IN SEARCH OF OPTIMUM ENERGY FROM TREES INDIGENOUS WESTERN TO KENYA

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ABSTRACT This study discusses analytical evaluation of wood fuel energy content of certain indigenous trees in Western Kenya. These trees are used for the provision of timber for general construction work as well as fencing materials for homes and farms in the rural areas.

Specifically, the paper discusses the estimation of major energy parameters such as moisture, ash, and carbon content which affect or contribute to the magnitude of the specific heat energy of the trees. The study also analyses how each one of these factors contributes to the specific heat energy content of the fuel wood.

The external factors affecting the availability of fuel woods such as ecological factors, human influence as guided by convenience, and circumstantial economic factors are also discussed. Consequently, specific policy recommendations for agroforestry management for the area covered in this paper are given.

Key Words: Fuel heat energy; Agroforestry; Volatile matter; Fixed carbon; Charcoal.

INTRODUCTION

Wood and other forms of plant material have continually been put exploited economically by mankind since the beginning of civilization, leading to vast degradation of the environment in certain parts of the world. Some trees have been endangered or brought to extinction through usage in certain parts of the world. In the rural areas, shelter construction and farm fencing are made from trees to provide the necessary protection for man and his animals, and to provide the required protection of his crops or his farm animals against wilder beasts. Selected wood species of trees have also been used by man for the production of furniture, and specific farm implements like farm tool handles, sledges, yokes and other tools. Above all, wood has been used to provide the heat energy required for daily cooking as well as for other heating requirements in the rural areas.

Wood is made of chemical compounds which decompose to simple compounds and eventually to water, carbon dioxide, and other gases when burnt. During the burning process, the intrinsic energy is released in the form of heat energy. This is the heat energy required for, among others, cooking and heating purposes. The other forms of wood usage mentioned above would require certain wood species for specific tasks on a non-routine basis. Cooking, which is done using virtually all types of wood trees, is a daily operation which requires very careful consideration in government's macroeconomic plans, given the kind of degradation this activity poses on the environment. There are other indirect ways of wood destruction such as farming and paper milling. With the increase in population in Kenya, adequate supply of energy in one form or the other is required for cooking purposes. It is difficult for both industrial and domestic energy needs to be satisfied by the installed hydroelectric power capacity of 842 megawatts (Kimura, 1994).

In most cases, trees are cut and used as farm fencing material to protect the crops and to supply domestic energy needs without any provision for replenishment, thereby rendering the regeneration of the trees very difficult to achieve.

A REVIEW OF THE IMPOSSIBLE

In Kenya, more than 80% of the population live in the rural countryside as peasant farmers, depending wholly on their farm produce for their livelihood (Kenya Government, 1993). In these areas, cooking is done largely by use of fuel wood. Conventional sources of heat energy material such as kerosene, gas, and electricity are not accessible to the rural poor. Where such commodities reach commercial centres, the cost is prohibitive to the peasant. Indeed, no incentive is given to the rural households to reduce their excessive dependence on wood material. Wood, therefore, remains the only source of heat energy for all requirements in these areas. In Kenya's urban areas, just as in most developing countries, charcoal is still widely used to supplement the use of burning gas, kerosene, or electricity. For instance, in Africa and India between 50% and 70% of urban dwellers tend meet their cooking needs through the use of wood fuel (Hughart, 1979). In sub-Sahara Africa, every 28 out of 29 people who reside in rural areas use traditional sources of energy for cooking and heating purposes, while in India 23 out of 24 people use the same source of energy. This situation is not different from that in Eastern and Central Africa (Hughart, 1979).

For this reason, the hazardous overuse of trees prompted the Government of Kenya to enact the Tree Protection Legislation. Tree planting programmes were launched by Government Departments, such as one of forestry. They were assisted by Non-Governmental Organizations (NGO's) like the Kenya Wood fuel Development Programme (KWDP) supported by the GTZ, the Kenya Wood Cycle Project (KWCP) supported by the Swedish Beijer Institute, the KENGO, and the Green Belt movement. These bodies and many others took the lead in tree-planting programmes. All the organizations mentioned above are pioneers of afforestation programmes which plant trees for the protection of the environment, the provision and retention of soil nutrients, and in some cases, for the provision of foliage and fodder. Although the KENGO and the Appropriate Technology groups have undertaken construction and provision of economic cooking stoves *(Jikos)* for the rural poor, the main aim of these organizations is to reduce the cooking cost elements without necessarily considering which particular trees would provide the best high energy charcoal for these utilities.

