17
			A. auriculiformis	6.17	5.93	6.36
			A. mangium	3.58	2.96	1.82
		1986	*E.camaldulensis*	11.29	8.11	13.54
			A. auriculiformis	*	*	*
			A. mangium	*	*	*
		1987	*E.camaldulensis*	8.43	6.01	7.20
			A. auriculiformis	*	*	*
			A. mangium	*	*	*

Note : * not planted

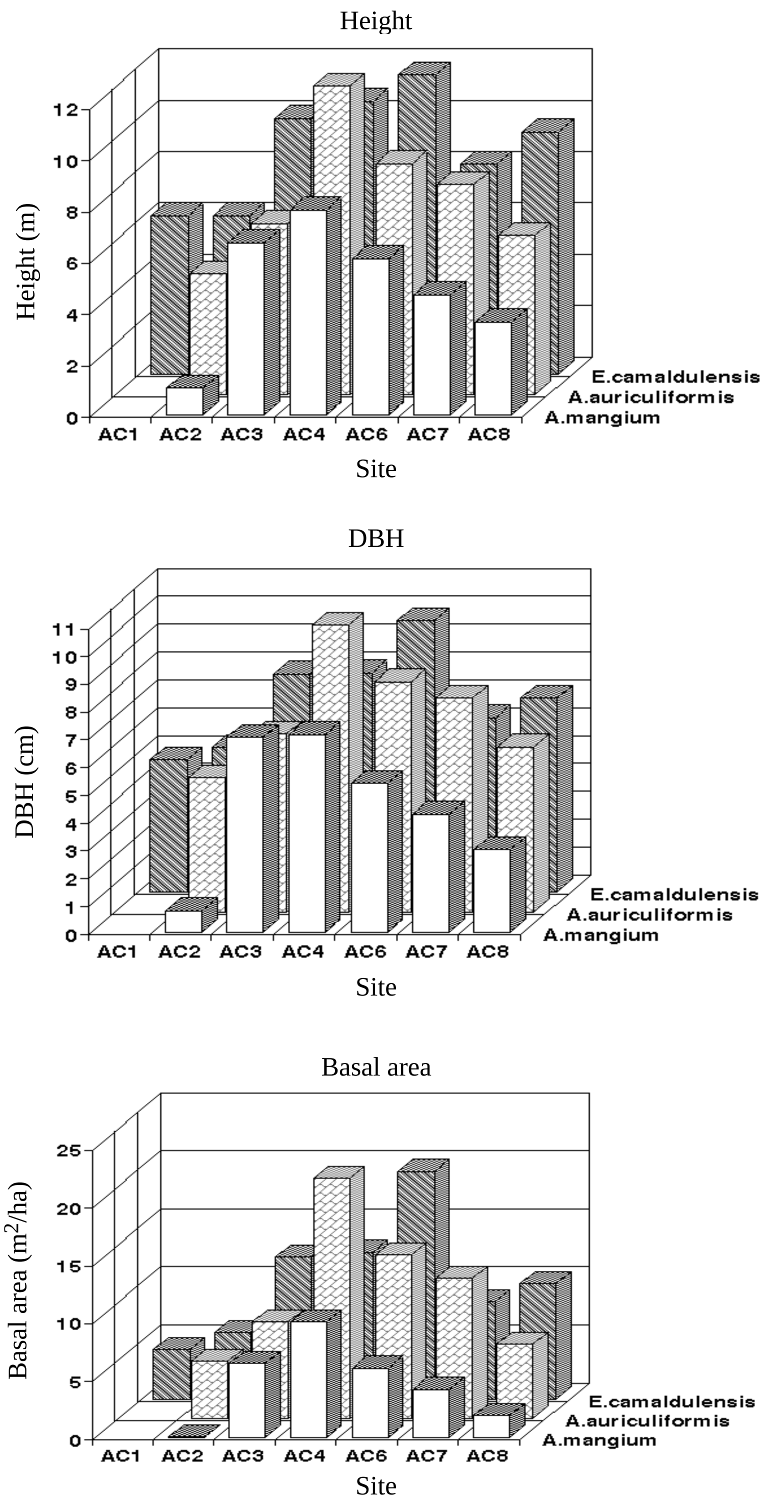

Figure 2 Growth of *E.camaldulensis, A.auriculiformis, A.mangium* at 3 years of age.

