GROWTH, WOOD YIELD AND ENERGY CHARACTERISTICS OF *LEUCAENA LEUCOCEPHALA, GLIRICIDIA SEPIUM* AND *SENNA SIAMEA* AT AGE FOUR YEARS

ANTHONY AUGUSTUS MAINOO[1] AND FRANCIS ULZEN-APPIAH[2]

[2]AGROFORESTRY DEPARTMENT, I.R.N.R., U.S.T. KUMASI, GHANA

ABSTRACT

Growth, wood yield, specific gravity, calorific value and chemical composition (ie. % Lignin, Alpha-Cellulose and Beta and Gamma-Cellulose Contents) were determined for Leucaena leucocephala, Gliricidia sepium and Senna siamea at age four years. The study was conducted to assess the wood biomass productivity and energy potentials of the species for use as fuelwood.

Trees were spaced 2m x 0.6m (8333 plants/ha) and were established on a gritty clay loamy soil classified as Ferric Acrisol (FAO/UNESCO) with pH ranging between 4.2 and 5.3. There were three blocks each of which carried one tree species. Within each species block, four sampling plots were demarcated and used as replications in a completely randomised design.

Tree height varied from 5.94m for L. leucocephala to 9.16m for S. siamea and diameter at breast height from 4.46cm for L. leucocephala to 5.80cm for S. siamea. Wood yield (on oven-dry weight) of S. siamea was 86.2 t/ha and was the highest. L. leucocephala produced 39.3 t/ha and was the least. Branch of the species contributed between 12 and 24% of total wood yield. Wood specific gravity ranged from 0.63 for S. siamea to 0.67 for L. leucocephala. There was a general decrease in specific gravity from the butt end towards the crown for all the species. Calorific values did not differ significantly between species. However, stems of all species had significantly higher calorific values than branches. Chemical composition varied within and between species. Energy production of S. siamea was 385 x 10^6*Kcal/ha and was the highest for all the species. G. sepium was intermediate between S. siamea and L. leucocephala in all the parameters measured.*

On selection of species for fuelwood plantation establishment, S. siamea would be a better choice than L. leucocephala and G. sepium in terms of higher wood energy production per hectare, (385 x 10^6*Kcal/ha). However, in terms of fuel burning quality expressed as Fuelwood Value Index (FVI) L. leucocephala can be the best (FVI, 2488).*

Key words: *Calorific value, chemical composition, energy productivity, specific gravity, wood yield.*

INTRODUCTION

Woody biomass is the major source of energy in the developing countries of the world. FAO (1986) reported that about 13% of the world's primary energy was derived from woody biomass. According to Davidson (1987), fuelwood production in the year 2000 may be only about 1.5 billion m^3 short of estimated minimum requirement. This coupled with the wood energy demands of the rapidly increasing world population may result in acute fuelwood shortages by the end of this century.

1 Graduate Student - now with ADRA, Ghana, Tamale

In Ghana, fuelwood shortage has been identified as a pressing domestic problem affecting many households (Otsyina, 1989). The need for establishing wood energy plantations have been recognized. However, effective planning of energy plantation programme require adequate information on the energy characteristics of various fast-growing tree species. Anderson et al. (1984) have reported that, the most useful indices of woody biomass quality that influence its suitability for efficient conversion with respect to energy are specific gravity, chemical composition, fuel value and size. Davidson (1987) also reported that suitable species to be selected for bio-energy plantation should have high wood calorific value, ability to produce wood of high specific gravity and capacity for rapid growth on a wide range of sites.

Several multipurpose tree species and shrubs (MPT's) have been recommended in Ghana for use in different land-use systems to reduce or solve the pressing fuelwood problems which face many households in the country (Quashie-Sam et al. 1990). However, quantitative and qualitative documentation and informatioin on energy characteristics of these species are scanty and almost non-existent (Chow and Lucas, 1988). There is the need to investigate and assess the wood productivity, chemical and fuel values of some of the recommended species under the local environmental conditions so as to aid in a better selection of species for fuelwood use. Consequently, the aim of this study was to assess the wood yield and the energy characeristics of three MPT's *Leucaena leucocephala, Gliricidia sepium* and *Senna siamea*. These species have been widely planted in many parts of the country in response to the call for tree planting to improve the environment, satisfy local demands and to create a sustainable wood energy development programme.