As far as we are aware, no group has engaged in any kind of studies to identify which group of trees possess high specific heat energy for exploitation without undue degradation of the environment.

RESEARCH OBJECTIVES

It is with the foregoing in mind that we decided to seriously embark on fuel wood energy content research with the ultimate aim of providing a solid boost to agroforestry management, enhancing the environmental conservation and unearthing alternative energy sources. Consequently our research objectives were:

1. To identify scientifically indigenous trees likely to produce high energy content charcoal;
2. To determine their specific heat values;
3. To formulate criteria governing specific heat content;
4. To provide policy recommendations, based on the findings, that can help in enhancing energy supply efforts and environmental conservation through agroforestry.

THE AREA OF STUDY COVERED

The study covered the area of potential fuel wood crisis of the Lake Victoria region. This area covers some of the highly populated highland region of Western Kenya and the dry lake shore area. Administratively, the study area covers two provinces with an approximate density of 170 persons per square kilometre.

The area covered is occupied by mixed ethnic inhabitants with variable economic activities done in the context of a subsistence economy system. It is an area of total agrarian life with mixed farming practices. In some areas there are complex income generating activities which include crop farming, animal raising, and fishing. Consequently, the area is prone to unplanned felling of trees to clear land for tilling. Also, firewood is fetched for fish smoking, tobacco curing, and other uses such as farm fencing and village house construction.

The staple foods of the region include maize, banana, sorghum, millet, cassava, potatoes, and fish. Cash crops include cotton, pyrethrum, coffee, tea, tobacco, and sugar cane. In order to increase production of the above, large tracts of land must be cleared.

Because of the high density of population in the study area, the need to raise cash crops, perpetual drought in the relatively scantily populated lake region area, and the high population density in the rainy highland areas, the natural regeneration of wood trees is almost impossible in the region covered by this study.

METHODOLOGY

I. The Collection of Tree Samples

A multi-stage random-sampling procedure was employed in the study for purposes of data collection (Cochran 1977). The study area was first divided into eight administrative districts. The districts were then sub-divided into divisions, and by means of random sampling two divisions were selected from each district for a total of sixteen divisions. Trees in the selected divisions then formed the basis of the research survey.

The trees were called out with the help of local charcoal dealers and plant taxonomists who authenticated samples collected to avoid repetition during the investigation process. Up to twenty trees were cut down a day, and short logs made from each were ferried to the camp for calcination into charcoal, within 24 hours of cutting down. Only trees with above-the-ground-stems of one half a foot to one foot in diameter were considered mature enough and not too old experimental purposes.

II. Charcoal-Making Process

Trees were cut down at one foot from the ground. Thereafter a three feet log was chopped off from the freshly cut end of the felled tree. The log was cut to three equal pieces before splitting each piece open to provide uniform pieces for the study work. The prepared pieces of wood were arranged in an earthen kiln sunk two feet underground on a 5×5 foot base area. The carbonization was allowed to continue for 24 hours before the charcoal was harvested.

III. Heat Energy Evaluation

The charcoal was dehydrated by heating it in an oven at 110°C till there was no further depreciation in the mass by weight. The dehydrated charcoal was kept in a descicator and samples were taken for parallel heat evaluation tests. Complete overall energy was estimated by the bomb calorimeter method, taking three replicates per charcoal sample for each tree.

A parallel heat energy evaluation was carried out by the correlation method, whereby the charcoal was heated to a constant temperature and further heating at a higher temperature till ash was formed. The first heating was made in a muffle furnace at 300°C till constant weight, to rid the charcoal of all possible volatile matter. The second round of heating was made at 800°C or till ash was formed. After this final heating, when all volatile matter was removed, only fixed carbon (FC) was left.