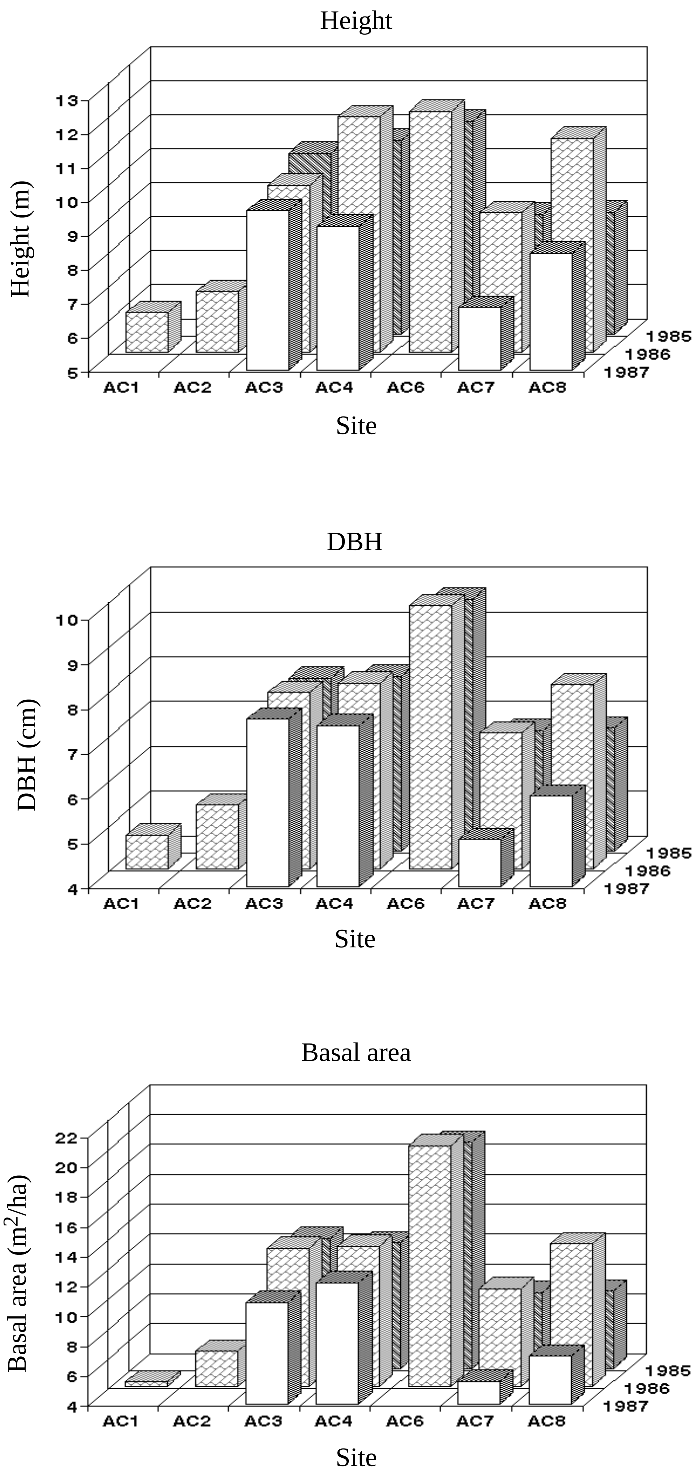

Figure 3 Growth of *E.camaldulensis* planted in 1985, 1986 and 1987.