The objectives of the study were to determine growth (ie. total height, diameter at breast height) and wood yield (ie. of branch and stem on volume and dry weight basis); the chemical composition (ie. % Lignin, Alpha-Cellulose and Beta and Gamma-Cellulose) of branch and stemwood and energy characteristics (ie. specific gravity and calorific value) of branch and stemwood of the species.

METHODOLOGY

Each of the three species *Leucaena leucocephala, Gliricidia sepium* and *Senna siamea* were established in separate blocks measuring 30 x 12m. The trees were spaced 2m between - rows and 0.6m within - rows giving a stand density of 8333 plants/ha. When the trees were at age four years (June 1990 - June 1994), four sampling plots each measuring 6.6 x 2m were demarcated within each species block. The sampling plots were used as replicates in a Completely Randomised Design.

The study was conducted at the Institute of Renewable Natural Resources farm, University of Science and Technology, Kumasi. The study site is located about 287m a.m.s.l (latitude 06° 43'N, longitude 01° 36'W) in the semi-deciduous rainforest ecological zone of Ghana. The area experiences a dry period from December to February. Mean annual rainfall ranges between 1300 and 1600mm. Temperature range is 22°C to 31°C with a an average of 26.2°C. Soils of the area belong to the Asuansi series, classified as Ferric Acrisol (FAO/UNESCO) or Oxic Haplustalf (USDA) and are moderately deep well drained, gravelly with concretions and with pH ranging between 4.2 and 5.3.

All trees within each sampling plot were measured for diameter at breast height (DBH). The trees were then severed at 20cm from the groundline and measured for total height. The tree with average dimensions of height and DBH or closest to the average dimensions was selected as the sample tree. A total of twelve sample trees, four from each species were used for the determination of chemical composition, specific gravity and calorific value.

Wood Yield

All trees were separated into component parts (stem, branches and leaves). Fresh weights of the woody components were measured and recorded. Moisture content of small samples of each component part was determined and used to convert component fresh weight to oven-dry weight. A preliminary approximation of bole volume of the species was calculated from Spurr's (1952) equation by which volume is represented as:-

$$Vp = \pi r^2 h\ (0.5) \ldots\ldots\ldots\ldots \text{eqn (1)}$$

where r = bole radius at breast height
h = tree height

Chemical Composition

Stem and branch sub-samples of sample tree were ground separately in a Willey mill and screened. The fractions passing through 40 mesh screen (0.40mm diameter) but retained on 60 mesh screen (0.25mm diameter) was used for the analyses following the Technical Association of Pulp and Paper Industry (TAPPI) standard and suggested methods which were:-

Extraction free sample preparation, T6m - 73;
Lignin determination, T13m - 54;
Alpha, Beta and Gamma-Cellulose determination, T203 OS - 74.

Specific gravity

A total of 20 discs (10 stem discs and 10 branch discs) each of thickness 2.5cm were cut from along the lengths of each sample tree. These were oven dried at 103 $\pm$ 2°C, weighed and dipped into hot paraffin to give the samples waterproof coating and re-weighed. The weight of an equal volume of water was determined by the water displacement method as described in the standard and suggested methods of TAPPI (1972). Specific gravity was then calculated as the ratio of the oven-dry weight of the disc over the weight of an equal volume of water.

Calorific Value

The adiabatic bomb calorimeter method was used. Test samples of weight approximately 0.7g were sawn from each disc cut from along the lengths of sample tree stems and branches. The test sample was placed in a crucible inside the bomb and subjected to rapid combustion at 25 atmospheres. Thermometer readings of the calorimeter were monitored until the maximum temperature was recorded. Temperatures thus recorded were corrected for by radiation loses and the gross calorific value of each test sample was calculated using the temperature correction formula from Mtetwa and Vilakati (1983) as:

$$\text{Gross calorific value} = \frac{WE_T \times C_w \times \Delta TC}{w} \quad \text{eqn. (2)}$$

Where WE_T = Total water equivalent
C_w = Specific heat capacity of water
ΔTC = corrected rise in temperature
w = weight of wood sample

Energy Production

This was calculated following the method used by Bunyavejchewin et al. (1989). The product of component dry wood yields per hectare and the respective calorific value was determined as energy production.

