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CHARCOAL PRODUCTION IN TANZANIA USING IMPROVED TRADITIONAL EARTH KILNS

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Summary

A preliminary field survey of earth kilns was carried in nine villages in Tanzania. Only one design of the traditional earth kiln was found commonly adopted in the surveyed villages. The effect of the basic design on charcoal yield and production cost was evaluated for comparison among villages.

The charcoal recovery percentages from single kiln-charges in the villages are unexpectedly quite high, ranging from 17 to 37 per cent. The yield variations between villages are significant due to lack of field control of certain factors of production: tree species, wood density, billet moisture content, kiln capacity, operating skills and prevailing weather conditions. The unit production costs show no significant diffferences between village charges.

Experimental charcoal burnings were then conducted at Kileo Forest Reserve, Mwanga District, to measure the technical and economical performances of five earth kiln models. The results show quite significant variations in yields of charcoal between and within kiln designs. The recoveries between kiln designs range from 15 to 31 per cent. The unit production costs also differ quite significantly between the kiln designs tested, ranging from Tsh.1 per kg. (Tsh.39 per bag) to Tsh.3 per kg. (Tsh.108 per bag).

The results obtained at Kileo indicate that the Senegalese Casamance earth kiln is the most technically and economically efficient design, followed by the metal channel kiln, an improved version of the basic earth kiln. The adoption of either of these two designs by the rural charcoal producers may greatly improve the present traditional method of charcoal production in the country.

Introduction

Tanzania has a population of over 22 million people, of which 90 per cent lives in the rural areas. The rate of growth of this population is 3.4 per cent per annum (Tanzania Government, 1982). Wood is the most important source of energy in Tanzania, supplying about 90 per cent of the country's total energy demand. The other two sources are oil and hydro-electricity, accounting for 7 per cent and 3 per cent respectively.

Most of the woodfuel (90 per cent) is consumed by the rural population in the form of firewood. The average per capita consumption is 2.2 m^3 per year, but varies according to local availability, climatic zones and whether it is for domestic or industrial use, rural or urban use. Fuelwood is used for cooking, heating and lighting in homes, cooking and heating in restaurants, for bakeries, fish smoking, brick burning, pottery making, and for brewing native beers. It is also used to cure tobacco and tea leaves.

Only about 10 per cent of the total woodfuel produced in the country is converted into charcoal. Yet, charcoal provides 85 per cent of the domestic energy needs of the urban population. It is used in household cooking and heating, bakeries, restaurants, barbecues, and for ironing clothes in laundries.

The amount of charcoal consumed annually per person in urban centres is about 0.8 m^3 on the average, which is approximately 1.6 m^3 in roundwood equivalent. Because the rate of urbanization is now more than 8 per cent per annum (Tanzania Government, 1982), charcoal consumption will continue to increase quite rapidly. The charcoal market will be stimulated in two ways: charcoal is a significant fuel in urban areas, while its production forms an important source of income to the rural dwellers (FAO, 1984).

Charcoal is the preferred form of fuel in the urban centres because it is:

- more affordable by the majority of the urban dwellers compared to electricity, kerosene, or gas
- more economical than wood to transport long distances
- occupies less space in the already congested quarters of the urban centres
- suitable for use in small stoves in the limited space of urban households
- more energy efficient in application due to having twice the calorific value per unit weight of wood
- smokeless and sulphur-free, making it ideal for towns and cities
- not liable to deterioration by insects and/or fungi as in the case of wood
- used in barbecues because it imparts a distinctive and delicious flavour to the food

The project to study charcoal production in Tanzania was initiated in March, 1984 with financial support from the International Development Research Centre (IDRC), Ottawa, Canada. The long-term objectives of the project were to: increase the efficiency of charcoal production using traditional earth kilns, reduce wood waste, improve forest utilization, and meet national energy needs at reasonable prices.

The specific objectives of the project were to:

- survey the various types of earth kilns used in Tanzania, and evaluate the effect of their designs on charcoal yield and quality
- measure the technical and economic performance of some improved models of earth kilns
- determine the acceptability of the most appropriate earth kiln model for use by rural charcoal producers

This report presents the research findings of the investigations made so far, with these objectives in mind.

Background

Wood Carbonization

The simplest way of upgrading the value of wood as a fuel is to convert it into charcoal. The process of converting an organic material (like wood) into charcoal is called carbonization. In this process, the organic material undergoes destructive distillation in a limited supply of oxygen. During carbonization, water, combustible gases, methanol, acetic acid and tars are driven off. At the end of pyrolysis, the black solid residue remaining behind charcoal, composed mainly of pure carbon (75-85 per cent).

The yield and composition of charcoal varies with temperature of carbonization (FAO,1983). Low carbonizing temperatures give a higher yield of charcoal but lower content of fixed carbon in the charcoal (Table 1). A temperature of 450^{o}C to 500^{o}C gives an optimum balance between a high fixed carbon content and friability of the charcoal. Another important observation is that slow carbonization at low temperature tends to produce greater yields of charcoal than fast carbonization at high temperature (Earl, 1974). This is particularly true for earth kilns.

TABLE 1: *Effects of Carbonisation Temperature on Charcoal Yield and Composition*

Carbonization Temperature	Chemical Analysis of Charcoal		Charcoal Yield based on ovendry weight (%)
	Fixed Carbon (%)	Volatile Matter (%)	
300	68	31	42
500	86	13	33
700	92	7	30

Source: FAO, 1983.

The carbonization process may be decisive in charcoal production systems. Unless it is carried out as efficiently as possible, it can be put the whole charcoal production operation at risk since low yields in carbonization are reflected throughout the whole chain of operation—roading, felling, bucking, splitting, transportation, drying and storage of billets—thus increasing costs and wasting resources (FA0, 1983).

Charcoal Production Devices

Charcoal production devices can be classified either as kilns or as retorts. In kilns, a portion of the charge is burned to initiate the carbonization process. In retorts, the heat needed to carbonize the charge is applied from outside the walls of the device. Whereas in kilns the wood is converted into charcoal without recovering by-products, in retorts both charcoal and by-products are recovered.

Charcoal production efficiency varies with wood density, moisture content and the method (device of carbonization). A satisfactory kiln yield or recovery of lump charcoal from ovendry wood ranges from 15 to 30 per cent on weight-by-weight basis. Retorts bear a higher range of 30 to 40 per cent recovery.

In Tanzania almost all charcoal is produced by using traditional earth kilns. Other devices, like the portable steel kiln (Mark V) and some kinds of brick kilns, have already been introduced into the country at the experimental level. Retorts are not yet used in Tanzania.

Independent villagers and small-scale farmers are conversant with traditional earth kilns (mound or pit) which require few specialized skills and zero capital investment. These rural charcoal burners operate on quite informal regulations and, to most of the villagers, charcoal burning is only a part-time job for supplementing their income from agricultural activities. It is this informal nature of traditional charcoal production that favours the use of temporary earth structures which need only minimal investment, mainly only a few hand-tools.

