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Climate change impact of introducing a biochar cook stove to Western Kenyan farm households: a system dynamics model

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Introduction

Improved cook stove projects in developing countries have been promoted for decades driven by the desires to improve health by decreasing indoor air pollution from cooking, to limit forest degradation and deforestation while decreasing the burden on those who collect the biomass fuels and, more recently, to mitigate climate change.

While methodologies for quantifying the carbon (C) savings of improved cook stoves have been developed and extensive research has been done on improved cook stoves in Mexico [1], this research was limited to direct stove impacts, while the current study examines a more complex stove system. Cook stoves that produce biochar as well as cooking energy are a relatively recently developed technology, and have yet to be rigorously investigated for their climate change mitigation potential [2]. These cook stoves add another layer of complexity to the climate impacts of the system due to (i) the effects of biochar applied to soil on crop yields, (ii) the stabilization of the relatively labile C from fresh biomass as biochar, and (iii) possible changes in the sources of biomass that can be used as fuel.

This study uses system dynamics modelling to (i) investigate the climate change impact of biochar-producing cook stoves and improved combustion cook stoves in comparison to conventional cook stoves, (ii) assess the relative sensitivity of the stoves to key parameters, and (iii) quantify the effects of different climate change impact accounting decisions.

Methods

The modelled system is a rural farm household in the highlands of western Kenya. The region is characterised by common use of traditional 3-stone biomass cook stoves and declining biomass fuel availability. Farm households primarily grow maize, but some also grow sukuma-wiki or banana trees, among other minor crops. The region is also marked by declines in maize yields over the time since the farms were converted from primary forest. This decline has been shown to be mitigated by the application of biochar to soils, increasing yields [3].

We employed the system dynamics modelling approach to determine the GHG impact of the introduction of improved biomass cook stoves using either pyrolysis or combustion technology to a western Kenyan farm household. Our model consists of four interlinked modules: on-farm production, soil carbon, cook stove fuel use and emissions, and GHG impact.

The model was run (i) to predict the GHG impact deviation from the 3-stone stove baseline. (ii) to explore the sensitivity of this value to six key parameters, and (iii) to evaluate the impact of two policy decisions.

Results and Discussions

Simulated reductions in GHG impact range between means of 2.58-4.74 tCO_2e/ household/ year for the prototype pyrolytic stove, 3.33-5.80 for the idealized pyrolytic stove, and 2.56-4.63 tCO_2e/household/year for the improved combustion stove. These numbers are similar to those calculated by Johnson et al. [1] for Kyoto emissions from improved cook stoves in Mexico – a 95% confidence interval of 2.3-3.9tCO_2e/household/year. This rate of emissions reductions could allow stove projects to access carbon financing if the monitoring costs were similar to those discussed in Johnson et al. [1]. However, if the values of biomass stabilization as biochar and changes in SOC stocks are ignored and only reductions in gaseous emissions were counted, this would reduce the annual emission reductions by 16-36% for the idealized biochar cook stove, and 29-57% for the prototype biochar cook stove, thus decreasing the economic viability of the project for biochar-producing cook stoves.

The magnitude of the GHG reductions is most sensitive to the fraction of non-renewable biomass (fNRB) of the off-farm biomass fuel sources and the baseline fuel wood use. The impact of changing this value depends on how much reductions depend on stove emissions as compared to biochar production.

If there is no change in maize stover gathering (25%), non-biochar soil carbon increases over time, resulting in a negative deviation from baseline. If gathering is increased, there is an initial depletion, but increased yields due to biochar result more stover being returned to the soil, increasing non-biochar soil carbon.

Conclusions

Our modelling shows that even the prototype biochar stove is likely comparable to other improved cook stoves in terms of reducing GHG impact, but has the fascinating additional dynamics of biochar production and the associated crop yield increases, which could have important effects on food security in developing regions such as the one considered in this study. While this aspect of biochar cook stoves would be considered an advantage for its users, it is an additional challenge for those hoping to account for its GHG reductions.

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