Table 5 Mean monthly maximum and minimum temperatures and annual rainfall at the trial sites.

Site	Maximum temperature (°C)	Minimum temperature (°C)	Annual rainfall (mm)
AC-1	33	20	991
AC-2	30	17	1006
AC-3	34	23	1016
AC-4	31	22	1287
AC-6	33	22	1293
AC-7	31	19	1221
AC-8	32	20	1655

Table 6 Average values for each site and depth of soil chemical properties of plots used in this study.

Site	Depth	pH	EC	OM	P	Na	K	Ca	Mg	CEC	BS
	cm		mS/cm	%	mg/g	meq/100g					%
AC1	0-20	6.06	0.07	2.00	3.20	0.79	0.37	6.74	2.16	14.99	54.74
	20-50	6.68	0.07	1.96	0.83	0.28	0.27	21.98	2.30	28.29	60.58
	50-70	7.51	0.18	1.17	2.05	1.45	0.47	20.35	4.17	29.47	81.66
AC2	0-20	5.17	0.02	1.96	7.67	0.10	0.15	0.55	0.58	4.43	33.68
	20-50	5.37	0.01	0.60	2.38	0.11	0.20	0.43	0.66	3.81	39.57
	50-70	5.38	0.01	1.26	2.82	0.12	0.40	0.83	1.56	6.85	43.57
AC3	0-20	5.07	0.04	2.55	7.46	0.20	0.23	0.97	0.85	6.18	35.12
	20-50	5.04	0.03	1.86	5.47	0.20	0.23	1.15	1.11	6.40	34.70
	50-70	5.29	0.04	1.49	4.67	0.20	0.25	3.04	1.15	8.27	41.95
AC4	0-20	4.36	0.05	0.72	4.62	0.08	0.04	0.17	0.14	3.00	13.47
	20-50	4.31	0.02	0.34	5.01	0.07	0.02	0.11	0.12	2.49	12.75
	50-70	4.46	0.01	0.30	3.71	0.08	0.02	0.16	0.16	2.51	16.07
AC6	0-20	4.85	0.04	1.59	1.61	0.14	0.03	0.72	0.64	5.37	27.82
	20-50	4.94	0.02	1.20	1.87	0.13	0.02	1.13	0.42	4.88	25.59
	50-70	4.87	0.02	0.84	3.09	0.13	0.02	1.61	0.37	5.52	23.79
AC7	0-20	4.48	0.05	2.71	4.89	0.06	0.25	1.22	0.84	10.14	23.20
	20-50	4.53	0.03	2.01	4.51	0.06	0.21	1.11	0.90	10.62	20.38
	50-70	4.48	0.03	2.11	5.65	0.06	0.22	0.65	0.91	10.82	17.25
AC8	0-20	5.96	0.06	5.06	10.01	0.29	0.33	6.54	4.57	18.15	64.20
	20-50	6.01	0.04	3.07	5.14	0.32	0.19	5.20	4.92	16.43	64.21
	50-70	6.20	0.03	1.22	3.77	0.42	0.12	4.43	5.50	15.56	66.85

Table 7 Correlation matrix for growth, soil and climatic factors measured at *E. camaldulensis* plots (0-20cm soil depth).