Although temporary earth kilns have stood the test of time, most of the designs employed are less efficient when compare to portable steel kilns or brick kilns. All the basic designs function with direct up-drafts instead of reverse down-drafts (incorporating chimneys) to control ventilation. Various sizes and shapes of billets of different species are mixed up together in traditional earth kilns. The billets are not properly seasoned before carbonization starts. The attention of the operators to the kilns during carbonization is very inconsistent. Based on all these drawbacks, traditional earth kilns require some 12 m^3 of wood (compared to 6 m^3 for metal kilns) to produce one tonne of charcoal (Earl, 1974).

Efforts by the government to encourage and popularize the use of portable steel kilns have been unsuccessful. This is because of the high capital investment involved, the unavailability of the metal in the country, the need for a reliable supply of homogeneous raw material, and lack of operating expertise. Metal kilns are not very effective in carbonizing large pieces of wood due to their high loss of heat through the walls and quick cooling. Wood raw material must, of necessity, be cut and split to recommended small sizes. Although portable, vehicular transportation is needed to move the steel kilns across hilly terrain.

Available Raw Material

Charcoal-making can only be a successful industry where the raw material resource is properly managed to provide a continuing supply. The main sources of wood for producing charcoal in Tanzania are the natural woodlands (miombo and savannah), tropical highland forests, fuelwood plantations and, to a lesser extent, individual trees on farmland.

Currently the bulk of raw material comes from the miombo/savannah woodlands. Typical yield at clear felling considered as good practice are about 35 m^3/ha. for savannah woodlands (FAO/UNEP, 1981) and about 60 m^3/ha. for miombo woodlands (Temu, 1979).

In order to sustain supply, a number of strategies have to be pursued:

- conservation of existing fuelwood species
- village afforestation projects and peri-urban fuelwood projects
- fuelwood harvesting schedules (cycles, coupes, etc.)
- economizing on the use of wood in various industries, such as charcoal-making

Thus, one way of reducing pressure on the natural woodlands from charcoal production is to improve the present charcoal-making techniques. This project's aim was to increase the efficiency of the traditional earth kilns through modifications and introducing improved designs that incorporate chimneys to reverse the drafts for better ventilation control.

Methodology

Field Survey of Existing Earth Kilns

The study area

Ten regional development directorates were contacted by mail so that their regional forestry officers could identify at least three villages in each region where charcoal production is a major activity. Out of thirty villages planned for the survey, nine were visited.

Yield measurements. For each kiln charge investigated, the parameters recorded are as shown in Appendix 1. The weight of the charge, billet size, stack volume, soil vegetation cover thickness and ventilation design, were appropriately measured and noted. After carbonization, the yield of marketable charcoal was determined by number of bags and total weight. The recovery percentage was calculated on ovendry weight-by-weight basis after determining the moisture content of the billets (at time of firing) in the laboratory. (See Table 2 footnote).

Cost estimations. Due to the informal nature of charcoal production in the villages (mostly a part-time job), it was difficult to precisely determine total production costs per charge. To most charcoal burners, the cost of the raw material is considered equal to zero. Trees from natural woodlands are free of charge so long as they are available. However, central government royalty is supposed to be Tsh.5 per bag and village government fee Tsh.2 per bag, making a total of Tsh.7 per bag of charcoal produced. Labour costs, in terms of mandays (at Tsh.31.15 per manday) were estimated for each of the nine charges by considering only the effective times spent on the various work elements normally found in logging and burning operation—from wood cutting to end of carbonization.

In the villages, investment cost is also considered equal to zero. The few handtools used in both logging and burning operations have multiple uses: the same, common tools (pangas, shovels, hoes, rakes, digging forks and axes) are used in various day-to-day activities like agriculture, grazing, house-building, road-building, and other village industries.

Test Burning of Five Kiln Designs

Raw material and test site. Experimental charcoal burning was conducted at Kileo Forest Reserve, Mwanga District. The tree species *Acacia xanthophloea* used was abundant at the test site. The trees were felled and crosscut to 2m-long billets. These were left at the test site to season for at least six months before the burning started.

The handtools employed in logging were: a two-man crosscut saw, two axes, a bowsaw, and a chainsaw for very large butts and forks. Large wood billets had to be split using wedges (metal and wooden) and sledge hammer to speed up their seasoning.

Kilns and carbonization. The following five earth kilns designs were tested at Kileo Reserve:

- basic earth kiln (BEK)—figure 1, photo 1
- metal channel kiln (MCK)—figure 2, photo 2
- modified metal channel kiln (MMCK)—figure 3 photo
- Casamance earth kiln (CEK)—figure 4, photo 4
- earth pit kiln (EPK)—figure 5, photo 5

Each kiln charge had a capacity of 8 m^3 stack volume, replicated four times per design, making a total of 20 burns. A standard layer of soil/grass cover (of 30/20 cm.) was used in all kilns. Carbonization was conducted according to the structural dictates of each kiln design combined with the practical experiences of the kiln operators.

Yield measurements. For each kiln charge under investigation, the parameters recorded are as shown in Appendices 2 and 3. The weight of the charge, stack volume, billet size and moisture content were all appropriately measured and noted. After carbonization, the yield of lump charcoal was determined by number of bags and total weight. The recovery percentage was calculated on ovendry weight-by-weight basis.

Cost estimations. The total charcoal production cost per charge was estimated from logging and burning operation costs.

- *Logging operations costs.* At Kileo, most of the A. xanthophloea trees had large-diameter trunks and forks, necessitating the use of a chainsaw and its accessories. The capital equipment cost per charge was Tsh. 109.20 using a chainsaw, a bowsaw and 2 axes. A chainsaw currently costs Tsh. 30,000 a bowsaw Tsh.500 and 2 axes Tsh.448. A depreciation period of 3 years and an interest rate of 9 per cent were applied.

  The consumable equipment cost per charge was Tsh. 313 using 2 bowsaw blades, 2 axes files, 2 chainsaw files, 30 litres oil for the chainsaw. The labour cost per charge was Tsh.240 based on one chainsaw operator and his assistant. These two loggers would fell, crosscut and stack 4 cm^3 of billets per 7 hour working day (A. xanthophloea is very thorny). The rate of payment is Tsh.60 per manday for such skilled labour.

  Thus the total logging cost per charge was Tsh.662.20 using a chainsaw for all the kiln designs tested.

- *Burning Operation Costs:* The following handtools constitute the general capital equipment for each kiln design—2 pangas, 2 shovels, 2 hoes and 2 rakes. By depreciating their current values as for logging equipment above, the cost was Tsh.6.30 per charge.

All kiln designs had additional capital equipments except for the basic earth kiln which acted as a control design, see Table 4. The MCK had two metal chimneys and four metal channels incorporated in its construction. The additional equipment depreciated cost was Tsh.88.20 per charge.

The MMCK had three metal chimneys and four metal channels, costing Tsh.97 per charge. The CEK had a corrugated-iron-sheet (CIS) chimney with its CIS channel, costing Tsh.105.85 per charge. The EPK had 2 metal chimneys costing Tsh.17.65 per charge.

