STUDIES ON THE EARLY GROWTH RATES OF SELECTED NITROGEN-FIXING TREES

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By

Kenneth Glenn MacDicken

Thesis Committee:

James L. Brewbaker, Chairman
Peter P. Rotar
Jake Halliday

We certify that we have read this thesis and that in our opinion it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Agronomy.

THESIS COMMITTEE

James L. Brewbaker

Chairman

Peter P. Rotar

J. Halliday

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ABSTRACT

A series of five species comparison trials were planted in Hawaii and the Philippines during 1981-82. These trials were of the augmented block design and included a total of 23 species of nitrogen-fixing trees (NFT). Height, diameter and wood volume growth were measured at 3, 6 or 12 month intervals. Additional data were collected to allow estimation of the minimum sample and plot sizes required to obtain various levels of precision.

Leucaena leucocephala and *Leucaena diversifolia* were the most productive species over all sites in height growth and wood volume. *L. leucocephala* was more productive than *L. diversifolia* on the best sites in the trial, while *L. diversifolia* significantly outgrew *L. leucocephala* on the less productive sites at Waipio and Niulii. It appears that *L. diversifolia* is more tolerant to the cooler temperatures at Niulii than *L. leucocephala*.

Yields of all species were lower at the Waipio site than those at the Waimanalo and Molokai sites, yet wood volume yields of the leucaena species still exceeded $24 m^3$/ha/yr. This suggests that the acidic Ap horizons at Waipio did not severely limit the growth of these species which are thought to be intolerant of acid soils. The fact that *Acacia*

auriculiformis, which is reportedly an acid tolerant species did poorly on the Waipio site further suggests that this soil acidity is not the only important limiting factor at work.

Sesbania grandiflora exhibited rapid early growth overall and equalled at least one of the leucaena species in wood volume yields at every site at one year. Calliandra calothyrsus did not grow as rapidly as expected overall, but was least affected by the cooler temperatures at the Niulii site. Acacia auriculiformis was generally the slowest growing core species at each site and was most severely stunted at Niulii.

Volume prediction equations were derived from 100 sample trees at 3 locations for the replicated species. Three variable equations using easily measurable parameters explained between 89 and 95% of the variation for wood volume.

Of the augmented species, Eucalyptus saligna, Casuarina equisitifolia, Albizia falcataria and Acacia mearnsii merit inclusion as replicated species in all future trials.

Assuming height, basal area and wood volume are all characteristics which must be measured over time in future NFT trials, a minimum sample size of 20 samples per plot is required to attain an estimate with a margin of error of less than 20 % for all of the measured characteristics. Ten samples per plot appears adequate for site adaptability

trials utilizing height as a measure of species adaptation.

Border effects were found between border and data rows in the 28 m^2 plots used in these experiments. The minimum plot size required to supply 20 samples per plot appears to be 72 m^2 assuming border effects to be severe before two years of age on some sites. The use of 8 x 9 row plots would insure the availability of 20 samples free of border effects.

TABLE OF CONTENTS

Appendices

LIST OF TABLES

LIST OF APPENDIX TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BA - Basal area

DBH - Diameter at breast height (1.37m)

NFT - Nitrogen-fixing trees

Species codes
Acr-*Acrocarpus fraxinifolius*
Apr-*Albizia procera*
Aur-*Acacia auriculiformis*
Cal-*Calliandra calothyrsus*
Cas-*Casuarina equisitifolia*
Cit-*Eucalyptus citriadora*
Dal-*Dalbergia sissoo*
Div-*Leucaena diversifolia*
Ent-*Enterolobium cyclocarpum*
Ery-*Erythrina poepiggiana*
Euc-*Eucalyptus saligna*
Fal-*Albizia falcataria*
Gli-*Gliricidia sepium*
Leb-*Albizia lebbek*
Leu-*Leucaena leucocephala*
Lys-*Lysiloma acapulcense*
Man-*Acacia mangium*
Mea-*Acacia mearnsii*
Mel-*Acacia melanoxyln*
Mim-*Mimosa scabrella*
Pro-*Prosopis pallida*
Sam-*Samanea saman*
Ses-*Sesbania grandiflora*

SRIC - Short Rotation Intensively Cultured

UH - University of Hawaii

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

A. Introduction

Over a third of the world's population suffers from an energy crisis caused by a scarcity of fuelwood. This shortage is particularly serious in the rural areas of the developing world, where at least 80% of all energy needs, other than human and animal, are supplied by wood and charcoal (NAS,1980; Arnold and Jongma,1978; Eckholm,1975). Indeed, some 14% of total world energy consumption is supplied by wood (Coombs,1980).

The importance of wood fuels is even more striking when viewed on a regional basis. Wood and charcoal use account for two-thirds of all energy other than human in Africa, one-third in Asia and one-fifth in Latin America (Arnold and Jongma,1978). Thus it can be seen that a shortage of fuelwood in the third world is an energy crisis of enormous magnitude.

Serious as the lack of fuel for cooking and other basic uses is, such shortages are by no means the only problems associated with the fuelwood crisis. While most of the wood fuel used in the third world is burned as cooking fuel, wood is burned for a large number of other purposes from small-scale industrial uses to home food processing (Avery,1978; Chittenden and Breag,1980).

Increased demand for fuelwood has dramatically increased the gathering of wood from tropical forests. Along with other forest uses such as shifting cultivation, it substantially contributes to the denudation of the already dwindling closed forest area (Barney,1978; Brewbaker et al.,1981).

Although an estimated 1.15 billion hectares of closed canopy forests still exist in the tropics, this resource is being depleted at a rate estimated to be from 15 to 95 million hectares per year (Brewbaker et al. 1982; Barney,1978). Assuming an annual loss of 20 million hectares per year, approximately one-half of the present tropical forest resource will be lost within 30 years, largely due to the demand for firewood (Brewbaker et al.,1982).

The denudation of tropical forests is all too often accelerated with the initiation of economic growth, with the ecological damage associated with denudation too often ignored (Earl,1975). Thus, unless efforts to improve long-term land use management planning are instituted soon, the outlook for the millions of people dependent on existing tropical forests resources for a myriad of uses is grim indeed (Earl,1975; FAO,1977; Chittenden and Breag,1980).

Two major options emerge as means of reducing the pressure of increasing population and consumption pressures on dwindling forest resources: 1)conservation of existing wood resources by decreasing consumption; 2)increasing the supply of wood. Decreasing consumption through improvements in cooking efficiencies has good potential since traditional cooking fires are often very thermally inefficient (NAS,1980; Moss and Morgan, 1981). Efforts to distribute more efficient stove designs have met with mixed success, even though such designs greatly reduce the amount of wood required for cooking (Evans,1978; NAS,1980).

While efforts to encourage more efficient use of existing fuelwood resources is vitally important,and may ultimately have a major impact in slowing the rate of deforestation, it appears obvious that the pressures of population growth, increasing levels of consumption and dwindling resources demand increases in fuelwood supplies. A number of investigators have shown that fuelwood can be grown as a crop suited to conditions ranging from small backyard plantings to large scale energy plantations (Singh,1978; Sharma,1978; Eimers,1978; Grantham and Ellis,1974; Fege et al.,1979; Brewbaker,1980).

B. Literature review

The fact that woodfuel resources can be established economically has led to increasing interest in fuelwood tree species in recent years (Arnold and Jongma,1978; World Bank,1978; Fege et al.,1979). Fuelwood crops have been shown to be an economical source of energy on the village level as well as the commercial level (Chaugale,1977; Arnold,1979; Avery,1978; Cecelski et al.,1979).

Since fuelwood has been a vitally important and widely used resource there are few technical or social constraints to its use in village conditions (Chittenden and Breag,1980). However, maximization of the productivity of fuelwood plantings is only possible when the proper fuelwood species are selected for local conditions (Burley,1980; Brewbaker et al.,1981).

The cultivation of fuelwood trees in short-rotation, intensively cultured (SRIC) plantations is a relatively new concept in forestry practice. Indeed, SRIC plantations may require as many agronomic practices such as irrigation, fertilization and high population densities as they do traditional silvicultural practices (Rose,1977; Henry,1979).

Species trials of tropical hardwoods have been conducted in a limited way in Hawaii and throughout Asia (Faustino et al.,1977; Burley and Wood,1976; Burgan and Wong,1971; Whitesell and Isherwood,1971; Mendoza and de la Cruz,1978). However, few have been done to compare biomass yields of tropical fuelwood species .

This is particularily true with nitrogen-fixing tree (NFT) species even though it has been shown that a number of NFT species have excellent potential as "energy trees" (Wiley,1972; Wiley and Manwiller,1976; Felker and Bandurski,1979; Smith,1977; Brewbaker,1980).

A number of species of tropical nitrogen-fixing trees (NFT) have been identified as promising fuelwood species for use in SRIC plantations (Brewbaker et al.,1981; NAS,1980; NAS,1979). Most of these species have been known to tropical foresters for years. However, many species have not been studied thoroughly due to their poor form, soft wood, poor timber or pulping qualities. Many aggressive, fast-growing species have been branded as weeds because they lack the wood characteristics required for higher value wood products.

Fuelwood species on the other hand often have few of the form or wood qualities required of timber or pulpwood species, but have not generally been studied at the close spacings used for biomass production. Nitrogen-fixing trees (NFT) are of particular interest as fuelwood species due to their ability to fix nitrogen as well as carbon (Brewbaker et al.,1982). NFT have long been used as shade crops (Alconero et al.,1973), fodder crops (Holm,1972; Ernest and Rodricks,1981), green manure crops (Kang et al.,1982; Chagras et al.,1981; Guevarra,1976), shifting cultivation improvement crops (Parfitt,1976; MacDicken,1981) as well as for a number of other uses (Felker and Bandurski,1979; NAS,1979; Weaver,1979).

NFT have in recent years also been studied as nitrogen sources for traditional forest tree crops such as Douglas-fir (Atkinson et al,1979; DeBell and Radwan,1979; Haines and DeBell,1979). Recent studies by the Bioenergy Dev. Corp. have shown significant increases in the growth of *Eucalyptus saligna* and *Eucalyptus grandis* interplanted with *Albizia falcataria* (Bioenergy Dev. Corp.,1982). It is this multiplicity of uses that make NFT attractive multipurpose fuelwood species.

Biomass productivity studies have been carried out for temperate species such as *Populus* spp. and *Alnus rubra* (Cannel and Smith,1980; DeBell and Radwan,1979) and tropical species such as *Leucaena leucocephala* (Brewbaker et al.,1981). Although research has been conducted on nitrogen-fixing species such as *Acacia auriculiformis* (Nicholson,1965; Wiersum and Ramlan,undated; Banerjee,1973) and *Sesbania grandiflora* (Bhat et al.,1971) most of these efforts have been concentrated on pulpwood and timber production rather than fuelwood production. Notable exceptions are *Calliandra calothyrsus* (Yudibroto,1981; Suyono,1975; Anonymous,1977) and leucaena which are widely used fuelwoods in parts of South East Asia.

The need for future research on these species as fuelwood crops has been recognized by a number of writers (NAS,1980; Brewbaker et al.,1981; Brewbaker et al.,1982). This need is further evidenced by the dearth of literature on the fuelwood yields and wood characteristics of most of these species.

It was the purpose of the studies undertaken for this thesis to evaluate the productivity of a number of promising NFT species over the first year of growth at several sites. Plant growth characteristics such as height, diameter and wood volume were measured over a one to one and a half year period at four different sites. A series of experiments have been established to assess the growth rates of some of the most promising of the tropical NFT as fuelwood species (Brewbaker et al.,1981). A core of five species have been replicated at each of the sites and will be discussed here briefly. These species are:

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

1. *Acacia auriculiformis* is a fast-growing, moderately sized tree (to 25 m) native to coastal Northern Australia, Southern Papua New Guinea and the Solomon Islands. Natural habitats are characterized by an annual rainfall of about 1600mm with a 5-6 month dry season. Form of mature trees is often poor, with crooking and low branching predominating.

The species has been shown to perform well on soils with pH ranging from extremely acid (pH=3.0) to extremely alkaline (pH=9.5) (NAS,1979). It is widely recommended in Asia as a reclamation and erosion-control species for degraded lands, mine spoils and nutrient depleted soils abandoned by shifting cultivators. Low rainfall and elevations over 600m appear to be limiting environmental factors (NAS,1980).

Growth is moderate in early years with mean annual increment approaching up to 20 m^3/ha/yr on 10 year rotations. Yields of up to 5 m^3 /ha/yr are more likely on semi-arid, poor quality sites (Banerjee,1973). Diameters of 15 cm and heights of 15-20 m are commonly reported at this age. Stem form is usually poor with multiple stems per stump.

Because of its poor form, the use of Acacia auriculiformis as a timber species is limited. Never the less, it is considered a very useful tree, especially for replanting waste areas and where construction materials are in short supply (Nicholson,1965). It is used in some regions as a pulpwood, producing high yields of pulp with good strength properties. The wood is ideal for fuelwood, with a specific gravity of .6-.7 and a calorific value of 4,800 kcal/kg (CSIRO,1980; NAS,1980). The wood is also highly suited for charcoal making.

2. Calliandra calothyrsus is a small, fast-growing bush native to Central America, now widely planted in Indonesia as a fuelwood crop. At maturity trees may reach 8 m in height and 20 cm in diameter (NAS,1980). Adapted to the humid tropics, calliandra is thought to be limited in distribution to areas less than 1500 m in elevation with at least 1,000 mm annual rainfall. It is able to withstand drought of several months, and tolerates a fairly wide range of soils.

