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Intercropping, Weeding and Spacing Effects on Growth and Nutrient Content in *Leucaena leucocephala* at Morogoro, Tanzania

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ABSTRACT

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The study was conducted to evaluate the suitability of *Leucaena leucocephala* for fuelwood and pole production using agroforestry in a semiarid environment. The trial site, planted in February 1980 at Mafiga, Morogoro, was a split plot design with four main plots: (1) *Leucaena* intercropped with maize; (2) *Leucaena* intercropped with beans; (3) *Leucaena* monoculture and clean weeded; and (4) *Leucaena* monoculture and spot weeded. Each main plot included three tree-spacing subplots, 3×3 m, 4×4 m and 5×5 m, and replicated four times. Each of the subplots comprised at least 25 trees.

Twenty-four trees representing all the diameter classes in the trial were harvested in March 1984 and used to determine mean plot height, volume and biomass by regression analysis. Nutrient content was determined using routine laboratory methods. Mean subplot height varied from 7.0 to 7.8 m, whereas diameter at the stem base varied from 10.2 to 14.9 cm. The volume varied from 10.3 to 32.8 m^3 ha^{-1} and total biomass values from 13.5 to 31.1 metric t ha^{-1}. Trees under spot weeding showed the poorest growth, whereas those under clean weeding showed the best. Spacing influenced both diameter and height growth, with the widest spacing producing the largest trees. Because of a higher tree population, however, the lowest spacing showed the highest volume and biomass production. Intercropping with maize and beans showed significantly higher volume and biomass production as compared to spot weeding. However, there was no significant difference between trees under clean weeded treatments and those under intercropping. Nutrient concentrations were high and comparable to other pasture legumes. The total nutrient accumulation in the aerial biomass in kg ha^{-1} was 201, 25.1, 267, 106, 34 and 18 for nitrogen, phosphorus, potassium, calcium, magnesium and sodium, respectively.

INTRODUCTION

More than 15 years ago, King's (1968) review of agroforestry drew attention to the advantages of multiple cropping systems which combined trees and

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annual or relatively short-lived agricultural crops. This led to a great deal of interest in long established but relatively unknown agroforestry practices of this kind, particularly among foresters who saw the possibility of much more widespread tree planting as a way to address soil and water conservation problems and fuelwood shortages.

Much effort has since been made to identify global agroforestry systems and the associated tree species (Evans and Rombold, 1984; Fernandes et al., 1984; Torquebiau, 1984). Recent surveys in Malawi, Nepal and Tanzania (Arnold, 1984; O'Kting'ati et al., 1984) indicate that tree species are intercropped in farms mainly for their multiple use and rarely for just one benefit. In Tanzania, the commonest tree species provide two or more of the following — fuelwood, food, poles, fodder, shade, medicine and timber (O'Kting'ati et al., 1984).

The woody perennial *Leucaena leucocephala* (Lam) de Wit has not been used widely in agroforestry systems in East Africa (Fernandes et al., 1984; O'Kting'ati et al., 1984). However, it has a great potential for intercropping with food crops (Maghembe and Redhead, 1982), improvement of soil fertility through biological nitrogen-fixation (Högberg and Kvanstrom, 1982) and it produces an excellent fodder (National Academy of Sciences, 1977). In addition *L. leucocephala* grows fast, is a prolific seeder and can be easily regenerated by coppice .

As a first step in promoting the exploitation of the multiple uses of *L. leucocephala*, the tree was grown under intercropping with maize and beans and in monoculture at the university farm, Mafiga, Morogoro. Data on initial growth, food crop yield and biological nitrogen-fixation have been published earlier (Maghembe and Redhead, 1982; Högberg and Kvanstrom, 1982). This paper presents data on the growth, yield and nutrient content of *L. leucocephala* four years after planting. At this stage, the trees can be clear felled for fuelwood and poles.

MATERIALS AND METHODS

The study area

The trial was established at the university farm, Mafiga, Morogoro, 6°50′S latitude, 37°40′E longitude at 500 m a.s.l. The annual total rainfall at Mafiga varies between 500 and 1200 mm with a mean of 860 mm. The rainy season stretches from December to May with a dry spell in January and February. The estimated total potential evapotranspiration is 1430 mm per annum. Monthly mean temperature maxima vary between 28 and 34°C and minima between 19 and 25°C. The area is nearly level, with a slope of less than 5%. Soils in the area have been described earlier (Kesseba et al., 1972). They are formed by alluvial deposits and thus are very uniform, being sandy loams, pH in water, 6.5; organic carbon, 0.7%; total Kjeldahl nitrogen, 0.04%; Bray 1 available phosphorus, 8.8 ppm and exchangeable bases 10.5 meq/100 g.