Consumable equipment was found in the first two charges of the EPK alone (Table 4). This was a cover of six CIS replacing the normal vegetation cover and valued at Tsh.3,000 per charge. The CIS would be completely burnt by the end of the charge.

During the burning operation, labour cost per charge was determined by considering only the effective time spent on the following work elements (Table 3): site preparation, loading kiln, covering kiln, attending to kiln, unloading kiln, bagging charcoal. The wage rate used was Tsh.31.15 per manday, the minimum labour payment in Tanzania.

Results and Discussion

Yields of Lump Charcoal

The yields of lump charcoal in terms of number of bags, ovendry weight and recovery percentages are presented in Table 2 for the field survey, and in Tables 5 and 6 for the test burnings. All data was collected under field conditions and the measurements are not of the same accuracy as those from more closely controlled laboratory conditions.

As stated earlier, the kiln yield of lump charcoal from ovendry wood is considered satisfactory when it ranges from 15 to 30 per cent on weight-by-weight basis (Earl, 1974). Tables 2, 5 and 6 show that most of the recoveries fall within the above range, exception those from the earth pit kiln.

For the data shown in Table 2, only a single charge was observed at every village. Replicated observations in each of the surveyed village burnings could quite possibly affect the current results. However, these nine single observations were made on a traditional common earth kiln design generally adopted in every village, see Figure 1, and photos 1 and 2.

Compared to most estimates done elsewhere, the charcoal recovery percentages in Table 2 are unexpectedly high. It is a general assumption that most of the traditional earth kilns used in charcoal burning would normally produce low yields of between 10 and 15 per cent (Mabonga-Mwisaka, 1983). In Kenya, for instance, the efficiency of the earth kilns used varies between 9 per cent (Kionga-Kamau, 1983) and 12 per cent (The Beijer Institute, 1982). Again, replicated figures from the surveyed village charges could present a truer picture of the current field situation.

Despite the high rates obtained, great variations in charcoal yields between charges of the basic earth kiln design had to occur since the burning operations were lacking field control in the following factors: tree species used, wood density, billet moisture content,kiln capacity, operation skills, and weather conditions.

Kiln charges 1, 3 and 4, used mixed tree species. Although the rest of the charges used a single species the yields in charges 2, 8 and 9 were the lowest. The recovery percentages in kiln charges 2, 7 and 9 are opposing the general principle that the yield of charcoal is directly related to the density of the raw material used (Earl, 1974). Quite unexceptedly, kiln charge 7 gave the highest yield against a very low stack wood density. Kiln charge 9 with the highest density produced the lowest recovery followed by kiln charge 2.

Naturally the larger the kiln (of any type), the larger the volume of charcoal produced due to the advantage of more successful carbonization of oversized billets (U.S. Forest Products Laboratory, 1961). Kiln charges 2 and 9 failed to show this advantage in the field survey results.

Although most of the billet moisture contents shown in Table 2 are within the acceptable range, high proportions of large-diameter billets found in some kilns could have higher moisture contents than those determined. Planned pre-drying of billets before charcoaling is not traditionally practiced by the rural charcoal burners. Thus, even the idea of splitting huge billets for seasoning is out of the question. In most cases, green wood is preferred to seasoned wood.

Ventilation was controlled by direct updrafts in all kiln charges. Consistent attention to the kilns during carbonization was generally lacking since charcoal burning is a part-time activity for most of the village producers.

Table 2: *Field Survey Data from Nine Charges of the Basic Earth Kiln (BEK)*[a]

Region	Charge No.	Airdry Wood Weight (kg.)	Stack Vol. (m^3)	Stack Density (kg./m^3)	Billet Mean Length (m.)	Billet mean Diam. (cm.)	M.C. (%)	Bags (no.)	Charcoal Weight (kg.)	Ovendry Recovery Wt./Wt.[b] (%)	Duration of burn (days)	Labour, Logging & Burning (mandays)	Prod. Cost per Kiln (Tsh.)	Prod. Cost per Bag (Tsh.)	Prod. Cost per Kg. (Tsh.)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Arusha	1	3,812	7	544	1.5	14	28	21	821	27	9	8	249.20	11.90	0.30
Arusha	2	8,511	16	532	2.2	24	18	38	1,319	18	12	18	560.70	14.75	0.40
Arusha	3	2,444	4	611	1.5	14	25	16	610	31	8	10	311.50	19.50	0.50
Singida	4	1,059	3	353	1.2	11	61	3	155	23	5	4	124.60	41.50	0.80
Singida	5	1,837	6	306	1.7	9	64	6	290	26	9	3	93.45	15.60	0.30
Singida	6	1,484	6	247	1.7	8	25	7	298	25	7	3	93.45	13.35	0.30
Singida	7	810	3	270	1.4	9	33	5	228	37	6	3	93.45	18.70	0.40
Tabora	8	3,647	6	608	1.7	16	31	12	563	20	8	6	186.90	15.60	0.30
Tabora	9	24,375	20	1,219	2.0	16	40	65	2,990	17	25	15	465.25	7.20	0.15

a. Basic Earth Kiln (BEK) is the most common design traditionaly adopted by the village charcoal burners in Tanzania,

b. Yield % = $\frac{\text{Wt. of charcoal produced}}{\text{Wt. of charge (ovendry)}}$ x 100 (Karch and Boutette, 1983).

N.B. (i) Ovendry Wt. of charge = $\frac{\text{Airdry Wt. of charge}}{1 + \text{M.C.\% (in decimal form)}}$

(ii) M.C.% = $\frac{A-B}{B}$ x 100, Where A is airdry weight and B is ovendry billet sample

Table 3: *Labour Costs for Charcoal Burning Operations at Kileo (Tsh.)* [a]

Kiln Design[b]	Charge No.	Burning Operations: Site preparation	Site kiln (Loading kiln)	Covering kiln	Attending kiln	Unloading charcoal	Bagging per charge	Total per charge	Average per kiln
BEK	1	12.46	124.60	62.30	34.27	31.15	31.15	295.90	304.50
	2	12.46	124.60	62.30	49.84	31.15	31.15	311.50	
	3	12.46	124.60	62.30	34.27	31.15	31.15	295.90	
	4	12.46	124.60	62.30	52.96	31.15	31.15	314.60	
MCK	1	12.46	140.18	62.30	24.92	31.15	31.15	302.20	291.30
	2	12.46	124.60	62.30	28.04	31.15	31.15	289.70	
	3	12.46	124.60	62.30	21.81	31.15	31.15	283.50	
	4	12.46	124.60	62.30	28.04	31.15	31.15	289.70	
MMCK	1	12.46	124.60	62.30	24.92	31.15	31.15	286.60	295.70
	2	12.46	124.60	62.30	30.22	31.25	31.15	291.90	
	3	12.46	140.18	62.30	31.15	31.15	31.15	308.40	
	4	12.46	130.83	62.30	28.04	31.15	31.15	295.90	
CEK	1	12.46	155.75	62.30	56.07	31.15	31.15	348.90	305.70
	2	12.46	124.60	62.30	26.79	31.15	31.15	288.45	
	3	12.46	124.60	62.30	28.04	31.15	31.15	289.70	
	4	12.46	124.60	62.30	34.27	31.15	31.15	295.90	
EPK	1	12.46	143.29	6.23[c]	21.80	52.96	31.15	267.90	280.35
	2	12.46	155.75	6.23[c]	40.50	46.72	31.15	292.80	
	3	12.46	124.60	31.15	52.95	46.73	31.15	299.00	289.70
	4	12.46	124.60	31.15	34.27	46.72	31.15	280.35	

a. To obtain number of mandays, divide tabulated figures by Tsh. 31.15, which is national wage rate per manday.

