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Biochar stoves for socio-ecological resilience: Lessons from small-scale farms in rural Kenya

Introduction

Majority of households in sub-Saharan Africa (SSA) cook with charcoal and/or firewood using inefficient stoves. This leads to high consumption of wood fuel as well as exposure to the negative effects of indoor air pollution, which disproportionately affects women and children. Concurrently, the rural population in SSA depends on agriculture, which faces the challenges of low soil fertility and high cost of mineral fertilizers. This brief presents an innovative way of cooking with an improved and more efficient gasifier stove that converts biomass to heat for cooking while producing biochar as a by-product. Cooking with the gasifier reduces fuel consumption and indoor air pollution. In addition, biochar, when used as a soil amendment, improves soil fertility leading to increased crop yields. The effect of biochar on soil fertility can last for over a decade (Kätterer et al., 2019); use of biochar for soil improvement stores carbon underground, thus resulting in carbon dioxide removal, and mitigating the effects of climate change (Sundberg et al., 2020). This novel bioenergy-biochar system should thus be included in agriculture, energy, gender and climate change policies for improved socio-ecological farming systems.

Project Overview

This brief describes knowledge and experiences generated in research projects from the period 2013 to 2019. It aims to assess the potential of cleaner and more efficient cooking using a gasifier stove that also produces biochar for soil fertility enhancement and yield improvement in small-scale farms in Kenya

How the Gasifier Works

Chopped firewood is tightly stacked in a 19 cm-high canister (Fig 1a) and lit at the top using small pieces of wood and a matchstick. This is done outside the kitchen to reduce smoke. The well-lit fuel-filled canister is moved into the insulated casing (with a 5.5 cm x 4.5 cm air inlet at the bottom) (Fig 1b) in the kitchen with the holder (Fig 1c). The combustion chamber (Fig 1d) is placed at the top, plus the skirting for holding pot (Fig 1e). The biomass is gasified under limited air supply producing energy-rich gases which are burned with secondary air to generate heat for cooking. When the flames from the burning die out, the biomass will be converted into char which is then harvested by covering the canister with a snuffer (Fig 1f) to cut off oxygen supply and allow it to cool down. The cooled char can then be used as charcoal for cooking or as biochar which is applied as a soil amendment.

Figure 1: Gastov

Training of 150 households in Embu, Kwale and Siaya on (i) gasifier use, biochar production, biochar use in crop production (Figure 2a).

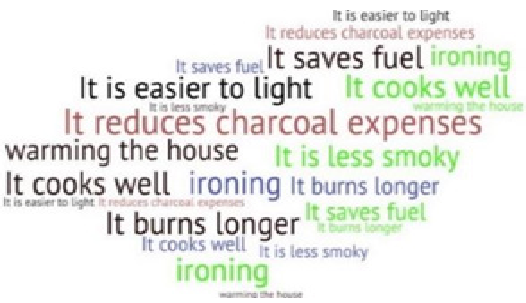
Baseline and adoption studies

- Participatory cooking tests on fuel use efficiency and indoor air pollution
- Biochar application in furrows (2-3 cm deep) in farmer-managed planned comparison plots of 10-20 m2 (Fig 2b)
- Biochar application rates determined by amounts produced and saved by households
- Maize (Zea mays) and kale (Brassica oleracea) grown under local practice (Fig 2c)
- A transdisciplinary (TD) community of social and natural scientists from the Global North and South who worked with community researchers – co-design and co-learning
- Technical capacity development internationally and locally: 1 PhD, 5 Master's and 5 Bachelor's Degrees in energy systems, engineering, sustainable technology, sustainable development, environmental and bioresources management and governance.