Generally managed as a fuelwood crop, calliandra is most often planted at populations of 2,500-10,000 stems/ha and is harvested on very short rotations of 1-2 years. The foliage is high in protein (22%) and tannins and is used as a fodder and green manure crop (NAS,1982b). It has also been widely used as an erosion control crop with establishment by direct seeding or seedlings. Calliandra calothyrsus coppices vigorously, often producing 10-20 shoots/stump. Wood yields on short rotations have been reported from 5-20m^3/ha/yr. Specific gravity ranges from .5-.8, with calorific values of 4,500-4,700 kcal/kg (Yudodibroto,1981). Annual forage yields have been estimated to be as high as 7-10 tons of dry matter per year.

3. Leucaena leucocephala is one of 10 species in this genus of small to medium-sized Latin American trees. Most species include shrubby varieties and arboreal types, which grow to 20m and are known as the "Salvador type". Leucaena is distributed pantropically, and is the subject of an annual publication, "Leucaena Research Reports" (Brewbaker,1982) and several review papers (NAS,1977; Brewbaker and Hutton,1979).

Leucaena is adapted generally to low-elevation tropics, but does not tolerate acid or poorly drained soils (Brewbaker and Hutton,1979; Ahmad and Ng,1982). Its drought tolerance is high and the species will tolerate long dry deasons or regions with annual rainfall in excess of 500 mm. Leucaena is widely and easily grown as a forage crop in dense populations (75,000/ha) under continous grazing or harvest. Its forage has a high protein and carotene content, and pellets or cubes are internationally marketed as feed. The arboreal varieties have been widely planted in the past decade for both wood and forage uses. Energy and pulpwood tree farms are planted by seed or seedlings at dense spacings (1x.5 m or 1x1 m).

Leucaena has been used as a green manure crop and as a fallow improvement crop in shifting cultivation (Kang et al.,1982; MacDicken,1981) as well as a number of other utilizations such as furniture and flooring. Wood yields from experiments at 11 sites in Asia and the Pacific area average 38 m^3/ha/yr at 1x1 m spacing and 41m^3/ha/yr at 1x.5 m spacings (Van Den Beldt and Brewbaker, unpublished). Leucaena wood is an excellent quality fuelwood with a specific gravity of .45-.55 and a higher heating value of 4,600 kcal/kg. Indeed, the use of the species as a fuelwood has been studied for over 70 years.

4. *Leucaena diversifolia* is an arboreal leucaena of Mexico and Central America. Native to mid-land elevations, *L. diversifolia* is thought to have many of the same fuelwood qualities as *Leucaena leucocephala* and greater cold tolerance.

5. *Sesbania grandiflora* is a rapidly growing, short-lived, deciduous tree which at maturity may reach 10 m in height and 30 cm in diameter. This species is native to S.E.Asia and is now widely distributed in parts of Florida, the Carribean, Central and South America. The species is distinguished by its alternate, pinnate leaves, large white or red pea-shaped flowers and long light-brown pods.

It is adapted to the humid tropics, generally at elevations less than 800 m, with evenly distributed annual rainfall of 1,000 mm or greater. The species tolerates a fairly wide range of soils, although it apparently cannot tolerate excessively well-drained or moderately to strongly acidic soils. In India and throughout southern Asia the flowers, green pods and young leaves are eaten in salads, curries and soups (Holm,1973). The leaves are also good fodder with crude protein content as a percentage of dry matter reported to be from 23-33% (Holm,1972). Sesbania has traditionally been managed as a food and fodder tree along paddy dikes and in backyard gardens. As a fuelwood or pulpwood, however, it has been successfully grown at population densities of up to 10,000 stems/ha. Under favorable moisture conditions, rapid early growth enables the plant to compete with most weed species (NAS,1980).

Wood yields of 20-25 m^3/ha/yr have been reported in Indonesia on short rotations (NAS,1979). The wood is soft, lightweight and weak with a specific gravity of approximately .42 making it poorly suited for other than short-haul transport. The wood has been used extensively as a pulpwood (fiber length of 1.1mm) and the bark yields gum, fiber and tannin.

6. Experimental procedures. Even though the need for further research on the biomass yields of these five species is clear, biomass estimation can be an expensive procedure, and one for which there remains a wide variety of approaches (Saucier,1979). The lack of well defined, standard assessment methodologies has caused a number of problems. Forest tree trials often give limited results due to the lack of attention given to the statistical requirements of experimen-

tal design (Wollons,1980). Experimental methods common to other types of agricultural research such as randomization, replication etc. are often neglected in forest research due to the generally large plot sizes used (Wollons,1980).

The minimum plot size required to obtain accurate estimates of growth rates of a number of tree species grown at high population densities on short rotations has been discussed by a number of investigators. Cannel and Smith (1980) reviewed the yields of SRIC plantings of a number of temperate species. They suggested that the use of small plots could lead to serious overestimation of yields if the ratio of the height of the measured trees (inside the plots) to their distance from the edge of the plot exceeded four. This ratio was first suggested by Gomez and De Datta (1971) in their study of border effects in rice experimental plots. Smith (1975) also suggested that the use of small plots can result in the overestimation of basal area and wood volume yields.

Rockwood et al (1982) reported that a 36 tree net plot centered within a 100-tree gross plot was adequate for studies of densities as high as 10,000 trees/ha and basal areas up to 25 m^2/ha at 24 months. However, a number of other investigators have reported sucess with smaller plots (Smith and DeBell,1974; DeBell and Radwan,1979; Bioenergy Dev. Corp.,1982).

If woody biomass yields of promising species are to be successfully estimated it is apparent that species trials which are designed to provide accurate information at a minimum cost must be designed and implemented. In addition to the growth studies discussed earlier, studies of minimum sample and plot sizes necessary to obtain accurate information at a minimal cost are included in this thesis.

C. THESIS OBJECTIVES

The objectives of this thesis are:

1. To study the early growth rates of selected NFT species at several sites in Hawaii and S.E. Asia.
2. To determine the minimum experimental plot size necessary to obtain accurate estimates of the growth of selected NFT.

CHAPTER 2

GENERAL METHODS AND MATERIALS

The University of Hawaii began a series of NFT trials in 1981 designed to compare growth rates of some 23 species of fast-growing tropical NFT (Brewbaker et al., 1981). A core of five replicated species are included in each of the six trials currently in place, with varying combinations of unreplicated species planted at each site. The core species are:

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

Experimental data on the growth rates of these species have been collected for the period 1/81 to 11/82 and are presented in an attempt to accomplish objectives 1 and 2 outlined in Chapter 1.

A. Decription of NFT Trials

Field trials have been established at six sites and provide 5.0 site-years of data for this thesis. A brief description of these trials is found in Table 2.1 with detailed site descriptions in Appendix A.

The augmented block design as described by Federer (1975) and Brewbaker (1978) was used in each of the trials, with the number of replicated species ranging from 5 to 12,

Table 2.1 Summary of Nitrogen-Fixing Tree Trials

Trial number and location	Date planted	Number of treatments	Species
81-1 Waimanalo, Oahu, Hawaii	1/15/81	3 reps 13 rep.spp. 5 augments 44 plots	Replicated: Aur,Cal,Cas,Dal,Div,Ent, Euc,Fal,Leu,Man,Pro,Sam, Ses. Augmented: Cit,Gli,Leb,Lys,Mel.
81-3 Hoolehua, Molokai, Hawaii	9/5/81	3 reps 5 rep. spp. 15 augments 30 plots	Replicated: Aur,Cal,Div,Leu, Ses Augmented: Acr,Apr,Cas,Dal,Ent,Ery, Fal,Gli,Leb,Man,Mea,Mim, Pro,Sam,Scs
81-4 Waipio, Oahu, Hawaii	11/10/81	4 reps 5 rep. spp. 12 augments 32 plots	Replicated: As in 81-3 Augmented: Acr,Apr,Cas,Dal,Ent,Ery, Euc,Fal,Gli,Man,Mea,Mim
81-5 Niulii, Hawaii	11/12/81	As in 81-4	
81-6 Nakau, Sumatra, Indonesia	2/2/82	As in 81-4	Replicated: As in 81-4 Augmented: Acr,Apr,Cas,Dal,Ent, Ery,Euc,Fal,Gli,Man, Mea,Mim
81-7 Davao City, Mindanao Philippines	2/23/82	As in 81-6	

Key to abbreviations:

Acr-*Acrocarpus fraxinifolius*
Apr-*Albizia procera*
Aur-*Acacia auriculiformis*
Cal-*Calliandra calothrysus*
Dal-*Dalbergia sissoo*
Div-*Leucaena diversifolia*
Ent-*Enterolobium cyclocarpum*
Mea-*Acacia mearnsii*
Mim-*Mimosa scabrella*
Sam-*Samanea saman*
Ery-*Erythrina poepiggiana*
Euc-*Eucalyptus saligna*
Fal-*Albizia falcataria*
Gli-*Gliricidia sepium*
Leb-*Albizia lebbek*
Lys-*Lysiloma acapulcense*
Man-*Acacia mangium*
Mel-*Acacia melanoxyln*
Pro-*Prosopis pallida*
Ses-*Sesbania grandiflora*

and the number of replications being either 3 or 4. The number of augmented species varied from 5 to 12, with a total of 23 species of 16 genera planted as either augments or replicated treatments. The plot size used was 28 m^2 with a constant spacing of 1x1 m used in all treatments. Data was collected from the 10 internal trees, which were bordered on all sides by trees of the same species (Fig.2.1). The perimeters of the trials were bordered by a single row of leucaena (K8).

Figure 2.1 Simplified plot layout of two adjacent plots

X	X	X	X	X	X	X	X	X	X
X	O	O	O	O	O	O	O	O	X
X	O	10	1	O	O	10	1	O	X
X	O	9	2	O	O	9	2	O	X
X	O	8	3	O	O	8	3	O	X
X	O	7	4	O	O	7	4	O	X
X	O	6	5	O	O	6	5	O	X
X	O	O	O	O	O	O	O	O	X
X	X	X	X	X	X	X	X	X	X

X= K8 border O=plot border trees 1...10=sample trees 1 to 10

B. Description of sites.

The six experimental sites described in Table 2.2 are of five soil families and cover a range of annual rainfall from 700 mm to over 2500 mm. More detailed descriptions of these

TABLE 2.2 SUMMARY OF SITE CHARACTERISTICS

TE	RAINFALL	ELEVATION	SOIL FAMILY**
aimanalo NFT 81-1 Hawaii	1270-1525mm	21m	Vertic Haplustolls, very fine,kaolinitic, isohyperthermic
olokai * NFT 81-3 Hawaii	700mm	100m	Ustollic Camborthids, fine-loamy, kaolinitic isohyperthermic
aipio * NFT 81-4 Hawaii	1000mm	150m	Tropeptic Eutrustox, clayey,kaolinitic isohyperthermic
Niulii NFT 81-5 Hawaii	2000-2550mm	545m	Hydric Dystrandepts, thixotropic,isothermic
Nakao NFT 81-6 Indonesia	NA	NA	Typic Paleudults, clayey,kaolinitic isohyperthermic
BPI,Davao NFT 81-7 Philippines	NA	200m	Typic Paleudults, clayey,kaolinitic isohyperthermic

* drip irrigated

** Soil family classification used is a unit of soil classification in the U.S. Soil Taxonomy

NA = data not available

sites are presented in Appendix A.

C. Species selection

For the purpose of this thesis, only those species which have the following attributes will be considered as suitable fuelwood species (Henry,1979; MacDicken et al.,1982):

1. Rapid growth; Proven to grow at rates which equal or exceed a mean annual increment of 20 m^3/ha/yr.

2. Coppicing ability; Stumps produce coppice shoots after the stem has been harvested. Although actual coppice yields have not been studied adequately for most NFT species, initial reports indicate that coppice yields could exceed yields of seedling stands.

3. Ease of establishment; Each of the species discussed is easily established by seed, stem cuttings or stump cuttings.

4. Suitability of wood as fuel; Shown to produce wood with a higher heating value of >4500 kcal/kg and a specific gravity of >.40.

The wood characteristics of each of the species selected for these trials are presented in Table 2.3.

D. Establishment of trials

1. Seed preparation. The seed lots used in these trials

Table 2.3 Characteristics of NFT in U. Hawaii international network trials (Scale. 1 Good - 3 Poor).

	Acacia auriculiformis	Acacia mangium	Acacia mearnsii	Acrocarpus fraxinifolius	Albizia falcataria	Albizia lebbek	Calliandra calothyrsus	Casuarina equistifolia	Dalbergia sissoo	Enterolobium Cyclocarpum	Gliricidia sepium	Leucaena diversifolia	Leucaena leucocephala	Mimosa scabrella	Prosopis pallida	Samanea saman	Schizolobium parahyba	Sesbania grandiflora
UTILIZATION																		
Forage	3	3	2	3	3	1	2	3	2	2	1	1	1	3	1	2	3	1
Fuelwood	1	2	1	-	3	1	1	1	1	2	1	1	1	1	1	2	3	1
Roundwood	3	2	1	-	3	1	3	1	2	3	1	1	1	-	3	3	-	1
Lumber	3	1	-	1	3	2	3	3	1	1	3	3	3	2	3	1	3	3
Pulpwood	1	1	-	-	1	-	3	2	2	1	3	-	1	1	3	-	2	-
Green Manure	3	3	2	3	2	1	1	3	2	3	1	1	1	1	2	3	3	1
Craftwood	3	2	-	2	3	1	3	3	1	1	2	-	2	-	1	1	3	3
Food	3	3	3	3	3	3	3	3	3	2	2	3	1	3	2	2	3	1
ADAPTABILITY																		
Acid Soils	1	1	-	-	-	-	2	1	-	-	-	3	3	-	3	-	-	3
Cold Soil	3	3	1	3	2	1	2	2	1	3	3	2	3	1	3	3	2	3
Drought	2	2	2	3	3	2	2	1	1	1	2	1	1	-	1	1	2	2
Min. Rain (mm)	750	750	1000	1000	1500	600	1000	300	500	750	1500	600	600	-	250	600	750	1000
Coppicing Ability	1	1	1	-	1	1	1	2	1	-	1	1	1	-	2	-	-	1

SOURCE: Brewbaker, VanDenBeldt and MacDicken, 1981 were obtained from four sources: 1)existing collections stored at the Hawaii Foundation Seed Facility; 2)research or commercial sources; 3)collections made expressly for this series of trials; 4)Niftal Project seed collections on Maui. Whenever possible, seed for each species was used from a single seed lot for every site. A listing of seedlot numbers is found in Appendix D. Seedlots were disinfected with a solution of 10% sodium hypochlorite (Chlorox) for 3-5 minutes, rinsed and air dried. Seed scarification was done just prior to planting using either a fingernail clipper, file or sharpening stone.

