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A comparison of traditional and improved basic earth charcoal kilns in Kilosa District, Tanzania

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Summary

MJUMITA carried out an assessment of charcoal kiln efficiencies for traditional earth mound kilns and improved basic-earth mound kilns (IBEK) in Kilosa District, Tanzania in 2015. The average yield for 5 traditional earth mound kilns (21.01%) was higher than for 10 IBEK kilns (16.8%). After excluding novice charcoal makers from the analysis, the IBEK kiln yield for 6 kilns was 19.4%. The results suggest that IBEK kilns are not necessarily more efficient than traditional earth mound kilns, and that kiln management and the expertise of the charcoal maker are probably more important factors in determining efficiency than the choice between IBEK or traditional mound styles. This suggests that requiring that charcoal producers use a particular kiln style will not necessarily result in higher efficiencies in practice and that instead, to encourage higher efficiencies, charcoal producers should be charged for the wood they use rather than the charcoal they produce.

1) Introduction

MJUMITA and the Tanzania Forest Conservation group (TFCG) supported 10 villages in Kilosa district to develop systems for sustainable charcoal production on their lands as part of the Transforming Tanzania's Charcoal Sector Project (TTCS). MJUMITA and TFCG have helped these villages establish community based forest management (CBFM) and harvesting plans for sustainable charcoal production in discreet forest management units. As part of the work to support this project, MJUMITA carried out a study examining the efficiencies of the traditional basic earth-mound charcoal kilns historically used in the project area and improved basic earth-mound kilns (IBEK) that have been introduced by the project with the help of the Tanzania Traditional Energy and Development Organization (TATEDO). While previous studies of kiln efficiency have been conducted in Tanzania, these previous studies only involved traditional earth mound kilns (Ellegard *et al.* 2002). IBEK kiln efficiencies are also stated in some reports (Van Beukering *et al.* 2007), but it is not clear how these were calculated. The baseline assessment performed by TATEDO for the TTCS project includes a table showing some data related to efficiency, but input wood is only roughly estimated to the nearest half cubic meter based on the size of the kiln and often only the number bags of charcoal obtained is noted without any indication of the weight of the bags. Thus, it is not clear that any carefully controlled studies of IBEK kilns have been conducted. Furthermore, it is not clear that the TATEDO tests involve real world conditions, rather than kilns built and managed under the supervision of TATEDO staff members.

The study described in this report sought to establish the efficiency of each method of kiln building in terms of conversion of cut dry wood to commercially marketable charcoal (bagged charcoal) based on weights. Also, this study looked at the actual efficiencies that people are obtaining in the field rather than the results obtained from idealized versions of each kiln. Knowing the exact efficiencies will help the project make recommendations to charcoal producers on the best kiln types to use and the training that is required. It will also help village natural resource committees better estimate expected charcoal production and revenue from a given stand of trees.

Since the study involved harvesting trees and weighing them, this study also offered the opportunity to evaluate the accuracy of newly developed allometric equations (Mugasha *et al.* 2013) for estimating biomass in Miombo woodland in Tanzania. Biomass allometric equations are models that relate easily measurable tree attributes, like height and diameter at breast height, to the biomass of the whole tree. If the biomass of a group of trees can be accurately predicted from simply measurements, then it is possible to also predict how much charcoal will be produced from those trees at a given level of efficiency. This could allow communities to charge charcoal producers based on the wood they use rather than the charcoal they produce. Additionally, accurate biomass estimates are important for calculating reduced emissions (carbon-dioxide) from deforestation and degradation (REDD).

Both kiln styles examined in this study are earth mound kilns that use soil and vegetation to cover wood during pyrolysis. The IBEK kiln requires a chimney that is supposed to improve control over the rate of gases escaping from the kiln. IBEK kilns also use a different method of stacking wood which is supposed to prevent the soil on the outside from directly touching the main logs on the inside and thus creating a separate chamber for pyrolysis. According to TATEDO, IBEK kiln efficiencies are between 20 and 25% (Van Beukering *et al.* 2007). According to different empirical studies the efficiency of traditional earth mound kilns ranges from 7.5% ((Nahayo, Ekise, and Mukarugwiza 2013) to 19% (Ellegard *et al.* 2002).