Experimental design

A local seed source of the 'Hawaiian giant', *L. leucocephala*, was used for the study. Container grown seedlings were planted in February 1980 in ploughed and harrowed land that had been fallow for several years. The experiment was arranged in a split plot design with food crops (maize or beans) and weeding regimes (clean weeding or spot weeding) forming the main plots and tree spacing forming the subplots. Four replications of the main treatments and subplots were used. Crop rotation was not practiced.

The main plots consisted of four treatments planted with *L. leucocephala* and intercropped or weeded as follows:

1. Maize — planted in March 1980, February 1981 and March 1983 with a spacing of 75 cm between rows and 30 cm within rows. A circle of 50 cm radius was left unplanted around each tree.
2. Beans — planted in April 1980, 1981 and 1982 with 40 cm between rows and 20 cm within rows. A circle of 20 cm radius was left unplanted around each tree.
3. Clean weeding — *L. leucocephala* monoculture kept free from weeds by regular harrowing and hoeing around each tree.
4. Spot weeding — Spot weeding using a hoe to remove weeds around each tree so that the tree stands on a weedless circle of 50 cm radius.

Three tree spacing subplots were included in each main plot. They included *L. leucocephala* planted at 3×3 m, 4×4 m and 5×5 m spacing. The subplots were 20×20 m square containing 49, 36 and 25 trees for the 3, 4 and 5 m spacing, respectively. Nine trees in the middle of each subplot were permanently marked and used as the measurement unit to overcome bias from border rows (Zavitkovski, 1981). The whole experiment covered an area of 2.56 ha.

Analysis of biomass and nutrients

In March 1984, the basal diameter (tree diameter at 10 cm from ground level) of each tree in the experiment was determined and the trees arranged into one-cm basal diameter classes. Twenty-four trees, representing all the diameter classes in the trial, were felled and their representative basal diameters and heights measured. They were then separated into foliage, branches and stems, and weighed in the field. Foliage and branch samples were taken from each sample tree for dry matter determination. Before weighing, stems were separated into 2-m logs and their top and bottom diameters measured. Samples of stem discs (5 cm long) were cut from each sample tree to represent the bottom, middle and top of the stem then weighed. The samples were dried to equilibrium weight at 70°C and used to determine the dry weight of individual sample tree stem, branches and foliage by simple extrapolation. Volume was determined by Smalian's method (Husch et al., 1983).

Allometric models of the form $\ln Y = a + b \ln B$ were developed separately for stem, branches and foliage (Table 1). In the models, $\ln Y$ represented the natural logarithm of tree component dry weight, $\ln B$ the natural logarithm of basal diameter while a and b were regression coefficients. Similar equations were developed to relate tree height and tree volume to basal diameter (Table 1).

The equations were used to determine tree component biomass for each tree in a subplot. Data were corrected for systematic bias due to logarithmic transformation (Baskerville, 1972). The total tree component biomass for each subplot was obtained by summation and extrapolated to a hectare basis.

The dried branch and foliage samples from each tree were subsampled and ground in a Wiley Mill for chemical analysis. Stems were sawn across and the saw dust collected for nutrient analysis. N was determined by the macro-Kjeldahl procedure. Subsamples for the determination of other elements were ashed in a muffle furnace at 450°C and then digested in 6N HCl. Portions of these solutions were used for colorimetric determination of P, determination of K and Na by flame photometry, and for Ca and Mg determination by atomic absorption spectroscopy.

Data on tree growth were subject to standard analysis of variance and significant means were compared by Duncan's new multiple range test as described by Alder and Roesler (1972).