2. Nursery methods. Seedlings were grown for 3-4 months in the Hawaii dibble tubes described by Walters (1981) at the Waimanalo Research Station and at the Mauka campus facility of the Agronomy and Soil Science Dept. in Honolulu. The potting media used was a 1:1 mixture of unsterilized peat moss and vermiculite. The dibble tubes were cleaned with a weak solution of chlorox. The Waimanalo and Molokai seedlings were not inoculated with the exception of _Sesbania grandiflora_, which was inoculated with soil from under a small sesbania stand at Waimanalo. Nodulation was found in the replicated species with or without inoculation. Seedlings for the Waipio and Niulii plantings were inoculated with a mixture of six _Rhizobium_ strains provided by the Niftal Project on Maui. The inffectiveness of these strains on selected species of NFT based on limited analyses by P.

Nakao are shown in Appendix E.

Seedlings were fertilized with 3-5 pellets of slow-release Osmocote (14-14-14) and foliar applications of Gaviota (16-16-16). Subsequent nursery plantings have suggested that seedling growth is more vigorous when dolomite and micronutrients are added along with a low N basal application of complete fertilizer. Dolomite was applied at a rate of 4.8 g/l, Micromax at a rate of .7 g/l and MagAmp (7-40-6) at 3.0 g/l. These rates were found to be the most effective in studies with eucalyptus (Bioenergy Dev. Corp.,1981). Low N fertilizers (7-40-6) were used to minimize inhibition of nodulation by nitrogen in the rooting medium.

3. Field establishment. Site preparation was done with a moldboard plow, disk or rotovator leaving a well-prepared seedbed. A pre-emergence application of the herbicide Dacthal (2 kg/ha) was made at the Molokai site and successfully controlled weeds for approximately 2-3 months. Seedlings were planted using step bar planting bars designed for use with dibble tube seedlings. Post-plant irrigation was applied as necessary for the first 2-3 weeks.

4. Maintenance. The Molokai and Waipio sites were both drip irrigated. 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.

Weed management was done with a variety of mechnical and chemical means. Of the combinations of weed control techniques used, the most successful was a pre-tillage application of Roundup, followed by either post-plant shallow tillage with a rototiller or post-plant wick applications of Roundup (mixed 1:3 with water). In areas where a large number of weed seed are present, a pre-plant application of either Dacthal or Lasso would be appropriate. Hand hoeing was also effective, but very labor intensive. Hand weeding and Roundup application by inexperienced farm workers can result in damage to seedling stands, particularily when seedlings are small, resulting in missing trees. Close supervision of workers may alleviate this problem in future trials.

E. Data collection and analysis

As shown in Figure 2.1, data were systematically collected from the sample trees in the same order at each collection. This procedure was utilized to insure the pairing of height, diameter and volume data for each individual tree. The only exceptions to this procedure were at Waimanalo at ages 3 months, six months and nine months. It might be noted that at the Waipio and Iole sites, the numbering system was changed beginning with the 3 month data collection. Sample numbers were changed with sample number 10 becoming sample 1, sample 9 becoming sample 2, sample 1 becoming sample 6 and so on. Height and diameter measurements were taken at 3 or 6 month intervals, with the frequency of collection dependent on site and cooperator. The measurements taken were:

1. Total tree height
2. Basal diameter at a stump height of 10cm
3. Diameter breast height (dbh), measured at 1.37m
4. Diameter measurements at 50cm intervals along the main stem(s)

Measurements from multiple stemmed trees posed a problem due to the need to compare treatments on a 10 tree sample basis. This problem was solved through the combination of diameters using the equation:

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

where: Dx=adjusted diameter, D1=first stem diameter, D2=second stem diameter

A maximum of 3 of the largest stems per tree were used in the calculation of BA and wood volume. Although a number of species had multiple stems, only calliandra and Gliricidia sepium commonly had >2 stems per tree. The contribution of the smallest stems to total volume was very small, while the amount of effort required to measure and record every stem was substantial. Thus, the number of stems included in the adjusted diameter calculations was limited to 3. The arithmetic mean was used for height values of multiple stemmed trees.

All data were recorded on form 1 (Appendix C) which was designed to allow the punching of IBM cards just as read from the form while volume data were recorded on form 2 (Appendix

C).

All statistical analyses were performed by computer using either the Statistical Analysis System (SAS) package at the UH Computing Center or software currently available on the Hewlett-Packard 41CV. HP41 programs written for the augmented block analysis and in the computation of wood volume are found in Appendix B.

CHAPTER 3

GROWTH RATES OF SELECTED NFT SPECIES

This chapter discusses the specific methods used in the mensuration of the trials described in Chapter 2 and the results of these experiments for the period from January, 1981 to November, 1982.

A. METHODS AND MATERIALS

Height, diameter and wood volume measurements have long been accepted measures of tree growth (Davis,1966; Tesch, 1981). Height measurements are the basis of site-index curves designed to show height in relation to age over the rotation period (Roth,1916). Height growth is comparatively insensitive to population density over a wide range of stocking densities, and is thus used as a convienient measure of site quality (SAF.1923; Davis,1966). Bowersox and Ward (1976) have shown that height growth of poplar is insensitive to high population densities over the first two years of growth.

Basal area (BA) converts basal diameter into a measure that can be readily used to compare diameter and stocking densities per unit area. BA is commonly used in forestry practice because it is a consistent, easily calculated and relatively stable measure of stand growth over both age and site (Davis,1966).

Wood volume is the ultimate statistic of stocking and productivity in traditional forestry practice (Davis, 1966; Tesch.1981). It is also an important measure of productivity for SRIC plantations since most studies of fuelwood demand and production in the rural tropics are based on wood volumes. However, volume measurements fail to take into account differences in specific gravity and moisture content. Thus as a measure of feedstock for combustion systems, it has limited utility. Wood weights at a specific moisture content are a far more useful statistic for such purposes. Unfortunately, weight is a difficult measure to obtain in on-going growth trials. Thus, wood volumes were used in these trials.

Wood volumes were calculated on the basis of the measurements listed in Chap.2 through the use of Newton's and Smalian's formulae, both of which have been widely used in wood volume assessment (Chapman and Meyer,1949; Avery,1967; FAO,1980a).

Newton's formula: $$\text{Volume} = \frac{B1 + 4B2 + B3}{6} \times L$$

Smalian's formula: $$\text{Volume} = \frac{B1 + B3}{2} \times L$$

where B1=cross sectional area at large end of segment
B2=cross sectional area at mid-point of segment
B3=cross sectional area at small end of segment
L =length of segment

Segment lengths of 1m were measured when possible and wood volumes determined using the more accurate Newton's formula. Newton's formula gives a precise estimate of the true volume of any log whether the shape of the stem resembles the frustrum of a paraboloid, cone or neiloid provided the form is symmetrical (Chapman and Meyer,1949; FAO,1980a).

Diameters of sample trees were obtained at a 10 cm stump height (basal diameter) and up the stem at 50 cm intervals. Upper stem diameters were obtained from a ladder to a height of 3-4 m. These measurements were used to determine wood volumes using Newton's formula. The volume of wood in the top section of the stem, beyond reach, was determined by using the uppermost measurement as the basal diameter and 1 cm as the top diameter. The length of the segment from the basal diameter to the estimated top diameter of 1 cm was determined, and the wood volume subsequently obtained using Smalian's formula.

Wood volumes were calculated using a computer program written on the HP41 (Appendix B). Calculated volumes for each tree were paired with height, basal diameter and dbh measurements.

Due to the large number of species included in the trials, only the core species are described in detail herein. Data for the augmented species were analysed using the technique described by Brewbaker (1978) and the results presented in a summary format.

For the core of replicated species the following analyses were conducted:

1. Analysis of variance for the following variables:
    1. Total height
    2. Basal area
    3. Wood volume
    4. DBH

   These analyses were done by location and age, and were also combined to determine species x location interactions. Mean separations were done using Duncan's Multiple Range Test at the $p=.05$ level.

2. Linear and non-linear regression procedures available in SAS and on the HP41 were used to fit experimental data to linear and non-linear models.

3. Stepwise regression for the dependent variable wood volume was performed by species to obtain regression equations for wood volume based on height, diameter, DBH etc. These equations were based on 100 data trees/species from the Waimanalo, Molokai and Waipio sites at 1 and 1.5 years of age.

It might be noted that local volume tables or weight tables are often based on as few as 30 sample trees (Chapman and Meyer,1949; Saucier,1979; FAO,1980b).

Adjusted mean values for height growth of the augmented treatments were used to group species into low, medium and high productivity classes. The "medium" range was defined as the mean plus or minus one standard deviation times the appropriate t value (Fernandez and Struchtemeyer,1982).

The five replicated core species are referred to by a three letter code:

Aur= *Acacia auriculiformis*

Cal= *Calliandra calothyrsus*

Div= *Leucaena diversifolia*

Leu= *Leucaena leucocephala*

Ses= *Sesbania grandiflora*

Ages cited are months or years after transplanting.

B. RESULTS AND DISCUSSION

1. Replicated species comparisons

a. Height. Height growth was the least variable parameter in this study, with coefficients of variation (c.v.) at one year from 15-20% compared to basal area c.v. of 50-60%. Height differences between species at a given site were generally constant over time with the ranking of species at six months identical or very similar to the ranking at one year.

Height differences between species were significant (p=.05) at every age. Growth at Waimanalo (Table 3.1.1) over a 1.5 year period indicates that after an initial establishment period of 3-6 months, the growth rates of the core species changed very little in relation to one another. During this period only *Acacia auriculiformis* made a significant improvement in rank, moving up to equal Calliandra.

At the Molokai site (Table 3.1.2) differences between species at one year were identical to those at six months. Growth at Waipio also followed this pattern (Table 3.1.3). *Leucaena diversifolia* exhibited the most rapid early growth overall at each of these sites, although this difference was

Table 3.1.1 Mean height growth of replicated species at Waimanalo

SPECIES	AGE years				
	.25	.50	.75	1.0	1.5
	m				
Leu	0.9ab*	2.9a	4.2a	5.1a	6.7b
Div	1.0a	2.8a	3.7a	4.7ab	6.5b
Ses	0.7b	2.0b	2.3bc	3.1b	4.7b
Cal	0.8ab	1.8c	2.0c	2.6c	4.0c
Aur	0.4c	1.4d	2.1bc	2.9c	4.2c
Euc**	0.8b	2.3b	3.6b	4.5ab	7.8a
Fal**	0.7b	2.2bc	2.8b	4.0b	5.7b

* means within a column followed by the same letter are not significantly different at the .05 level of probability as determined by Duncan's Multiple Range Test.

** fastest-growing non-core replicated species extracted from Tables in Appendix F.

Table 3.1.2 Mean height and basal area growth of replicated species at Molokai site

SPECIES	Age=.5		Age=1.0	
	Height	Basal area	Height	Basal area
	-m-	$-cm^2-$	-m-	$-cm^2-$
Leu	2.1a	5.7b	5.9a	29.8b
Div	2.4a	5.5b	5.6a	20.9c
Ses	2.1a	13.6a	5.4a	38.1a
Cal	1.2b	1.9c	3.2b	11.0d
Aur	0.8b	1.1c	3.1b	7.6d
Fal*	2.2	11.5	5.9	32.4
Mea*	1.3	3.0	4.7	24.5

*/ fastest growing augmented species

Table 3.1.3 Mean height growth of replicated species at Waipio

SPECIES	.25	.50	.75	1.0
	AGE years			
	m			
Leu	0.4b	1.2b	2.5b	4.5a
Div	0.6a	2.1a	3.5a	4.9a
Ses	0.4b	1.1b	2.0c	3.1b
Cal	0.3c	0.9c	1.4d	2.1c
Aur	0.3c	0.7d	1.3d	2.1c
Euc*	0.4	1.1	2.1	3.8
Mea*	0.3	1.2	2.3	3.8

*/ Fastest-growing augmented species

only significant at Waipio.

Height growth was severely suppressed at the Niulii site, reflecting the poorer suitability of the site for the species used in these trials (Table 3.1.4). The lag phase of growth appeared to continue through at least the first six months, followed by relatively rapid growth in the last half of the year.

Significant height differences were found between species across all sites at six months (Table 3.1.5). Leucaena diversifolia was the fastest growing species overall during the six month establishment period followed by Leucaena leucocephala, Sesbania grandiflora, Calliandra calothyrsus and Acacia auriculiformis. Significant differences in height growth between sites over all species were also found. The Davao site was the most productive followed by Waimanalo, Molokai, Waipio and Niulii. Although analyses have not yet been conducted to determine the relative importance of various climatic and edaphic factors on growth, factors such as base saturation, pH, solar radiation, rainfall, wind and temperature are thought to be important limiting factors in the growth of these NFT

Assuming that these factors are indeed the most important in regulating growth helps to explain the growth differences between locations at one year (Table 3.1.6). The highest productivity site was Molokai which has high insolation, high base saturation, a pH of 5.6-6.0, windbreak protection and drip irrigation.