b. BEK = Basic earth kiln; MCK = Metal channel earth kiln; MMCK = Modified metal channel earth kiln; CEK = Casamance earth Kiln; EPK = Earth pit kiln.

c. Corrugated iron sheets replaced vegetation cover.

Table 4: *Equipment and Labour Costs for Charcoal Burning Operations at Kileo (Tsh.)*

Kiln Design	Charge No.	Capital Equipment		Consumable Equipment	Labour	Total per Charge	Average per Kiln Design
		Handtools	Addition				
1	2	3	4	5	6	7	8
BEK	1	6.30	-	-	295.90	302.20	310.80
	2	6.30	-	-	311.50	317.80	
	3	6.30	-	-	295.90	302.20	
	4	6.30	-	-	314.60	320.90	
MCK	1	6.30	88.20	-	302.20	396.70	385.80
	2	6.30	88.20	-	289.70	384.20	
	3	6.30	88.20	-	283.50	378.00	
	4	6.30	88.20	-	289.70	384.20	
MMCK	1	6.30	97.00	-	286.60	389.90	399.00
	2	6.30	97.00	-	291.90	395.20	
	3	6.30	97.00	-	308.40	411.70	
	4	6.30	97.00	-	295.90	399.20	
CEK	1	6.30	105.85	-	384.90	461.05	417.90
	2	6.30	105.85	-	288.45	400.60	
	3	6.30	105.85	-	289.70	401.85	
	4	6.30	105.85	-	295.90	408.05	
EPK	1	6.30	17.65	3,000[a]	267.90	3291.85	3,304.30
	2	6.30	17.65	3,000[a]	292.80	3316.75	
	3	6.30	17.65	-	299.00	322.95	313.60
	4	6.30	17.65	-	280.35	304.30	

a. Corrugated iron sheets replaced vegetation cover.

Table 5: *Summary of Data from Test Burnings of Charcoal (*Acacia xanthophloea*) at Kileo*

Kiln Design	Charge No.	Airdry wood weight (kg.)	Stack Density kg./m^{3} [a]	Billet mean length (m.)	Billet mean Diam (cm.)	M.C. (%)	No. of Bags	Charcoal Weight (kg.)	Ovendry Recovery wt./wt. (%)	Duration of Burn (days)	Production cost [b] (Tsh.)
1	2	3	4	5	6	7	8	9	10	11	12
BEK	1	3,327	416	1.9	24	33	20	713	28	8	964.40
	2	3,502	438	1.9	29	17	20	679	23	11	980.00
	3	3,338	417	1.9	20	19	16	531	19	8	964.40
	4	3,350	419	1.8	23	18	24	848	30	12	983.10
MCK	1	3,307	413	2.0	26	22	24	769	29	6	1,058.90
	2	3,051	381	1.8	21	21	25	843	33	6	1,046.40
	3	3,400	425	1.9	24	15	25	852	29	5	1,040.20
	4	3,435	429	1.8	24	16	22	757	25	6	1,046.40
MMCK	1	3,290	411	1.8	21	20	14	487	18	6	1,052.10
	2	3,421	427	1.7	20	27	21	698	26	7	1,057.40
	3	3,358	420	1.8	32	21	26	901	32	7	1,073.90
	4	3,356	419	1.8	25	15	23	733	25	6	1,061.40
CEK	1	3,553	444	1.9	22	28	22	756	27	12	1,123.25
	2	3,880	485	1.9	26	16	31	1,036	31	7	1,062.80
	3	3,538	442	1.8	21	14	32	1,070	34	6	1,064.05
	4	3,555	444	1.9	26	13	29	1,009	32	8	1,070.25
EPK	1	2,981	373	1.9	118	24	15	500	21	5	3,954.05
	2	2,617	327	2.0	20	16	7	235	10	9	3,978.95
	3	2,400	300	1.7	20	14	7	232	10	12	985.15
	4	2,800	350	1.8	19	13	12	398	16	8	966.50

a. Stack wood volume was 8 m^{3} for each charge.
b. A constant logging operation cost of Tsh.662.20 per charge added to Column 7, Table 4.

Table 6: *Mean Yields and Production Costs of Charcoal (*Acacia xanthophloea*) at Kileo*

Kiln Design	Airdry Wood Weight	Stack Density (kg/m^3)[a]	Billet length (m.)	Billet Diam. (cm.)	M.C. (%)	No. of Bags	Charcoal Weight (kg.)	Ovendry Recovery Wt./wt.	Duration of Burn (days)	Production Cost per Kiln (Tsh.)	Production Cost per Bag (Tsh.)	Production Cost per Kg. (Tsh.)
1	2	3	4	5	6	7	8	9	10	11	12	13
BEK	3379	422	2	24	22	20	697	25	10	973.00	48.65	1.40
MCK	3298	412	2	24	19	24	812	29	6	1,048.00	43.70	1.30
MMCK	3356	420	2	25	21	21	705	25	7	1,061.20	50.50	1.50
CEK	3631	454	2	24	18	28	968	31	8	1,080.10	38.60	1.10
	2799	350	2	19	20	11	367	16	7	3,966.50	360.60	10.80[b]
EPK	2600	325	2	20	14	9	315	14	10	975.80	108.40	3.10[c]

a. Stack wood volume was 8 m^3 per kiln.
b. Production cost for EPK No. 1 and 2 (corrugated iron sheets replaced vegetation cover).
c. Production cost for EPK No. 3 and 4 (Normal covering with vegetation).

The test burning results are shown in tables 5 and 6. Statistical analyses of the recovery percentages—even after angular transformation—show quite significant variations in yields of charcoal between the kiln designs.

The Casamance earth kiln (CEK) has proved to be technically the most efficient of the five designs tested. The mean recovery was 31 per cent based on ovendry weight of *Acacia xanthophloea* wood, which had been air-seasoned to an average moisture content of 18 per cent and having an average stack density of 454 kg./m^3 for the 8 m^3 kiln capacity. The duration of burn (i.e., from time of firing to time of sealing up the kiln for cooling) was eight days on average. Earlier reports state that the Casamance kiln has a production cycle of three to seven days and an ovendry weight yield of 20-30 per cent (Mabonga-Mwisaka, 1983).