2) Methods

2.1 Study Area

For the study location, 3 project villages (Ihombwe, Ulaya Mbuyuni, and Nyali) where people are using IBEK kilns and 2 future project villages (Muhenda and Kitunduweta) where people are still producing charcoal using traditional earth mound kilns were chosen. The three project villages were chosen because they cover a variety of Miombo types in the project area and the geographical distribution of project villages from north to south. Muhenda and Kitunduweta villages fall in between the three project villages and were convenient to work in because they have a history of charcoal making using traditional kilns and were in the process of joining the project. Therefore, it was hoped that they would be less nervous about the work, which was important given that most charcoal making in these two villages at the time was illegal (done without permits).

The study was based on weighing input wood biomass and output bags of charcoal in 10 improved kilns from the 3 project villages and 10 traditional kilns from the 2 future project villages. Samples of green wood were taken and dried by the Ilonga Agricultural Research Institute in a laboratory to determine the percentage of the weight of each part of each tree that was moisture. Then, the efficiency of each kiln was calculated by dividing the sum of the dry biomass entering the kiln by the sum of the bagged charcoal exiting the kiln. Cut tree biomass was also estimated based on newly developed allometric equations for predicting above ground biomass in Miombo woodlands in Tanzania (Mugasha *et al.* 2013). This provided a backup measure of tree biomass in case of problems with estimating moisture content of the weighed biomass and also an opportunity to compare the wood weights of cut trees with the predicted weights of the equations.

2.2 Field work methods

This part of the study was conducted by a consultant.

Step 1: Visiting the field with charcoal producers and identifying all trees they plan to include in the kiln, including any smaller trees that will be used as pylons.

Using a unique color of paint not used by the communities for other purposes, spray a number on the bole below and above the expected cut height of each tree so that the trees can be tracked back to their stumps after they have been cut. Record DBH, total tree height, and species name of all trees to be included. Record the GPS location of the site where the kiln will be located. Instruct charcoal producers to make separate piles of wood for each tree they cut up. Exchange contact details and obtain an estimated date of when the trees will have been cut and piled.

Step 2: Revisiting the field with the charcoal producers to weigh the biomass that will go into the kiln.

Confirm that all of the trees that were selected have been cut and that no other trees are to be included in the kiln and note any changes to the plan. If new trees are to be added to the kiln in addition to the original plan, then their DBH must be estimated based on the height of the residual stump and the first part of the bole and an entry for the tree must be added to the kiln form.

Measure the height above 30 cm and the top diameter of each stump of each tree to be included in the kiln.

Then, for each tree to be included in the kiln, take the green weight of all parts of the tree to be included in the kiln and the green weight of samples from each part of the tree to be included in the kiln (do not weigh any parts of the tree that will not be included in the kiln - such as leaves or very small branches).

Sampling should be based on the diameter class of the part of the tree being measured for green weight. Size classes should be (1) < 4 cm, (2) 4 to 7cm, (3) 7 to 20 cm, and (4) > 20 cm. For samples in size class (1), the samples should be 10 cm long sections of branches. For other size classes, disks 3 to 5 cm in thickness can be cut. The number of samples to be taken for each tree should be 12, 9, 6, and 3 for branches of size classes 1, 2, 3, and 4 respectively and 3 samples from the bole.

Each sample should be placed into its own labeled paper bag and weighed in the bag immediately after being cut from the larger piece of wood, which should also be weighed at the same time (this will require two scales (one large and one small). Paper bags should be used because the samples will go into an oven to dry and the heat of the oven may melt plastic bags.

It is good practice to measure each size class separately so that samples are taken from around the same time that all the cut pieces from a particular size class are weighed.

Step 4: Revisit the field with the charcoal producers to weigh the charcoal coming out of the kiln.

Make sure that 100% of the charcoal that will be sold from the kiln is packed and ready for transport. Make sure that the charcoal is dry and has not been rained on before it was packed for transport. Weigh each bag of charcoal. If charcoal is wet, also bag and weigh four samples per charcoal bag from different parts of the bag and take to the lab for drying.