The Waimanalo site is similar in that there are no severe limitations to the growth of these species. However solar radiation is lower than on Molokai due to the larger number of cloudy days/year as evidenced by the differences in annual rainfall (Table 2.2).

Growth at Waipio may be limited by greater annual windspeeds, lower base saturation (42-66 %), pH (4.9-6.4) and rainfall. The site was drip irrigated during establishment, but experienced an extended dry period during the third quarter of the trial. The low pH (4.9) of the Ap2 horizon may have had the effect of slowing root growth during the establishment period, thus making the trees more suceptible to drought stress. Finally, the Niulii site is in an area

Table 3.1.4 Mean height growth of replicated species at Niulii

SPECIES	AGE years .25	 .50	 .75	 1.0
	m			
Leu	0.1b	0.2c	1.2c	2.0b
Div	0.2a	0.5a	2.0a	3.1a
Ses	0.2a	0.3b	1.1c	1.5c
Cal	0.1b	0.3d	1.6b	2.3b
Aur	0.2a	0.2c	0.5d	1.0d
Euc*	0.4	0.7	1.7	2.7
Mea*	0.4	1.3	2.4	3.3

*/ Fastest-growing augmented species

Table 3.1.5 Mean tree heights at six months

SPECIES	LOCATION Waimanalo	 Molokai	 Waipio	 Niulii	 Davao	 Mean
	m					
Leu	2.9a	2.1a	1.2b	0.2c	4.2a	2.0b
Div	2.8a	2.4a	2.1a	0.5a	4.2a	2.3a
Ses	2.0b	2.1a	1.1b	0.3b	3.8b	1.7c
Cal	1.8c	1.2b	0.9c	0.2c	2.8c	1.3d
Aur	1.4d	0.8b	0.7d	0.2c	2.0d	0.9e
MEAN	2.2 b	1.7 c	1.2 d	0.3 e	3.4a	1.6

Table 3.1.6 Mean tree heights at one year

	LOCATION				
SPECIES	Waimanalo	Molokai	Waipio	Niulii	Mean
	m				
Leu	5.1a	5.9a	4.5a	2.0b	4.4a
Div	4.7ab	5.6a	4.9a	3.1a	4.6a
Ses	3.1b	5.4a	3.1b	1.5c	3.3b
Cal	2.6c	3.2b	2.1c	2.3b	2.6c
Aur	2.9c	3.1b	2.1c	1.0d	2.3c
MEAN	3.7b	4.6a	3.3b	2.0c	3.4

with average annual wind speeds of 6-10 mph and is the only site in the cooler isothermic temperature regime. Although the pH at the Niulii site was higher (5.2-6.0) than the Waipio site, base saturation was much lower (1-28 %). The high rainfall at Niulii (>2000 mm) suggests that solar insolation is also lower than the other sites. Further research will be required to determine which of these effects have been most limiting to growth at Niulii.

The growth rates of each species over the first year at three locations suggest that several species have shown slow growth over the first year at the Niulii and Waipio sites, but may have begun a logrithmic phase of growth (Table 3.1.7). This is evidenced by the regression coefficients for height growth at Waipio and Niulii, which are much higher than those at the Waimanalo site. If these coefficients are reflective of continuing growth trends, significant differences between species at two years will be greatly different for those observed at one year (Table 3.1.7).

However, these coefficients may reflect changes in environmental conditions which have not been quantified to date. For example. an extended dry period at the Waipio site between 6 and 9 months likely limited growth during that period, while adequate moisture between 9 months and 1 year may explain the increased growth rates during the last 3 months of measurement. Another factor may be the nearly neutral pH of the B22 - B24 horizons underlying the stongly-acidic Ap1 and Ap2 horizons which may have limited early growth .

Since height growth is the best available indicator of site adaptability, it appears that future efforts to understand the specific environmental efforts will need to focus on height growth per unit insolation, temperature or rainfall.

b. Basal area. Basal area values were more variable than height with c.v. ranging from 50-66 %, however significant differences were observed between species at all sites at every age (Appendix F). Sesbania grandiflora had the greatest basal area values of any of the replicated species (Table 3.1.8-3.1.9). This was largely due to the high degree of butt swell in the segment from ground level to 20-30 cm above stump height. This segment was also covered with the thickest bark of any of the species.

Table 3.1.7 Non-linear regression of mean height growth by species and location

Species/ location	regression coeff.(a)	regression coeff.(b)	predicted ht. at 2 yrs.	R^2
			m	
LEU				
Waimanalo	5.06	1.11	10.9	.95
Waipio	4.25	1.73	14.1	.99
Niulii	1.79	2.27	8.6	.91
DIV				
Waimanalo	4.73	1.03	9.7	.97
Waipio	5.31	1.52	15.2	.99
Niulii	3.00	2.06	12.5	.96
SES				
Waimanalo	3.22	1.02	6.5	.97
Waipio	3.08	1.47	8.5	.99
Niulii	1.40	1.54	4.1	.89
CAL				
Waimanalo	2.76	0.85	5.0	.97
Waipio	2.15	1.39	5.6	.99
Niulii	2.37	2.39	12.4	.96
AUR				
Waimanalo	2.64	1.30	6.5	.97
Waipio	1.99	1.39	5.2	.99
Niulii	0.74	1.14	1.6	.76

prediction equation: $\text{Height} = a(\text{age})^b$

Table 3.1.8 Mean basal area growth of replicated species at six months

	LOCATION				
SPECIES	Waimanalo	Molokai	Waipio	Niulii	Mean
	cm^2				
Leu	6.2b	5.7b	3.4b	0.1c	3.5 b
Div	5.6bc	5.5b	3.7b	0.4ab	3.6b
Ses	14.1a	13.6a	9.3a	0.6a	8.8a
Cal	3.6c	1.9c	0.8c	0.3bc	1.5c
Aur	1.9d	1.1c	1.0c	0.2bc	1.0c
MEAN	6.3a	5.6a	3.6b	0.3c	3.7

Table 3.1.9 Mean basal area at one year

	LOCATION				
SPECIES	Waimanalo	Molokai	Waipio	Niulii	Mean
	cm^2				
Leu	16.2a	29.8b	14.2c	5.4c	16.4 b
Div	10.2b	20.9c	18.7b	9.6b	14.9b
Ses	20.5a	38.1a	25.8a	13.5a	24.5 a
Cal	5.6c	11.0d	2.8d	4.2c	5.9 c
Aur	3.8bc	7.6d	4.1d	3.2c	4.7c
MEAN	11.3 b	21.5 a	13.1 b	7.2 c	13.3

Leucaena leucocephala and *L. diversifolia* were not significantly different across all sites at either six months or one year. However, species x locations interactions were significant with the BA of *Leucaena leucocephala* being significantly greater than L. *diversifolia* at Waimanalo and Molokai and *L.diversifolia* greater than *L.leucocephala* at Waipio and Niulii (Table 3.1.9). *Calliandra calothyrsus* and *Acacia auriculiformis* were not significantly different over all sites at six months or one year.

Differences between locations for BA were similar to those found for height. Basal area at the Waimanalo and Waipio sites was not significantly different at one year while both height and wood volume were. This may be due to the higher wind velocities at Waipio than those at Waimanalo, resulting in greater basal diameter growth at Waipio. Similar effects have been described by Daubenmire (1974) and Kramer and Kozlowski (1979).

c. Wood volume. Differences in wood volume were significant between species and between locations at one year (Table 3.1.10). The leucaena species were most productive over all. L.*leucocephala* was most productive on the best sites demonstrating significantly greater volume growth than L. *diversifolia* on Molokai. At the Waipio and Niulii sites, L. *diversifolia* outproduced *L . leucocephala*. An important aspect of growth at the Niulii site was the apparent suitability of *L. diversifolia* to the isothermic temperature regime.

Sesbania grandiflora was highly productive at the Molokai site and ranked third over all sites. Actual wood volumes of Sesbania were overestimated by up to 10 % due to the corky bark in the basal portion of the stem. *Calliandra calothyrsus* and *Acacia auriculiformis* were not significantly different over all sites. Calliandra was not well suited to the Waipio site, but exhibited uniform growth at the other 3 sites. A. *auriculiformis* was highly variable across sites and did not perform well at the Niulii, Waipio and Molokai sites.

As was the case for height growth, the most productive site was Molokai, followed by Waimanalo, Waipio and Niulii. The fact that the differences between the Waipio and Waimanalo sites in BA were not reflected in volume growth supports the explanation that wind stress at Waipio resulted in exaggerated basal diameter growth. The Niulii site was dropped from the volume equations shown in Table 3.1.11, since wind and other stresses appear to have made the allometric relationships at that site non-homogenous with the other sites.

The equations in Table 3.1.11 represent 100 sample trees at 1 and 1.5 years. The three variable model was selected since it resulted in substantial increases in R^2 values over the two variable model. All three variables in these equations are easily obtainable measures of growth.

Table 3.1.10 Wood volumes at one year

SPECIES	Waimanalo[1]	Molokai	Waipio	Niulii	Mean
		LOCATION			
		m³/ha/yr			
Leu	49.4a	67.8a	24.5b	3.8cd	33.2a
Div	35.8ab	42.2b	32.5a	13.9a	30.0a
Ses	24.3bc	56.8b	19.6b	5.5bc	24.6b
Cal	11.9cd	12.4c	3.1c	8.1b	8.4c
Aur	15.0cd	6.8c	2.5c	0.7d	5.6c
MEAN	27.3 b	37.2 a	16.4 c	6.4 d	21.8

1/ MAI from 1.5 year calculations

Table 3.1.11 Volume prediction equations

SPECIES	Equation	R^2
Leu	$Y = -2445 + 480(ht) + 137(BA) + 106(DBH)^2$	.91
Div	$Y = -927 + 55(BD)^2 + 160(DBH)^2 + 48(ht)^2$	.89
Ses	$Y = -302 + 20(BA) + 206(DBH)^2 + 40(ht)^2$	.95
Cal	$Y = -182 + 25(BD)^2 + 126(DBH)^2 + 39(ht)^2$	.94
Aur	$Y = 616 - 514(BD) + 134(BD)^2 + 116(DBH)^2$	.92

Y= wood volume in cm^3/tree (to convert to m^3/ha divide by 100)

2. Augmented species comparisons

Only two of the augmented species at any of the sites grew rapidly enough to be classified as fast-growing species at 1 or 1.5 years of age (Table 3.2.1). The growth rates of the two fastest growing augmented species at eash site are presented in the tables in section 3.1. *Eucalyptus saligna* and *Acacia mearnsii* both grew faster over the first year of growth than the mean of the replicated species at Niulii and grew at approximately the same rate as the mean at the other sites, suggesting that these species should be included as replicated treatments in future trials in similar locations. Several other species grew at rates comparable to the mean growth of the replicated species. Site specific comparisons between replicated species and augmented species are found in Appendix G.

Species such as *Albizia procera* which have not performed well to date but are known to have special adaptations or wood qualities, should be retained as augmented species for further evaluation.

Table 3.2.1 Summary of mean height growth for augmented species.

Species	Waimanalo	Molokai	Waipio	Niulii
Acr	-	S	M	S
Apr	-	S	S	S
Cas	S*	M	M	M
Cit	M	-	-	-
Dal	S*	M	S	S
Ent	M*	M	M	S
Ery	-	M	S	S
Euc	F*	-	M	F
Fal	M*	M	M	M
Gli	S	M	M	S
Leb	M	S	-	-
Man	M	M	S	M
Mea	-	M	M	F
Mim	-	M	S	M
Pro	-	S	-	-
Sam	M*	S	-	-
SCS	-	M	-	-

*/ Replicated non-core species

where: F = fast growing, M = moderate, and S = slow growing

Key to augmented species abreviations:

Acr - *Acrocarpus fraxinifolius*
Apr - *Albizia procera*
Cas - *Casuarina equisitifolia*
Cit - *Eucalyptus citriodora*
Dal - *Dalbergia sissoo*
Ent - *Enterolobium cyclocarpum*
Ery - *Erythrina poeppigiana*
Euc - *Eucalyptus saligna*
Fal - *Albizia falcataria*
Gli - *Gliricidia sepium*
Leb - *Albizia lebbek*
Man - *Acacia mangium*
Mea - *Acacia mearnsii*
Mim - *Mimosa scabrella*
Pro - *Prosopis pallida*
Sam - *Samanea saman*
SCS - *Erythrina fusca*

C. SUMMARY

The two leucaena species were the most productive species over all sites in height growth and wood volume. *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. It appears that *L. diversifolia* is more tolerant to the cooler temperatures at Niulii than *L. leucocephala*.

It is worthy of note that while yields of the leucaena species at Waipio were lower than those at Waimanalo and Molokai, wood volume yields still exceeded $24m^3$/ha/yr. This suggests that the acidic Ap horizons did not severely limit the growth of these species which are thought to be intolerant of acid soils. Base saturation at Waipio however was > 40%. Indeed, the fact that *Acacia auriculiformis*, which is reportedly acid tolerant did poorly on the Waipio site further suggests that this acid horizon is not the only important limiting factor at work.

Sesbania grandiflora exhibited rapid early growth overall and equalled at least one of the leucaena species in wood volume yields at every site at one year. *Calliandra calothyrsus* did not grow as rapidly as expected overall, but was least affected by the cooler temperatures at the Niulii site. *Acacia auriculiformis* was generally the slowest growing species at each site and was most severely stunted at

Niulii.

Of the augmented species, Eucalyptus saligna, Casuarina equisitifolia. Albizia falcataria and Acacia mearnsii merit inclusion as replicated species in all future trials.