ht	1.000					
dbh	**0.940**	1.000				
basal	**0.916**	**0.982**	1.000			
ph	-0.139	-0.145	-0.145	1.000		
ec	0.076	0.062	0.020	0.168	1.000	
om	-0.183	-0.181	-0.219	0.491	0.018	1.000
P	-0.174	-0.162	-0.187	0.201	0.156	0.428
K	-0.332	-0.367	-0.398	0.553	0.095	0.674
Ca	-0.145	-0.181	-0.208	**0.782**	0.243	0.538
Mg	-0.143	-0.177	-0.192	0.586	0.080	0.674
Na	-0.214	-0.237	-0.191	0.183	0.028	0.017
bs	-0.062	-0.071	-0.090	**0.885**	0.223	0.648
cec	-0.270	-0.309	-0.325	0.664	0.127	**0.724**
rain	0.368	0.277	0.251	0.304	0.126	0.427
tmax	0.364	0.414	0.406	0.253	-0.022	0.010
tmin	0.687	0.676	0.646	-0.123	0.053	-0.304
msl	**-0.702**	-0.645	-0.601	0.020	-0.112	0.164
	ht	dbh	basal	ph	ec	om
P	1.000					
K	0.233	1.000				
Ca	0.180	0.523	1.000			
Mg	0.189	0.587	0.569	1.000		
Na	-0.046	0.350	0.088	0.470	1.000	
bs	0.176	**0.724**	**0.796**	**0.755**	0.274	1.000
cec	0.219	0.685	**0.824**	**0.841**	0.353	**0.781**
rain	0.096	0.122	0.356	0.615	0.020	0.430
tmax	-0.161	0.192	0.152	0.139	0.195	0.299
tmin	-0.209	-0.235	-0.100	-0.144	0.014	-0.080
msl	0.190	0.124	-0.057	-0.061	-0.064	-0.069
	P	K	Ca	Mg	Na	bs
cec	1.000					
rain	0.474	1.000				
tmax	0.126	-0.099	1.000			
tmin	-0.234	0.031	**0.763**	1.000		
msl	0.029	-0.286	**-0.701**	**-0.951**	1.000	
	cec	rain	tmax	tmin	msl	

Table 8 Multiple Regression Relationships.

	Constant	pH	EC	OM	P	K	Ca	Mg	Na	BS	CEC	Rain	Max	Min	MSL	r^2
E. camaldulensis																
0-20 cm																
Ht	-11.53						-0.173	-0.855		+0.037		+0.006				**0.72**
DBH	-34.45	-0.962				-2.250		-0.482		+0.058		+0.006		+1.752	+0.011	**0.73**
BA	-120.6	-2.521				-7.690		-1.252		+0.158		+0.017		+5.485	+0.035	**0.71**
20-50 cm																
Ht	-38.28						+0.181		-11.100		-0.260	+0.008	+1.276			**0.73**
DBH	-27.93		+7.650				+0.086		-7.980		-0.177	+0.005	+0.966			**0.75**
BA	-141.30		+21.600				+0.396		-31.71		-0.676	+0.022	+4.172		+0.007	**0.76**
50-70 cm																
Ht	-9.51								+0.667		-0.055	+0.004		+0.687		**0.72**
DBH	-12.57					-2.957	+0.123				-0.171	+0.003	+0.852			**0.73**
BA	-71.90					-8.330	+0.471				-0.625	+0.010	+2.355		+0.005	**0.71**
A. mangium																
0-20 cm																**0.85**
Ht	-0.47	-2.582		-1.230		+8.010	+0.776							+0.896		**0.79**
DBH	-11.27	-0.759		-0.941	-0.083	-9.980									-0.008	**0.25**
BA	-20.40			-1.219									+0.902			
20-50 cm																
Ht	5.72												-0.961	+1.462		**0.67**
DBH	6.62			1.148				-0.556					-1.155	+1.645		**0.76**
BA	-273.00			+2.790		+44.400	-1.548					+0.041	-8.110	+21.570	+0.127	**0.49**
50-70 cm																
Ht	-9.30					-4.720								0.762		**0.72**
DBH	8.56	77.600		-9.260		-0.936	-2.520			+0.189	+0.410		-0.920	+1.031		**0.76**
BA	-75.60	+10.480	+193.80		-20.220	-1.610						+0.028				**0.45**

Table 8 (continued).