The metal channel earth kiln (MCK) followed the Casamance, with 29 per cent ovendry weight recovery, using the same tree species and at about the same moisture content. A recovery of 25 per cent was jointly revealed by the basic earth kiln (BEX) and the modified metal channel kiln (MMCK). The earth pit kiln (EPK) had the lowest recovery of 14 per cent.

The yield variations between and within kiln designs were as expected although they are higher than those generally quoted in various reports on traditional earth kilns. The following conditions, which were under field control, brought about such encouraging results:

- only one tree species (*Acacia xanthophloea*) was used throughout the experiment
- the billets were previously seasoned to a moisture content of around 20 per cent for all kiln designs
- the stack wood density applied was almost constant since the species was the same
- the kiln capacity was the same (8m^3) for all kiln designs
- constant attention to the kilns was exercised by the operators from the time of firing to the end of carbonization for every charge
- the effects of macro-climate on the kiln charges was considered equal during carbonization since firing of the charges was always done concurrently in batteries of five different designs

The Casamance kiln was superior to the other four due to the following unique features:

- firing was done at the centre and the carbonization front advanced towards the periphery
- the radially-arrange stringers and the circumferential air space below the apron ensured constant air and gas flows in the mound
- the chimney at one side of the mound encouraged a very effective reverse, down-draft system
- sagging started at the centre, leaving the circumferential air chamber intact throughout the burning period of the charge for continued ventilation

The control of ventilation in the other four designs posed some difficulties, although three models (MCK, MMK and EPK) had chimneys fitted in them to reverse the drafts. These kilns were fired from one end, causing the soil cover to flow and accumulate around the channel collars. Some of the soil would enter into the collars, blocking the passage of air and gases, Also the interior ends of the channels became blocked by charcoal and ashes when the fired ends sunk. Switching round the chimneys in order to change the direction of the carbonization front was quite impossible. Central firing could be tried out to in these three kiln designs mentioned.

The earth pit kiln had the poorest performance due to the nature of the system itself. One portion would be completely burnt to ashes because too much air was circulating. Another portion would be partly carbonized and produced brands because it was never properly heated and dried out during the burn. Thus, although the moisture content was the lowest in the earth pit kiln charges, the yields were also the lowest. The pit method just proved to be wasteful in resources.

In the first two charges of the earth pit kiln, six corrugated iron sheets were used to replace the vegetation layer. During carbonization, the sheets would be completely burnt to ashes, causing many leaks and cracks in the soil layer. Sealing the pit was difficult and also dangerous to the operators. Overburning of charcoal was therefore inevitable. In the last two charges of the earth pit kiln, the normal soil/vegetation cover was maintained and the results were the same as in the first two charges.

Unloading charcoal from the pit kilns was very difficult and laborious. The hot charcoal would continue glowing for longer periods compared to mound kilns due to the lack of cold air circulation in the pits. Raking the hot charcoal out of the pits to allow faster cooling is therefore necessary, hence exhausting the operators.

Costs of Charcoal Production

The results of the investigations of charcoal production costs are presented in Table 2 for the field survey and in Tables 3 to 6 for the test burnings. In Table 2, the total production cost per kiln varies between regions and also between villages within a region. This is a reflection of the different periods spent on the various work elements in logging and charcoal burning operations while applying different skills and experiences.

Logging operations were found to occupy about two-thirds of the total production time, since all wood cutting is done by simple handtools. During loading, plenty of small wood and branches is needed to fill the interspaces between logs so that oxygen supply becomes limited during carbonization. These small pieces of wood and branches are more labour-intensive to billet and load in the kilns that larger materials (Ishengoma and Klem, 1979). Again, during loading, a special billet arrangement is required, i.e., large billets at the base, followed by medium billets, then small billets on top (U.S. Forest Laboratory, 1961).

Collecting billets within a small radius of the kiln site also takes some time. Some billets require short-distance skidding, using crowbars and improvised wooden railings.

The production cost per kiln is positively correlated to the capacity of the kiln under construction. Kilns 2 and 9 were exceptionally large, costing 18 and 15 mandays, respectively. However, kiln 9 was expected to cost more than kiln 2 since the duration of burn was almost a full month.

Despite all the physical variations between regions and between villages, the unit cost values per bag and kilogram of charcoal show no practical differences between the village charges. The mean production cost (ex-factory) is Tsh.17.60 per bag (containing about 40 kg. hardwood charcoal) or Tsh.0.40 per kg. of hardwood charcoal. These findings correspond quite well to those of an earlier investigation which found that the total production cost was around Tshs.0.60 per kg. marketable hardwood charcoal, roughly equal to the roadside cost of around Tsh.20 per bag of about 30 kg. hardwood charcoal (Ishengoma and Klem, 1979).

In the test firing, more precise labour expenditures were measured and are presented in Table 3. The total effective labour required per charge from site preparation to charcoal bagging differed quite significantly between and within kiln designs. This was caused mainly by different lengths of time taken from firing to closing up of the charges (attendance to kilns during carbonization). Effective kiln supervision time ranged from 5 to 13 hours.

Once a kiln is fired, constant supervision by the operators is needed until carbonization gets completed. The turning point for charcoal burning operation is the carbonization period. This is the time during which the kiln ventilation system needs close attention for maximum conversion efficiency. Regulation of air inlets and sealing of cracks and leaks need careful attention.

The supervision cost actually reflect more of the structural behaviour of the kiln designs rather than the differences in the moisture contents of the billets. The latter was already controlled for all kiln designs (Table 6).

Another cost item with marked variations between kiln designs is the additional capital equipment tested, which ranged from Tsh.18 for the earth pit kiln (EPK) to Tsh.106 for the Casamance earth kiln (CEK). The effect of the consumable equipment cost found only in the first two charges of the earth pit kiln is too obvious. This "special" arrangement will however, be out of the range of rural charcoal burners.

The unit costs summarized in the last three columns of Table 6 indicate the possible alternative choices that are both economically and technically appropriate. Again, the Casamance earth kiln ranks first, followed by the metal kiln, the modified channel kiln and the basic earth kiln. From this experiment, the earth pit kiln would need major improvements before any consideration for adoption.

A kilogram of charcoal from a Casamance earth kiln of 8 m^3 capacity would cost Tsh.1.10 using *Acacia xanthophloea* hardwood, air seasoned to a moisture content of 18 per cent and having a stack density of 454 kg./m^3 at a recovery rate of 31 based on ovendry weight. The indicated cost is for charcoal packed in bags at kiln site ready for transport. The calculations assume field conditions in charcoal production and do not allow royalties, labour overheads or other generral administrative costs.

Conclusions and Recommendations

Observations from the field indicate that the present supply of charcoal is affected by the following:

- Charcoal production is a small-scale activity done on a part-time basis by independent villagers. Full-time producers have just started to emerge.
- Unplanned and uncontrolled harvesting of the raw material in the natural woodlands is leading to environmental degradation.

