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GROWTH RATES OF FIVE TROPICAL LEGUMINOUS FUELWOOD SPECIES

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MACDICKEN, K.G. & BREWBAKER, J.L. 1988. **Growth rates of five tropical leguminous fuelwood species.** Productivity of the multipurpose, leguminous trees *Leucaena leucocephala, Leucaena diversifolia, Acacia auriculiformis, Calliandra calothyrsus* and *Sesbania grandiflora* was examined under close spacing and intensive management. These trees are important components of tropical farming systems and are capable of supporting nitrogen-fixing root nodules by *Rhizobium.* Experiments to compare the growth rates of the five species were conducted at five sites in Hawaii and the Philippines. Height, diameter and wood volume increments up to two years of age are reported. Wood volume equations are also presented for small diameter stems for each species. *Leucaena leucocephala* and *L. diversifolia* consistently produced the largest wood yields, as much as 97 $m^3/ha/y$ on agricultural soils. Significant location x species inter-actions were found which reflect different site requirements for each species.

Key words: Nitrogen fixing trees – productivity – growth rates – site requirements.

Introduction

Considerable interest has been shown in producing wood fuel from fast-growing trees in recent years. Optimizing the productivity of fuelwood plantings is only possible when the proper species are selected for local conditions (Burley 1980).

A number of promising, tropical, nitrogen-fixing trees (NFT) have been identified as fuelwoods for small-farm or plantation use (NAS 1980). Most of these species have been known to tropical foresters for years. Few of them have been studied thoroughly due to their poor form, soft wood and poor timber or pulping qualities. Fuelwood species often have few the form or wood qualities required for timber or pulpwood, and have not generally been studied at the close spacings used to maximise biomass production.

Nitrogen-fixing trees are of particular interest as fuelwoods due to their ability to support nitrogen fixation as well as fix carbon. NFT have long been used as multipurpose trees for shade, fodder, green manure, shifting cultivation improvement, timber, and a number of other uses. It is this range of uses that make NFT attractive multipurpose fuelwood species. Over 600 woody species are presently known to fix nitrogen (Halliday and Nakao 1982).

Studies were undertaken cooperatively by the University of Hawaii, the Benchmark Soil Project and the Nitrogen Fixing Tree Association to compare the height, diameter and wood volume growth rates of some 23 NFT species on five sites (Brewbaker *et al.* 1981, MacDicken *et al.* 1985). This paper describes the results of these multilocation experiments and presents wood volume equations which were derived for the five replicated species.

Materials and methods

Five locations were selected on four soil families in Hawaii and the Philippines to evaluate the growth rates of five NFT species. These species were replicated in all of the planting sites:

Acacia auriculiformis A. Cunn. ex Benth.
Calliandra calothyrsus Meissn.
Leucaena diversifolia (Schlecht.) Benth.
Leucaena leucocephala (Lam.) de Wit.
Sesbania grandiflora (L.) Pers.

Field experimentation

Field trials of the augmented randomized complete block (ARCB) design were established on five experimental sites between January, 1981 and November, 1982 (Table 1). The five experimental sites ranged in annual rainfall from 700 *mm* to over 2500 *mm* and in elevation from 21 to 545 *m*. Mean annual soil temperatures at four of the sites were in the isohyperthermic class (22° C or higher) and one site was in the isothermic (15° to 22° C) temperature regime. Seedlings were grown in plastic dibble tubes and transplanted at an age of 2 – 4 *months* into level or nearly-level agricultural soils following thorough land preparation.

The augmented block design as described by Federer and Raghavarao (1975) was used in each of the trials, with the number of replicated species ranging from five to twelve in either three or four replications. A core of five species was replicated at every site using standard seed lots (Table 2). The number of augmented species also varied form five to twelve, with a total of 23 species of 16 genera planted either as augments or replicated treatments. The plot size used was 7 x 4 *m* with a tree spacing of 1 x 1 *m* for all treatments. Data were collected from the ten innermost trees which were bordered on all sides by trees of the same species.