RESULTS AND DISCUSSION

Tree growth and biomass production

The trees sampled for the current analysis varied from 4.0 to 25.7 cm and 4.9 to 9.3 m in basal diameter and height, respectively. The above-ground dry

TABLE 1

Regression equations for predicting height, volume and above ground biomass for four year old *Leucaena leucocephala* at Mafiga, Morogoro

Parameter estimated	Equation	Correlation coefficient r	Standard error[a], $Sy{\cdot}x$
Height	$\ln(\text{HT}) = 1.265 + 0.301 \ln D^{b}$	0.88	0.73
Volume	$\ln(V) = -8.767 + 0.960 \ln D$	0.95	0.05
Foliage biomass	$\ln(Y)^{c} = -3.323 + 1.851 \ln D$	0.93	2.68
Branch biomass	$\ln(Y) = -3.829 + 2.269 \ln D$	0.89	9.50
Stem biomass	$\ln(Y) = -2.275 + 1.935 \ln D$	0.96	9.95

[a]Data used to compute $Sy{\cdot}x$ were in kg.
[b]D = basal diameter.
[c]Y = tree component.

matter of the trees was calculated to be: foliage, 0.23–16.80 kg; branches, 1.15–43.49 kg; and stem, 1.84–50.78 kg. The large trees were, in relation to stem diameter, much heavier than the small ones because of multiple stem formation among dominant trees.

Weeding practices significantly influenced diameter, volume and both tree component and total biomass production (Tables 2, 3 and 4). In all cases, spot weeded plots showed the lowest growth.

Compared to spot weeding, clean weeding increased total above ground biomass production by 60% and volume production by 57%. These results are often encountered in the establishment of tree crops, especially under semiarid conditions (Allan, 1976), because of competition for water nutrients and light during the short growing season.

The introduction of maize and beans showed no negative effects on the growth of *L. leucocephala* in diameter, height, volume or biomass production (Tables 2 and 4). Intercropping with maize, however, generally showed lower growth compared to beans or clean weeded *Leucaena* monocultures. In all cases, the reduction in volume and biomass resulting from maize intercropping was less than 10% when compared to the clean weeded monoculture. Therefore, maize and beans can be included in *L. leucocephala* woodlots (at the current spacing) without risking much in fuelwood yields.

Growth in diameter, height, volume and biomass were all influenced significantly by tree spacing (Tables 1 and 2). Whereas the diameter and height increment of individual trees were favoured by wide spacing, total volume and

TABLE 2

Growth and yield of four year old *Leucaena leucocephala* under intercropping with maize or beans and in clean weeded or spot weeded monocultures at Mafiga, Morogoro

Cropping pattern	Spacing (m)	Diameter[a] (cm)	Height[a] (m)	Volume[a] ($m^3 ha^{-1}$)
Intercropped maize	3	11.0 DE	7.3 CDE	31.0 A
	4	12.7 BCD	7.6 BC	22.6 BC
	5	13.3 ABC	7.7 ABC	21.8 C
Intercropped, beans	3	11.5 CDE	7.0 E	27.6 AB
	4	12.5 BCD	7.5 BCD	26.8 ABC
	5	13.8 AB	7.8 AB	23.0 BC
Monoculture, clean weeded	3	10.8 DE	7.4 BCDE	32.8 A
	4	12.9 ABCD	7.6 BC	25.8 ABC
	5	14.9 A	8.1 A	23.3 BC
Monoculture, spot weeded	3	10.2 E	7.0 E	27.0 AB
	4	10.4 E	7.0 E	14.5 DE
	5	11.3 CDE	7.1 DE	10.8 E

[a]Within each column, means followed by the same letter do not differ significantly at the 0.05 level.

biomass per hectare increased under close spacing because of a higher tree density. Except for height, these results are in general agreement with findings in the literature (Wang, 1977; Guevarra et al., 1978; Van den Beldt, 1982). Tree height may be influenced more by site conditions than by spacing (Smith, 1962), except at very high stocking (Van den Beldt, 1982). The soils at the experimental site were quite uniform, so height growth differences due to site

TABLE 3

Biomass production of four year old *Leucaena leucocephala* under intercropping with maize or beans and in clean weeded or spot weeded monocultures at Mafiga, Morogoro