2.3 Laboratory methods

This part of the study was conducted by laboratory personnel at Ilonga Agricultural Research Institute.

Step 3: Lab measurements

Carefully unpack and weigh each sample in its paper bag to track any loss of moisture that has occurred since the field. Then place the samples in their bags into an oven set to 105 C. Select a few samples of different size classes as controls and measure them each day until their weight no longer continues to decrease. Then remove the samples one by one from the oven and weigh them to obtain the final dry weight of the sample.

2.4 Data analysis

This part of the study was conducted by the MJUMITA Technical Adviser.

Step 4: Calculate average kiln efficiencies for each type of kiln using three approaches

Compare the final dry weight of each sample to its green weight in the field to determine the average moisture content of each sample. Scale the green weights of each tree by the average ratio of dry to green weights of the samples from the same size class of each tree to arrive at dry weights. Total the dry weights for all trees in each kiln to calculate the total dry biomass weight input into the kiln. Divide output charcoal weights by input dry biomass weights to arrive at kiln efficiency per kiln. Calculate average efficiencies for each kiln type.

Estimate biomass using newly developed allometric equation for Miombo woodlands (Mugasha *et al.* 2013): AGB = 0.0763*(DBH^2.2046)*(HT^0.4918) where AGB is above ground biomass, DBH is diameter at breast height (1.2 m) and HT is total tree height.

Estimate the biomass of the tree stump above 30 cm (the allometric equation predicts biomass above 30 cm) using the stump diameter, the volume equation for a cylinder, and the Global Tree Density Database (Zanne *et al.* 2009). Use a density of 0.65 g/cm^3 for any trees for which the density is not known. Subtract this biomass from the total above ground tree biomass estimates with the allometric equation.

Repeat the efficiency calculations using the biomass weights estimated from the allometric equation after removing the stump biomass.

3) Results

The number of trees of each species utilized for charcoal making are listed in Table 1 using local and scientific names together with their wood densities. The majority of trees in all kilns were *Brachystegia* species (usually either *B. boemii* or *B. spiciformis*), and there was no obvious difference between the kiln efficiencies associated with different species of *Brachystegia*. The DBH of trees cut for charcoal making ranged from 13 cm to 70 cm, with an average of 37 cm. Most cut trees (93.6%) had a DBH between 20 and 50 cm.

Table 1: Number of each tree species used by charcoal makers in study and average wood densities

Local Name(s)	Scientific Name	Number of trees used in kilns	Relative frequency used in kilns	Wood Density (g/cm^3)*
Myombo	*Brachystegia boemii*	66	60.6%	0.65
Mtondoro/Mhani	*Brachystegia spiciformis*	26	23.9%	0.67
Mgelegele	*Brachstegia bussei*	7	6.4%	0.65
Mnyenye	*Xeroderris stuhlmannii*	4	3.7%	0.63
Mkungugu	*Faidherbia albida*	2	1.8%	0.58
Mndulu	?	1	0.9%	?
Mnyangali	*Pteleopsis myritifolia*	1	0.9%	0.54
Mrama	*Combretum* sp.	1	0.9%	0.76
Mwanga	*Periocopsis angolensis*	1	0.9%	0.72

* source: (Zanne *et al.* 2009)

Average efficiencies were obtained for 15 kilns including 10 IBEK kilns and 5 traditional kilns (Table 2). Despite assurances from the consultant that he would not share their identities with authorities, charcoal producers in Muhenda village decided not to cooperate with the study and thus 5 traditional kilns in Muhenda village were not established. Average efficiencies by kiln type are shown in (Table 3).

It should also be noted that an anomaly in the weight of charcoal from the 5 traditional kilns was detected. The individual bag weights were much more than bag weights from any other kiln, which was impossible given that they were using the same size bags. It was discovered that these bags of charcoal were weighed with a spring scale because the table scale that had been used in the study up until that point had a piece of it break off and was sent for welding. When the field consultant compared the weights of charcoal bags using both scales, he found that the spring scale gave systematically higher weights than the table scale. Fortunately, the difference between the scales was very consistent. Of six charcoal bags weighing between 90 and 104.5 kg on the table scale (which was correctly calibrated), the spring scale overestimated the weights by between 42.3% and 44.8%. Therefore, the weights of the charcoal bags from traditional kilns were adjusted by the average difference between the two scales (44%).