Table 1. Description of sites

SITE	RAINFALL (*mm*)	ELEVATION (*m*)	SOIL FAMILY**
Waimanalo Hawaii	1270 – 1525	21	Vertic Haplustolls, very fine, kaolinitic, isohyperthermic
Molokai* Hawaii	700	100	Ustollic Camborthids, fine-loamy, kaolinitic isohyperthermic
Waipio* Hawaii	1000	150	Tropeptic Eutrustox, clayey, kaolinitic isohyperthermic
Niulii Hawaii	2000 – 2550	545	Hydric Dystrandepts, thixotropic, isothermic
BPI, Davao Philippines	1500 – 2000	200	Typic Paleudults, clayey,kaolinitic isohyperthermic

* drip irrigated
** Soil family classification used is a unit of soil classification in the United States Soil Taxonomy (USDA 1975)

Table 2. Listing of seed sources by experiment location

SPECIES	LOCATION				
	Waimanalo	Molokai	Waipio	Niulii	Davao
	Seedlot numbers *				
Acacia auriculiformis	N5	N5	N5	N5	N1
Calliandra calothyrsus	N17	N17	N63	N63	N63
Leucaena diversifolia	K156	K156	K156	K156	K156
Leucaena leucocephaia	K8	K8	K8	K8	K8
Sesbania grandiflora	N28	N28	N36	N36	N36

* Seedlot numbers are from the collection of the Nitrogen Fixing Tree Association, P. O. Box 680, Waimanalo, Hawaii 96795, USA.

Irrigation water was applied as needed up to six months after transplanting at Waipio, when irrigation was discontinued. The Molokai site was irrigated every 1 – 2 weeks as necessary. Other sites received no supplemental water.

Growth measurements

Height to the tip of the apical bud, basal diameter at 10 *cm* above the ground, and diameter at breast height (dbh) were measered from the ten interior trees every three *months* for the first year and every six *months* thereafter. For species with multiple stems, a maximum of the three largest stems per tree were measured and recorded for calculation of basal area and wood volume. Basal diameter and dbh multiple stemmed trees were combined using the formula:

$$Dx = \sqrt{D1^2 + D2^2 + D3^2}$$

where: Dx = adjusted diameter, D1, D2, D3 = individual stem diameters at 10 *cm* or 1.37 *m*.

Wood volume was measured at every site at one year after transplanting, and was calculated for all but the Niulii site at two years of age using volume equations derived from measured trees. Samples from the Niulii site were excluded from the computations due to severe wind stress which made the allometric relationships at that site non-homogenous with the other sites. Equations were derived for four nitrogen fixing tree species as 1 to 1.5 *y* of age.

These equations represent height and diameter measurements of a minimum sample of 100 trees per species drawn from replicated small plot experiments at four sites in Hawaii with population densities of 10,000 trees per *ha*. Diameters were measured every 50 *cm* along the stem up to a minimum top diameter of 1 *cm*. Stem wood volumes were calculated using Newtons and Smalians formulae. Several models were computed using height, basal diameter, DBH, the square and logarithm of each variable and the height x DBH^2 interaction.

Statistical analysis

Analyses of variance were done by location and age, and were combined to determine species x location interactions. Mean separations were done using Duncan's Multiple Range Test at the $P = .05$ level. Spearmans Rank Correlation test was used to compare ranking of species at six and 24 months of age.

Results and discussion

A combined analysis of variance of height growth indicated highly significant differences ($P = .01$) between locations and between species (Table 3). The location x species interaction was also highly significant, demonstrating the variation in environmental requirements among the five species.

Table 3. Combined analysis of variance for height growth of five NFT species on five sites at two years of age

Source	df	MS	F
Location	4	79.56	162.7 **
Replicates within locations	12	0.49	–
Species	4	39.77	106.6 **
Location x species	16	5.49	14.7 **
Pooled error	48	0.37	

** significant at P = .01

The two leucaena species were the most productive species over all sites in height growth and wood volume (Table 4). *L. leucocephala* was more productive than *L. diversifolia* on the best site in the trial, while *L. diversifolia* significantly outgrew *L. leucocephala* on the less productive sites at Waipio and Niulii. *L. leucocephala* was severely limited by cold temperatures at the Niulii site (isothermic temperature regime). while *L. diversifolia* demonstrated much better cold tolerance (Figures 1 & 2).