	Constant	pH	EC	OM	P	K	Ca	Mg	Na	BS	CEC	Rain	Max	Min	MSL	r^2
Acacia auriculiformis																
0-20cm																
Ht	37.27	-2.249				-3.480			-12.400	+0.059	+0.161		-1.651	+1.621		**0.88**
DBH	33.05	-1.181	+22.850										-1.343	+1.064		**0.69**
BA	95.60	-3.505	+43.200										-4.254	+3.232		**0.68**
20-50cm																
Ht	-69.80		+22.800				-1.144	-1.516		+0.075	+0.840	+0.014	-3.665	+7.830	+0.041	**0.88**
DBH	-97.20		+31.600				-1.090	-1.315		+0.063	+0.875	+0.014	-3.480	+8.710	+0.049	**0.70**
BA	97.40	-2.855											-4.377	+3.266		**0.66**
50-70 cm																
Ht	25.27		+21.700								+0.152	+0.008	-1.870	+1.557		**0.91**
DBH	27.44			0.419					43.300			+0.020	-1.477		-0.005	**0.76**
BA	78.40								92.700			+0.043	-3.877		-0.014	**0.68**

DISCUSSION

Soil conditions and climatic factors are major influences affecting tree growth. The soils used for the trials analysed here were of moderate to low fertility. The results of the statistical analyses show that much of the variation in growth data can be explained by regression models including soil and climatic factors. The r^2 values for *E. camaldulensis* were all above 0.70 and the values were approximately similar for each soil depth. The models indicated that soil factors especially pH, exchangeable cations and base saturation influence the growth of *E. camaldulensis.* Climatic factors including mean maximum and mean minimum temperatures as well as mean annual rainfall are also important. The results indicated that of the sites evaluated *E. camaldulensis* grows best at Si Sa Ket. The soil there is slightly acid, as well as being high in base saturation and organic matter. Most eucalypts will not thrive on alkaline soil, which have quantities of free calcium carbonate or sulphate in the profile (Turnbull and Pryor 1984).

The regression models for *A. mangium* were based on a relatively small sample and showed high variation in growth data. Moderate r^2 values ranging from 0.67 to 0.85 were obtained at all depths with height and DBH growth, but the r^2 values were poor (0.25 to 0.49) for basal area relationships. *A. mangium* was a relatively new species in Thailand when these trials were first established in 1985. In retrospect the provenances chosen for the trial were not the best choices for growing in Thailand. Most of the trees died within three years and seedlot 13621 in particular also failed at other trial sites in Thailand. However, the lack of suitable symbionts was probably a primary cause of the failures. Seedlings were not inoculated with appropriate *Rhizobium.* They all had very yellowish foliage even after a few growing seasons and no evidence of root nodulation was observed. More recently, provenances of *Acacia mangium* from Claudie River in Papua New Guinea planted in 1987-88 at Sai Thong have grown well (Pinyopusarerk, pers. comm.). Good growth and survival of *Acacia mangium* has also been reported at a number of tropical sites with loam texture soils and 1500-2000mm mean annual rainfall (Awang and Taylor, 1993; Nguyen Hoang Nghia, 1996).

The models for *A. auriculiformis* produced some high r^2 values, especially for height and DBH relationships, with values ranging between 0.66 and 0.91. The relationships should be useful for making tentative predictions of potential growth at other sites with generally similar soil and climatic conditions. The results indicated that *A. auriculiformis* grew well at all trial sites included in the project especially at Sai Thong (AC-4). The growth of *A. auriculiformis* in height and DBH was higher than *E. camaldulensis* and *A. mangium,* although measured soil fertility was low. *A. auriculiformis* can grow in a variety of soil including very poor soil, clay, salt-affected and seasonally water-logged soils, including sandy soils and acid sulfate soils (Nguyen Hoang Nghia, 1996).

