Assessment of trade-off balance of maize stover use for bioenergy and soil fertility

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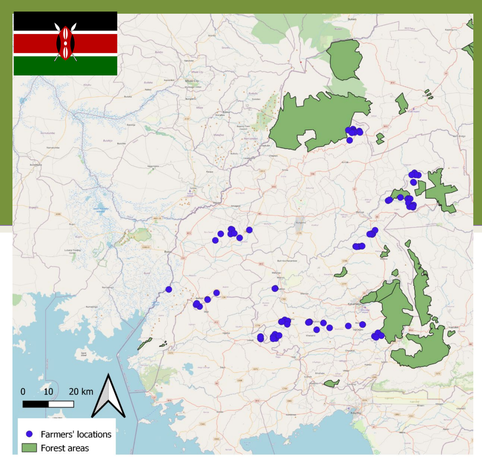


Background:

-**Forest:** The Kakamega Forest, located in the Western Kenya Region where population growth is quite high, is the only remaining patch of tropical rainforest in Kenya, covering an area of about 238 square kilometres (Muoria & Odera, 2016). Deforestation is a significant threat in Kenya, including in the Kakamega Forest and Mt. Elgon, and it is often driven by the need for firewood and charcoal for cooking and heating, as well as the expansion of agricultural lands and new settlements.

-Energy: Anaerobic digesters and bioslurry are important for smallholder farmers living in sub-Saharan Africa because they can help to address several challenges faced by these communities, including deforestation, poverty, and reliance on chemical fertilisers. Deforestation is a major issue in sub-Saharan Africa, and it is often driven by the need for firewood and charcoal for cooking and heating. Anaerobic digesters can provide an alternative source of fuel by converting animal waste and other organic materials into biogas, which can be used for cooking and lighting, reducing the demand for firewood. Smallholder farmers in sub-Saharan Africa also often face poverty and struggle to make ends meet. Bioslurry, which is the nutrient-rich residue left after the anaerobic digestion process, can be used as a natural fertiliser, providing a low-cost alternative to chemical fertilisers that are often expensive and difficult to access. In addition, chemical fertilisers can have negative impacts on the environment, including pollution of waterways and soil degradation.

-**Crop Residue:** Maize stover is a promising feedstock for biogas generation and bioslurry production due to its high lignocellulosic content and wide availability. The use of maize stover for biogas generation can not only produce a renewable energy source but also alleviate waste management issues in maize-producing regions. Generally, maize stover can yield 200-400 litres of biogas per kg of dry matter, which can generate approximately 3.6-7.2 kWh of electricity per kg of dry matter. This energy output can meet the needs of small-scale energy users, such as rural households, and provide a sustainable alternative to fossil fuels. On the contrary, maize stover plays a vital role in maintaining soil fertility and preventing soil erosion. Leaving maize stover in the field after harvesting can help to protect the soil from erosion, and the decomposition of the stover can add organic matter to the soil, improving soil health and structure. Thus, leaving maize stover in the field can be an important agricultural practice to promote sustainable soil management.

Aim:This study aims to obtain a better understanding about the household status related to field management and then analyse the trade-off balance of utilisation of maize stover for energy generation and soil erosion in the Western Kenya region, where the population is strongly increasing.

METHOD

Farmer socio-economic information was collected during the interview (n=91), conducted after the cropping season. The interview data includes household status, social-economic background of the household and agronomic practices that were applied in the past. A digital questionnaire including 33 questions was used. The questionnaire was implemented in a smartphone application. All sections are inserted into digital forms using Open Data Kit (ODK) software, available on Android based mobile phones. Completion took approximately 30 minutes per farmer. After the collecting the data (n=91), the energy consumption per household is calculated based on the types and the frequencies of the different resources (Firewood, charcoal, and gas) (Kitayi et al., 2011; FAO 1985). We deployed The Revised Universal Soil Loss Equation (RUSLE) at county level (Ouellette, 2021) which is an empirical erosion model recognised as a standard method to calculate the average risk of erosion on crop fields. This model allows us to understand the contribution of maize stover for soil erosion (Gan et al., 2014; Benavidez et al., 2018). The geographical data including slope, altitude, landside is taken from digital elevation model of JAXA-AW3D30 (30m resolution). Soil texture type of 91 different fields is taken from Soil-Grids (250m resolution) ISRIC dataset. The distance from the nearest forest area to household house is measured based on GPS points by using QGIS. T-test and linear regression is conducted Additionally, principal Component Analysis (PCA) and Correlation analysis is conducted.