Data Analysis

For growth and wood yield, statistical analyses were performed to determine differences in the test species in tree height, DBH, wood dry weight and wood volume. For specific gravity, chemical composition and calorific value, statistical analyses were performed to determine differences between and within species. These were done using the Least Significant Difference Test for means separation.

RESULTS AND DISCUSSION

Growth and Wood Yield

Results of growth and wood yield of the species are given in Table 1. The species differed significantly in height, DBH and wood yield. Height of *Senna siamea* (9.61m) was significantly higher than *Gliricidia sepium* (6.71m). *Leucaena leucocephala* gained tree height of 5.94m and was significantly lower than the other species. There was no significant difference between DBH of *S. siamea* (5.80cm) and *G. sepium* (5.68) however, DBH of *L. leucocephala* (4.64) was significantly lower. Wood yield (on oven dry weight) of *S. siamea* was 86.15 t/ha and was significantly higher than the yields of *G. sepium* (40.92 t/ha) and *L. leucocephala* (39.30 t/ha). The dry wood yields of *G. sepium* and *L. leucocephala* were not significantly different. Branches of the species contributed between 12 and 24% of total wood yield. Total fresh wood volume of the species at age four years ranged from 56^3/ha for *L. leucocephala* to $137m^3$/ha for S. siamea. Fresh total and stemwood volume of the species were significantly higher for *S. siamea* than for *G. sepium* and for *G. sepium*, significantly higher than *L. leucocephala* (Table 1).

Annual mean total fresh wood volume increment of the best performing species *S. siamea*, was $34m^3$/ha/yr (NAS, 1980). *L. leucocephala* produced an annual wood volume increment of $14m^3$/ha/yr and was largely below the annual expected average wood volume of between 30 and 40 m^3/ha/yr but the productivity of *G. sepium* of $25m^3$/ha/yr compared favourably with reported yields (Davidson, 1987; *L. leucocephala* grows and performs poorly on soils of pH < 6.0 and will usually fail to produce adequate biomass on more acid soils (pH < 5.5). However, *S. siamea* and *G. sepium* perform better on soils with pH from neutral to acidic (Davidson, 1987; NAS, 1980). The pH of soils of the study site averaged 4.5 which is far below the tolerable range of *Leucaena* growth but are within the favourable range for the good growth of *S. siamea* and *G. sepium*. Therefore, the comparatively lower heights, DBH and wood yield attained by *L. leucocephala* could have been due to unfavourable soil pH of the study site. The higher growth and yield performance of *S. siamea* compared to the other species could be attributed to a more suitable site and environmental conditions for the species.

Chemical Composition

Chemical composition varied between and within species. Percent Klason-Lignin (K-Lignin), Alpha-Cellulose and Beta and Gamma-Cellulose in stem and branch components of all species have been presented in Table 2.

Percent K-Lignin of stems ranged from 21.91% for *S. siamea* to 32.6% for *L. leucocephala* whiles branch % K-lignin ranged from 21.54% to 30.73% respectively. Stem and branch % K-Lignin of *G. sepium* were between those of *L. leucocephala* and *S. siamea*. *L. leucocephala* stems contained significantly lower % Alpha-cellulose of 38.2%. Alpha-Cellulose content in stem components of *S. siamea* and *G. sepium* did not differ significantly. Both Alpha-Cellulose and Beta and Gamma-Cellulose levels did not differ significantly between branch components of species.

Table 1: Mean Height, DBH and Wood Yield of Sample Trees of *Senna siamea, Gliricidia sepium* and *Leucaena leucocephala* at age four years.