Cropping pattern	Spacing (m)	Tree component biomass[a] (t/ha)			
		Leaves	Branches	Stem	Total
Intercropped, maize	3	4.4 AB	9.7 AB	13.9 ABC	28.0 AB
	4	3.1 BCDE	7.4 B	11.2 ABCD	21.7 B
	5	2.9 CDE	7.4 B	10.5 CDE	20.8 BC
Intercropped, beans	3	4.6 A	10.3 A	16.2 A	31.1 A
	4	3.7 ABC	9.3 AB	12.1 ABC	25.1 AB
	5	3.6 ABC	7.5 B	11.1 BCD	22.2 AB
Monoculture, clean weeded	3	4.4 AB	10.4 A	15.7 AB	30.5 A
	4	3.5 ABC	8.6 AB	12.4 ABC	24.5 AB
	5	3.1 BCDE	8.1 AB	11.2 ABCD	22.4 AB
Monoculture, spot weeded	3	3.7 ABC	8.2 AB	13.6 ABC	25.5 AB
	4	1.7 E	3.4 C	6.9 DE	12.0 C
	5	2.0 DE	4.6 C	5.8 E	12.4 C

[a]Within each column, means followed by the same letter do not differ significantly at the 0.05 level.

TABLE 4

The effect of intercropping and weeding on volume and biomass production by four year old *Leucaena leucocephala* at Mafiga, Morogoro

Cropping pattern	Volume (m^3 ha^{-1})	Biomass[a] (t ha^{-1})			
		Leaves	Branches	Stem	Total
Intercropping, maize	25.4 A	3.5 A	8.2 A	11.9 A	23.6 A
Intercropping, beans	25.8 A	3.8 A	9.0 A	13.1 A	25.9 A
Monoculture, clean weeded	27.3 A	3.7 A	9.0 A	13.1 A	25.8 A
Monoculture, spot weeded	17.4 B	2.5 B	5.4 B	8.8 B	16.7 B

[a]Within each column, means followed by the same letter do not differ significantly at the 0.05 level.

class variations were not detected. The differences in height can therefore be ascribed to within-plot competition .

Data have recently been accumulated on the field performance of *L. leucocephala* plantings in terms of growth, volume and biomass production (National Academy of Sciences, 1977; Ralwaini et al., 1982; Van den Beldt, 1982; Van den Beldt and Brewbaker, 1983; Hu and Kiang, 1982). However, direct comparisons between our data and those in the literature are hampered by differences in stocking, site and the treatments employed. The current study examined growth and production in plots of 1250, 900 and 625 trees per ha compared to data of stands with a stocking level of 5000–40,000 trees per ha reported in the literature (Visuttipitakul et al., 1983; Ralwaini et al., 1982). Under the best conditions and at high stocking, *L. leucocephala* may yield 20–40 $m^3 ha^{-1} y^{-1}$ and 20–25 t $ha^{-1} y^{-1}$ in volume and biomass, respectively (Visuttipitakul et al., 1983; Van den Beldt and Brewbaker, 1983).

The mean annual increment for our trial was of the order of 4.3–6.8 $m^3 ha^{-1}$ for volume and 4.2–6.5 t ha^{-1} for biomass. These yield levels could be increased by raising the stem density per ha, although increasing it to more than 2000 stems per ha would be unadvisable given a semiarid environment. In addition, such an increase in stocking would defeat the objectives of agroforestry. In any case, this yield data is comparable to the yield of three-year old plantings of *Eucalyptus tereticornis* in the same area (Ahimana, 1982) and to the yield of closely-spaced culture plantations of some hardwood species in the southeastern United States (Wittwer and Immel, 1980). Of most significance, however, is that fuelwood can be harvested from *L. leucocephala* in the relatively short period of four years.

Fuelwood consumption rates vary from 1.0–2.0 m^3 per capita (Arnold and Jongma, 1978; O'Kting'ati, 1984) , the high consumption of 2.0 m^3 per capita being for communities close to fuelwood sources. Assuming a fuelwood consumption level of 2.0 m^3 per capita at Morogoro, a hectare of four-year old *L. leucocephala* at 3 m spacing and under intercropping would produce enough fuelwood for two households of six people each. This benefit alone would save nearly 500 man-days per annum used by the households to procure fuelwood. The stands of *L. leucocephala* would also provide fodder and poles and would relieve the families of the sometimes unrewarding task of fuelwood collection.

These benefits are in addition to soil improvement through litter fall and biological nitrogen-fixation. The extent to which *L. leucocephala* litter has improved the physical and chemical properties of soil at Mafiga has not yet been quantified. It is, however, considered to be significant given that over 2.5 t of litter fall on the soil annually in three- to four-year old *L. leucocephala* stands (Maghembe, unpublished data).