CHAPTER 4

SAMPLE and PLOT SIZE ESTIMATION

An important consideration in the design of NFT experiments is the determination of the sample and plot sizes required to insure a desired level of accuracy. Investigators such as Cannel and Smith (1980) and Wollons (1980) have demonstrated some of the shortcomings in forestry experimentation caused by the lack of consideration given to the statistical requirements of experimental design. During the conduct of the growth rate studies described in Chapter 3, additional data was collected in to quantify the variances necessary to estimate minimum sample and plot sizes.

A. METHODS AND MATERIALS

1. Sample size determination. A major reason sampling designs are used is to allow the researcher to minimize the unnecessary time and expense which would be incurred if every possible sample in a plot were measured. Although the use of very small plots, including single tree plots, has been shown to statistically valid (Franklin,1971) the high degree of variability in some NFT species requires a sample size large enough to accurately compare sample populations.

Thus an important consideration in designing replicated trials is the determination of sample size (Gomez and Gomez.1976).

Data collected from the trials previously described was used to compare the relative efficiencies of each of five sampling intensities. The intensities to be examined were 2,4,6,8 and 10 samples per plot.

Data sets containing 2,4,6,8 and 10 samples per plot were derived through random selection of data from the master data set and the following procedure used as per Gomez and Gomez (1976).

1. A nested ANOVA was performed for each of the sampling intensities as shown in Figure 4.1.

Figure 4.1 Nested ANOVA for evaluation of sampling intensities

Source	df	SS	MS
Between plots	p-1	SS1	MS1
Between units within plots	p(s-1)	SS2	MS2
Between samples within plots	ps	SS3	MS3

where p=No. of plots, s=no. of sample trees per plot

2. The variance among samples within plots was computed using the formula:

$$S^2 = \frac{(MS2)(df2) + (MS3)(df3)}{df2 + df3}$$

3.The results of the ANOVA shown in Fig. 4.1 were organized by sampling intensity as shown in Fig. 4.2.

Figure 4.2 ANOVA for height based on five sizes of sampling unit

	SAMPLING INTENSITY (Samples/plot)				
Source	2	4	6	8	10
	df	df	df	df	df
Between plots	35	35	35	35	35
Between units within plots	36	108	180	252	324
Between samples in units in plots	72	144	216	288	359

4. The efficiency of these sample sizes relative to a single-unit sample were calculated using the formula:

$$\text{relative efficiency (R.E.\%)} = \frac{S^2}{\text{MS between units within plots}} \times 100$$

The standard error of the treatment mean was calculated for each sample size and compared with estimates of standard errors obtained using the following procedure outlined in Gomez and Gomez (1976):

1. The margin of error (d) was computed using the formulae:

$$d = 2(cv(\bar{X}))$$

$$cv(\bar{X}) = \frac{v(\bar{X})}{\bar{X}} \times 100$$

$$V(\bar{X}) = \frac{S^2 + nS^2}{rn}$$

where S^2= MS sampling error

$$S^2 = \frac{\text{MS exp. error} - \text{MS sampling error}}{\text{n samples per plot}}$$

r= number of replications

Values for r and n were substituted in various combinations to derive estimated standard errors for varying numbers of samples and replications.

These analyses were performed on one year data from the the four Hawaii sites.

2. Plot size estimation. The importance of border effects in small-plot experimentation has been pointed out by a number of invesitgators (Gomez and DeDatta, 1971; Smith,1975). The minimum tree height:border width ratio of 4:1 suggested by Cannel and Smith (1980) is often exceeded by the fast-growing NFT species in less than 1 year using the

28 m^2 plots which have a border width of 1.5 m. Burley and Wood (1976) have suggested that 1-2 border rows are adequate to prevent edge effects. However, this recommendation is made with much lower population densities in mind (e.g. 1,100 stems/ha). In order to quantify the edge effects of the 28 m^2 plots (at 10,000 stems/ha) additional data was collected from the border rows.

Border row effects within plots were analysed by species on one year data from the Waimanalo and Waipio sites. Measurements of 10 sample border row trees per plot were taken and compared with data taken from the 10 internal data trees. A simple RCB ANOVA was performed for each species to test for differences in growth between border and internal data trees (Figure 4.3).

Figure 4.3 ANOVA for comparisons of border rows and data rows

Source	df
Replications	2
Position	1
Experimental error	56
Total	59

B. RESULTS AND DISCUSSION

1. Sample size. The standard error of the mean as

calculated using data from the master data set, generally decreased as a power function of increasing sample size over the sampled range of 2 to 10 samples per plot. Actual and estimated standard error values were calculated using the procedure from Gomez and Gomez (1976) described earlier. Predicted values were calculated by the least-squares method. Standard errors shown are generally greater for the Waimanalo site than for other sites due to the larger number of replicated species at that site.

a. Height. The improvement in the standard error predicted in Table 4.1 indicates that an increase in sample size from the 10 samples per plot used in the studies conducted to date to 20 samples per plot would result in a decrease in the standard error of 8-30%. Assuming the margin of error (e.g. the % of deviation from the true mean) to be approximately 2X the standard error, the improvement in accuracy associated with an increase in sample size from 10 to 20 samples would be 1.2 to 4.4%.

The magnitude of the improvement in accuracy over the range of actual standard errors is better explained by the prediction equation than by the method suggested by Gomez and Gomez. If this equation is assumed to be the best estimator of improvement in the standard error increasing the sample size to over 20 samples would yield very little improvement in accuracy for the variable height.

The increases in efficiency relative to a single sample unit are shown in Table 4.2.

Table 4.1 Standard error of the mean (%) for the variables height (Ht) and basal area (BA) in a three replication trial with varying sample sizes.

Number of samples/plot	Actual		Estimated		Predicted*	
	Ht	BA	Ht	BA	Ht	BA
	%					
2	9.6	26.1	16.8	37.6	9.5	25.3
4	8.5	18.4	11.9	26.6	8.7	21.2
6	8.4	23.4	9.7	21.7	8.2	19.2
8	8.1	16.8	8.4	18.8	7.9	17.9
10	7.5	16.8	7.5	16.8	7.6	16.9
12	-	-	6.9	15.4	7.4	16.1
14	-	-	6.4	14.2	7.3	15.5
20	-	-	5.3	11.9	6.9	14.2
40	-	-	3.8	8.4	6.3	11.9
60	-	-	2.4	3.1	5.9	10.8

*/ standard error (Ht) = $10.51\ (X)^{-.14}$, $R^2=.94$

(BA) = $30.04\ (X)^{-.25}$, $R^2=.58$

where X = sample number

Table 4.2 Efficiency of various sample sizes relative to a single-tree unit for the variable height.

Sample size	Relative efficiency (%)
2	50
4	118
6	120
8	136
10	166

Table 4.3 Estimated standard error of treatment mean (%) for height with varying numbers of sample trees per plot for different numbers of replications

Number of samples/plot	Estimated standard error* 3 Reps	4 Reps	5 Reps
	%	%	%
4	11.9	10.4	9.2
6	9.7	8.4	7.5
8	8.4	7.3	6.5
10	7.5	6.5	5.8
12	6.9	5.9	5.3
14	6.4	5.5	4.9
20	5.3	4.6	4.1
40	3.8	3.3	2.9
60	3.1	2.7	2.4

*derived using variances from a sample population of 30 trees each of 11 species.

The estimated increases in precision in height measurements due to increasing the number of relications per trial are shown in Table 4.3. Increasing the number of samples taken is generally less costly than increasing the number of replications (Gomez and Gomez,1976). The improvements in precision attainable by increasing the number of replications could be more economically attained by increasing the number of samples.

b. Basal area. Standard errors for basal area were approximately two times those found for height, thus requiring a larger number of samples per plot in order to attain the same level of precision. The greater variability in BA resulted in a much poorer curve fit (R^2=.58) than that calculated for height (Table 4.1). The estimated decreases in standard error with increasing sample size for the Molokai, Waipio and Niulii sites are shown in Appendix F.

It can be estimated from either the Gomez and Gomea formula or the derived regression equation that an increase in sample size from 10 samples to 20 samples would decrease the standard error by 6-10 %. Assuming deviations from the true mean to be approximately 2X the standard error, such an increased sample size would result in decreasing the margin of error from 20-30 % to approximately 12-20 %. Thus for basal area measurements, such an increase in sample size would likely be a worthwhile investment.

c. Wood volume. Estimates made using the Gomez and Gomez formula, show volume to have higher standard errors than either height or basal area (Appendix G). Ten samples per plot resulted in standard errors of 12-18 %. Twenty samples resulted in an improvement of 3-5 % or a reduction in the margin of error of 6-10 %. The greater expense involved in the actual calculation of wood volumes may prohibit major increases in the number of samples taken for volume estimation. However, in cases where volume equations already exist increases in sample size from 10 to at least 20 samples would be recommended.

2. Plot size. Border effects were evident in both the Waimanalo and Waipio sites. At the Waimanalo site (Table 4.4) the detectable effects were those of interspecific competition rather than intraplot effects. Significant differences in height and diameter were noted in four of the eleven replicated species at Waimanalo. In each of these species the data trees were significantly larger than the border trees. In most of these plots observations indicated that border trees from an adjacent plot had overtopped the border of the affected plot, causing severe shading effects.

However, at Waipio significant differences in DBH were detected in L. leucocephala and L. diversifolia. Border row trees had significantly greater DBH's than the data trees (Table 4.5). Bormann (1965) reported that diameter growth is much more sensitive to competition than height growth, and this appears to be confirmed by the fact that no differences in height were found at Waipio with significant differences in height found with only one species at Waimanalo.

The differences in DBH at Waipio might be explained by the fact that at the Waipio site the competition between border rows of adjacent plots was not generally as great as between data trees and border trees in the leucaena plots.

Table 4.4 Border row analysis for Waimanalo site at 1.5 years

	Height		Basal diameter		DBH	
Species[1]	Border	Data	Border	Data	Border	Data
	m		cm		cm	
AUR	4.1	4.2	4.1	4.4	2.8	2.9
CAL	4.0	4.1	3.5	3.6	2.8	2.6
Cas	3.0	3.3	2.5*	3.1*	1.5*	1.9*
Dal	3.2	3.3	2.5*	2.8*	1.5	1.6
DIV	6.7	6.5	5.2	5.4	4.0	3.8
Ent	4.7	4.5	5.0*	5.8*	3.3*	4.2*
Euc	7.7	7.8	6.4	5.9	5.0	4.5
Fal	5.5	5.7	5.3	5.5	4.4	4.5
LEU	6.8	6.7	6.6	6.1	4.9	4.6
Man	4.4	4.6	4.4	4.8	3.2	3.6
Sam	3.7*	4.5*	4.1*	5.4*	2.7*	3.5*
SES	4.5	4.7	6.8	6.5	3.3	3.4

*tree position significantly different at .05 level

1/ Core species are shown in capital letters

Table 4.5 Border row analysis for Waipio site at one year

	Height		Basal diameter		DBH	
Species	Border	Data	Border	Data	Border	Data
	m		cm		cm	
Aur	2.2	2.1	2.1	2.2	0.8	0.8
Cal	2.1	2.1	1.8	1.8	1.0	1.0
Div	4.8	4.9	5.2	4.8	3.6 *	3.2 *
Leu	4.5	4.5	4.5	4.2	3.2 *	2.8 *
Ses	3.2	3.1	5.9	5.5	2.7	2.3

* Significantly different at .05 level using LSD test

Inter-plot competition was generally greater at Waimanalo and may have limited the shading of data rows by slowing the growth of the border trees.

These results suggest that the 1:4 ratio proposed by Cannel and Smith is not valid for these trials at the age of 1 to 1.5 years. A number of species at the Waimanalo site exceeded the 6 m height limit (based on a border width of 1.5 m) without any detectable border effects. Differences in DBH between data and border rows at Waipio for the species *Leucaena leucocephala* and *L. diversifolia* suggest that there were border effects in plots with a border width:height ratio of < 3.5.

It appears inevitable that border effects will become significant at some point in time for small-plot tree trials such as these. However, for short-term experiments with relatively uniform competition between plots the 4 x 7 m row plot size is adequate. This is especially true if height measurements are the primary observations to be collected as in site adaptability trials. For future trials utilizing species with unknown growth rates or where species of widely disparate growth rates are grown in adjacent plots it is recommended that a minimum of 2 border rows be utilized for small-plot NFT trials.

C. SUMMARY

The minimum sample size of 10 trees per plot utilized in these trials to date appears to be adequate for measurement of height, resulting in a margin of error of 8-15 % for the variable height and 18-34 % for the variable basal area. Improvements in the margin of error of 8-10 % for the variable height could be obtained by increasing the sample size to 20. Estimates of wood volume would be greatly improved by an increase in sample size to 20 trees per plot.

Assuming height, basal area and wood volume are all characteristics which must be measured over time in future NFT trials, a minimum sample size of 20 samples per plot is required to attain an estimate with a margin of error of less than 20 % for all of the measured characteristics. Ten samples per plot appears adequate for site adaptability trials utilizing height as a measure of species adaptation.

The minimum plot size required to supply 20 samples per plot appears to be 72 m^2 assuming border effects to be severe before two years of age on some sites. The use of 8 x 9 row plots would insure the availability of 20 samples free of border effects. Border effects might also be reduced by segregating species into slow, medium and fast growing species. This would possibly reduce the inter-specific shading effects found at Waimanalo, and by increasing the inter-plot competetion, reduce the types of border effects observed at Waipio.

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APPENDIX A

DETAILED SITE INFORMATION

SITE: Waimanalo

Trial number: 81-1

Soil classification: Vertic Haplustolls, very fine, kaolinitic

Location: Waimanalo, Island of Oahu, Hawaii, on Univ. of Hawaii Research Station, east of Hawaii Foundation Seed Facility.