The results of the statistical analysis have shown that much of the variation in tree growth can be explained by the regression models, though some of the relationships were poor. Some of the better relationships could be used to predict potential growth of particular species at other sites. However, these relationships could only be expected to be reliable where generally similar soil and climatic conditions are experienced. A major limitation of the work reported here was the small number of sites involved. Though these trials are extremely useful for determining factors influencing tree growth in Thailand they are insufficient to represent the full range of variation in climatic and soil factors found in Thailand. It would be desirable to establish further trials on potential sites for large scale plantations to sample the full range of site quality and environmental conditions.

ACKNOWLEDGEMENTS

We are grateful to the Australian Centre for International Agricultural Research (ACIAR), under its Project 9127 for their financial support of these studies. We particularly thank Mr.Tom Jovanovic, CSIRO Division of Forestry and Forest Products for his help in the preparation of this paper, also Mr. Viroj Ratanapornchareon and Chief of the experimental stations of Royal Forest Department (RFD) for their help with data collection. We thank Mr.Vitoon Luangviriyasaeng (RFD) for his comments on the data analysis, as well as Dr. Chris Harwood and Mr. Khongsak Pinyopusarerk (both CSIRO) for their comments on a draft manuscript.

LITERATURE CITED

Awang, K. and D. Taylor. 1993. *Acacia mangium* Growing and Utilization. MPTS Monograph Series No. 3. Bangkok, Thailand : Winrock International and FAO. 280 p.

Black, C.A. 1965. Methods of Soil Analysis Part II : Chemical and Microbiological Properties. American Society of Agronomy, Inc. 801 p.

Bouyoucos, G.T. 1936. Direction for making mechanical analysis of soils by hydrometer method. *Soil Sci.* 42: 225-229.

FAO Project Staff and Land Classification Division. 1973. Soil Interpretation Handbook for Thailand, Land Classification Division, Department of Land Development, Ministry of Agriculture and Cooperatives. Bangkok. 189 p.

Janmahasatien, S., C. Viriyabuncha, and P. Snowdon 1996. Soil sampling and growth prediction in Thailand, pp 101-106. *In* Matching Trees and Sites. Proceedings of an International Workshop held in Bangkok 27-30 March 1995. ACIAR Proceeding No. 63

Nguyen Hoang Nghia. 1996. Climatic requirements of some main plantation tree species in Vietnum, pp 43 - 49. *In* T.H. Booth, (ed.). Matching Trees and Sites. Proceedings of an International Workshop held in Bangkok 27-30 March 1995. ACIAR Proceeding No. 63

Payne, R.W., P.W. Lane, A.E Ainsley, K.E Bicknell, P.G.N. Digby, S.A. Harding, P.K. Leech, H.R. Simpson, A.D. Todd, P.J. Verrier, R.P. White, J.C. Gower, and Wilson, G. Tunnicliffe. 1987. Genstat 5 reference manual. University Press. New York. 749 p.

Pinyopusarerk, K. 1989. Growth and surviral of Australian tree species in field trial in Thailand, pp 109 - 127. *In* D.J. Boland (ed.). Trees for The Tropics: Growing Australian Multipurpose Trees and Shrubs in Developing Countries. ACIAR Monograph No. 10

Turnbull, J.W. and L.D. Pryor. 1984. Choice of species and seed sources, pp 6 - 65. *In* W.E. Hills and A.G. Brown (eds.). Eucalyptus for Wood Production. CSIRO, East Melbourne, Victoria, Australia.

Viriyabuncha, C. and K. Pitpreecha. 1989. Climatic Data (1978/1987) and Diagram of Station under Silvicultural Research Sub-Division, Division of Silviculture, Royal Forest Department. Technical paper No. 23 , Bangkok. 78 p.

Viriyabuncha, C., T.H. Booth, and H. Zuo. 1996. Climatic mapping program for Thailand, pp 18 - 23. *In* Matching Trees and Sites. Proceedings of an International Workshop held in Bangkok 27-30 March 1995. ACIAR Proceeding No. 63

Received date : 24/09/97
Accepted date : 2/07/98