Data on biological nitrogen-fixation show that 110 kg of elemental nitrogen (equivalent to 550 kg fertilizer-grade ammonium sulphate with 20% N) are fixed annually by *L. leucocephala* in young plantations at Mafiga (Högberg and Kvanstrom, 1982) . The contribution of the fixed nitrogen to soil fertility at Mafiga is therefore higher than the recommended level of inorganic nitrogen fertilizer for growing maize in the area (Singh and Uriyo, 1980). In relation to nitrogen, growing *L. leucocephala* under short rotations of three to four years can therefore be used effectively to overcome the need for the traditional fallow periods needed to replenish soil fertility in tropical soils under shifting cultivation (Nye and Greenland, 1960).

These findings are of great significance in view of the great pressure on land for cultivation from the fast growing populations in the tropics. The high populations have meant short fallow periods, low soil fertility and lower yields per unit of land. It is therefore recommended that for semiarid areas similar to Mafiga, *L. leucocephala* woodlots be used under intercropping or in monocultures to meet the needs of fallowing.

Nutrient concentration and uptake

Nutrient concentration values in this study are average values for tree components of all trees analysed for biomass, as nutrient concentration variations between treatments were not determined (Table 5). For the nutrients studied, the concentration values in the foliage were generally lower than those reported by other workers (Hutton, 1982), probably reflecting differences in our sampling procedures. In this study a composite sample of leaves from each sample tree was taken randomly to include all categories of the foliage, i.e. young, mature and dying leaves. Another important source of variation is site conditions. However, the values presented (Table 5) are within the range reported for *L. leucocephala* (National Academy of Sciences, 1977) and are generally comparable to other forage legumes (Ahmed and Quilt, 1980; Maghembe et al., 1983). As often reported for other tree species (Lundgren, 1978; Singh, 1982; Maghembe et al., 1983), the concentration of nutrients was generally highest in the foliage, decreasing in the order: foliage > branches > stem. The advantage of a proportionately greater amount of nutrients in the foliage and

TABLE 5

Nutrient concentrations in different tree components of four year old *Leucaena leucocephala* at Mafiga, Morogoro

Tree component	Nutrient concentration (%)					
	N	P	K	Ca	Mg	Na
Leaves	2.31	0.13	1.96	1.14	0.40	0.08
Branches	0.95	0.16	1.30	0.35	0.14	0.10
Stem	0.42	0.07	0.84	0.36	0.08	0.06

branches (Table 6) is that these components are likely to be left at the site during conventional tree harvesting. For example, whereas the mean contribution of foliage and branches to the total biomass is only 49% (Table 4), these components together hold respectively 76%, 68%, 63%, 61%, 72% and 60% of the total N, P, K, Ca, Mg, and Na in the aerial biomass (Table 6). Conventional harvesting would therefore remove only negligible amounts of nutrients from *L. leucocephala* stands at Mafiga, Morogoro.

Multiple use of the species under agroforestry entails the use of the foliage for fodder and both branches and stems for fuelwood. This total tree utilization is similar to whole tree harvesting as practiced in industrial forestry (White, 1974). When repeated often, under short rotations (3–4 y) using coppices, a sustained high production may not be assured in the long term because of frequent removals of nutrients held in the biomass (Table 6). Therefore, the yield of *L. leucocephala* in successive rotations needs to be monitored carefully for possible deleterious effects on the site and all its consequences.

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TABLE 6

Distribution of nutrients in components of *Leucaena leucocephala* according to treatments

Treatment	Nutrient accumulation (kg ha^{-1})					
	N	P	K	Ca	Mg	Na
Leaves						
Maize	80.1	4.5	67.9	39.6	13.9	2.8
Beans	91.6	5.2	77.7	45.2	15.9	3.2
Clean weeded	84.7	4.8	71.9	41.8	14.7	2.9
Spot weeded	57.0	3.2	48.3	28.1	9.9	2.0
Branches						
Maize	77.6	13.1	106.2	29.4	11.4	8.2
Beans	85.8	14.5	117.4	32.5	12.6	9.0
Clean weeded	85.8	14.5	117.4	32.5	12.6	9.0
Spot weeded	51.3	8.6	70.2	19.4	7.6	5.4
Stem						
Maize	49.8	8.3	99.7	42.7	9.5	7.1
Beans	55.2	9.2	110.3	47.3	10.5	7.9
Clean weeded	55.0	9.2	110.0	47.2	10.5	7.9
Spot weeded	36.8	6.1	73.6	31.6	7.0	5.3

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