Biomass availability, energy consumption and biochar production in rural households of Western Kenya

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Introduction

Biomass is one of the most important resources in smallholder farms in Africa. It provides rural households with ecosystems services such as soil organic matter, nutrient recycling to crops, fuel, building materials and animal feed. Inefficient policy interventions, unfair pricing structure, weak institutional structure, and lack of strong research priority and implementation [1] contribute to the continued use of biomass and the existing pressure on land resources. In order to reconcile the need to increase food production, energy needs, and environmental conservation, technology innovations must be identified that are able to mitigate these problems while making sure that existing natural resources are protected. An alternative to conventional cook stoves based on biomass burning is the pyrolysis of biomass residues while cooking, which can provide both cooking energy and biochar as a soil amendment [2, 3]. Our goal was to determine whether on-farm biomass production was capable of supplying sufficient fuel energy to sustain household cooking energy needs as well as of producing sufficient biochar by way of pyrolysis as a soil amendment.

Materials and Methods

For purposes of this study, we measured the biomass of vegetation identified by farmers as sources of fuel for pyrolysis. Total aboveground biomass was measured for four major biomass classes; woody biomass, maize residues (cobs and stover), collard green stalks and banana pseudo stems. Based on total aboveground biomass calculations, available biomass energy was calculated for each farm. The quantity of energy currently used for cooking was assessed through daily cooking tests in a subsample of 20 households. Fuelwood and wood char residue measurements were made in each household during daily cooking activities with traditional stoves. For the pyrolysis stove, fuelwood, biomass, wood char residues and biochar were measured. Energy consumption per capita serves as a baseline to compare the current energy consumption of the household and the consumption when a pyrolysis stove is introduced.

Results and Discussions

Biomass availability for bioenergy across conversion ages

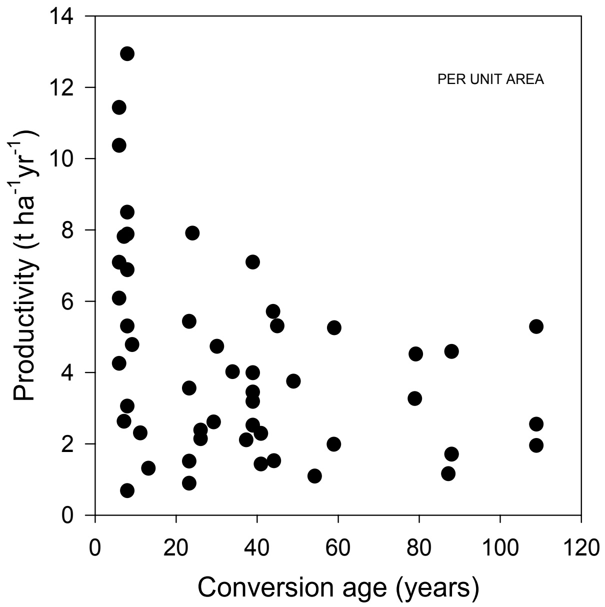

Figure 1. Total aboveground biomass productivity for all farms with increasing age of conversion on a hectare basis (N=50).

Biomass availability for pyrolysis varied widely from 0.7 to 12.4 t ha^{-1} yr^{-1} with an average of 4.3 t ha^{-1} yr^{-1} (Figure 1), across all 50 studied farms. Recently converted farms with high soil fertility presented the highest variability (CV=83%), which was a result of the wide range of farm size and feedstock types in the farm. Smaller farms allocated more land to the production of food crops, while larger farms distributed land among a greater diversity of plants and therefore bioenergy feedstocks. Biomass variability was two times lower for old conversion farms with low soil fertility (CV=37%). The reduction in variability is a direct consequence of the soil quality, coupled with farm size and feedstock type. A lower soil fertility led to lower biomass productivity and variability.

Household energy requirement and biomass available for pyrolysis

While most of the farms currently have some form of wood production, the total wood energy available in the farms is not sufficient to meet the current cooking energy needs. However, total biomass productivity usable in pyrolytic cook stoves including crop residues, shrub and tree litter can provide 18.2 GJ capita^{-1} yr^{-1} of energy for cooking needs, which is well above the average cooking energy consumption of 10.5 GJ capita^{-1} yr^{-1} (Table 1).

Table 1. Total mean available energy for pyrolysis on per capita basis for each conversion category.

Conversion	Energy Available for Pyrolysis (GJ capita^{-1} yr^{-1})	Energy Consumed (GJ capita^{-1} yr^{-1})
Recent <20	22.7a	13.0a
Intermediate 21-49	18.7ab	11.4a
Old >50	10.1b	8.4a

In our study, a household using a traditional three-stone stove or a chepkube stove consumes 7.1 and 9.7 GJ capita^{-1} yr^{-1}, respectively (Table 2). A traditional cook stove studied in Mexico was shown to consume 19.7 GJ capita^{-1} yr^{-1}, with significant reductions found for improved cook stoves with 6.5 capita^{-1} yr^{-1} [4].

Table 2. Total biomass energy used per capita and total production of biochar per hectare (±SE).

Stove type	N	Total Energy Used (GJ capita^{-1} yr^{-1})	Total Biochar Produced (ton ha^{-1} yr^{-1})
Three Stone	9	7.11ab ± 1.16	-
Chepkube	10	9.65a ± 1.10	-
Pyrolysis	19	6.69b ± 0.80	0.46 ± 0.07

In comparison, the households in our study would consume 6.7 GJ capita^{-1} yr^{-1} with the studied pyrolysis stove. Therefore the introduction of the studied pyrolysis stove may lead to a reduction of 27% overall wood energy used. As a result, the introduction of a pyrolysis stove to a smallholder farming system, similar to gasification stoves or other improved cook stoves, could lead to gains in energy efficiency [4, 5], bearing in mind that significant improvements in stove designs can be expected in the near future. In addition to improved energy efficiencies, the studied pyrolysis stove would produce annually 0.46 t ha^{-1} of biochar (Table 2).

Conclusions

Our study was able to demonstrate the capacity of on-farm biomass production to meet the energy needs of households in western Kenya, if pyrolysis cook stoves are used instead of combustion cook stoves. If biomass is harvested and used sustainably; households are able to use different combinations of biomass to meet cooking energy need through pyrolysis due to the wider feedstock types that can be utilized. In addition, the production of biochar and its use as a soil conditioner could increase on-farm crop productivity, leading to an overall increase in food production for the household. A system that combines the production of biochar and bioenergy may be able to reduce off-farm biomass gathering, improve energy security, and produce sufficient biochar to improve soil productivity in resource-poor farms in Africa.

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