RESULTS AND DISCUSSION

In the initial stages, our survey revealed that the women who do the cooking preferred heavy to light charcoal. They said that the light-weight charcoal ashed heavily during cooking and would not cook a meal in one cooking phase without restuffing the cook stove *(jiko)*. It was also found that certain trees, mainly the acacia, gave popular charcoal with very high demand.

We therefore started our work by analysing acacia charcoal. Four components, water, volatile matter, fixed carbon, and ash were found in all charcoals. However, their concentrations were found to vary from tree to tree, and even within the same tree the concentration of each of the components was not uniform. Each of these material components of charcoal was evaluated for the percent content of the dehydrated charcoal except for moisture which was estimated as a percent of the raw non-dehydrated charcoal.

Charcoal from several acacia trees was analysed for the quantity of ash content, volatile matter content, and fixed carbon content. As can be seen in Table 1, there seems to be a very consistent negative correlation between the amount of ash content and the specific heat content as estimated through a bomb calorimeter. The ash content seems to increase with a corresponding decrease of specific heat content.

The moisture content (MC) comprises either the amount of moisture which the charcoal absorbed from the atmosphere, or that which is formed during combustion as a result of the nature of the chemical composition of the woody component of the tree. This is the non-productive heat-forming component, since the same will absorb any available heat to allow for its vaporization and consequent evaporation.

Volatile matter (VM) is defined as that part of the woody material made of low-molecular-weight hydrocarbons with low combustion temperatures and which decomposes at low temperatures, losing energy during charcoal production or during the lighting of the *jikos*.

Fixed carbon (FC) is defined as the major part of the charcoal composed of high molecular weight hydrocarbons, with high decomposition temperatures. At these temperatures, the hydrocarbons decompose to release carbon dioxide (CO_2), water, and organic gases. The latter burn to release their intrinsic energy in the form of heat energy.

Ash is the silvery-grey material that remains after ample combustion has taken place. It is made up of inorganic salts, mainly the oxides and sulphates of potassium, sodium, calcium, magnesium, and iron. The decomposition temperatures of these oxides are high and above the cooking temperatures. Moreover, the fine ash particle size allows these residues to fall down to the cool bottom part of the cooking stove, where they cannot undergo further combustion.

Apart from the above acacia tree species from one family, a total of twenty-eight tree families were studied. The charcoal from fourteen families was analysed and the mean results for given parameters per family were compiled, as shown in Table 2. The table shows that the specific heat decreases as the ash content increases, and that the heat energy content increases with the corresponding increase of the fixed

Table 1. Heat Energy Parameters of Certain Acacia Trees.*

Tree Species	Mean MC%	Mean VM%	Mean Ash%	Mean FC% $\times 10^1$	Mean Cal/gm $\times 10^3$
1. *Acacia polycantha*	5.2	2.1	3.0	9.14	9.997
2. *Acacia drepanolobium*	4.7	2.0	3.5	9.00	9.637
3. *Acacia* sp. (Ruga)	6.3	2.4	3.3	9.03	9.599
4. *Acacia* sp. (Orengo)	5.7	8.5	3.1	8.53	9.476
5. *Acacia seyal* (R)	5.9	6.9	4.2	8.10	8.916
6. *Acacia seyal* (W)	6.1	7.5	4.5	7.98	8.910
7. *Acacia lahai*	4.6	8.4	4.5	8.00	8.789
8. *Acacia* sp. (Saye)	9.4	3.0	4.6	7.84	8.532
9. *Acacia gerrardii*	5.4	5.3	5.2	6.85	7.768
10. *Acacia senegal*	5.9	8.4	6.2	6.04	6.971
11. *Acacia* sp. (Ongorro)	4.0	9.7	6.3	5.62	6.503

* The table of trees has been arranged in order of increasing energy content. MC = Moisture content, FC = Fixed carbon, VM = Volatile matter
Source: Field Survey, 1992.

carbon content. Another fourteen families were studied, from which only one tree was taken as a sample to represent the family. The result from this work is shown in Table 3. As will be seen, the pattern of the results is similar to that shown in Table 2.