A. auriculiformis did not perform well at any site and was most severely stunted at Niulii (Figure 3). The early growth of this acacia, which is reportedly acid tolerant (Turnbull 1986), was much slower than the leucaenas even on the Waipio site (pH = 4.9 – 6.4).

S. grandiflora exhibited the greatest variability between locations (Figure 4). Sesbania was killed before reaching two years of age by the cool, moist conditions at the Niulii site. Height growth up to one year was rapid overall, but slowed significantly after one year of age. *C. calothyrsus* was least affected by the cooler temperatures at the Niulli site, although growth rates were generally lower than the other four species at all other sites (Figure 5).

Height growth

Height growth was the least variable parameter measured in this study, with a coefficient of variation (c.v.) of 10.9% for the combined analysis. Height differences between species were significant (P = .05) at every site at every age.

Height differences between species were generally constant over time. The rankings of species at six months were identical or very similar to the rankings at one year (Spearmans r = .77**). Growth over a two year period indicates that after an initial establishment period of 3–6 months, the growth rates of the species changed very little in relation to one another.

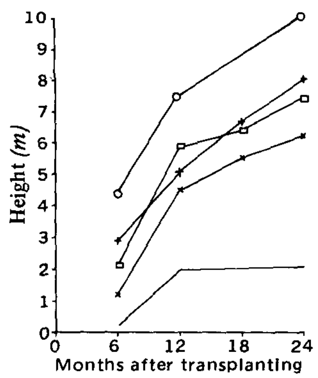

Figure 1. Height growth of *Leucaena leucocephala*

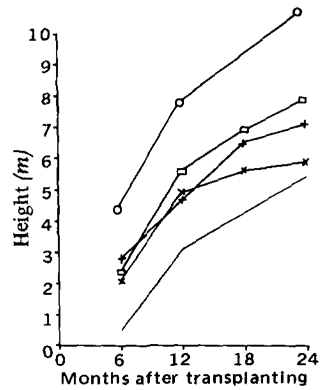

Figure 2. Height growth of *Leucaena diversifolia*

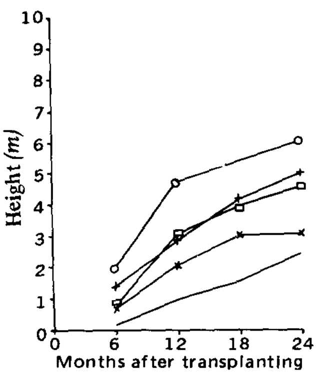

Figure 3. Height growth of *Acacia auriculiformis*

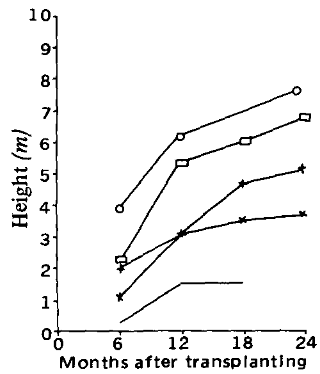

Figure 4. Height growth of *Sesbania grandiflora*

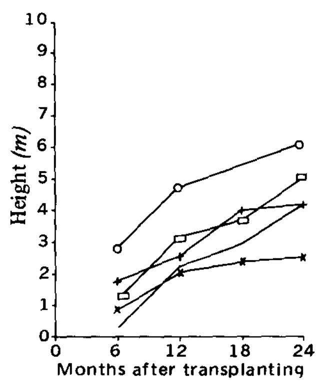

Figure 5. Height growth of *Calliandra calothyrsus*

+	=	Waimanalo site, vertic Haplustolls, isohyperthermic
x	=	Waipio site, Tropeptic Eutrustox, isohyperthermic
▭	=	Molokai site, Ustollic Camborthids, isohyperthermic
	=	Niulii site, Hydric Dystrandepts, isothermic
O	=	Davao site, Typic Paleudults, isohyperthermic

Table 4. Height, diameter and wood volume growth at two years after transplanting