Vegetation: Cultivated, california grass, nutsedge, sandburr, spiny amaranth.

Climate: Isohyperthermic, mean annual temperature is 23C. Mean annual rainfall 1270-1525mm.

Parent material: Weathered basic igneous rock.

Physiography and slope: Nearly level, < 4% slope.

Elevation: 21m.

Drainage: Well drained.

Laboratory data of Waialua clay variant at the Waimanalo Experiment Station

Depth	Horizon	Organic Carbon	Extractable bases Ca	Mg	Na	K	Sum	pH (H_2O)
- cm -		- % -	---- meq/100 soil -----					
0-18	Ap1	1.98	15.5	9.4	0.5	1.2	26.6	6.1
18-38	Ap2	1.90	15.8	9.8	0.5	1.2	27.3	6.2
38-94	B21	0.80	12.3	9.1	0.9	0.2	22.5	6.4
94-127	B22	0.39	15.0	12.5	2.2	0.2	29.9	6.6

Depth	Cation exch. capacity	Base Saturation	Bulk Density	Water Content 15-bar
- cm -	-- meq/100g --	--- % ---	- g/cc -	-- % --
0-18	33.3	80	1.18	27.5
18-38	33.7	81	1.22	27.4
38-94	28.9	78	1.10	24.6
94-127	36.7	81	1.06	26.5

SITE: Molokai

Trial number: 81-3

Soil classification: Ustollic Camborthids, fine-loamy, kaolinitic.

Location: Plant Materials Center, Hoolehua, Island of Molokai, Hawaii.

Cooperator: Soil Conservation Service, USDA.

Vegetation: cultivated, apple of peru, sandburr, california grass.

Climate: Isohyperthermic, mean annual temperature is 20-22C. Mean annual rainfall is 700mm.

Parent material: Volcanic ash.

Physiography and slope: Nearly level, < 2% slope.

Elevation: 100m.

Drainage: Well drained.

mixed

SOIL FAMILY Ustollic Camborthid, fine-loamy, [redacted], isohyperthermic

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

SOIL SERIES Holomua silty loam SOIL Nos. S62Ha-5-2 LOCATION Maui County, Hawaii
Lincoln Lab Nos. 17396 - 17401

Depth (cm)	Horizon	Mineralogical Analysis Allophane	Montmorillonites	Micas	Kaolinites	Gibbsite	Boehmite	Goethite	Amorphous SiO_2	Amorphous Al_2O_3	Magnetite etc.	Anatase	Quartz	Volcanic glass	Feldspar	Olivine	Pyroxene	Pyrite
		Percent of Whole Soil																
0-30	Ap			10	50	3		20			10	5						
30-58	B21			10	50	4		20			10	5						
58-70	B22																	
70-80	IIB3b1			5	50	7		20			15	5						
80-108	IIB3b2			2	50	3		20			10	5						
108-163	IIB3b3			1	50	2		15			15	5						

Depth (cm)		Total Chemical Analysis SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO_2	MgO	CaO	Na_2O	K_2O	P_2O_5	L.O.I.	Total	Extractable Iron 6C1a Fe	Fe_2O_3	Carbonate as $CaCO_3$ 6E1b	0.5N NaOH Soluble SiO_2	Al_2O_3
		Percent of Whole Soil																
0-30	Ap	27.8	5.2	30.1	21.9	0.30	0.73	0.06	0.15	0.66	0.37	12.7	100.0	11.2	16.0		11.41	12.56
30-58	B21	26.3	5.3	30.1	23.4	0.27	0.68	0.06	0.14	0.61	0.32	12.9	100.1	11.8	16.9		13.03	15.14
58-70	B22													11.8	16.9			
70-80	IIB3b1	23.3	5.7	30.2	26.2	0.14	0.59	0.04	0.15	0.26	0.35	13.1	100.0	11.6	16.6		11.45	15.23
80-108	IIB3b2	23.9	6.4	30.1	24.3	0.13	0.63	0.04	0.15	0.17	0.35	13.1	99.3	11.0	15.7		12.43	13.89
108-163	IIB3b3	26.1	6.4	28.9	24.6	0.18	0.79	0.06	0.11	0.10	0.39	12.4	100.0	9.0	12.9		15.16	14.20

Depth (cm)	6A1a a/ Organic carbon Pct.	6B1a Nitrogen Pct.	C/N	Extractable bases 5B1a 6N2a Ca	6O2a Mg	6P2a Na	6Q2a K	Sum of bases	Extr. acidity 6H2a	Cation exch capacity 5A1a NH_4OAc	Sum	NH_4OAc 6I2a extr. SO_4	KCl extr. Al 6G1D	Base saturation 5C1 NH_4OAc	5C3	pH 8C1a H_2O	8C1c KCl
				Meq./100 g.										Percent		1:5	1:5
0-30	0.90	0.13	7	4.4	1.2	0.30	1.10	7.0		14.1		0.2		50		6.4	5.5
30-58	0.70	0.11	6	2.0	2.1	0.20	0.90	5.2		10.9		0.7		48		6.8	5.8
58-70	0.50	0.08	6	1.9	1.9	0.40	0.70	4.9		10.2		1.1		48		7.1	6.1
70-80	0.49*	0.06	8	1.9	1.8	1.00	0.90	5.6		7.2		1.1		78		6.8	5.9
80-108	0.53*			2.2	1.6	1.50	1.20	6.5		11.1		0.9		58		6.8	5.8
108-163	0.41*			2.2	1.4	2.00	1.20	6.8		9.6		0.6		71		6.8	5.8

Depth (cm)	Size class and particle diameter (mm) 3A1 Sand (2-0.05)	Silt (0.5-0.002)	Clay (<.002)	Coarse fragments >2mm pct. of whole soil	Atterberg limits Plastic limit	Liquid limit	Plastic index	Bulk density 1/3 bar	Oven dry	Field moist	Particle density	Water content	1/3 bar	15 bar	Extensibility 4D1 COLE	COLE
	Pct. of 2mm.							g/cc				Pct. of whole soil			cm/cm	
0-30				-						1.03	2.94		30.4	18.5		
30-58				-						1.06	2.96		30.7	19.5		
58-70				-						1.23	3.00		28.3	20.7		
70-80				-						1.25	3.00		29.0	21.4		
80-108				-						1.21	3.05		29.9	23.1		
108-163				-						1.19	3.08		29.8	22.4		

a/ 7.5 kg of organic carbon per square meter to a depth of 1 meter.

* Assumed to be older than Holocene age.

SITE: Waipio

Trial number: 81-4

Soil classification: Tropeptic Eutrustox, clayey,
kaolinitic.

Location: Waipio, Island of Oahu, Hawaii. East of road leading
to Mililani Cemetary from Kamehameha Hwy.

Cooperator: Benchmark Soils Project.

Vegetation: Abandoned pineapple field.

Climate: Isohyperthermic, mean annual temperature is 22C.
Mean annual rainfall is 1000mm.

Parent material: Weathered olivine basalt.

Physiography and slope: Nearly level upland, 2% slope.

Elevaton: 150m.

Drainage: Well drained.

Soil name: Wahiawa　　Classification: Tropeptic Eutrustox, clayey, kaolinitic, isohyperthermic
Soil no.: 77HA-7-1　　Location: Waipio, Island of Oahu, Hawaii

		Particle size analysis				Water content						Extractable iron	
Depth	Horizon	Sand 2-.05	Silt .05-.002	Clay < .002	Bulk density	.1-bar	.3-bar	15-bar	Organic C	Total N	C/N	Fe	Fe_2O_3
--cm--		pct < 2 mm			--g/cc--	pct			pct			pct	
0-10	Ap1	9.9	30.3	59.8					2.27	0.32	7	8.51	12.16
10-27	Ap2	8.5	28.6	62.9					1.72	0.26	7	7.52	10.75
27-40	AB	8.5	35.7	55.8					1.41	0.24	6	7.72	11.03
40-65	B21	8.2	39.4	52.4					0.59	0.14	4	8.10	11.58
65-90	B22	1.6	24.8	73.6					0.36	0.11	3	9.75	13.93
90-120	B23	4.2	20.9	74.9					0.27	0.08	3	7.30	10.43
120-150	B24	6.4	23.7	69.9					0.24	0.08	3	9.56	13.66

	Extractable bases					Extractable	Cation-exchange capacity		Extractable	Base saturation		pH		
Depth	Ca	Mg	Na	K	Sum	acid	NH_4OAc	Sum	Al	NH_4OAc	Sum	H_2O	KCl	Difference
--cm--	meq/100 g soil									pct				
0-10	6.52	4.35	0.17	2.69	13.73	9.16	20.81	22.89	0.03	66	60	5.41	4.80	-0.61
10-27	4.93	2.36	0.10	0.85	8.24	11.48	18.43	19.72	0.30	45	42	4.95	4.18	-0.77
27-40	6.07	3.05	0.12	0.11	9.35	9.93	17.58	19.28	0.05	53	48	5.31	4.48	-0.83
40-65	5.28	3.13	0.12	0.20	8.73	6.26	13.74	14.99	0.03	64	58	5.78	5.13	-0.65
65-90	4.78	3.64	0.13	0.23	8.78	5.15	13.01	13.93	—	67	63	6.12	5.61	-0.51
90-120	4.77	3.68	0.16	0.21	8.82	4.79	14.11	13.61	—	62	65	6.27	5.77	-0.50
120-150	5.19	3.46	0.36	0.38	9.39	4.71	14.42	14.13	—	65	66	6.37	5.85	-0.52

Source: Hawaii Benchmark Soils Project

SITE: Niulii

Trial number: 81-5

Soil classification: Hydric Dystrandepts, thixotropic.

Location: North Kohala, Island of Hawaii, Hawaii. Approx. 7km SW of Kapaau.

Cooperator: Benchmark Soils Project.

Vegetation: Pangola grass, previously in sugar cane.

Climate: Isothermic, mean annual temperature is 20-22c. Mean annual rainfall is 2000-2550mm.

Parent material: Volcanic ash over pahoehoe lava.

Physiography and slope: Moderately sloping to stongly sloping, 6% slope.

Elevation: 545m.

Drainage: Well drained.

Soil name: Niulii Classification: Hydric Dystrandepts, thixotropic, isothermic
Soil no.: 75HA-1-2 Location: North Kohala, Island of Hawaii, Hawaii

		Particle size analysis				Water content						Extractable iron	
Depth	Horizon	Sand 2-.05	Silt .05-.002	Clay < .002	Bulk density	.1-bar	.3-bar	15-bar	Organic C	Total N	C/N	Fe	Fe_2O_3
--cm--		pct < 2 mm			--g/cc--	pct			pct			pct	
0-17	Ap1								8.12	0.72	11	10.92	15.61
17-29	B21								5.04	0.39	13	11.42	16.33
29-48	B22								4.35	0.46	9	11.51	16.46
48-79	B23								5.52	0.40	14	8.18	11.69
79-107	IIC								4.04	0.66	6	4.25	6.08

	Extractable bases					Extractable	Cation-exchange capacity		Extractable	Base saturation		pH		
Depth	Ca	Mg	Na	K	Sum	acid	NH_4OAc	Sum	Al	NH_4OAc	Sum	H_2O	KCl	Difference
--cm--	meq/100 g soil									pct				
0-17	7.93	0.94	0.27	0.86	10.00	26.26	64.76	36.26	0.02	15	28	6.01	4.90	-1.11
17-29	0.38	0.01	0.23	0.07	0.69	46.60	56.21	47.29	0.68	1	1	5.22	4.56	-0.66
29-48	1.03	0.01	0.15	0.02	1.21	41.84	55.07	43.05	0.37	2	3	5.20	4.80	-0.40
48-79	0.17	0.01	0.10	0.04	0.32	56.61	80.54	56.93	0.29	< 1	< 1	5.20	5.02	-0.18
79-107	0.13	< 0.01	0.10	0.03	< 0.27	47.07	80.66	—	0.19	< 1	< 1	5.08	4.99	-0.09

Source: Hawaii Benchmark Soils Project

SITE: Davao

Trial number: 81-6

Soil classification: Typic Paleudults, clayey, kaolinitic.

Location: San Gabrial, Davao City, Island of Mindanao, Philippines. Bureau of Plant Industry Station, approx. 25 km from Davao City proper.

Cooperator: Benchmark Soils Project

Vegetation: Cultivated, previously used for maize and upland rice.

Climate: Isohyperthermic. Udic moisture regime.

Parent material: Andesite.

Physiography and slope: Gently sloping, 2-5% slope.

Elevation: Approx. 200m.

Drainage: Well drained.