After the investigation of the twenty-eight families the recorded results show that the amount of fixed carbon content has a direct relationship with the magnitude of the specific heat energy content; and conversely, the amount of ash content bears a negative relationship to the heat energy values of any tree. These findings may be attributed to the fact that all woody matter of the trees investigated contains cellulose, proteins, lignans, and certain secondary metabolites of variable molecular mass and composition (Robinson, 1967). The variation in types and quantities of this latter group of chemical compounds would bring about the structural and chemico-physical variations in the trees from family to family. These chemical compounds

Table 2. Mean Values of Parameters and Heat Energy Content of Certain Trees.*

Families	No. of Species	Mean MC%	Mean VM%	Mean Ash%	Mean FC%$\times10^1$	Mean Cal/gm$\times10^3$
1. Capparidaceae	3	6.3	8.8	3.8	8.64	9.414
2. Meliaceae	2	6.3	6.4	3.7	8.20	9.231
3. Anacardiaceae	6	5.1	15.6	4.2	8.23	9.170
4. Combretaceae	3	4.4	12.2	3.9	8.31	9.164
5. Bignoniaceae	3	5.9	14.4	4.1	7.76	9.052
6. Olacaceae	2	5.6	1.6	4.2	7.75	8.750
7. Caesalpiniaceae	4	6.1	14.6	4.5	7.77	8.664
8. Mimosaceae	15	6.1	6.0	4.3	7.78	8.645
9. Rubiaceae	4	5.9	8.8	5.3	6.91	7.855
10. Moraceae	3	6.0	14.8	5.3	6.73	7.554
11. Tiliaceae	2	6.2	10.3	5.6	6.56	7.461
12. Euphorbiaceae	3	7.2	24.8	6.1	5.90	6.904
13. Papilionaceae	3	6.2	20.5	6.3	5.79	6.540
14. Apocynaceae	2	5.1	15.3	8.0	4.22	5.145

Table 3. Parameters and Heat Energy Content in Other Trees.*

Families	No. of Species	Mean MC%	Mean VM%	Mean Ash%	Mean FC%$\times10^1$	Mean Cal/gm$\times10^3$
1. Oleaceae	1	5.0	6.5	3.5	8.53	9.368
2. Boraginaceae	1	7.3	17.5	3.5	8.31	9.309
3. Hypericaceae	1	5.1	9.9	3.8	8.01	9.011
4. Simaroubaceae	1	4.1	6.3	4.2	7.59	8.945
5. Rutaceae	1	7.1	5.9	4.8	7.33	8.379
6. Sapindaceae	1	4.9	9.8	4.9	7.30	8.119
7. Violaceae	1	5.3	3.3	5.0	7.00	8.050
8 Annonaceae	1	6.0	19.1	5.2	6.70	7.669
9. Rhamnaceae	1	7.5	24.4	5.6	6.27	7.202
10. Celastraceae	1	7.3	21.2	5.8	6.10	7.168
11. Canellaceae	1	6.0	40.3	6.0	5.89	6.953
12. Flacourtiaceae	1	2.9	27.1	7.2	4.82	5.810
13. Malvaceae	1	8.0	22.4	8.2	4.38	5.249
14. Sterculiaceae	1	7.9	22.1	8.3	3.85	4.778

* The table of trees has been arranged in order of increasing energy content. MC=Moisture content, FC=Fixed carbon, VM=Volatile matter
Source: Field Survey, 1992.

decompose, releasing intrinsic heat energy at certain temperatures. This depends on each individual compound. They break down to more simpler compounds, some of which will ignite to flames.

From Tables 2 and 3 we concluded that either ash content or fixed carbon content may be used as a guiding parameter for evaluation of heat energy content of any given tree species.