SPECIES	LOCATION *					Mean
	Waimanalo	Molokai	Waipio	Niulii	Davao	
			Height (*m*)			
LEU	8.1a	7.5a	6.2a	2.1c	10.4a	6.9
DIV	7.1a	7.9a	5.9a	5.4a	10.7a	7.4
AUR	5.0b	4.6b	3.2c	2.5c	6.1bc	4.3
SES	5.2b	6.8ab	3.8b	– – – **	7.6b	5.8
CAL	4.2b	5.1b	2.6c	4.3b	6.0c	4.4
LSD (.01)	1.26	2.38	.76	.61	1.53	
			Basal diameter (*cm*)			
LEU	6.5a	7.5a	5.8a	3.1b	8.3ab	6.2
DIV	5.6ab	6.3ab	5.7a	6.0a	8.4a	6.4
AUR	4.9bc	3.8b	3.2b	4.7a	6.6bc	4.6
SES	7.0a	7.9a	6.2a	– – – **	9.8a	7.7
CAL	3.5c	4.4b	2.5b	4.7a	5.8c	4.2
LSD (.01)	1.59	2.58	.98	1.43	1.80	
			Wood volume ($m^3/ha/y$)			
LEU	47.3a	64.8a	32.4a	1.0c	91.3a	47.4
DIV	32.4b	43.9b	29.8a	32.0a	96.6a	46.9
AUR	12.5d	5.8c	3.6c	11.0b	30.9c	12.8
SES	23.4c	37.5b	14.3b	– – – **	74.8b	37.5
CAL	7.4d	12.9c	2.9c	13.1b	25.2c	12.3
LSD (.01)	7.1	14.2	3.5	4.4	14.7	

* values within locations not followed by a common letter are significantly different at $P = 0.01$.

** *Complete mortality of SES at Niulii site.*

The Davao site was the most productive site overall with nearly ideal field conditions of well-distributed rainfall and fertile soils. The isothermic site (Niulii) was least productive, indicating the suitability of the tested species to warmer sites.

Wood volume

Differences in wood volume were significant between species and between locations at two years (Table 4). The leucaena species were most productive over all sites.

L. leucacephala demonstrated significantly greater volume growth than *L. diversifolia* on the high base saturation Waimanalo site and on the high solar radiation, drip-irrigated site on Molokai. *L. diversifolia* outproduced all other species at the cool, moist Niulii site.

S. grandiflora was highly productive at the Molokai and Davao sites and ranked third over all locations, excluding the Niulii site where mortality was high, apparently due to the cool temperatures.

C. calothyrsus and *A. auriculiformis* were not significantly different at any site, and had the lowest mean annual increment at every site except Niulii, *Calliandra* was not well suited to the Waipio site, but exhibited uniform growth at the other three sites. *A. auriculiformis* was highly variable across sites and did not perform well at the Niulii, Waipio and Molokai sites.

Wood volume equations derived from sample trees in this experiment are presented in Table 5.

Table 5. Wood volume equations for four species of nitrogen fixing trees

SPECIES	Equation	R^2
Leucaena	$Y = -780 + 198\ (BD^2)$	.91
leucocephala	$Y = -186 + 108\ (BD^2) + 21\ (HT\ (DBH^2))$	.93
Leucaena	$Y = 703 + 44\ (HT\ (DBH^2))$	.90
diversifolia	$Y = 294 + 49\ (BD^2) + 34\ (HT\ (DBH^2))$	.91
Calliandra	$Y = -129 + 172\ (DBH)^2 + 36\ (HT)^2$	.93
calothyrsus	$Y = -182 + 25\ (BD)^2 + 126\ (BDH)^2 + 39\ (ht)^2$	.94
Acacia	$Y = -378 + 120\ (BD)^2$	.88
auriculiformis	$Y = -163 + 64\ (BD)^2 + 25\ (HT\ (DBH^2))$	.93

*/ Where: Y = wood volume in cm^3/tree (to convert to m^3/ha multiply by population/*ha* and divide by 1×10^2)
BD = basal diameter at a stump height of 10 *cm*
HT = tree height
DBH = diameter at breast height

Tree height and diameter limitations for volume equations

SPECIES	Height *(m)*	Basal Diameter *(cm)*	DBH *(cm)*
A. auriculiformis	1.5 – 6.0	1.0 – 7.0	0.5 – 5.0
C. calothyrsus	1.0 – 4.5	1.0 – 6.4	0.5 – 4.5
L. diversifolia	2.5 – 8.0	2.5 – 8.0	1.5 – 7.0
L. leucocephala	3.5 – 8.0	1.5 – 9.0	1.5 – 7.5

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