Table 2: Biomass, Charcoal and Kiln Efficiencies for 15 kilns.

Kiln ID	Kiln Type	Biomass estimated by equation (kg)	Green Biomass (kg)	Dry Biomass (kg)	Charcoal (kg)	Efficiency (estimated biomass)	Efficiency (weighed biomass)
NYKILN01*	IBEK	6,281	6,345	3,976	439	7.0%	11.0%
NYKILN02	IBEK	6,383	9,534	6,091	814	12.8%	13.4%
NYKILN03	IBEK	9,821	16,223	10,960	1,685	17.2%	15.4%
NYKILN04*	IBEK	8,896	12,036	7,043	832	9.4%	11.8%
UMKILN01	IBEK	8,166	10,879	7,490	1,596	19.5%	21.3%
UMKILN02	IBEK	6,936	12,666	8,736	2,280	32.9%	26.1%
UMKILN03	IBEK	6,848	9,822	6,770	1,469	21.5%	21.7%
IHKILN01	IBEK	8,987	15,758	10,227	1,720	19.1%	16.8%
IHKILN02	IBEK	7,893	13,961	9,743	1,300	16.5%	13.3%
IHKILN03	IBEK	7,577	10,497	6,698	1,150	15.2%	17.2%
KTKILN01	Traditional	4,920	7,424	4,808	977	19.9%	20.3%
KTKILN02	Traditional	6,338	10,309	6,606	1,428	22.5%	21.6%
KTKILN03	Traditional	5,156	10,292	6,696	1,955	37.9%	29.2%
KTKILN04	Traditional	4,778	8,264	5,495	979	20.5%	17.8%
KTKILN05	Traditional	4,484	6,557	4,303	694	15.5%	16.1%

* Field work consultant reported that the producers did not actively manage the kiln as they were busy working in their farms

Table 3: Average Biomass, Charcoal, and Kiln Efficiencies by Kiln Type

Kiln Type	Average Biomass estimated by equation (kg)	Average Green Biomass Weight (kg)	Average Estimated Dry Biomass Weight	Average Charcoal Weight	Average Efficiency (equation estimated biomass)	Average Efficiency (weighed biomass)
ALL	6,898	10,704	7,043	1,288	19.1%	18.2%
IBEK All	7,779	11,772	7,773	1,328	17.1%	16.8%
IBEK without Nyali Village	7,735	12,264	8,278	1,586	20.8%	19.4%
Traditional	5,135	8,569	5,581	1,207	23.3%	21.0%

4) Conclusions

In 2002, the CHAPOSA project examined efficiencies from 21 kilns in Miombo woodland near Morogoro which would have been very similar woodland to Kilosa (Ellegard *et al.* 2002). Using a volume based approach to measuring wood going into a kiln, they found a range of efficiencies from 11 to 30% and an average efficiency of 19%. These results are almost identical to our results from 15 kilns with a range from 11 to 29% efficiency and an average of 18.2% efficiency.

Overall, our study found IBEK kilns were less efficient than traditional kilns (16.8% and 21.0% respectively). However, if the results of the IBEK kilns from Nyali (where charcoal producers are novices and were distracted by farming activities) are excluded, then the averages of IBEK and traditional kilns are more similar (19.4% and 21.0% respectively). Regardless, our study suggests that IBEK kilns are not necessarily more efficient than traditional kilns and that charcoal producer expertise and commitment to kiln management are more important factors in determining efficiency.

Another study would be required to obtain firm conclusions regarding the relative efficiencies differences between IBEK and traditional earth mound kilns. The study would need to control for factors such as kiln building expertise, kiln management, tree type, and soil type used to construct the kiln. This could be accomplished by having a group of expert charcoal producers build kilns of each type side by side, dividing the wood from each tree between the kilns and taking responsibility for managing both kilns. However, given the very similar range of efficiencies obtained between the two kiln types in our study and previous studies, it is doubtful that there is a significant difference in efficiency.