Variable/Component	Species		
	S. siamea	*G. sepium*	*L. leucocephala*
DBH (cm)	5.80a ± 0.22	5.68a ± 0.22	4.46b ± 0.22
Height (m)	9.61a ± 0.15	6.71b ± 0.15	5.94c ± 0.15
DRY WEIGHT (t/ha)			
Stem	76.20a ± 2.15	32.71b ± 2.15	30.35b ± 2.15
Branch	9.95a ± 0.22	8.21a ± 0.22	8.95a ± 0.22
Total	86.15a ± 2.23	40.92b ± 2.23	39.30b ± 2.23
Volume (m^3/ha)			
Stem	121.44a ± 3.23	79.62b ± 3.23	42.42c ± 3.23
Branch	15.83 ± 0.34	20.23a ± 0.34	13.11b ± 0.34
Total	137.27a ± 3.53	99.85b ± 3.53	55.53c ± 3.53

Variables/components of species followed by a common letter are not significantly different ($P \leq 0.05$) as determined by LSD test.

Generally, stems of all species had higher lignin content than branches. For *L. leucocephala* and *G. sepium*, stem contained significantly higher % K-lignin and conversely, lower cellulose contents than branches. Browning (1975) reported average chemical composition of hardwoods as; 22% for Lignin; 43% for Cellulose and about 35% for hemicellulose. Chow and Lucas (1988) studied the chemical composition of several four year old multipurpose species and reported lignin content of 28.3% for *S. siamea*, and 23.1% for *G. sepium*. Chow et al. 1983, also studied the chemical composition of 2 year old hardwood species and reported average lignin content of 22-29%, Alpha Cellulose of 40% and Holocellulose content of 60-71%. The authors attributed the difference in chemical composition between averages they obtained and other reported averages, to growing site and age differences. Worster and Sugiyama (1962) concluded from a study of 200 trees of five species that as conditions for growth at a site become more favourable the proportion of carbohydrate formed rises and conversely a fall in the proportion of lignin.

Lignin contents of the three species obtained in this study were higher than reported averages. This could be due to growing site differences.

Sarkanen and Lugwig (1971) investigated the chemical contents of several hardwood species and reported higher lignin content at the base of stem swhich diminished progressively towards the branches. The authors attributed this trend to differences in distributioin of early and latewood cells within the tree. Early wood cells which usually contain higher lignin content than latewood cells were proportionately greater in number than latewood cells at the base of trees than at the top. Sarkanen and Lugwig (1971) and Middleton (1989) further reported that, various environmental factors especially wind speed could influence lignin contents in late and early wood cells and could therefore affect the chemical contents of the cells and hence within the trees.

The significant differences in lignin content between stem and branch component of species in this study could probably have resulted from differences in the distribution of cell types within the trees.

Specific Gravity

At age four years, reported wood specific gravity of multipurpose trees ranged from 0.45 to 0.70 (Chow and Lucas, 1988). NAS (1980) also reported range of specific gravity of some multipurpose trees as follows: *S. siamea* 0.60 - 0.80; *G. sepium*, 0.45 - 0.72 and *L. leucocephala* 0.48 - 0.72. These values confirm results obtained in this study.

Chemical composition of components of species followed by a common letter are not significantly different (P ≤0.05) as determined by LSD test.

Mean specific gravity of sections along the stems (from butt end towards branches) are given in Table 3. Specific gravity generally decreased from the butt end towards branches for all the species. This axial variations in specific gravity in this study conform to results reported by Chapola and Ngulube (1990).

Calorific Value

Calorific values of both stems and branches of the species did not differ significantly (P ≤ 0.05) (Table 4). Calorific values of stem components of the species were as follows: *L. leucocephala*, 4703 cal/g; *G. sepium*, 4569 cal/g and *S. siamea*, 4480 cal/g. The results obtained in this study were within values reported by Puri et al. (1994) of 4243-4937 cal/g for multipurpose hardwoods, and Davidson (1987) of 4200-4900 cal/g for most multipurpose tree species.

Table 2: Chemical Composition of Components of Sample Trees of *Senna siamea, Gliricidia sepium* and *Leucaena leucocephala* at age four years.