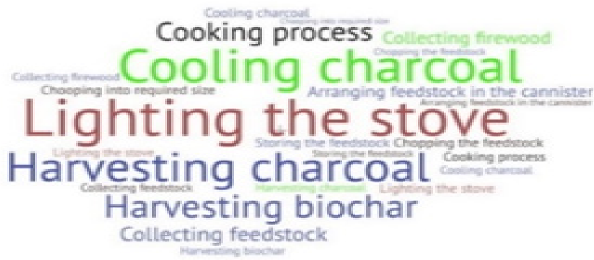
Figure 2: a) Biochar produced from the gasifier; b) biochar application; c) plot to the right has biochar

Results of Cleaner Cooking while Producing Biochar

1. Positive



2. Easiest



3. Most difficult

Figure 3. Gasifier user perceptions on performance of the gasifier cookstove

Table 1. Fuel use efficiency, emissions, biochar production and yield increase

Parameter	**Results: Sundberg et al., 2020; Gitau et al., 2019**
Uptake	>80% of households used the gasifier after 2-3 months
Biochar produced per cooking	193 g per cooking (17% of initial biomass)
Biochar production per household after about 3 months of stove use	1-20 kg produced. Application rate was 1-10t/ha based on what farmers produced
Carbon monoxide (CO) concentration in kitchen when cooking	Reduced by 73%
Fine particulate matter ($PM_{2.5}$) concentration in kitchen when cooking	Reduced by 90%
Crop yield: kale	Increases from 33%
Crop yield: maize	Increases from 0.9 to 4.4 Mg/ha reported. More results to be published
Carbon sequestration	Net negative carbon dioxide emission in case of sustainable biomass production

The char produced during cooking with this micro-gasification system has good fuel properties for another round of cooking (Table 2; Njenga et al., 2017). If used as a soil amendment, biochar lowers soil bulk density, increases soil pH, improves soil water holding capacity and provides important plant nutrients, especially potassium. Effects of biochar on yields was still evident and positive even after 10 years since application (Kätterer et al., 2019).

Table 2. Quality of feedstock, char as fuel and char as biochar for soil improvement

	Calorific value (heat capacity) in MJ/kg		**Plant-available nutrient levels in biochar in mg/kg**			
Type of firewood	Firewood	Charcoal	Mg	K	P	S
Neem (Azadirachta indica)*	18	32	240	4200	490	60
Casuarina (Casuarina equisetifolia)*	18	32	112	1200	85	31
Mukima(Grevillea robusta)**	19	33	133	2300	120	200
Macadamia (Macadamia integrifolia)**	18	33	204	2600	250	160

**=Kwale, **=Embu, Mg=magnesium, K=potassium, P=phosphorous, S=sulphur. Mehlich3-extraction used to determine nutrient levels*

Figure 4. Gasifier user perceptions on performance of the gasifier cookstove

Bioenergy-biochar system has multiple benefits as illustrated in Figure 4.

Research in Development and Policy Recommendations

- The new cooking system improves the health and economy of women and girls. However, chopping wood into required sizes and refilling of fuel if charring occurs before food is ready is additional work. This should be addressed through improvement of the cooking stove design and/or refinement of techniques for chopping wood.
- Biomass for biochar and cooking energy within the SSA context is intertwined with feedstock access, methods of production and the impacts. As such, biochar and bioenergy should be addressed as integrated systems through inclusion in agriculture and bioenergy policies and extension programmes.
- Innovations and technology development need to consider local innovations and user needs, perceptions and potential of extension programmes for agriculture.
- For optimal benefits in energy and food security, and mitigation and adaptation to climate change, biomass must be produced sustainably; for example, through agroforestry systems.
- The complexity of biochar-bioenergy systems requires a community of practice (CoP) comprising natural and social scientists. These two groups should work together with local communities, the private sector, policy makers, development practitioners and funders in a Transdiciplinary (TD) manner.

Partnerships and Other Contributing Organizations

Department of Sustainable Development, KTH Royal Institute of Technology, Environmental Science and Engineering (SEED), Stockholm, Sweden; Department of Energy and Technology and Department of Soil and Environment and Department of Ecology and Management, The Swedish University of Agricultural Sciences; World Agroforestry (ICRAF); Wangari Maathai Institute for Peace and Environmental Studies, University of Nairobi, Nairobi, Kenya; Department of Human Geography, Lund University, Sweden, International Institute of Tropical Agriculture (IITA), Nairobi, Kenya; Office of International Programs, College of Agricultural Sciences, The Pennsylvania State University, CGIAR System Organization and Kenya Industrial Research and Development Institute (KIRDI)

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Project website: www.biochar.abe.kth.se

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