Soil name: Classification: Typic Paleudults, clayey, kaolinitic, isohyperthermic
Soil no.: 77RP-2-1 Location: Davao City, Mindanao, the Philippines

		Particle size analysis				Water content						Extractable iron	
Depth	Horizon	Sand 2-.05	Silt .05-.002	Clay <.002	Bulk density	.1-bar	.3-bar	15-bar	Organic C	Total N	C/N	Fe	Fe_2O_3
--cm--		pct < 2 mm			--g/cc--	pct			pct			pct	
0-18	Ap	17.8	21.8	60.4					1.49	0.18	8	4.94	7.06
18-37	B21t	15.8	10.8	73.4					0.56	0.11	5	5.29	7.56
37-74	B22t	7.8	15.2	77.0					0.48	0.10	5	5.84	8.34
74-100	B23t	0.8	10.8	88.4					0.48	0.07	7	6.15	8.79
100-140	B24t	0	7.6	92.4					0.41	0.06	7	5.97	8.53
140-160	B3t	0	9.6	90.4					0.37	0.06	6	5.97	8.53
160-200	C	2.8	17.8	79.4					0.28	0.04	7	5.95	8.50

	Extractable bases						Cation-exchange capacity			Base saturation		pH		
Depth	Ca	Mg	Na	K	Sum	Extractable acid	NH_4OAc	Sum	Extractable Al	NH_4OAc	Sum	H_2O	KCl	Difference
--cm--	meq/100 g soil									pct				
0-18	7.49	1.84	0.06	1.98	11.37	9.13	20.58	20.50	0.06	55	55	5.05	4.40	-0.55
18-37	3.70	1.74	0.18	0.66	6.28	11.94	19.26	18.22	3.30	33	34	4.82	3.79	-1.03
37-74	2.24	1.79	0.19	0.46	4.68	12.79	20.28	17.47	3.97	23	27	4.69	3.62	-1.07
74-100	2.75	1.98	0.20	0.37	5.30	12.94	24.62	18.24	4.08	22	29	4.61	3.56	-1.05
100-140	3.17	1.86	0.26	0.36	5.65	12.32	21.25	17.97	4.25	27	31	4.65	3.58	-1.07
140-160	4.16	1.76	0.29	0.37	6.58	14.61	22.10	21.19	3.96	30	31	4.70	3.61	-1.09
160-200	5.22	1.75	0.35	0.37	7.69	13.11	24.33	20.80	3.54	32	37	4.70	3.59	-1.11

Source: Hawaii Benchmark Soils Project

APPENDIX B

HP41 COMPUTER PROGRAMS

A. Augmented block analysis.

```
01♦LBL "AUGBLOC"
02 CLRG
03 BEEP
04 SF 27
05 "REP 1 MEAN="
06 PROMPT
07 STO 00
08 ARCL X
09 AVIEW
10 "REP 2 MEAN="
11 PROMPT
12 STO 01
13 ARCL X
14 AVIEW
15 "REP 3 MEAN="
16 PROMPT
17 STO 02
18 ARCL X
19 AVIEW
20 "REP 4 MEAN="
21 PROMPT
22 STO 03
23 ARCL X
24 AVIEW
25 "GRAND MEAN="
26 PROMPT
27 STO 04
28 ARCL X
29 AVIEW
30 "MS ERROR="
31 PROMPT
32 STO 20
33 ARCL X
34 AVIEW
35 "T VALUE="
36 PROMPT
37 STO 22
38 ARCL X
39 AVIEW
40 "SAMPLES="
41 PROMPT
42 STO 09
43 ARCL X
44 AVIEW
45 "NO. OF REPS="
46 PROMPT
47 STO 10
48 ARCL X
49 AVIEW
50 "TRT/REP="
51 PROMPT
52 STO 19
53 ARCL X
54 AVIEW
55♦LBL F
56 "A,B,C OR D?"
57 PROMPT
58♦LBL A
59 CF 01
60 CF 02
61♦LBL a
62 "TU="
63 PROMPT
64 STO 05
65 ARCL X
66 AVIEW
67 "REP="
68 PROMPT
69 ARCL X
70 AVIEW
71 1
72 X<>Y
73 X>Y?
74 GTO 00
75 GTO 01
76♦LBL 00
77 2
78 X<>Y
79 X>Y?
80 GTO 02
81 GTO 03
82♦LBL 02
83 3
84 X<>Y
85 X>Y?
86 GTO 04
87 GTO 05
88♦LBL 01
89 RCL 05
90 RCL 00
91 -
92 RCL 04
93 +
94 STO 06
95 GTO 08
96♦LBL 08
97 RCL 21
98 X>0?
99 GTO 07
100 1
101 ST+ 21
102 GTO 06
103♦LBL 03
104 RCL 05
105 RCL 01
106 -
107 RCL 04
108 +
109 STO 06
110 GTO 08
111♦LBL 05
112 RCL 05
113 RCL 02
114 -
115 RCL 04
116 +
117 STO 06
118 GTO 08
119♦LBL 04
120 RCL 05
121 RCL 03
122 -
123 RCL 04
124 +
125 STO 06
126 GTO 08
127♦LBL 06
128 RCL 06
129 STO 07
130 RCL 07
131 "T ADJ1="
132 ARCL X
133 AVIEW
134 FS? 01
135 GTO c
136 FS? 02
137 GTO e
138 GTO a
139♦LBL 07
140 RCL 06
141 STO 08
142 RCL 08
143 "T ADJ2="
144 ARCL X
145 AVIEW
146 RCL 07
147 RCL 08
148 -
149 ABS
150 FS? 01
```

```
151 GTO d
152 FS? 02
153 GTO 26
154 GTO b
155◆LBL b
156 RCL 20
157 2
158 RCL 09
159 /
160 *
161 SQRT
162 RCL 22
163 *
164 "LSD="
165 ARCL X
166 AVIEW
167 X>Y?
168 GTO 10
169 GTO 09
170◆LBL 10
171 "N.S."
172 AVIEW
173 0
174 STO 21
175 CF 01
176 CF 02
177 GTO F
178◆LBL 09
179 "SIG. DIFF."
180 AVIEW
181 0
182 STO 21
183 CF 01
184 CF 02
185 GTO F
186◆LBL B
187 SF 01
188 CF 02
189◆LBL c
190 "TU="
191 PROMPT
192 STO 05
193 ARCL X
194 AVIEW
195 "REP="
196 PROMPT
197 ARCL X
198 AVIEW
199 1
```

```
200 X<>Y
201 X>Y?
202 GTO 11
203 GTO 12
204◆LBL 11
205 2
206 X<>Y
207 X>Y?
208 GTO 13
209 GTO 14
210◆LBL 13
211 3
212 X<>Y
213 X>Y?
214 GTO 15
215 GTO 16
216◆LBL 12
217 RCL 05
218 RCL 00
219 -
220 RCL 04
221 +
222 STO 06
223 GTO 08
224◆LBL 14
225 RCL 05
226 RCL 01
227 -
228 RCL 04
229 +
230 STO 06
231 GTO 08
232◆LBL 15
233 RCL 05
234 RCL 03
235 -
236 RCL 04
237 +
238 STO 06
239 GTO 08
240◆LBL 16
241 RCL 05
242 RCL 02
243 -
244 RCL 04
245 +
246 STO 06
247 GTO 08
248◆LBL d
249 RCL 20
250 2
```

```
251 *
252 RCL 09
253 /
254 1
255 RCL 19
256 1/X
257 +
258 *
259 SQRT
260 RCL 22
261 *
262 GTO 27
263◆LBL 27
264 "LSD="
265 ARCL X
266 AVIEW
267 X>Y?
268 GTO 10
269 GTO 09
270◆LBL C
271 CF 01
272 SF 02
273◆LBL e
274 "TRT AVERAGE="
275 PROMPT
276 STO 18
277 ARCL X
278 AVIEW
279 "AUGMENT="
280 PROMPT
281 STO 05
282 ARCL X
283 AVIEW
284 "REP="
285 PROMPT
286 ARCL X
287 AVIEW
288 1
289 X<>Y
290 X>Y?
291 GTO 20
292 GTO 21
293◆LBL 20
294 2
295 X<>Y
296 X>Y?
297 GTO 22
298 GTO 23
299◆LBL 22
300 3
```

```
301 X<>Y
302 X>Y?
303 GTO 24
304 GTO 25
305♦LBL 21
306 RCL 05
307 RCL 00
308 -
309 RCL 04
310 +
311 STO 06
312 GTO 26
313♦LBL 23
314 RCL 05
315 RCL 01
316 -
317 RCL 04
318 +
319 STO 06
320 GTO 26
321♦LBL 24
322 RCL 05
323 RCL 03
324 -
325 RCL 04
326 +
327 STO 06
328 GTO 26
329♦LBL 25
330 RCL 05
331 RCL 02
332 -
333 RCL 04
334 +
335 STO 06
336 GTO 26
337♦LBL 26
338 RCL 06
339 "AUG TRT="
340 ARCL X
341 AVIEW
342 RCL 10
343 1/X
344 RCL 19
345 1/X
346 +
347 1
348 +
349 RCL 10
350 RCL 19
```

```
351 *
352 1/X
353 -
354 RCL 20
355 RCL 09
356 /
357 *
358 SQRT
359 RCL 22
360 *
361 STO 19
362 RCL 19
363 "LSD="
364 ARCL X
365 AVIEW
366 RCL 19
367 RCL 18
368 RCL 06
369 -
370 ABS
371 X<=Y?
372 GTO 10
373 GTO 09
374 END
```

B. Volume calculations

```
01♦LBL "VOLUME"
02 BEEP
03 CLRG
04 FIX 0
05 ΣREG 12
06 SF 27
07♦LBL c
08 SF 12
09 ADV
10 AON
11 "SPP/REP="
12 PROMPT
13 AVIEW
14 AOFF
15 CF 12
16 1
17 STO 98
18 0.00901
19 STO 99
20 "TREE NO.=1"
21 AVIEW
22♦LBL A
23 0
24 STO 02
25 0
26 STO 07
27 "D1=?"
28 PROMPT
29 STO 04
30 "D2=?"
31 PROMPT
32 STO 05
33 "D3=?"
34 PROMPT
35 STO 06
36 100
37 STO 03
38 XEQ a
39 XEQ 03
40♦LBL a
41 0
42 STO 02
43 RCL 04
44 XEQ 01
45 SF 01
46 RCL 05
47 XEQ 01
48 CF 01
49 RCL 06
50 XEQ 01
51 RCL 02
52 6
53 /
54 RCL 03
55 *
56 STO 07
57 ST+ 00
58 "SEG. VOL.="
59 ARCL 07
60 ST+ 97
61 AVIEW
62 STOP
63 RTN
64♦LBL 01
65 X↑2
66 .7854
67 *
68 FS? 01
69 XEQ 02
70 ST+ 02
71 RTN
72♦LBL 02
73 4
74 *
75 RTN
76♦LBL 03
77 RCL 06
78 STO 04
79 "D2=?"
80 PROMPT
81 STO 05
82 "D3=?"
83 PROMPT
84 STO 06
85 XEQ a
86 XEQ 03
87 RTN
88♦LBL B
89 "SMALIANS"
90 AVIEW
91 "D1=?"
92 PROMPT
93 STO 08
94 "D2=?"
95 PROMPT
96 STO 09
97 "LENGTH=?"
98 PROMPT
99 100
100 *
101 STO 10
102 RCL 08
103 X↑2
104 .7854
105 *
106 STO 11
107 RCL 09
108 X↑2
109 .7854
110 *
111 ST+ 11
112 RCL 11
113 2
114 /
115 RCL 10
116 *
117 ST+ 00
118 "SEG. VOL.="
119 ARCL X
120 AVIEW
121 ST+ 97
122 STOP
123 GTO B
124♦LBL C
125 "TREE VOL.="
126 ARCL 00
127 AVIEW
128 RCL 00
129 Σ+
130 0
131 STO 00
132 0
133 STO 97
134 ADV
135 ISG 99
136 XEQ 55
137 XEQ c
138♦LBL 55
139 1
140 ST+ 98
141 RCL 98
142 "TREE NO.="
143 ARCL X
144 AVIEW
145 0
146 STO 00
147 XEQ A
148 STOP
149♦LBL D
150 "DOUBLE STEM"
```

```
151 AVIEW
152 "STEM VOL="
153 ARCL 97
154 AVIEW
155 0
156 STO 97
157 XEQ A
158♦LBL d
159 RCL 97
160 ST+ 00
161 0
162 STO 97
163 XEQ C
164♦LBL E
165 MEAN
166 100
167 /
168 "PER HA.="
169 ARCL X
170 AVIEW
171 .END.
```

APPENDIX C
DATA COLLECTION FORMS

Form 1

Augment	Location	Species	Age	Replicatio	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
	1	Aur	.5	1	2.4	2.0	2.3	2.6	.8	.9	1.5	2.0	1.8	1.9
X	1	Gli	.5	2	.8	.9	1.0	.9	.7	1.3	1.2	1.0	1.1	1.4
	1	Leu	.5	2	2.0	1.9	2.0	1.8	1.7	1.9	2.3	2.2	2.0	2.1
	1													
	1													
	1													
	1													

NFT data collection form

Character measured (circle one):

dbh [✓ height] basal diameter

Sample

Form 2

TREE VOLUME DATA
(Ht in m, D in cm)

Date__________
Species /Kep
Age__________

Tree number	DBH	Basal Diameter	Segment					Total volume
			D1	D2	D3	L1	Volume	

where D1 = basal diameter at large end of segment
D2 = basal diameter at mid-point
D3 = basal diameter at small end of segment
L1 = segment length

APPENDIX D

SEEDLOT INFORMATION

Species	81-1	81-3	81-4	81-5	81-6
	Trial number				
	seedlot numbers				
Aur	N5	N5	N5	N5	N1
Man	N6	N6	N6	N6	N6
Mea	---	N163	N163	N163	---
Mel	FS	---	---	---	---
Acr	---	N33	N33	N33	N33
Fal	N10	N10	N10	N10	N10
Leb	N12	N12	---	---	---
Apr	---	N53	N53	N53	N53
Cal	N17	N17	N63	N63	N63
Cas	FS	N64	N64	N64	N64
Dal	N18	N18	N18	N18	N18
Ent	N20	N20	N20	N20	N20
Ery	---	N47	N47	N47	N47
Cit	FS	---	---	---	---
Euc	FS	---	FS	FS	FS
Gli	N22	N22	N54	N54	N54
Lys	N31	---	---	---	---
Mim	---	N38	N39	N39	N39
Pro	N23	N23	---	---	---
Sam	N25	N25	---	---	N25
Ses	N28	N28	N36	N36	N36

Leucaena leucocephala was planted in each trial, seedlot: K8
Leucaena diversifolia was planted in each trial, seedlot: K156
Erythrina fusca was planted in 81-3 by stem cuttings
FS seed lots are from the U.S. Forest Service

APPENDIX E

INFFECTIVENESS OF SELECTED <u>RHIZOBIUM</u> STRAINS[1]

<u>Rhizobium</u> Strain

Species	TAL 1145	TAL 82	TAL 582	TAL 309	TAL 310	TAL 658
Aur						X
Mea	X			X		X
Acr			no nodules			
Fal				X		X
Apr				X		X
Cal	X					
Dal			no nodules			
Ent				X		X
Ery						X
Gli	X					
Leu	X					
Div	X					
Mim	X					
Ses	X					

1/ Based on limited samples from seedlings grown for Waipio and Niulii sites.