Another remaining question is on the relative quality of charcoal from the two kiln types. It has been widely reported by charcoal project staff that both charcoal makers and charcoal buyers claim that charcoal produced by IBEK kilns is higher quality than charcoal from traditional kilns. Reports are that IBEK charcoal is cleaner, has less dust, and better burning properties. However, the baseline study conducted by TATEDO for the TTCS project showed that charcoal produced from IBEK and traditional earth mound kilns in the project area have identical calorific content (about 24 MJ/kg), so there may not be as significant a difference as suggested. This is another important avenue for future research as it directly relates to the relative attractiveness of the product in the marketplace. Again, very carefully controlled studies would be required.

It is also worth discussing the relationship between wood weights obtained through direct measures and allometric equations. While there were some substantial differences between the cut biomass estimates based on allometric equations and the weighed biomass put into the kiln, the variance went equally in both directions. A paired t-test did not find a significant difference between the two measures. Overall, the estimated cut biomass based on the allometric equation using both DBH and height was slightly lower than the dry wood weights. Since very small branches and leaves do not make it into kilns and were not measured in this study, this suggests that the allometric equations used (which the authors of the allometric equation study state includes fine branches and leaves) systematically underestimate tree above ground biomass in the study area, though probably not by more than 5-10%. Thus, overall, the allometric equation including height from Mugasha *et al.* 2013 seems to produce estimates that are fairly accurate for miombo woodlands in the region. Estimates of biomass using the allometric equation with only dbh were lower. This may be because the equation is based on miombo trees from several different parts of the country and did not include Miombo from Morogoro region, which may have conditions favoring taller trees.

5) Recommendations

This study suggests that traditional earth mound kilns can be just as efficient if not more efficient than IBEK kilns. However, it does not identify what the specific factors are that lead to higher yields in some traditional kilns. Therefore, this study should be shared with charcoal producers in the study villages to get their views on the results. If the results seem realistic to them, then it would be helpful to interview the charcoal makers with the highest yielding kilns from both the IBEK and traditional kiln samples to determine what they are doing differently from other charcoal makers.

If there is little difference in efficiency between IBEK kilns and traditional kilns, then other factors become more important. The project should consult expert charcoal makers to determine which kiln type they prefer in terms of ease of construction and management. Also, the TATEDO baseline study produced some evidence that IBEK kilns may be safer for charcoal makers since more of the emissions leave the kiln through the chimney rather than through the sides of the kiln so this is another important consideration. Then, the project should employ expert charcoal makers who have proven techniques to obtain high efficiencies to lead charcoal making trainings.

The project should also consider conducting a study of charcoal quality from IBEK and traditional kilns to determine if there are real differences, including differences in combustion efficiencies for the end users.

Finally, it is clear that requiring that charcoal producers operating in the project villages use IBEK kilns, does not guarantee higher efficiencies. Even if an idealized IBEK kiln does achieve higher efficiencies, which our study suggests may not be the case, it is clear that a poorly managed IBEK kiln will give very low efficiencies. This means that the best way to encourage better efficiency is to charge charcoal producers for the wood they use rather than the charcoal they produce. Fortunately, the evidence from this study suggests that allometric equations from Mugasha *et al.* 2013 provide an easy way for village natural resource committee members to accurately estimate the biomass of the trees that charcoal makers use.

Thus, the project should encourage communities to charge charcoal makers based on the wood they use assuming a reasonable rate of efficiency using current technologies. Given the results of this study and others, an expected efficiency of about 20% would seem prudent. The permits issued by the village natural resource committee should then include both the amount of wood used, which will be the basis for the royalty charges, and the amount of charcoal produced, which will be the basis for the number of bags for which royalties can claim to have been paid. Having a record of each will help make sure that unreasonably high efficiencies are not being claimed, which would suggest that charcoal makers did not pay for all of the trees they used.

6) References

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