The details shown in Tables 2 and 3 were later used to derive a graphs shown in Figures 1 and 2. The merger of Graphs 1 and 2 led to the determination of the critical heat energy point as shown by the intersection of the two graphs in Figure 3. On the basis of the critical point, one can deduce different categories of trees which can be used in afforestation programmes for charcoal purposes. The trees on the right side of the critical point give not less than 60% fixed carbon, and are capable of pro-

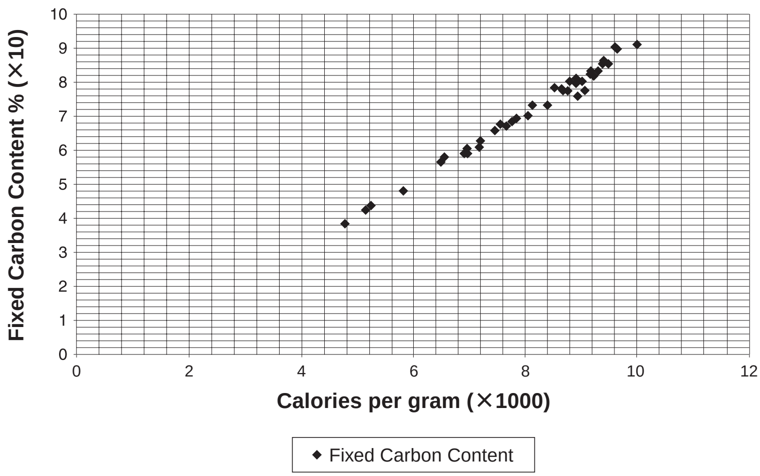

Fig. 1. Fixed Carbon Content vs. Energy.

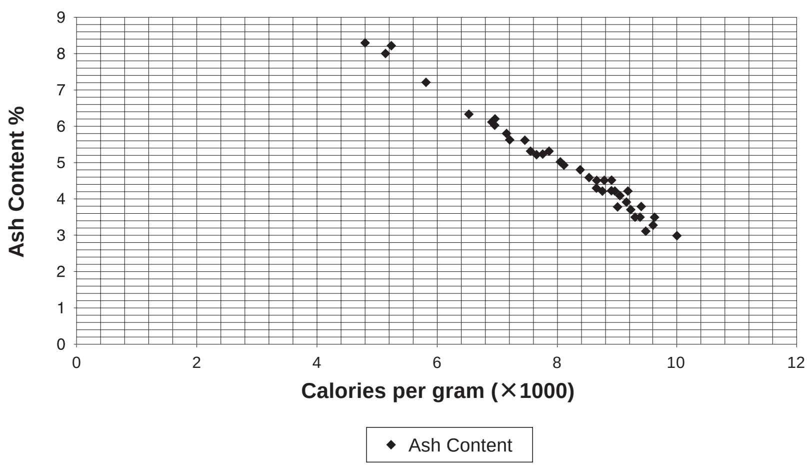

Fig. 2. Ash Content vs. Energy.

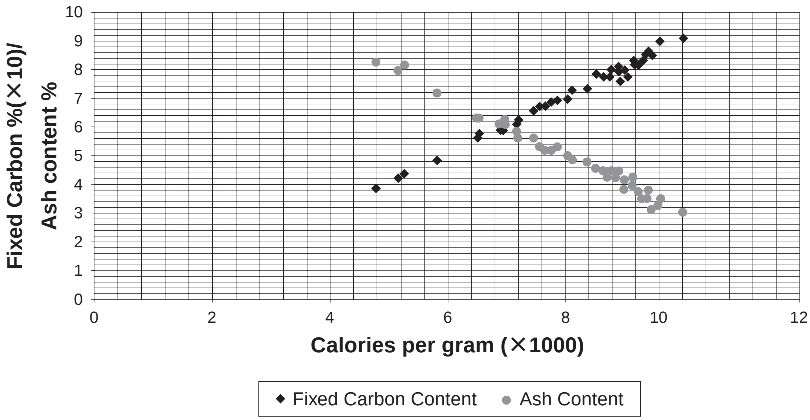

Fig. 3. Ash and Fixed Carbon Content vs. Energy.

ducing high energy content charcoal with not less than 7,000 Cal/gm (grouped into three sub-groups as high, medium, and low energy content charcoal trees). The trees on the left side of the critical point in the same figure are considered as very low heat-energy-providing trees unsuitable for charcoal production, and may not be given priority in afforestation programmes. However, the fast-growing lots in this latter group can be used as direct firewood trees.