Variable/Component	Species		
	S. siamea	*G. sepium*	*L. leucocephala*
% Klason-Lignin			
Stem Branch	21.9c ± 0.30 21.5c ± 0.32	27.1b ± 0.30 26.4b ± 0.32	32.6a ± 0.30 30.7a ± 0.32
% Alpha-Cellulose			
Stem Branch	42.9a ± 0.73 45.0a ± 1.65	43.4a ± 0.73 43.6a ± 1.65	38.2b ± 0.73 41.7a ± 1.65
% Beta and Gamma-Cellulose			
Stem Branch	33.5a ± 0.78 31.7a ± 1.10	29.6b ± 0.78 31.1a ± 1.10	28.9b ± 0.78 27.6a ± 1.10

Table 3: Mean specific gravity of sample trees of *Senna siamea, Gliricidia sepium* and *Leucaena leucocephala* at age four years.

Variable/Component	Species		
	S. siamea	*G. sepium*	*L. leucocephala*
Stem	0.64a $\pm$ 0.01	0.67a $\pm$ 0.01	0.69a $\pm$ 0.01
Branch	0.59a $\pm$ 0.01	0.61a $\pm$ 0.01	0.62a $\pm$ 0.01
% of Stem Height (from butt end)			
0 - 20	0.69	0.68	0.86
20 - 40	0.64	0.68	0.72
40 - 60	0.62	0.66	0.66
60 - 80	0.63	0.64	0.64
80 - 100	0.63	0.66	0.58

Component specific gravity of species followed by a common letter are not significantly different ($P \leq 0.05$) as determined by LSD test.

Table 4: Mean Calorific Value and Energy Production of Sample Trees of *Senna siamea, Gliricidia sepium* and *Leucaena leucocephala* at age four years.

Variable/Component	Species		
	S. siamea	*G. sepium*	*L. leucocephala*
Calorific Value (cal/g)			
Stem	4480a $\pm$ 49	4569a $\pm$ 49	4703a $\pm$ 49
Branch	4334a $\pm$ 41	4252a $\pm$ 41	4365a $\pm$ 41
Energy Production (Kcal/ha)			
Stem	342×10^6	150×10^6	143×10^6
Branch	43×10^6	34×10^6	39×10^6
Total	385×10^6a	184×10^6b	182×10^6b

Stem and branch calorific value of species and total energy production of species followed by a common letter are not significantly different ($P \leq 0.05$) as determined by LSD test.

For all species, stems had significantly higher calorific values than branches confirming the work of Bunyavejchewin et al (1989) and Pathak and Gupta (1991) who reported significantly higher mean calorific value for stems than branches for multipurpose trees. Wood having higher lignin content and specific gravity have greater calorific value (Baily, 1979; Haygreen and Boyer, 1982). In this study *L. leucocephala* had significantly higher % K-Lignin and higher specific gravity than the other species. However, for all the species, calorific values were similar ($P \leq 0.05$) which suggests that other parameters, possibly extractive content could influence the energy levels of the species.

Therefore, an investigation of the extractive content of the species and other chemical that affect heat production may be necessary to produce a more reliable explanation to the relationship between specific gravity and chemical content on calorific value.

Energy Production

Results on energy production have been provided in Table 4. Energy production was computed as the product of the two parameters, calorific value and dry wood production. *S. siamea* could produce 385 x 10^6 Kcal/ha total heat energy and was the highest. *L. leucocephala* could produce 182 x 10^6 while that of *G. sepium* was 184 x 10^6 Kcal/ha. There was no significant difference between the energy productioin of *L. leucocephala* and *G. sepium*.

Differences in energy production of the species could result from differences in the dry wood production between the species. Calorific values of the species were similar ($P \leq 0.05$) therefore, the significantly higher dry wood production of *S. siamea* over the other species resulted in its significantly higher energy production.