SOURCE: Patricia Nakao, Niftal Project, Maui

APPENDIX F

SUPPORTIVE TABLES FOR REPLICATED SPECIES

Basal area

Appendix Table F.1 Basal area growth at Waimanalo

SPECIES	AGE (in years) .25	.50	.75	1.0	1.5
	cm^2				
Leu	0.7b	6.2b	12.0b	16.2a	30.2ab
Div	0.9b	5.6bc	8.4c	10.2b	23.5bcd
Ses	3.4a	14.1a	18.0a	20.5a	33.9a
Cal	0.5b	3.6c	4.6d	5.6b	10.9d
Aur	0.2b	1.9d	3.8d	3.8d	6.7cd

Appendix Table F.2 Basal area growth at Waipio

SPECIES	AGE (in years) .25	.50	.75	1.0
	cm^2			
Leu	0.3bc	3.4b	8.5c	14.2c
Div	0.4b	3.7b	12.7b	18.7b
Ses	1.4a	9.3a	18.7a	25.8a
Cal	0.2c	0.8c	2.1d	2.8d
Aur	0.2c	1.0c	2.2d	4.1d

Appendix Table F.3 Basal area growth at Niulii

SPECIES	.25	.50	.75	1.0
	cm^2			
Leu	0.0c	0.1c	1.4c	5.4c
Div	0.1b	0.4ab	3.3b	9.6b
Ses	0.2a	0.6a	7.7a	13.5a
Cal	0.0b	0.3bc	1.9c	4.2c
Aur	0.1c	0.2bc	0.8c	3.2c

(AGE (in years) spans the .25–1.0 columns.)

DBH

Appendix Table F.4 DBH at one year

SPECIES	Waimanalo	Molokai	Waipio	Niulii	Mean
			LOCATION		
	cm				
Leu	4.6a	4.6a	2.8a	0.8c	3.2
Div	3.8ab	4.2b	3.2a	2.0a	3.3
Ses	3.4bcd	3.7ab	2.3b	0.8c	2.6
Cal	2.6d	2.3c	1.0c	1.2b	1.8
Aur	2.9cd	1.6d	0.8c	0.0d	1.3
MEAN	3.5	3.3	2.0	1.0	2.4

Sample size

Appendix Table F.5 Estimated standard error of the treatment means (%) for the variable volume

	Location			
Samples/plot	Waimanalo	Molokai	Waipio	Niulii
2	39.6	33.9	25.7	37.2
4	28.0	24.0	18.2	26.3
6	22.9	19.6	14.9	21.5
8	19.8	17.0	12.9	17.0
10	17.7	15.2	11.5	16.6
12	16.2	13.9	10.5	15.2
14	15.0	12.8	10.5	14.1
20	12.5	10.7	8.1	11.8
40	8.9	7.6	5.8	8.3
60	7.2	6.2	4.7	6.8

Appendix Table F.6 Estimated standard errors of the mean (%) for the variable basal area

	Location		
Samples/plot	Molokai	Waipio	Niulii
		%	
2	24.6	19.3	21.5
4	17.4	13.6	15.2
6	14.2	11.1	12.4
8	12.3	9.6	10.8
10	11.0	8.6	9.6
12	10.1	7.9	8.8
14	9.3	7.3	8.1
20	7.8	6.1	6.8
40	5.5	4.3	4.8
60	4.5	3.5	3.9

Replicated non-core species at Waimanalo

Data shown in Chapter 3 for core species at Waimanalo are drawn from the following tables. No values are shown for *Prosopis pallida* for ages of 1.0 year and over because these trees were harvested at 11 months due to extreme thorniness.

Height

Appendix Table F.7 Height growth of replicated species at Waimanalo

Species	Age .25	.50	.75	1.0	1.5
	m				
Div	1.0a	2.9a	3.7a	4.7a	6.5b
Leu	0.9ab	2.8a	4.2a	5.1a	6.7b
Cal	0.8abe	1.8cd	2.0cd	2.6cd	4.0cde
Euc	0.8bc	2.3b	3.6a	4.5ab	7.8a
Ses	0.7bcde	2.0bc	2.3bcd	3.1c	4.7c
Fal	0.7bcde	2.2bc	2.8b	4.0b	5.7b
Pro	0.7cde	1.5de	2.0cd	---	---
Cas	0.6de	1.4e	1.8d	2.3cd	3.3de
Dal	0.6e	1.5de	1.7d	2.0d	3.3e
Ent	0.5ef	1.9bcd	2.6bc	2.7cd	4.4cd
Aur	0.4f	1.4e	2.1bcd	2.9c	4.2cde
Sam	0.4f	1.2e	1.9d	2.7cd	4.5cd
Man	0.4f	1.4e	2.0cd	2.8cd	4.6c

Appendix Table F.8 Basal area growth of replicated species at Waimanalo

	Age (years)				
Species	.25	.50	.75	1.0	1.5
	----------------	--- cm^2 ---	----------------	----------------	----------------
Div	0.9b	5.6bc	8.4cd	10.2cde	23.5bcd
Leu	0.7bc	6.2b	11.7b	16.2ab	30.2ab
Cal	0.5bc	3.6cde	4.6def	5.6ef	10.9ef
Euc	0.7bc	4.3bcd	6.4cde	11.4bcd	28.4abc
Ses	3.4a	14.1a	18.0a	20.5a	33.9a
Fal	0.7bc	5.9bc	8.4c	11.2bcde	26.3abc
Pro	0.2c	2.1de	4.2ef	-----	-----
Cas	0.3bc	1.0e	1.6f	3.0f	8.3f
Dal	0.3bc	2.1de	3.1ef	3.4f	6.8f
Ent	0.8bc	6.3b	12.0b	13.8bc	28.3abc
Aur	0.2bc	1.9de	3.8ef	6.7def	16.1def
Sam	0.4bc	2.3de	5.8cde	10.0cde	23.7bcd
Man	0.5bc	2.6de	5.8cde	7.9def	19.7cde

Appendix Table F.9 DBH and wood volume growth of replicated species at Waimanalo at 1.0 and 1.5 years of age

	DBH		WOOD VOLUME	
	Age		Age	
Species	1.0	1.5	1.0	1.5*
	----- cm -----		-- m^3/ha/yr --	
Div	3.0ab	3.8ab	23.9bc	35.8ab
Leu	3.2a	4.6a	34.4a	49.4a
Cal	1.8de	2.6de	-----	11.9cd
Euc	2.7abc	4.5a	28.7ab	49.6a
Ses	2.4bcd	3.4bcd	20.5bc	24.3bc
Fal	2.9ab	4.5a	-----	46.5a
Cas	0.9f	1.9ef	-----	6.5d
Dal	0.8f	1.6f	-----	5.2d
Ent	2.3bcde	4.1ab	-----	30.7b
Aur	1.6e	2.9cd	-----	15.0cd
Sam	2.0cde	3.5bcd	-----	22.3bc
Man	2.4bcde	3.6bc	14.1c	23.7bc

*/ Mean annual increment

APPENDIX G

SUPPORTIVE TABLES FOR AUGMENTED TREATMENTS

Height

Appendix Table G.1 Adjusted mean height growth of augmented species at Waimanalo

		AGE				
SPECIES	REP	.25	.50	.75	1.0	1.5
				m		
Cit	1	0.5	1.1	1.6	2.0	4.0
Gli	3	0.4	1.9	2.4	2.8	3.2
Leb	2	0.3	0.9	1.3	1.9	4.3
Lys	3	0.3	1.0	1.3	1.6	2.6
Mel	2	0.6	1.2	1.5	1.9	3.3
LSD1		0.3	0.7	1.1	1.2	
LSD2		0.3	0.7	1.1	1.3	

LSD1 is to be used for augments in the same rep
LSD2 is to be used in comparing augments in different reps

Appendix Table G.2 Adjusted mean height and basal area growth of augmented species at Molokai

Species	Rep	Height	BA	Height	BA
		- m -	$-cm^2-$	- m -	$- cm^2 -$
Acr	2	0.3	0.8	2.2	7.6
Apr	1	0.2	0.2	1.8	7.3
Cas	2	1.1	3.6	2.9	13.5
Dal	2	0.5	1.0	2.8	11.5
Ent	3	0.7	2.7	3.3	10.0
Ery	3	0.7	4.0	3.1	21.8
Fal	3	2.2	11.5	5.9	32.4
Gli	1	1.0	1.9	2.8	8.5
Leb	3	0.2	0.0	1.6	1.9
Man	3	0.9	1.5	3.0	9.2
Mea	2	1.3	3.0	4.7	24.5
Mim	1	1.1	2.3	3.4	7.2
Pro	2	0.6	0.9	1.7	5.2
Sam	1	0.6	1.0	2.3	10.6
SCS	1	1.8	9.2	4.2	34.3
LSD1		1.4	5.4	1.9	13.4
LSD2		1.6	5.9	2.0	14.7

Appendix Table G.3 Adjusted mean height growth of augmented species at Waipio

		AGE			
SPECIES	REP	.25	.50	.75	1.0
		m			
Acr	1	0.1	0.7	1.4	2.4
Apr	1	0.1	0.4	0.7	1.5
Cas	2	0.3	0.8	1.3	2.3
Dal	4	0.1	0.2	0.0	0.4
Ent	2	0.2	0.9	1.8	2.7
Ery	3	0.2	0.5	0.6	1.3
Euc	3	0.4	1.1	2.1	3.8
Fal	4	0.4	1.7	2.1	3.1
Gli	2	0.2	0.6	1.4	2.4
Man	4	0.2	0.4	0.9	2.0
Mea	1	0.3	1.2	2.3	3.8
Mim	3	0.1	0.6	0.8	0.9
LSD1		0.2	0.4	0.6	0.8
LSD2		0.2	0.4	0.6	0.8

Appendix Table G.4 Adjusted mean height growth of augmented species at Niulii

		AGE			
SPECIES	REP	.25	.50	.75	1.0
		m			
Acr	2	0.0	0.2	0.4	1.1
Apr	2	0.1	0.3	0.1	0.4
Cas	4	0.2	0.5	1.1	1.7
Dal	1	0.0	0.4	0.4	0.7
Ent	2	0.2	0.2	0.2	0.4
Ery	4	0.1	0.2	0.4	0.7
Euc	4	0.4	0.7	1.7	2.7
Fal	3	0.1	0.3	1.5	2.5
Gli	3	0.2	0.2	0.2	0.4
Man	1	0.1	0.3	0.7	1.6
Mea	3	0.4	1.3	2.4	3.3
Mim	1	0.1	0.6	1.7	2.4
LSD1		0.1	0.2	0.5	0.7
LSD2		0.1	0.2	0.5	0.8

Basal area

Appendix Table G.5 Adjusted mean basal area growth of augmented species at Waimanalo

SPECIES	REP	AGE .25	.50	.75	1.0	1.5
		cm^2				
Cit	1	0.2	1.3	1.9	3.6	14.1
Gli	3	0.7	3.0	5.9	7.4	12.9
Leb	2	0.2	1.3	2.7	4.4	21.9
Lys	3	0.2	0.9	2.4	3.3	7.0
Mel	2	0.3	2.3	2.5	3.2	9.2
LSD1		1.1	4.0	5.4	8.6	15.5
LSD2		1.1	4.1	5.6	8.9	16.2

Appendix Table G.6 Adjusted basal area means of augmented species at Waipio

		AGE			
SPECIES	REP	.25	.50	.75	1.0
		cm²			
Acr	1	0.0	1.2	5.1	12.1
Apr	1	0.0	1.1	2.6	3.9
Cas	2	0.1	0.9	1.1	2.1
Dal	4	0.0	0.0	0.0	0.0
Ent	2	0.3	3.3	6.3	12.5
Ery	3	0.2	2.3	4.1	5.9
Euc	3	0.3	3.2	7.2	17.8
Fal	4	0.4	4.7	10.0	14.8
Gli	2	0.5	1.6	4.2	11.6
Man	4	0.2	0.7	2.5	5.4
Mea	1	0.2	2.3	6.8	9.8
Mim	3	0.0	0.8	1.6	1.7
LSD1		0.4	2.3	3.4	7.0
LSD2		0.4	2.5	3.7	7.6

Appendix Table G.7 Adjusted basal area of augmented species at Niulii

		AGE			
SPECIES	REP	.25	.50	.75	1.0
		cm^2			
Acr	2	0.0	0.0	0.5	2.9
Apr	2	0.0	0.0	0.0	1.2
Cas	4	0.0	0.2	1.1	3.6
Dal	1	0.0	0.0	0.5	1.1
Ent	2	0.1	0.1	0.1*	0.7
Ery	4	0.1	0.1	1.2	3.1
Euc	4	0.3	2.1	8.5	12.7
Fal	3	0.0	0.3	3.3	9.8
Gli	3	0.2	0.2	0.3*	1.5
Man	1	0.1	0.2	2.7	11.5
Mea	3	0.2	3.5	11.7	16.6
Mim	1	0.0	0.6	4.0	8.5
LSD1		0.1	0.5	2.6	4.3
LSD2		0.1	0.5	2.9	4.7

* Adjustment of means resulted in negative values, thus unadjusted values are shown