CONCLUSION AND POLICY IMPLICATIONS

From the results discussed in the preceding section, there appears to be enough evidence that a clear direct relationship exists between heat energy content (calorific value) and the magnitude of fixed carbon content. There is also an inverse relationship between ash content and heat energy.

The findings of this study relating to heat energy content of selected trees prompted us to classify the trees investigated into the following groups:

(a) GROUP I: High Energy Level (Above 9,000 Cal/gm = 80 − 90% FC)

1. *Acacia polycantha*
2. *Acacia drepanolobium*
3. *Acacia* sp. (Ruga)
4. *Acacia* sp. (Orengo)
5. *Boscia salicifolia*
6. *Cadaba farinosa*
7. *Chlorophora excelsa*
8. *Combretum binderianum*
9. *Combretum molle*
10. *Cordia ovalis*
11. *Ekebergia rueppeliana*
12. *Harungana madagascariensis*
13. *Lannea fulva*
14. *Lannea stuhlmannii*
15. *Markhamia platycalyx*
16. *Maerua angolensis*
17. *Olea africana*
18. *Phylanthus guinensis*
19. *Sclerocarya birrea*
20. *Sclerocarya caffra*
21. *Stereospermum kunthianum*
22. *Tarenna robusta*
23. *Terminalia brownnii*
24. *Turraea robusta*

(b) Group II: Medium Energy Level (8,000−9,000 Cal/gm = 70−80% FC)

1. *Acacia seyaleyal*
2. *Acacia lahai*
3. *Acacia* sp. (Saye)
4. *Balanites aegyptiaca*
5. *Blighia unijugata*
6. *Cassia didymobotrya*
7. *Cassia floribunda*
8. *Piliostigma thonningii*
9. *Rhus vulgaris*
10. *Rinorea poggei*
11. *Tamarindus indica*
12. *Teclea nobilis*
13. *Ximenia americana*
14. *Ximenia caffra*

(c) Group III: Low Energy Level (7,000−8,000 Cal/gm = 60−70% FC)

1. *Acacia brevispica*
2. *Acacia gerrardii*
3. *Annona senegalensis*
4. *Bridelia bicolor*
5. *Canthium gueinzii*
6. *Gardenia lutea*
7. *Grewia bicolor*
8. *Grewia similis*
9. *Kigelia africana*
10. *Maytenous senegalensis*
11. *Rhus natalensis*
12. *Ziziphus mucronata*

(d) Group IV: Very Low Energy Level (Below 7,000 Cal/gm ≤ 60% FC)

1. *Acacia senegal*
2. *Carissa edulis*
3. *Dombeya mukole*
4. *Dovyyalis macrocalyx*
5. *Euphorbia tirucalii*
6. *Erythrina abyssinica*
7. *Erythrina excelsa*
8. *Ficus thonningii*
9. *Saba florida*
10. *Sesbania sesban*
11. *Sida acuta*
12. *Warbugia ugandensis*
13. *Vangueriana linearsepala*

Therefore, based upon the findings and the resulting classification, we recommend that:

1. The trees falling within group one, high energy-providing trees, should be planted at farm borders as land demarcation trees. The trees in this group include those from families Mimosaceae, Capparidaceae, Moraceae, Combretaceae, Bignonaceae, Anacardiaceae, Hypraceae, Rubiaceae, Meliaceae, Oleaceae, and Boraginaceae. These are trees of the low land and high land ecology.

2. The trees of group four, low energy level trees, could be planted in the space between the high energy trees. These are fast-growing trees which could provide immediate supply of cooking material to the farmer while the high-energy-providing trees are maturing. This may also enable the farmer to spare arable land by planting the latter between the former.

3. Some new trees of the high energy providing class should be planted periodically to allow continuity of the supply for future consumption.

4. Charcoal resulting from high-energy-providing trees should fetch a premium price in order to make consumers appreciate the costly nature of this class of trees. Evaluation experts could be used to assist in pricing of charcoal of dissimilar energy values. Premium price paid to obtain charcoal with high energy values is expected to instil thrift consumption behaviour of the consumers, thus allowing high-energy-providing trees to attain desired maturity.

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