- The rural charcoal burners are particularly against pre-drying (air seasoning) of billets before charging their kilns.
- Mainly unimproved traditional earth kilns are used without the application of any standards.
- Inconsistent attention to the kilns during carbonisation is common among the producers.
- The rural charcoal burners are unaware of the existence of an improved charcoal technology.

The empirical results obtained at Kileo strongly support the extension of two designs which have proved to be both technically and economically viable. These are the Senegalese Casamance earth kiln (CEK) and the Tanzanian metal channel earth kiln (MCK). The adoption of these designs by the rural charcoal producers could revolutionise charcoal production. By economising on the use of wood in the charcoal industry, a more rational approach to the current forest management practices will be induced.

The following are a few proposals for the rational approach:

- The habitual preference to any particular tree species by the charcoal burners needs immediate adjustment in the charcoal market by way of re-educating the end-users.
- The production of wood for charcoal should gradually be changed to man-made forests. These forest plantations would produce more wood volumes per unit area, thus sustaining the supply of the needed raw material.
- The development and promotion of more efficient charcoal production methods should be combined with that of more fuel-efficient cook stoves.
- The national energy policy include charcoal production and utilisation for explicit government control (harvesting schedules) and support (financial credits and incentives).

For further research, the following is recommended:

- estimate precise time and costs for various work elements involved under actual field conditions in villages
- conduct acceptability studies of the two improve kiln models proposed for rural extension
- incorporate peripheral air space in the structural features of the MCK and MMCK models, with firing at one end still being maintained

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Figure 1: Basic Earth Kiln (BEK)

N.B. Capacity for all designs is $8m^3$

Figure 1a. Outline

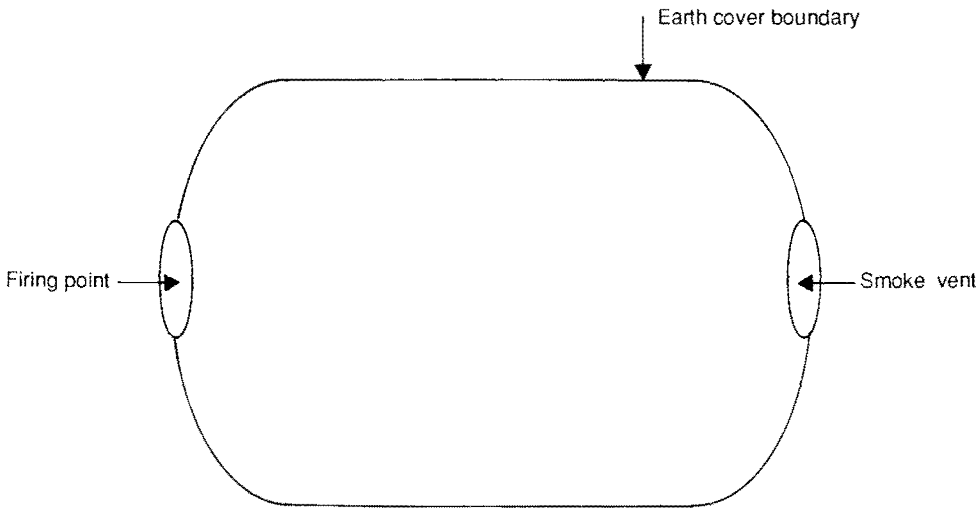

Figure 1b. Three dimensions

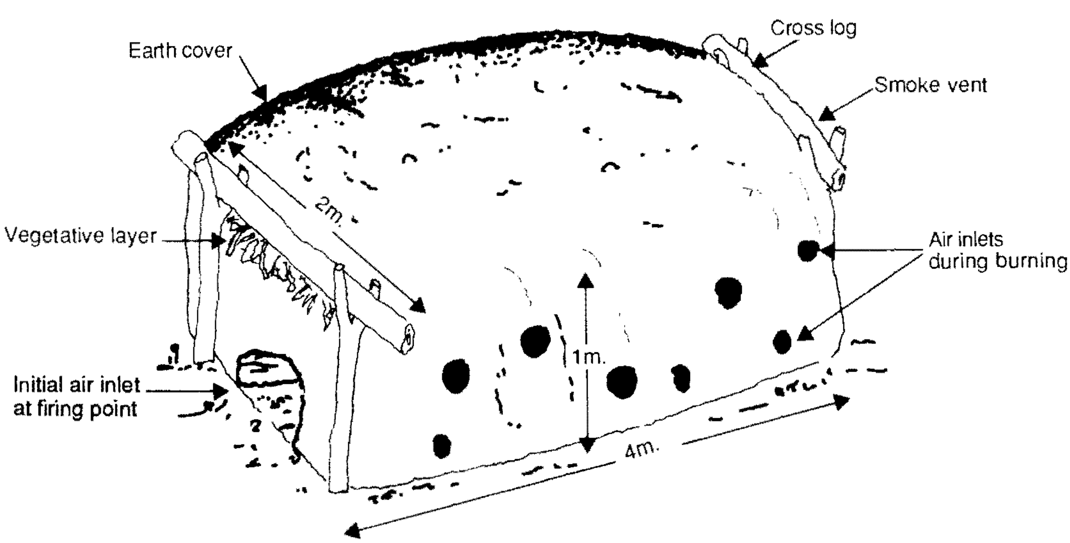

Figure 2: Metal Channel Kiln (MCK)

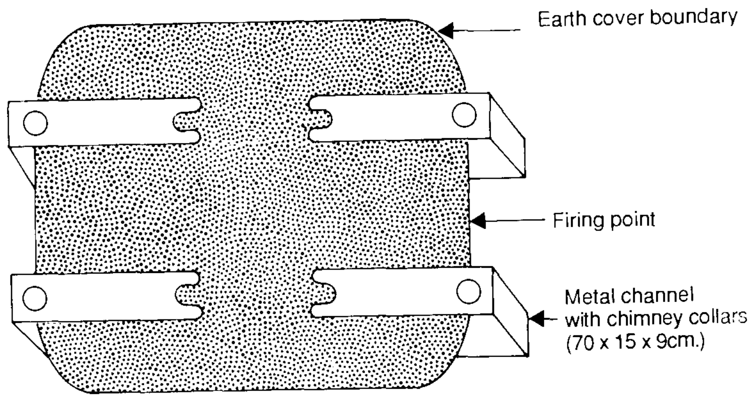

Figure 3: Modified Metal Channel Kiln (MMCK)