Selected Variables

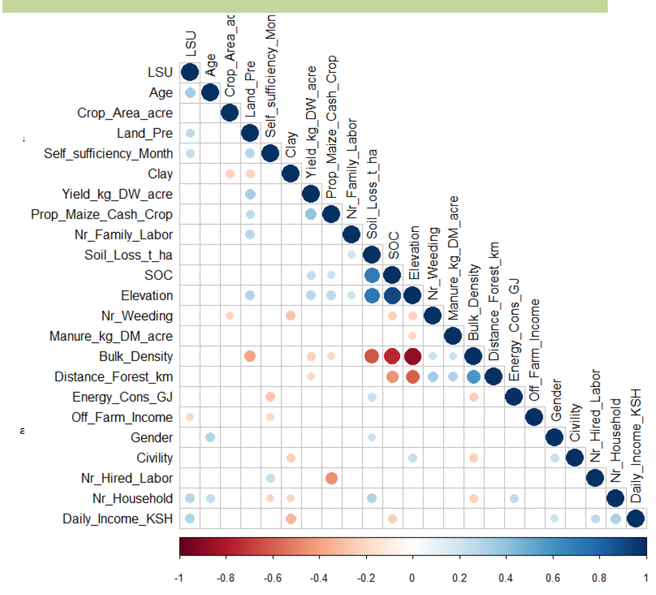
Variable	Abbreviation	Unit	Resource
Gender		Mr/Mrs	Interview
Civility		single, widow, married	
Age of household head	Age		
Number of household	Nr_Household		
Crop Area	Crop_Area_acre	acre	
Land Preparation	Manure_kg_DM_acre	manual, oxcart, tractor	
Number of weeding	Nr_Weeding		
Amount of manure Use	Manure_kg_DM_acre	kg/acre	
Maize crop yield	Yield_kg_DW_acre	kg/acre	
Energy consumption	Energy_Cons_GJ	Gigajoule/capita	
Hired labours	Nr_Hired_Labor		
Family labours	Nr_Family_Labor		
Livestock Unit (LSU)	LSU		
Daily income (DI)	Daily_Income_KSH	Kenyan Shelling	
Other income resource	Off_Farm_Income	Yes/No	
Selling maize as cash crop	Prop_Maize_Cash_Crop	%	
Duration of self-succifiency	Self_sufficiency_Month	Months	
Distance to the nearest forest	Distance_Forest_km	km	GPS
Bulk density		g/cm^3	SoilGrids
Clay		%	
Soil organic carbon	Soil_Loss_t_ha	%	
Soil loss		t/ha	
Elevation (altitude)		m	DEM

Results

Linear regression & T-test

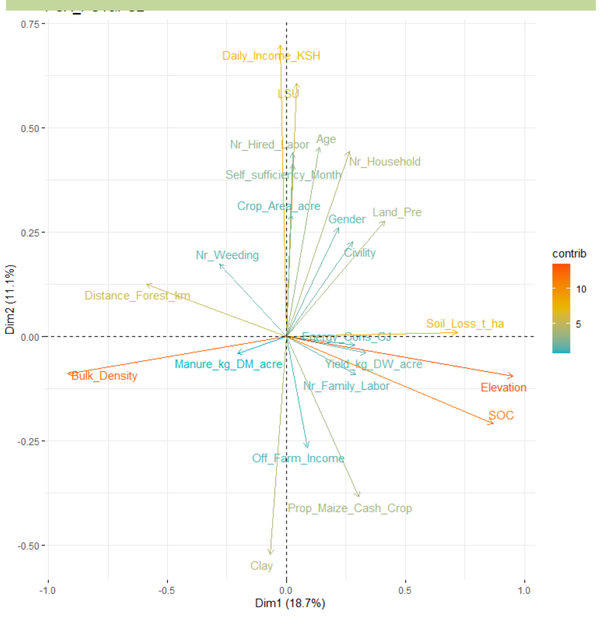
- Field management practices significantly impact maize yield, including land preparation ($p < 0.01$), manure utilization ($p < 0.05$), and the frequency of weeding ($p < 0.05$).
- No statistically significant effect is observed in relation to the number of labours on maize yield.
- Elevation (altitude) is a significant factor ($p < 0.05$) contributing to the estimated potential soil loss as determined by RUSLE.
- The number of households has a noteworthy influence on the duration of self-sufficiency ($p < 0.05$).
- Interestingly, farmers without off-farm income exhibit a superior duration of self-sufficiency (7.9 months compared to 6.6 months, $p < 0.05$).
- Households with larger family sizes demonstrate a significantly higher energy consumption per individual ($p < 0.05$).
- While not achieving statistical significance, farmers with off-farm income allocate a greater proportion of maize for sale compared to those without such income.
- No gender disparities are found in terms of maize yield, land size, and livestock assets (LSU).
- Widows and single mothers do not exhibit inferior performance or asset levels in relation to crop yield, land size, or livestock.

Correlation



- Elevation correlates strongly with soil properties (bulk density & SOC), estimated soil loss, and distance to the forest.
- No clear link between nearest forest proximity and energy consumption.
- Per capita energy consumption: slightly positive correlation with household count, negative correlation with self-sufficiency duration.
- Correlation between land preparation and bulk density.

PCA



- PC1 and PC2 account for 29.8% of variance.
- SOC, Elevation, Bulk density, Daily income, and LSU show higher loadings.
- Socioeconomic household variables load similarly on PC2 (e.g. “Daily income,” “Nr hired labour,” “Self-sufficiency duration,” “Crop area”).

Conclusion

1. Geography significantly affects maize stover choices: Highland households face soil erosion risks, making leaving stover on soil preferable over biogas use.
2. Diverse smallholder profiles matter: Larger families use more firewood per person, so using maize stover for biogas is advised, along with utilizing bioslurry for maize growth.
3. Field management is crucial: Proper practices like land prep, controlled manure use, and weeding boost maize yields and stover production. This stover can yield biogas and bioslurry, aiding farmers sustainably.

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