Species Ranking

Ranking of species were done in two ways; ranking in terms of wood energy productivity and in terms of wood quality for combustion expressed as Fuelwood Value Index (FVI). The ranking of species in terms of wood quality was done following the Puri et al. (1994) procedure. The authors evaluated fuelwood quality of some multipurpose trees and ranked the species based on energy characteristics of calorific value, specific gravity, moisture content, Fuelwood Value Index (FVI) and Ash.

Table 5 shows the energy characteristics of the species in this study. *L. leucocephala* contained wood with the highest calorific value, specific gravity and percent lignin. *Senna siamea* had the least calorific value, specific gravity and lignin content. Whiles *Gliricidia sepium* had an intermediate values between the two species. *G. sepium* contained the highest moisture compared to the other species.

An ideal fuelwood should have high calorific value, high specific gravity, high lignin content and low moisture content (Davidson, 1987; Haygreen and Boyer, 1982). On this basis FVI was calculated as:-

$$FVI = \frac{\text{Calorific value (cal/g) x specific gravity x \% lignin}}{\text{moisture content (\%)}}$$

taking calorific value, specific gravity and lignin as positive characteristics and high moisture contents as negative characteristics. *L. leucocephala* had the highest FVI. Therefore in terms of wood burning quality, the species can be ranked as:-

L. leucocephala > *S. siamea* > *G. sepium*

The FVI seems to have weakness of only expressing the magnitude of the fuel characteristics of calorific value, specific gravity, moisture and lignin contents of the species but does not give an indication of yield of the woody biomass, hence the energy productivity. However, energy productivity has been reported as one of the essential criteria for selection of tree species forfuelwood plantation establishment (Davidson 1987). Considering the acute shortages and increasing demand for firewood in both rural and urban areas in the country, energy productivity is more likely to be preferred by domestic fuelwood users in the selection of species than the burning quality.

Therefore, a new ranking order based on energy productivity (*Senna*, 385 x 106 Kcal/ha; *Gliricidia*, 184 x 106 Kcal/ha; *Leucaena*, 182 x 10 Kcal/ha) (Table 4) can be *S. siamea* > *G. sepium* = *L. leucocephala*.

Table 5: Fuelwood Characteristics of *Leuceana leucocephala, Gliricidia sepium* and *Senna siamea* at age four years.

Characteristics	Species		
	L. leucocephala	*G. sepium*	*S. siamea*
Calorific value (cal/g)	4703	4569	4480
Specific gravity	0.69	0.67	0.64
Moisture content (%)	39.3	62.3	45.8
Fuelwood Value Index	2488	1255	1327
Lignin content (%)	31.6	26.8	21.7

SUMMARY AND CONCLUSION

Under the local environmental conditions in which the study was conducted *Senna siamea* grew taller (9.61m) and larger (5.80cm) than *Gliricidia sepium* at the age of four years. *L. leucocephala* had the least DBH (4.46cm) and tree height (5.94m). The soil pH at the study site appeared unfavourable for the growth of *L. leucocephala* and could have affected its growth performance.

S. siamea produced 137m^3/ha of wood which contained 86t/ha of dry wood biomass and was the highest among the three species. *G. sepium* and *L. leucocephala* produced about the same quantity of dry wood biomass. However, the volume of fresh wood produced by *G. sepium* was significantly higher (100m^3/ha) than that of *L. leucocephala* (56m^3/ha) because *Gliricidia* contained a greater proportion of moisture. Lignin content, calorific value and specific gravity of *L. leucocephala* were higher than those of the other species.

To determine the quality of wood as fuel, the properties considered were:-

A. FVI which expresses the smooth burning quality of wood (determined in terms of specific gravity, calorific value, lignin content and low moisture content);

B. Heat energy productivity (expressed as the product of dry wood productivity and calorific value).

Senna siamea produced 385 x 10^{6}Kcal/ha of total energy and was higher than the combined energy productivity of both *G. sepium* and *L. leucocephala*. Therefore under the local environmental conditions in which the study was conducted, *S. siamea* can be a better choice for fuelwood plantation establishment than *L. leucocephala* and *G. sepium* if the user's interest is in high energy productivity. However if the users interest is in burning quality, *L. leucocephala* can be a better choice.

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