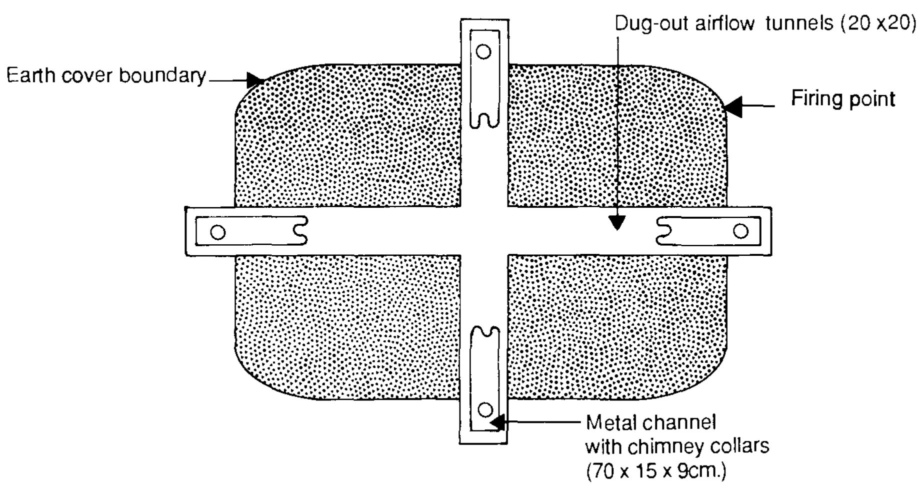

Figure 4: Casamance Earth Kiln (CEK)

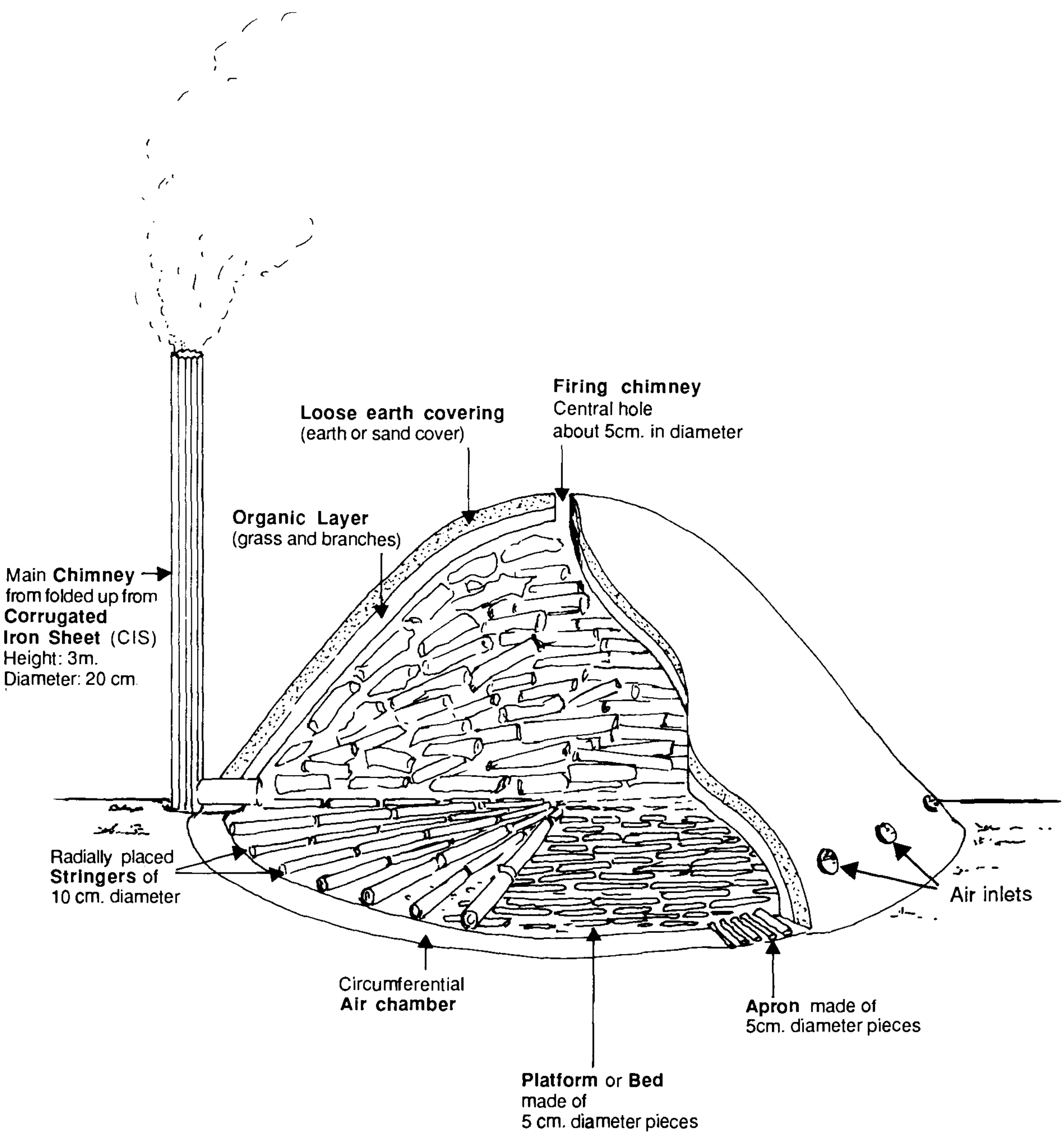

Figure 5: Earth Pit Kiln (EPK)

Figure 5a. Longitudinal view

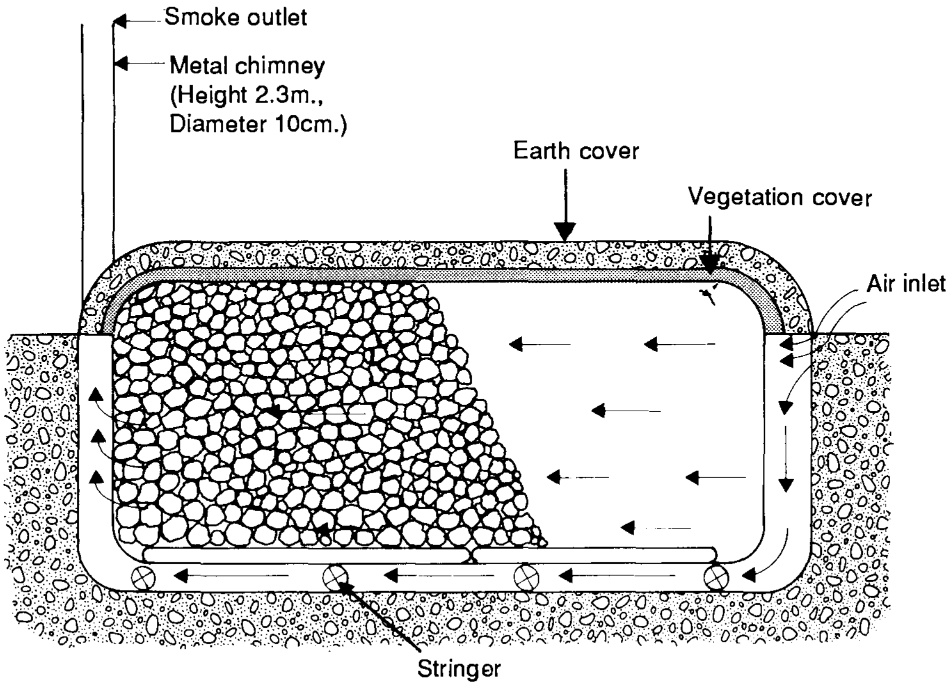

Figure 5b. Plan view

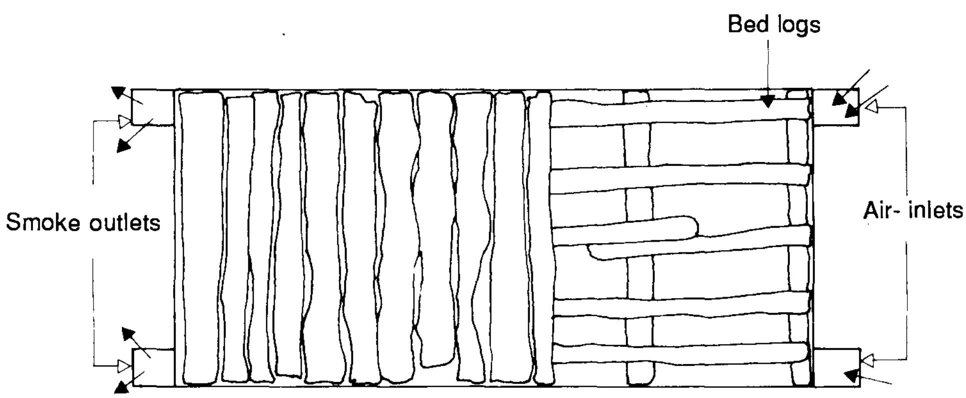

Photo 1: Basic Earth Kiln (BEK), side view

Photo 2: Metal Channel Kiln (MCK) under construction

Photo 3: Modified Metal Channel Kiln (MMCK) with chimneys inserted to indicate position of tunnels

Photo 4: Casamance Earth Kiln (CEK) showing central firing point and apron stakes

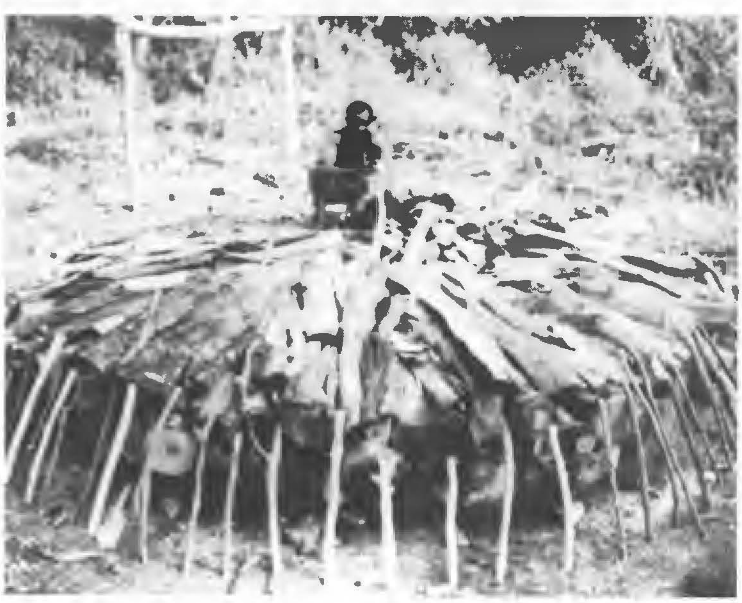

Photo 5: Earth Pit Kiln (EPK) under construction

Photo 6: Three earth pit kiln designs during carbonization (front: CEK; middle: MMCK; back: MCK)

Appendix 1

FORM TEK/84/1, Project 83-0248
TANZANIA FORESTRY RESEARCH INSTITUTE
TIMBER UTILISATION RESEARCH CENTRE, MOSHI

Data from Traditional Charcoal Earth Kilns in Tanzania

KILN NO. ....
VILLAGE ....
DISTRICT ....
REGION ....

PARAMETER	FIELD OBSERVATION	REMARK
Major tree species used		
Weight of wood in kiln-stack (kg, air dry)		
Billet size: length (m.) diameter (cm.)		
Form of wood (stem, branches, roots)		
Wood moisture content (%) at time of firing		
Kiln size (dimensions) length x breath x height (m.)		
Kiln capacity: stack vol. (m^3) solid vol. (m^3)	Reduction factor from stack to solid volume=0.7	
General layout (shape)		
Vegetative layer type		
Vegetative layer thickness (cm.) Soil cover thickness (cm.)		
Firing method		
Ventilation design		
Duration of burn (hrs.)		
Lump charcoal produced (kg.)		

Recovery per cent (wt./wt.)	(%)	Oven dry basis
Extent of contamination (purity of product)		
Season(s) of production		
Labour involved from wood cutting to end of carbonisation (mandays)		

Recorder: Designation:

Date:

Appendix 2

(TEK/84/2,Project 83-024)

TANZANIA FORESTRY RESEARCH INSTITUTE
TIMBER UTILISATION RESEARCH CENTRE MOSHI

Data from Test Burnings of Charcoal Using Five Designs of Traditional Earth Kilns

CHARCOAL KILN DESIGN ....
CHARGE NO. (replication) ....
VILLAGE ....
DISTRICT ....

PARAMETER	OBSERVATIONS
1. Major tree species used	
2. Weight of wood in kiln stack (air dry) (kg)	
3. Billet size (representative): length (m.)	
diam. (cm.)	
4. Form of wood: stems	
branches	
roots	
5. Wood moisture content at time of firing	
6. Kiln capacity—stack vol. (m^3)	
7. Kiln size (dimensions) Length x breath x height (m)	
8. Stack wood density (kg/m^3)	
9. General shape (refer respective drawing)	
10. Ventilation design:	
dug-out tunnels	
metal channels	
chimneys	
firing points	
11. Vegetative layer type	
12. Vegetative layer thickness	
13. Soil cover thickness:	
bottom (cm.)	
sides (cm.)	
top (cm.)	
14. Firing method	
15. Burning time (days)	
16. Lump charcoal produced:	
total weight (kg.)	
number of bags	
average weight per bag (kg.)	
17. Yield (recovery) per cent (wt./wt.)	

18. Purity of products: (extent of contamination)	brands fines soil/stones		
19. Labour costs		Mandays	Cost per operation (Tsh.)
Logging raw material:			
site preparation:			
kiln construction:			
covering charge:			
burning charge:			
cooling and raking charcoal:			
bagging charcoal:			
		Total per charge:	

Remarks:

Recorder: Designation:
Date: Place:

Appendix 3

Burning Data

Project No.	Sample No.	Round No.
Species		
Type of kiln/retort		
Size of kiln/retort		Capacity
Shape of kiln/retort		
Size of raw material		Moisture
Date assembled (heaped)		Date loaded
Date fired		Average kiln temperature
Date closed		Cooling time
Date unloaded		(packing for distribution)
Martketable charcoal (bags)	Average wt./bag	
Fine charcoal (bags)		Average wt./bag
Unburnt raw material (bags)	Average wt./bag	

Recovery percentage of marketable chacoal (wt./wt.)

Other important observations:

Recorder: Designation: