Workshop on Biochar Pilot Studies in Tanzania

Workshop Proceeding

Biochar Project in Tanzania-Workshop on Biochar Pilot Studies in Tanzania, 10-11 September 2020

Center for Climate Change Studies of the University of Dar es Salaam, Tanzania

1.0 Introduction

The workshop on Biochar Pilot Studies in Tanzania was held on 10th and 11th September to brainstorm on biocher as soil management as well as climate change mitigation technology. Biochar is a charcoal-like substance that is made by burning organic material from agricultural and forestry wastes (also called biomass) in a controlled process called pyrolysis. Although it looks a lot like common charcoal, biochar is produced using a specific process to reduce contamination and safely store carbon.

Although biochar technology is considered a more recent strategy for carbon sequestration, the practice of adding charred biomass to improve soil quality is not new. biochar has been applied on degraded soils in order to enhance its quality. Some of the ways that biochar may help improve soil quality include: enhancing soil structure, increasing water retention and aggregation, decreasing acidity, reducing nitrous oxide emissions, improving porosity, regulating nitrogen leaching, improving electrical conductivity, and improving microbial properties

Biochar production is a carbon-negative process, which means that it actually reduces CO2 in the atmosphere. When biochar is applied to the soil, it stores the carbon in a secure place for potentially hundreds or thousands of years. To put it simply, the feedstocks that were used for making biochar would release higher amounts of carbon dioxide to the atmosphere if they were left to decompose naturally. By heating the feedstocks and transforming their carbon content into a stable structure that doesn’t react to oxygen, biochar technology ultimately reduces carbon dioxide in the atmosphere.

Biochar also contributes to the mitigation of climate change by enriching the soils and reducing the need for chemical fertilizers, which in turn lowers greenhouse gas emissions. The improved soil fertility also stimulates the growth of plants, which consume carbon dioxide. The many benefits of biochar for both climate and agricultural systems make it a promising tool for regenerative agriculture.

Series of presentations were held from researchers and practitioners who have been involved in piloting this technology on the ground. Findings from these pilots formed a good basis for comparative analysis of results from these different pilots. Moreover, presentations shed light on challenges and opportunities for scaling these pilots.

2.0 Biochar niche-based technology for improving soil fertility and carbon sequestration in Tanzania

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Abstract

Literature synthesis shows that food production has to increase by 70% by 2050 due to growth in population projected to reach 9.1 billion. Food production is/will still be from a decreasing land where water and fuel are increasingly becoming the limiting resources and challenged by the impact of climate change. The biggest challenges facing the world are the need to increase food production through sustainable intensification, build resilience to adapt to the impact of climatic change and reduce greenhouse gas (GHG) emissions to the atmosphere. Engagements in biochar technology necessitate a critical investigation of the opportunities and risks for biochar production and integration into managed systems throughout the world. The adoption of biochar technology is relevant to preventing deforestation, promoting agricultural resilience, and producing renewable energy, and makes it an important issue particularly in developing countries. Biochar has the potential to improve soil fertility and increase food production for smallholder farmers from higher crop yields cultivated on degraded soils. The use of an improved source of heat for cooking that produces biochar could reduce indoor air pollution and saves time spent on fuel gathering. These two major benefits derived from biochar technology could potentially decrease the practice of clearing more forested land for agriculture and firewood or charcoal for cooking purposes. A pilot study conducted in 2019 indicated that information on biochar technology in Tanzania is scarce. There is a need to curiously map and establish the potentials of biochar technology, its implementation, and adoption by the smallholder farmers and other involved stakeholders in developing tropical countries including Tanzania.

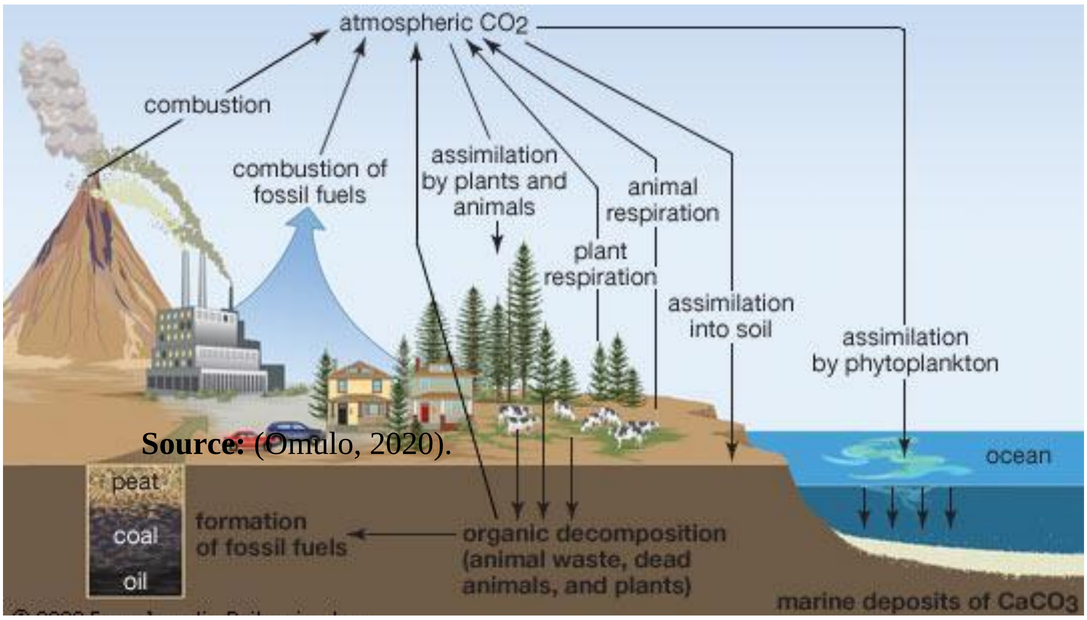
Keywords: carbon sources; carbon sinks; climate change; land productivity

2.1Introduction

The world’s population is projected to reach about 9.1 billion by 2050, which will simultaneously require an increase in agricultural food production by 70% (Mueller *et al*., 2012; Nassary *et al*., 2020). Along the same period, water scarcity, soil nutrients, and climate change will be the limiting factors of agricultural productivity (Nassary *et al*., 2020). The implementation of improved land management practices such as sowing different crop species in mixtures (intercropping), crop rotation, mulches, minimum tillage, cover crops, compost, or manure are used as options for enhancing soil organic carbon and crop productivity of cultivated land in the tropics (Mekuria and Noble, 2013; Nassary *et al*., 2020). However, the organic matter added to the soil is readily mineralized to carbon dioxide (CO_2), and therefore, carbon (C) does not remain in the soil through some cropping seasons. The options towards the management of black carbon (C), referred to as biochar, may be an alternative in overcoming some of those limitations and provide an improvement to soil fertility and carbon sequestration (Hansson *et al*., 2020). The relevance of biochar technology in developing countries is twofold (Scholz *et al*., 2014): - Firstly, biochar has a potential to improve soil fertility and increase food production for smallholder farmers from higher crop yields cultivated on degraded soils. Secondly, use of improved source of heat for cooking that produce biochar could reduce indoor air pollution and saves time spent on fuel gathering. These two major benefits derived from biochar technology could potentially decrease the practice of clearing more forested land for agriculture and firewood or charcoal for cooking purposes.

Therefore, with a strong connection to global challenges of nutrition, hunger, and climate change, it is critical to minimize further changes in land use, land degradation, and emissions of greenhouse gas (GHG) (Mehmood *et al*., 2017). Human activities such as deforestation, overgrazing, agricultural mismanagement, or mining are the main causes of land degradation. These activities stimulate the loss of organic matter through erosion, and physico-chemical deterioration of the soil (Barman *et al*., 2013). Agricultural related operations are the major GHG emitters [i.e. carbon dioxide (CO_2), methane (CH_4), and di-nitrous oxide (N_2O)] (Fig. 1) accelerating global warming (Gregory *et al*., 2005). The elevated CO_2 on non-CO_2 GHGs will also contribute to future climate change (van Groenigen *et al*., 2011), rising temperatures, and more extreme weather events, such as droughts and flooding (Mehmood *et al*., 2017).

Fig. 1: Carbon sources and carbon sinks – carbon cycle representing the global



Source: (Omulo, 2020).

2.2 Biochar Implementation Modalities

Biochar, the charcoal-like product resulting from the pyrolysis of biomass, is capable of C sequestration and other benefits including increased nutrients and water-use efficiency, decreased soil CH4, and N2O emissions, and improved habitat for microbial colonization. Although the process of biochar production often mirrors the production of charcoal (Fig. 2; Table 1), the difference is that biochar is produced with the intent to be applied to soil as a means of improving soil fertility, C storage (carbon sequestration), or filtration of percolating soil water. Biochar as a viable approach for carbon sequestration has the potential to help mitigate global warming and climate change. Mehmood et al. (2017) indicated that there is no detailed research done so far in developing tropical countries and this causes researchers to be missing important innovations related to biochar. The potential benefits of biochar in these countries can be realized by researchers through interdisciplinary research, knowledge sharing, and transfer, and investments of biochar to improve crop productivity and to mitigate climate change (Garb and Friedlander, 2014; Das, 2015). Carbon sequestration or CO_2 removal (CDR) is the long-term removal, capture, or sequestration of carbon dioxide from the atmosphere to slow or reverse atmospheric CO_2 pollution and to mitigate or reverse global warming (Fig. 3). The use of biochar in soil amendment is meant to improve soil organic matter and nutrient availability, water retention, and reduce leaching of agrochemicals to the surface and ground waters (Mekuria and Noble, 2013).

Biochar amendment also reduces the costs of investing in synthetic fertilizers in crop production (Leach *et al.*, 2010). Harley (2010) and Mekuria and Noble (2013) summarize the micro-chemical, nutrient, and biological promising effects of biochar for improving soil fertility (Fig. 4; Table 2).

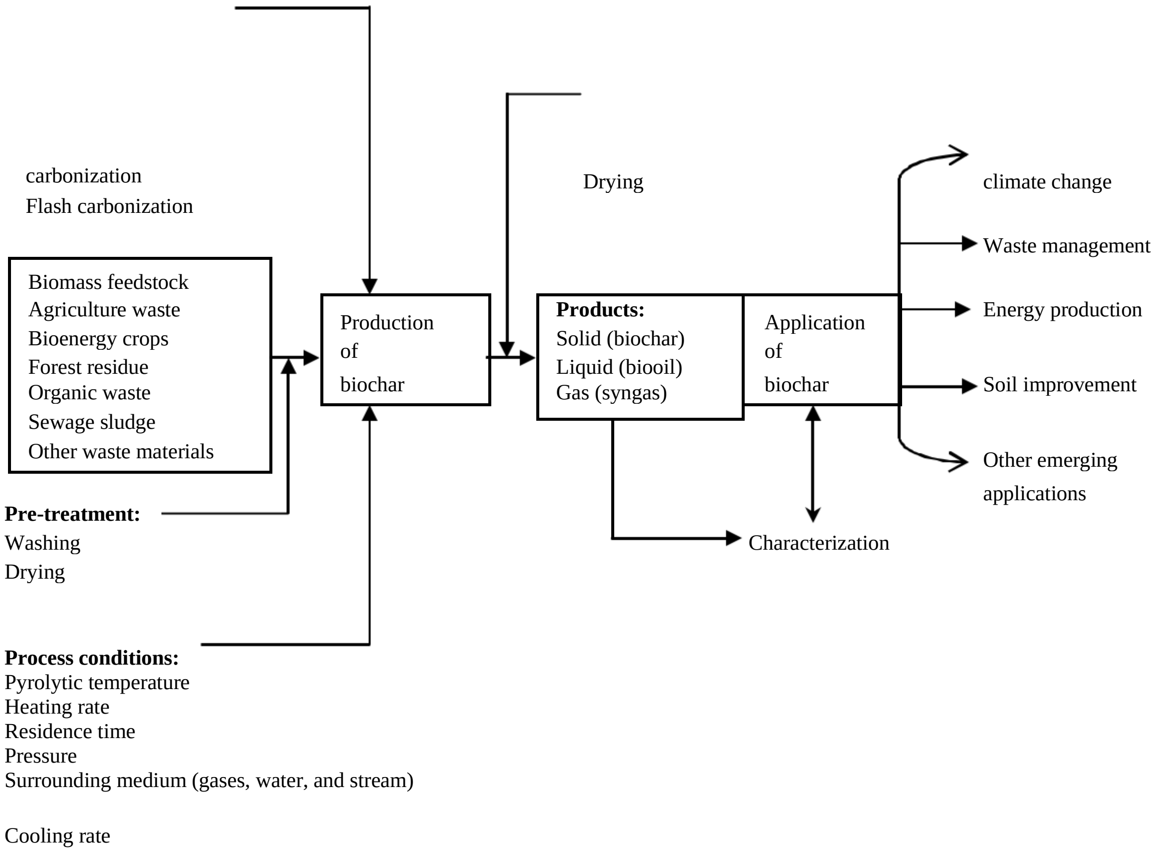
Fig. 2: Schematic process diagram for the factors affecting biochar production and application.

Pyrolysis processes:
Slow pyrolysis
Fast pyrolysis

Intermediate pyrolysis
Gasification
Hydrothermal

Post-treatment (if necessary):
Thermal/chemical activation
Separation

Mitigation of environmental

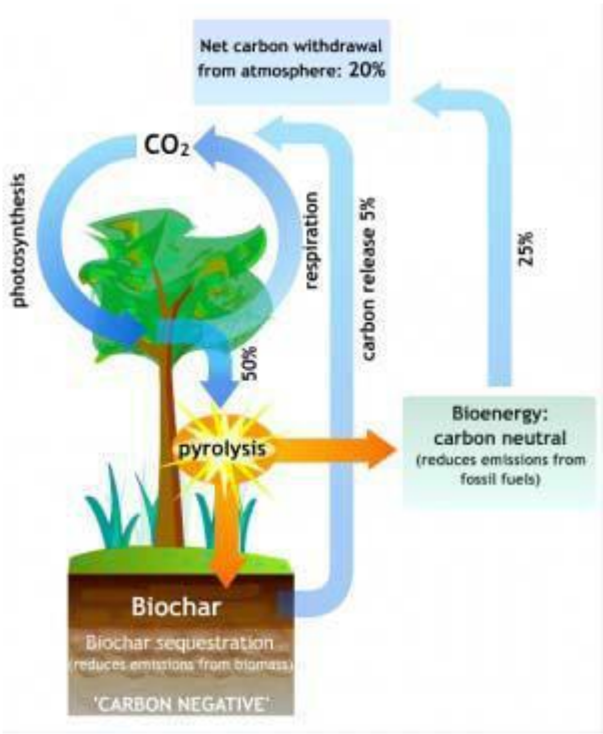


Source: (Nartey and Zhao, 2014)

Table 1: Biomass feedstock products of different types of pyrolysis

Process	Liquid (biooil) (%)	Solid (BC) (%)	Gas (syngas) (%)
Fast pyrolysis: moderate temperature (600 ◦C), short hot vapour residence time	75	12	13
Intermediate pyrolysis: low moderate temperature, moderate hot vapour residence time	50	25	25
Slow pyrolysis: low moderate temperature, long residence time	30	35	35
Gasification: high temperature (>700 ◦C), long vapour residence time	5	10	85
Hydrothermal carbonization: elevated temperature (200–250 ◦C) and elevated pressure	NRA	NRA	NRA
Flash carbonization: (350–650 ◦C), residence time below 30 minutes, at elevated pressure (1–3MPa)	NRA	50	50

*NAR = not readily available.



Source: (Nartey and Zhao, 2014).

Fig. 3: Schematic showing both terrestrial and geological sequestration of carbon dioxide emissions from heavy industry such as a chemical plant Source
Source: (Omulo, 2020)

The pH of biochar, similar to the other properties, is influenced by the type of feedstock, production temperature, and production duration (Table 2). Therefore, biochar application to soil is reported to increase the availability of basic cations (Calcium-Ca, Magnesium-Mg, and Potassium-K) and the concentrations of available phosphorus (P) and total nitrogen (N). Biochar can increase or reduce soil reaction (pH) depending on the pH of the biochar applied. The biochar which is alkaline in reaction (pH >7.3) and its mineral components (ash, N, P, K, and trace elements) can improve soil fertility and hence crop productivity (Mekuria and Noble, 2013). Acidic biochar could also increase soil acidity (lowering pH) when used in the soil which is acidic in reaction (lower pH) (Mekuria and Noble, 2013). Plate 1 shows differences in maize and rice plants with and without biochar applications.

Table 2: Role of biochar in ameliorating drastically disturbed soils. **Source:** Mekuria and Noble (2013).

Limiting factor	**Variable**	**Problem**	**Short-term treatment**	**Long-term treatment**	**Role of biochar**
Physical	Soil structure	Soil too compact	Rip or scarify	Vegetation	Decreased soil bulk density, increased infiltration, and decreased erodibility
	Soil erosion	High erodibility	Mulch	Regrade vegetation	Increased water retention due to surface area and charge characteristics
	Soil erosion	Too wet	Drain	Wetland construction	
	Soil moisture	Too dry	Organic mulch	Tolerant species	
Nutritional	Macronutrients	Nitrogen deficiency	Fertilizer	Nitrogen fixing plants, for example, leguminous trees or shrubs	Yield increases
		Other deficiencies	Fertilizer	Fertilizer, amendments, tolerant species	Slow nutrient release
					Soil organic matter stabilization
					Retention of released nutrients
					Increased microbial activity
					Habitat for mychorrhizal fungi hyphae
Toxicity	pH	Acid soils (<4.5)	Lime	Tolerant species	Designed for alkaline surface charge
		Alkaline soils (>7.8)	Pyritic waste, organic matter	Weathering, tolerant species	High CEC for Na retention
	Heavy metals	High concentration	Organic matter, tolerant cultivar	Inert covering, tolerant species	High surface area and cation exchange capacity allows for metal retention
	Salinity	EC > 4ds/m	Gypsum, irrigation	Weathering, tolerant species	Mixed with gypsum to reduce soil structural issues
		pH < 8.5, SAR < 13			Nutritional values as described
	Sodicity	EC < 4ds/m,	Gypsum, irrigation	Weathering, tolerant species	High CEC for Na retention
		pH > 8.5, SAR ≥ 13			

Plate 1: Biochar sustainably increases crop yields and sequesters historical carbon dioxide emissions.

Maize growing in biochar amended soils

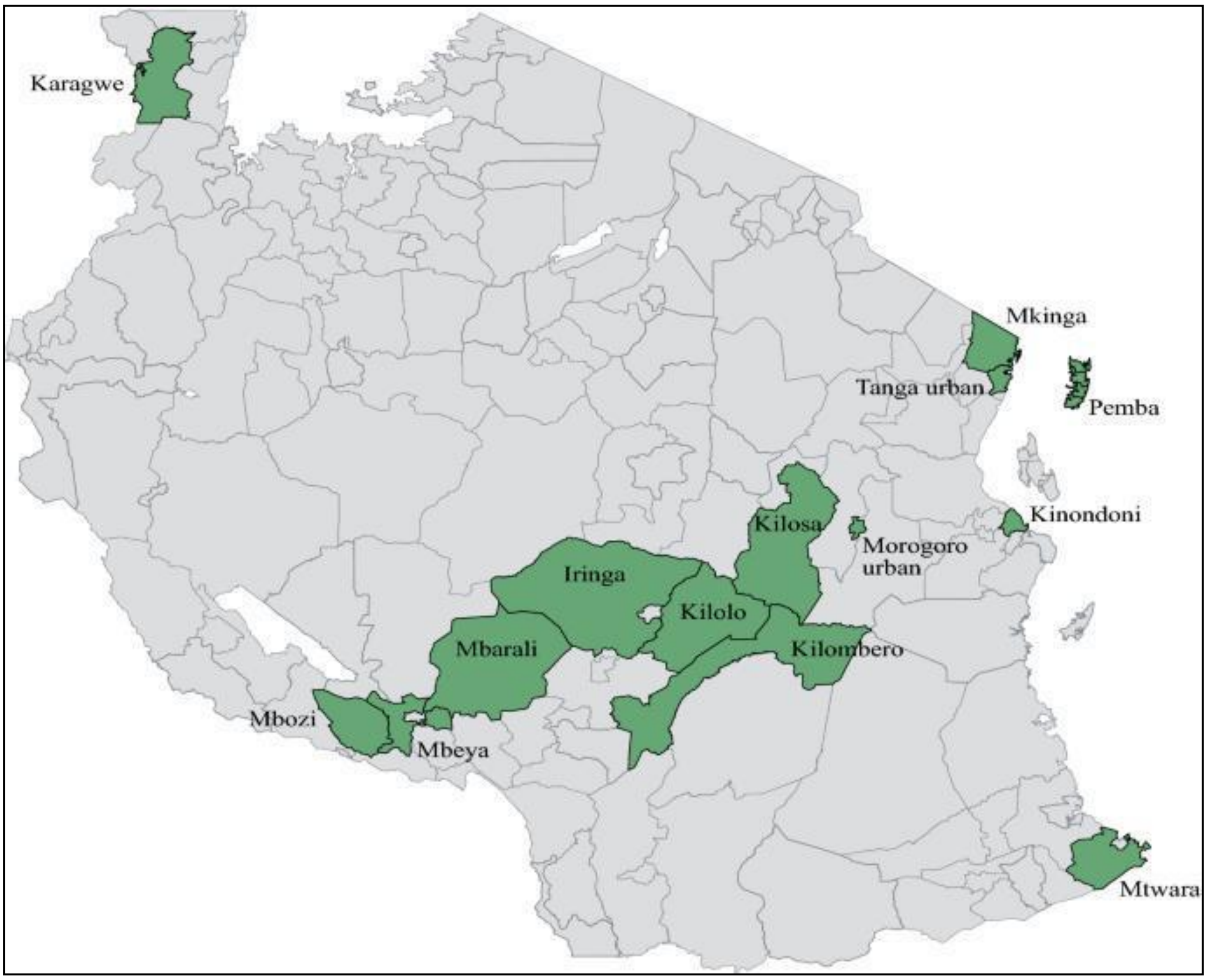
Maize growing in soils without biochar

Source: Rawat *et al*. (2019).

2.3 Biochar Niche-based Technology in Tanzania

Biochar modalities and implementing biochar projects in Tanzania are associated with trade-offs between the development and subsistence strategies among multi-disciplined stakeholders. A study conducted by Hansson *et al*. (2020) mapped and documented similarities and diversity of nine biochar projects in 17 districts of Tanzania (Fig. 5). The biochar niche-based technology projects are much concentrated in the southern highlands and eastern parts of the country. In the north-western part of the country, the technology projects are only unveiled in the Kagera region. Mtwara region is the only representative of the southern regions of the country with biochar technology projects. The study (Hansson *et al*., 2020) was primarily an empirical contribution to the underdeveloped literature on the deployment of negative emissions technologies in developing countries, which is insufficient. Further, this is an important study that has brought to a reflection on biochar as a mitigation technology to climate change and the potential of biochar in crop productivity.

Fig 5: Map of Tanzania showing districts with biochar projects as in 2019

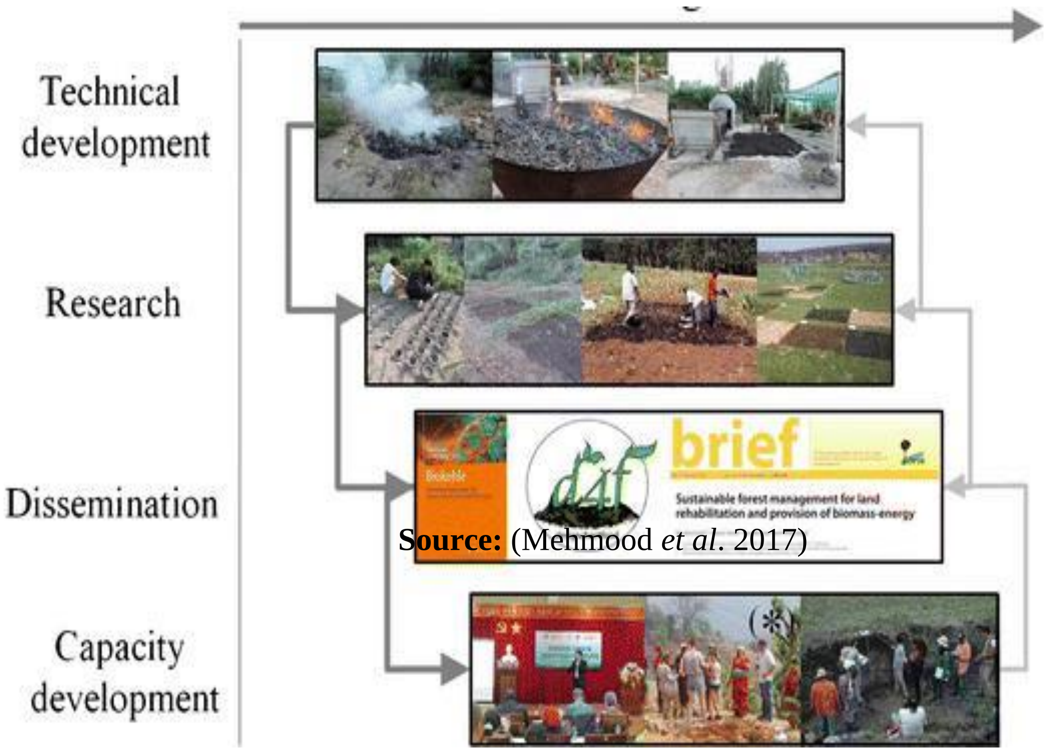


Source: Hansson *et al*. (2020).

2.4 Bridging Biochar Technology to Research, Policy, and End-Users

Biochar technology could potentially bridge research, policy, and end-users. Mehmood *et al*. (2017) provide a thematic structure for the outreach of biochar technology activities (Fig. 6). Arrows (in Fig. 6) indicate simple relationships and feedback loops between technical development, research, knowledge transfer/translation, and capacity development. The dissemination of biochar technology is important to convey scientific knowledge of biochar production, uses, and potential benefits to stakeholders including policy and decision-makers and practitioners. Innovations and selection of biochar to address specific soil limitations require the scientific exchange of results and information among scientists, stakeholders, and potential users (Mehmood *et al*., 2017). There should be a basis for local, regional, and international sharing of scientific findings derived from biochar technology for the sustainability of crop productivity and this ensures food security while mitigating the likely impact of climate change. It is clear that biochar technology and research in developing tropical countries is a young discipline (Gurwick *et al*., 2013; Mehmood *et al*., 2017; Hansson *et al*., 2020).

Fig 6: Biochar production, research execution, knowledge transfer/translation and capacity development in biochar technology



Source: (Mehmood *et al*. 2017)

2.5 Challenges of the Biochar System in Tanzania and Elsewhere

i. One major obstacle to the biochar system is the difficulty in obtaining biochar to work with. However, the possibility of undertaking integrated projects for combined biochar production and its use exists for a wide variety of scales and situations.

ii. Hansson *et al*. (2020) have indicated that implementing biochar projects in Tanzania will likely involve trade-offs between the development and subsistence strategies and needs of local communities, the motivational forces of different project participants, and the uneven regulatory capacity of the government.

2.6 Areas for Further Research

More efforts are required globally in biochar research to understand and manage its nutrient dynamics and impacts on GHG emissions. Based on the results of a review conducted by Mahmood *et al*. (2017), some research priorities to assess and promote the role of biochar technology in development of adapted and sustainable agronomic methods are stipulated hereunder:

iii. Much of the work on biochar has been carried out in tropical soils (but not in Tanzania), which are very poor and acidic in reaction. However, more research is needed, but perhaps these soil amendments of the future should accommodate biochar carriers like mycorrhizal inoculants, simultaneously addressing three vital global issues: soil and crop sustainability, atmospheric CO2 mitigation, and alternative energy needs.

iv. There is also a great need for investing on a testing and classification system for biochar, because biochar characteristics can vary tremendously depending on how it is made, what it is made from, and soil type where crops a grown.

v. The important aspects such as methods and costs of applying biochar to soils need to be critically resolved.

vi. Intensify transfer/translation of existing knowledge, and capacity building required to conduct climate-smart agriculture research across regions of different soil types. It is important to educate and train local experts in science, policy and best-practice examples to ensure effective research and successful implementation of new technologies and methods including biochar in tropical soils.

vii. Enhance research investments and technical cooperation used to conduct agronomic research across regions of different soil types. However, to understand the complex interactions among biochar, soil and plants, and to develop methods applicable for end-users, a mixture of simple and high technologies is required.

viii. Sustainable and climate-smart agriculture using biochar needs knowledge about soil chemistry and plant productivity that is required to manage nutrient application. Research using and managing soil biology and physics to enhance plant productivity are also needed.

ix. Research must be interdisciplinary to ensure greatest benefit from soil and biochar research. Cooperation among several scientific disciplines (e.g. plant science, soil science, and hydrology) is required to facilitate development of sustainable agronomic methods.

x. Research on the role of Biochar in arid and semi-arid areas of Tanzania

2.7 Conflict of interest

This work bears no conflict of interest from any individual, organization, institute, or NGO.

2.8 Acknowledgements

There is no financial support received for this review. However, we acknowledge inputs from a single but an important literature synthesis of a pilot study that mapped biochar projects in Tanzania conducted in 2019 by Anders Hansson, Simon Haikola and Mathias Fridahl from Linköping University, Linköping, Sweden; and Pius Yanda, Edmund Mabhuye and Noah Pauline from the University of Dar es Salaam, Dar es Salaam, Tanzania.

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highlands of Tanzania. *Agriculture*, 10, 117; doi:10.3390/agriculture10040117. exploring future potential for climate-smart agriculture.

3.0 Application of Biochar to Improve Coffee Productivity and Quality in Southern Highlands of Tanzania

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3.1 Background of the Project

The MIICO-TEMBO IVS Project is an innovative project which was formulated jointly by MIICO and TEMBO coffee company in 2017. The project was for one year and it was implemented from Jan-Dec 2017. The funding was provided by DEG (Germany investment and development cooperation) under *Innovation Voucher Scheme (IVS)* with a funding of US$ 25,000.

3.1.1 Main Objective

The project aim was to introduce and apply Biochar to improve coffee productivity and quality in Mbozi, Mbeya rural, Rungwe, Ileje, Momba and Sumbawanga districts.

3.1.2 Specific Objective

To create awareness to farmers on the beneficial effect of Biochar as soil amendment in coffee, build capacity of local extension officers on how to make and apply biochar, build kilns, produce and apply biochar, commercialize biochar in coffee farming system.

3.2 Methods

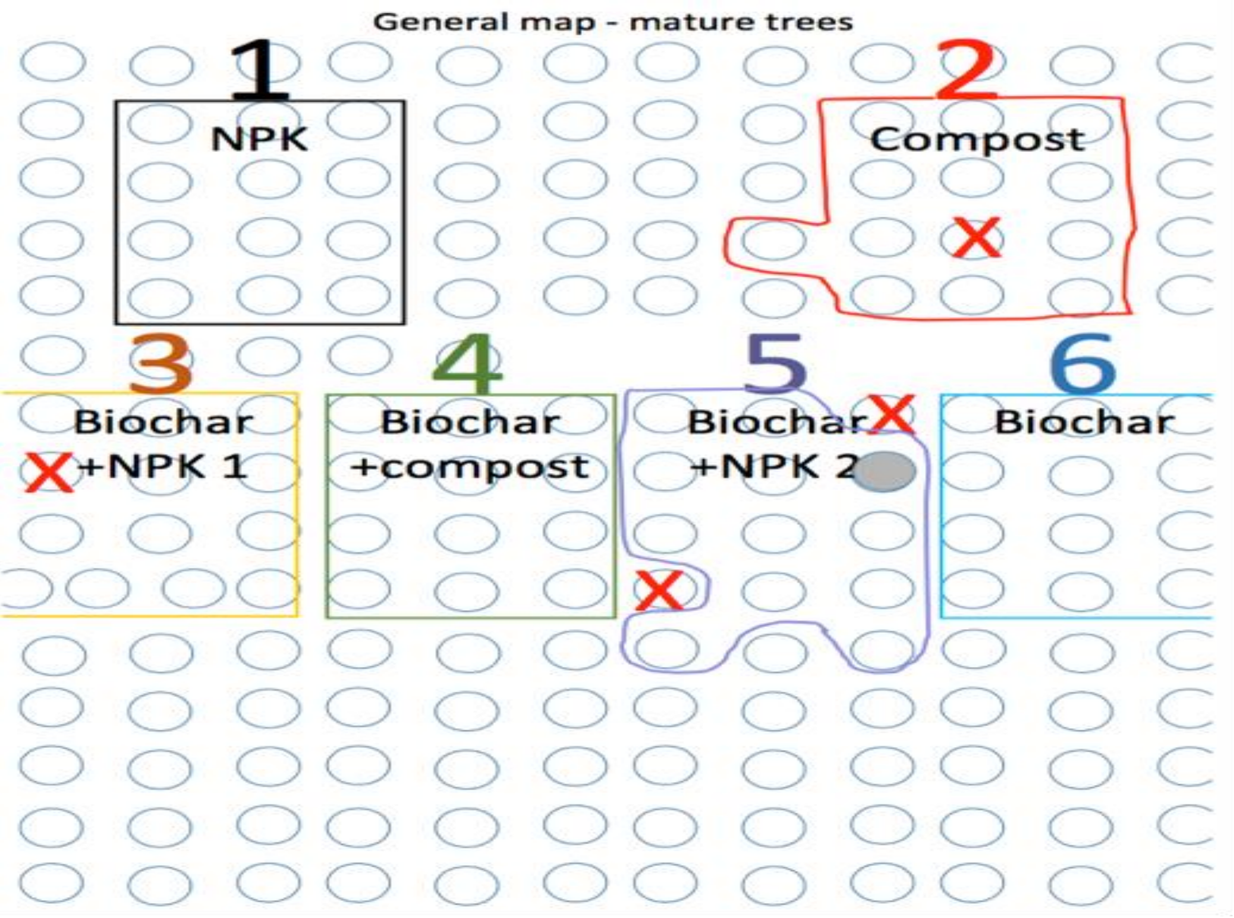
Soil analysis and Field trials

Soil samples were taken for analysis to determine the parameters of the soil before and after biochar application.

Field trials were conducted to investigate the effect of biochar on coffee productivity and quality. The study used one main plot for trials; the plot was divided into six sub plots of mature trees where 1.5 Kg of maize cobs biochar was added in each coffee plant. A total of six treatments were done each in a sub plot. No water or any other application was done to the plots prior to experimentation. Data were collected every week.

Apply Biochar in smallholder’s farms: a number of farmers in the project areas were selectedto apply Biochar in their coffee farmers. The idea was to see the effect under different farmers’ conditions.

Figure1: showing field trials



Training of field staff: Training manual of Biochar was made in collaboration with MIICO, TEMBO coffee and Radio Lifelinifeline, then training were conducted by Radio Lifeline and supervised by MIICO.

Awareness creation to farmers: we conducted a series of meetings to create awareness to farmers on the effects of Biochar to the soil. This was also done through demonstration in the field of farmers themselves.

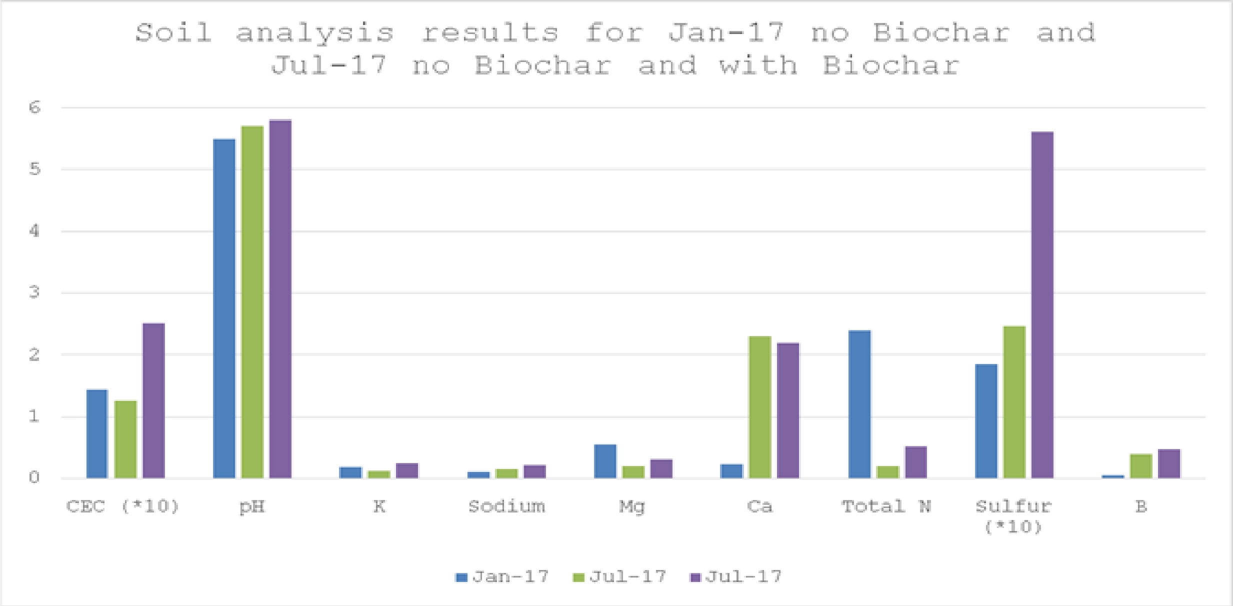
Design and fabricate kilns: with the assistant of the welder we designed and fabricated kilns and we produced Biochar using maize cobs as biomass.

3.3 Key Findings

Soil analysis showed improvement in almost all parameters after application of Biochar with a significant increase in soil CEC which indicates that biochar has the effect of making other elements become readily available for plant uptake. Biochar has a positive effect in all other nutrients except in Mg and TN, also, Boron increased by 20%.

Yield and Quality

All and only the ripe cherries were picked from trees of the 6 plots, the weight of picked cherries per tree were recorded. A total of three recording were done. Results shows that the treatment that involved Biochar with compost showed superior results in all three recordings



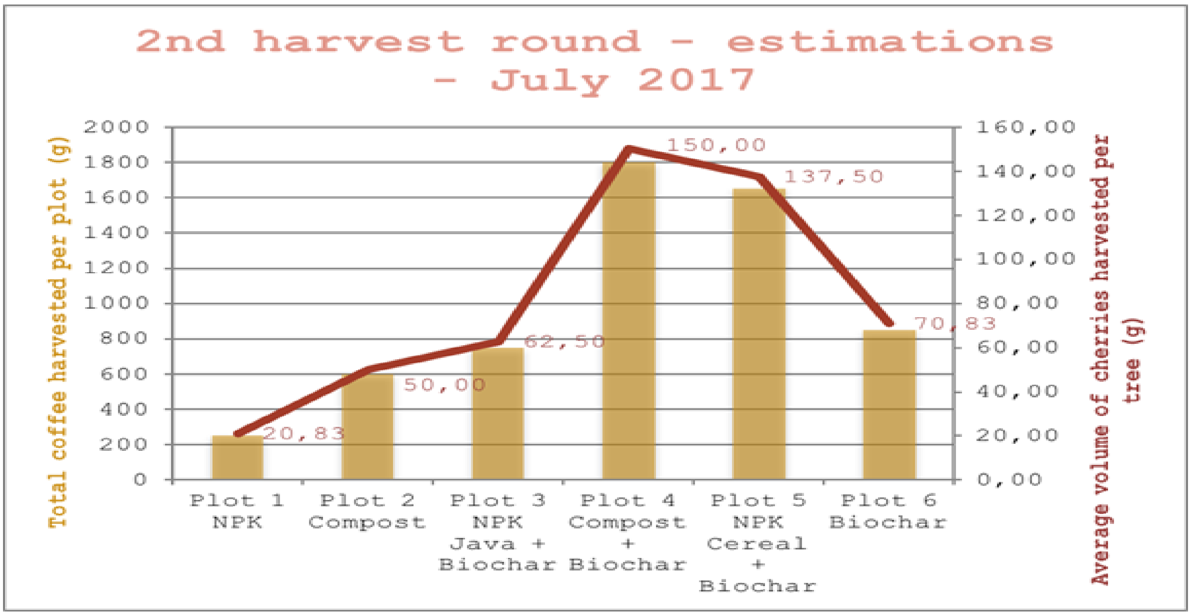


Figure 20: 2nd harvest round results - estimation

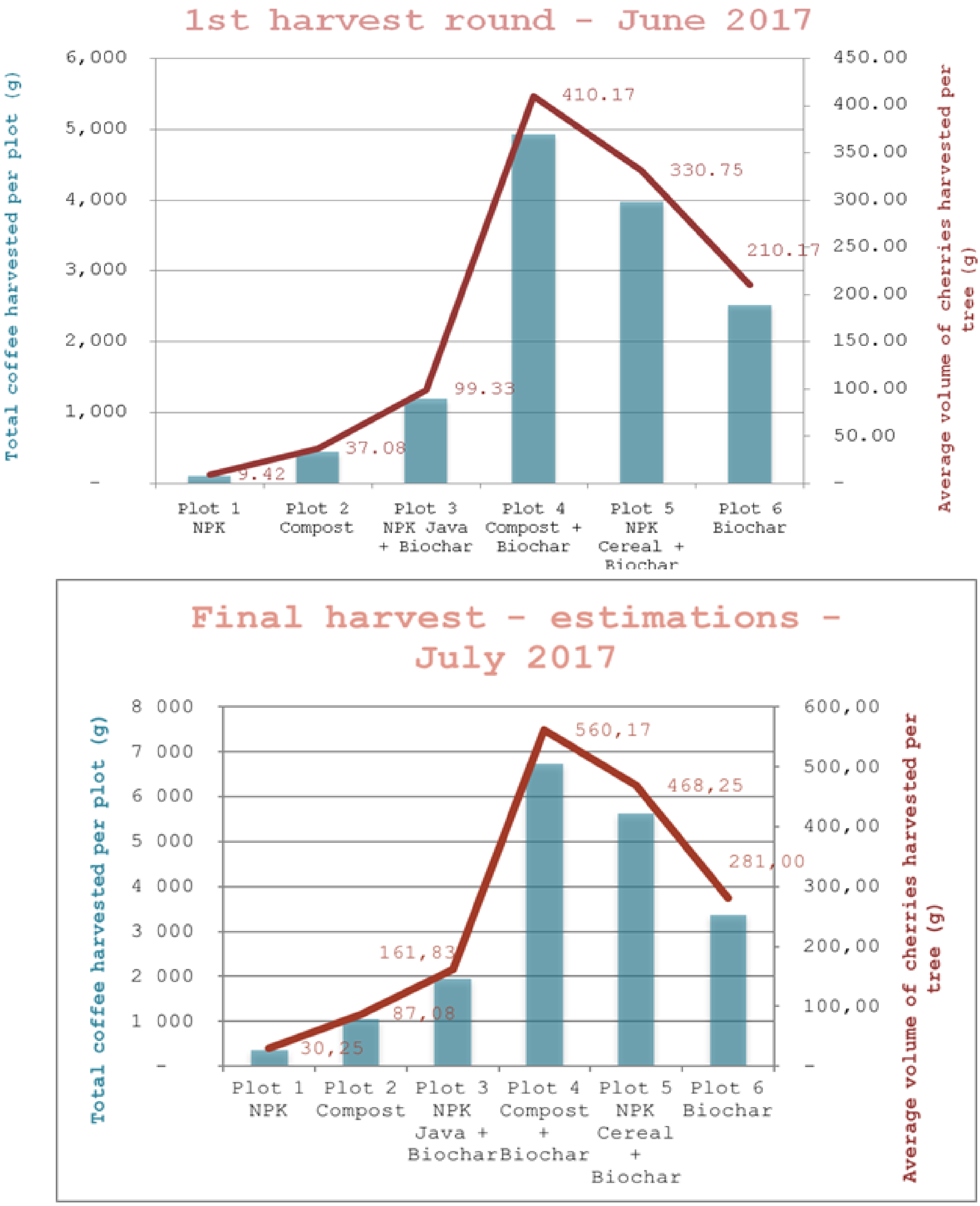


Figure 21: Final harvest results - estimation

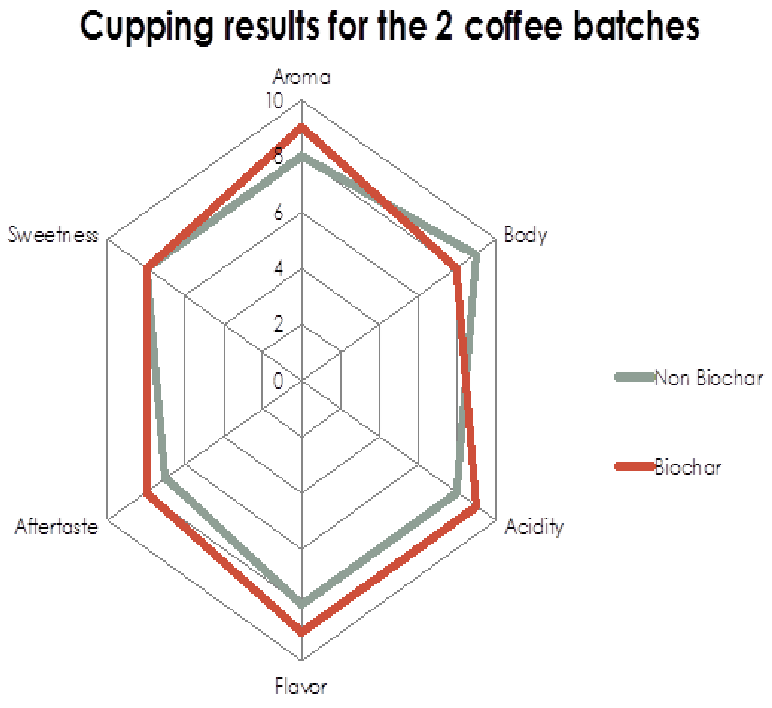
Cherry maturity

The plots that received biochar treatment had a higher number of ripe coffee cherries compared to the one without biochar. It seems like the application of biochar accelerates the maturity cycle of the cherries which could be explained by the fact that Biochar retains more water in the soil and therefore provides to the trees enough water for cherries development and maturity.

Coffee quality

The cupping was done in the first picking, however due to small batches, the samples were mistakenly mixed in the second and third picking. The cuppers didn’t know which sample was Biochar and which one was non-Biochar. So we suspected that the results from the only first picking could be biased

	Biochar	Non Biochar
Yield parchment to green	81.4 %	80 %
% First grades	74.2 %	69 %
% Lower grades	7.2 %	11 %
Comments	Chocolate and floral like aroma, med-light body, citric acidity, lemony, sweet, juicy, clean and consistent cups, tea like, brightness, slightly dry after taste	Dark chocolate and pulp like aroma, med body and acidity, sweet, creamy, wine-pulp like, slightly astringent and greenish aftertaste, inconsistent cups



It was realized that, coffee coming from trees with biochar application generally gave better results in term of defects count, screen sizes and even in the cup. Having a better parchment to green yield and a better first-grades yield is really important for the farmers because this is a crucial criterion for coffee buyers.

3.4 Success Stories

Training of staff and farmers: A total of 25 field staff were trained, tembo had around 3,700 registered farmers in the program in the project area, however, we could not train all of them due to financial constraints and failure to follow crop calendar.
Design and fabrication of kilns: 25 kilns were made, 20 for Tembo and 5 for MIICO. The kilns were stationed at TEMBO coffee buying centers. It was observed that biochar to rejuvenated the old coffee trees, this was evidently seen in fields in Mbeya rural and Mbozi.

3.5 Challenges

The production of biochar is still at small scale; the technology (kiln), In some cases there is competition for the biomass; maize cods are also used as fuel woods. Lack of packaging has resulted into some famers not accessing it. The fact that it is not fertilizer some farmers did not believe it. Lack of funds prevented us not to do the commercialization part.

3.6 Area for further research

To investigate the effect of biochar application in other crops especially maize.
To investigate the effect of biochar application in climate change mitigation.
Aspects of commercialization; e.g studies and packaging.
Investigate the suitability of other biomass e.g wood vs maize cobs.

4.0 Contribution of Biochar in Agricultural Production in the Southern Highlands of Tanzania

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Abstract

This study aimed to understand the contribution of biochar in soil fertility, agricultural production, and associated socio-economic benefits in the southern highlands of Tanzania. Field data collection methods were household interviews, soil sampling and nutrient analysis. Purposive sampling was used to identify villages that have been practicing biochar production, and application. Sampling frame consisted of households with farms, cultivating subsistence, and cash crops. A sample size of 172 was randomly drawn from the sample frame by considering at least 5% of total households in the study area as per Boyd *et al.*, (1981). A total of 12 soil samples, both topsoils, and subsoils were taken. Sampling protocols were used, aiming at reducing sampling error (Clay *et al.*, 2010). Quantitative data were analyzed using SPSS software version 20 and excel spreadsheets. Soil analysis was done to understand the quantity of soil nutrients in the biochar treated soil compared to control soil and their contribution to crop productivity.

The findings revealed that, socio-economic factors such as age, sex, level of education, farm size, family income, and household occupation determine farmers' engagement in biochar production and application. Findings revealed that, biochar increased soil pH, CEC, P, Total N, K, Ca, Mg, and SOM, especially on topsoils. Also, biochar regulated topsoils to medium level of Fe, Na, and Zn as plants don't need much of them. Biochar increased coffee and maize yields due to increased nutrients in the soil. The study revealed that, biochar improved foody security, and increased income to farmers. However, biochar faced challenges, such as alternative use of feedstocks, lack of farmers' awareness about biochar, lack of kiln availability, and lack of government involvement. Despite the challenges, the biochar system has opportunities to grow, due to the availability of feedstocks, and the presence of international experts. The study concludes that, socio-economic factors determine biochar production and application.

Key words: Biochar; Soil nutrients, Food Security, Climate Change adaptation, mitigation

4.1 Introduction

4.1.1 Background of the Study

According to Watts, (2017), third of the earth's soils is acutely losing its fertility at 24billion tonnes a year due to natural and anthropogenic activities. UNCCD, (2017) indicated that, from 1998 to 2013 soil decreased its productivity at the rate of 20% of the world's cropland, 16% of forest land, 19% of grassland, and 27% of rangeland. In Africa, cropland fertility decrease at average rate of 22 kg N ha^{-1}, 2.5 kg P ha^{-1}, and 15 kg K ha^{-1} over 30 years ago in 37 countries (Sanchez, 2002; Stoorvogel *et al.,* 1993). In Tanzania, N, P, K, Ca, Mg, and S are major deficient (Bekunda *et al.*, 2002; FAO & ITPS, 2015). Biochar was identified as a soil amendment to regain soil fertility (Lehmann *et al.,* 2014; IBI, 2018). Biochar is the solid black residue remaining after biomass is heated to high temperatures between 300°C and 700°C under a minimal oxygen condition (Lehmann *et al.,* 2014; IBI, 2018). A process in which biochar is made, is called pyrolysis. And the equipment is called a Kiln (Lehmann *et al.,* 2014; IBI, 2018; Gwenzi *et al.,* 2015). Lane, (2016) and Agegnehu *et al.,* (2017) marked biochar unique properties such as provision of soil nutrients, increase drainage and aeration, adsorption, promote living microbiology, enhancing Soil Food Web, and carbon sequestration.

4.1.2 Statement of the Problem

Few studies tried to investigate, and document the potential of biochar to address soil fertility challenges in Sub-Sahara Africa (Gwenzi *et al.,* 2015), and the impacts of biochar in crop production (Draper, 2018). There is limited information in socio-economic factors influencing the biochar system Ajewole, 2010), nutrients available in biochar (Laird *et al.*, 2010, benefits, and challenges of biochar in crop production (Draper, 2018), kilns management (Gwenzi *et al.,* 2015), and specific feedstocks for specific crop production (Draper, 2018). In addition, most studies have focused on pyrolysis as waste management strategy, and not biochar impacts on crop yields (e.g, Draper, 2018). Therefore, this study is designed to fill this knowledge.

4.1.3 Main Objective

To understand the contribution of biochar to soil fertility, agricultural production and socio-economic development as experienced in three villages in Mbeya and Songwe regions of Tanzania.

4.1.4 Specific Objective

To examine how the socio-economic factors influence biochar production and application in agriculture, to analyse soil fertility in biochar treated and non-treated (control) agricultural farms, and to determine socio-economic benefits, challenges, and opportunities for biochar adoption in the agricultural sector.

4.1.5 Research Questions

1. What socio-economic factors can influence the biochar production and application in agriculture?
2. Has biochar contributed to improve soil fertility?

3. Has biochar contributed to socio-economic benefits in the communities?
4. What challenges and opportunities have farmers experienced in biochar production and application for agricultural development

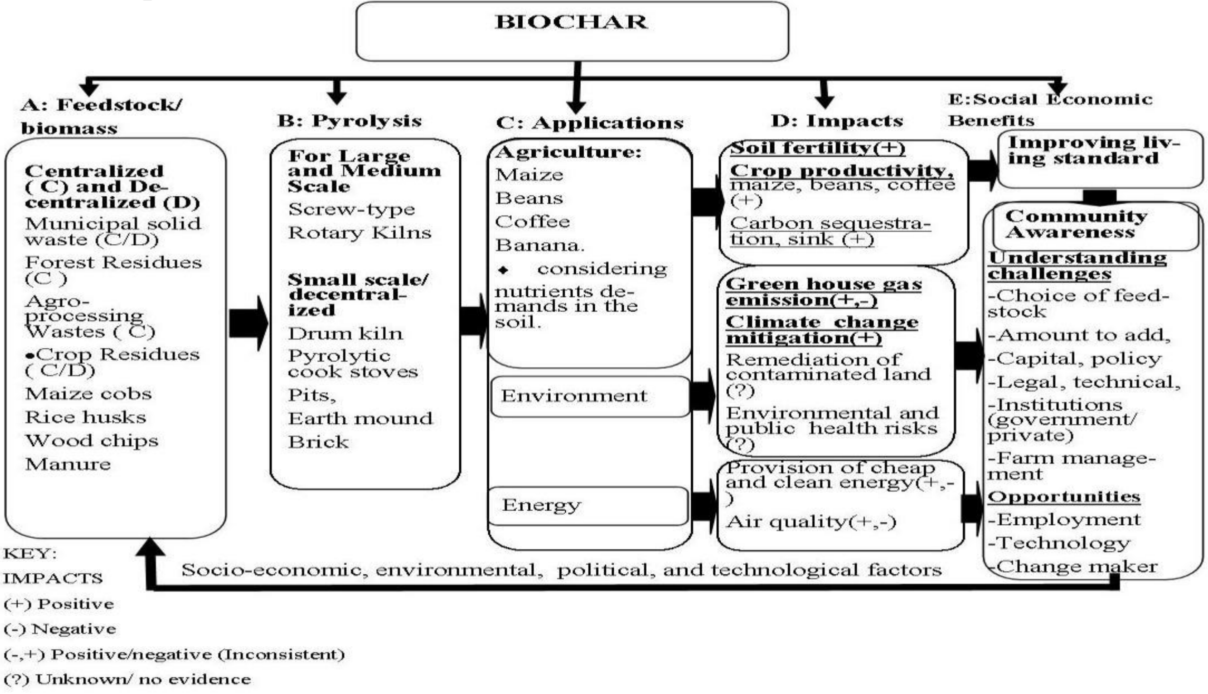
4.1.6 Significance of the Study

This study may inform agriculture stakeholders that biochar is:-

- ✓ Efficient, cheap, affordable and locally produced while serving costs
- ✓ Carbon sequestration and climate change mitigation
- ✓ Alternative to Industrial fertilizers

The study is in line with SAGCOT, ASDP II, Kilimo Kwanza, Big Results Now, Emission Reduction, Tanzania Development Vision 2025 and the Sustainable Development Goal.

1.7 Conceptual framework



Conceptual framework adopted and modified from (Gwenzi et al., 2015

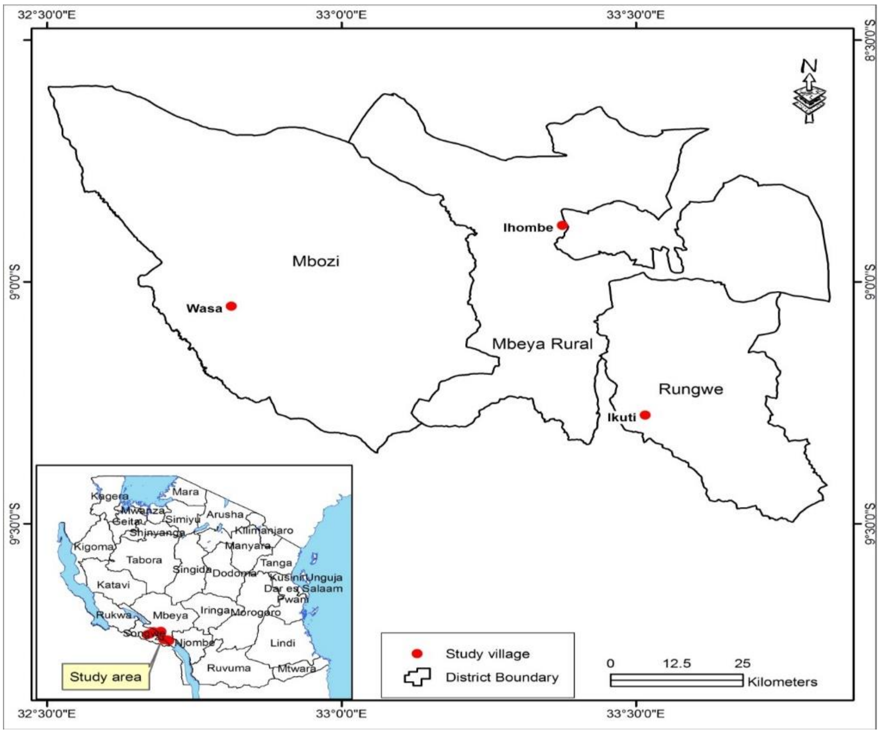
4.2 Research Gap

Literature showed varieties of feedstocks available, the difference in biochar nutrients, and amount of biochar to be added in the soil (Torres, 2011; Glaser *et al.,* 200; Brown *et al.,* 2017; Nanyuli *et al.,* 2018; IBI, 2018).

Also, there is inadequate information on socio-economic influence on biochar production and application (Draper, 2018). Moreover, there is a lack of knowledge on the contribution of biochar in soil fertility, its benefits and challenges for sustainable deployment. (Gwenzi *et al.,* 2015). This study intended to fill this gap.

4.3. Methodology

4.3.1 Location of the study



Source: GIS USDM, 2019

4.3.2Study design

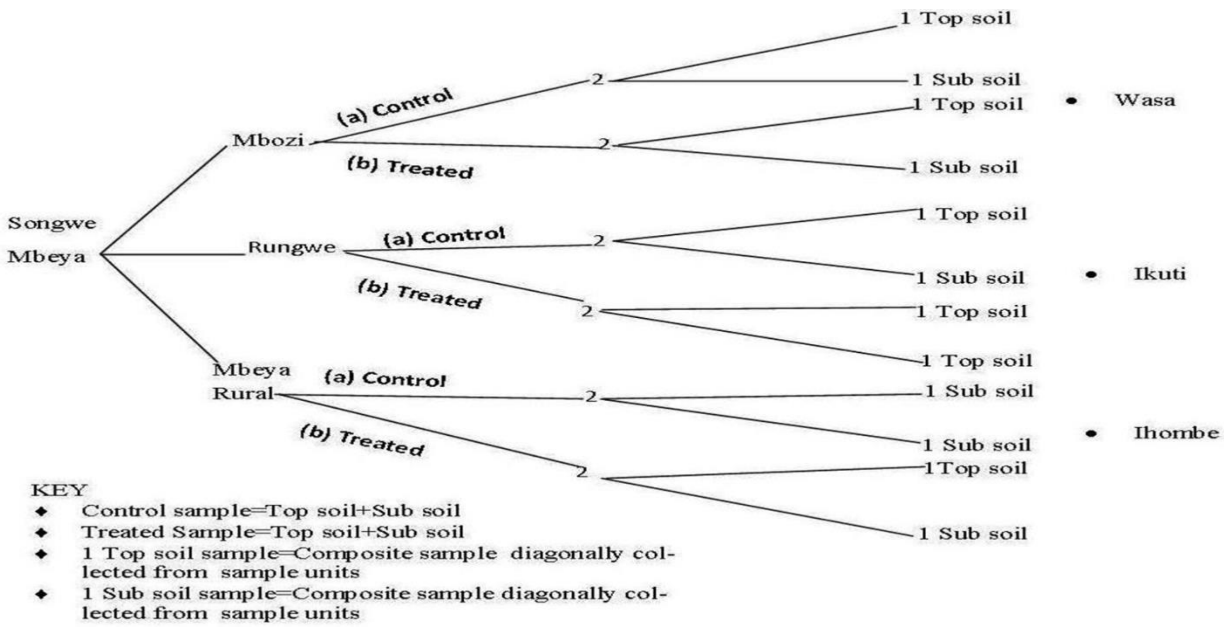
Quantitative method, data sources of questionnaires and soil sampling were deployed (Kothari, 2004).

4.3.3 Questionnaire Sampling

Population sample was of small scale farmers. Three villages were purposively selected based on their involvement in biochar. The sample frame consisted of households using agricultural inputs in crop production. A total of 172 respondents were randomly selected using a random number table considering sampling intensity of 5% of household size (Healey, 1993;Boyd *et al.,* (1981).

4.3.4 Soil Sampling

Two categories of compost soil samples mixed up from soil mapping units were considered (Tan, 2005). Samples were taken diagonally using manual auger from mixed cropping farms (coffee and maize), which was treated one year ago with 3t ha^{-1} of maize-cobs biochar produced using drum kilns, and control farms.



4.3.5 Data Analysis

Quantitative data were coded, computerised and analysed using SPSS version 20 and excel spreadsheet for descriptive statistics and inferential statistics to find the relationship between crop yields(dependent variable) and independent variables.

Soil samples were analyzed in the laboratory at Sokoine University of Agriculture (SUA), where both physical and chemical soil properties were analyzed using standard analytical methods. samples were homogenized and grounded to form tiny soil particles to pass through a 2-mm sieve. Samples were analyzed for pH using a ratio of 2.5 ml water to 1 g soil (McLean, 1982), available P using Bray-I method (Bray & Kurtz, 1945), SOC using the (Walkley & Black, 1934; Nelson and Sommers, 1982) method, total N content using the Kjeldahl digestion (McGill & Figueiredo, 1993), and CEC using ammonium acetate method (Black, 1965).

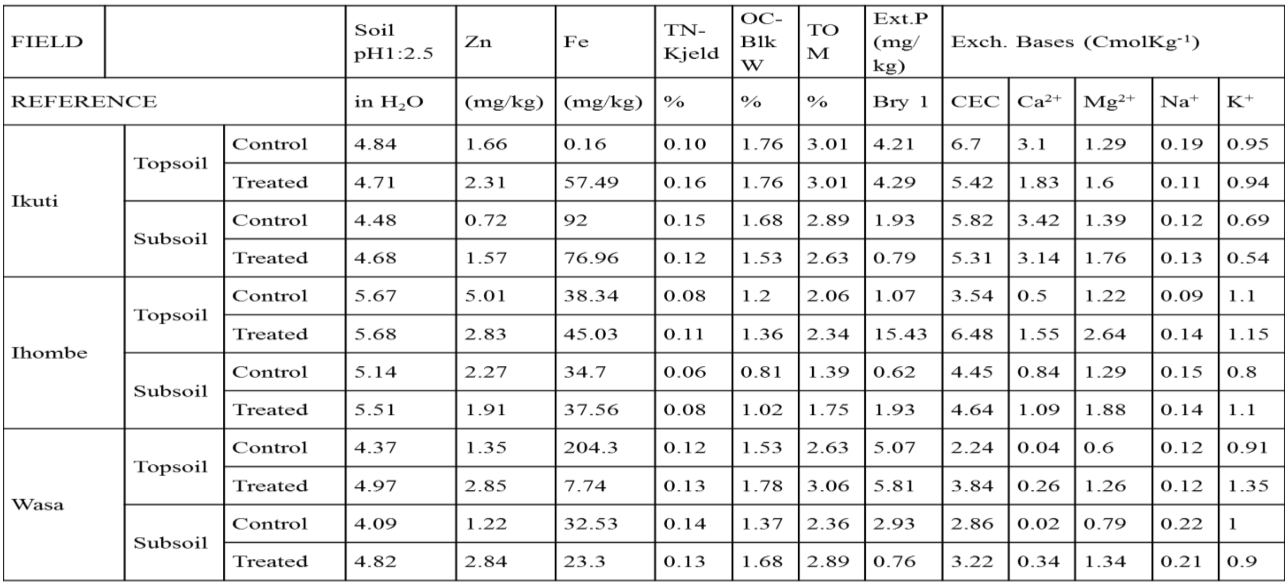
4.4 Findings

Of the 172 respondents, 68 (40.0%) had knowledge of biochar of which 44 (25.5%) continuously used it, and 2 had stopped using it.

4.4.1 Socio-economic Influence on Biochar Production and Application

An overwhelming majority of the respondents are smallholder farmers by 95.7%, with low levels of education by 75.8% primary level. 73.0% are mid age farmers between 40-59 years, 83.1% are males. Moreover, 56.3% of respondents earned low of less than 3m yr^{-1}, 72.2% of respondents owned one hectare of farm size with a local belief that applying black materials “char” in a farms was witchcraft. This finding corresponds to Gwenzi *et al.,* (2015), Ajewole, (2010) that, mid aged famers own resources, experienced, depend in agriculture, than youth who has alternative income generation, and elders who may have health challenges. Low level of education, farm size, local beliefs, and income may hinder the spread of the biochar technology

4.4.2 Contribution of Biochar in Soil Fertility



FIELD			Soil pH1:2.5	Zn	Fe	TN-Kjeld	OC-Blk W	TO M	Ext.P (mg/kg)	Exch. Bases (CmolKg^{-1})				
REFERENCE			in H_2O	(mg/kg)	(mg/kg)	%	%	%	Bry 1	CEC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
Ikuti	Topsoil	Control	4.84	1.66	0.16	0.10	1.76	3.01	4.21	6.7	3.1	1.29	0.19	0.95
		Treated	4.71	2.31	57.49	0.16	1.76	3.01	4.29	5.42	1.83	1.6	0.11	0.94
	Subsoil	Control	4.48	0.72	92	0.15	1.68	2.89	1.93	5.82	3.42	1.39	0.12	0.69
		Treated	4.68	1.57	76.96	0.12	1.53	2.63	0.79	5.31	3.14	1.76	0.13	0.54
Ihombe	Topsoil	Control	5.67	5.01	38.34	0.08	1.2	2.06	1.07	3.54	0.5	1.22	0.09	1.1
		Treated	5.68	2.83	45.03	0.11	1.36	2.34	15.43	6.48	1.55	2.64	0.14	1.15
	Subsoil	Control	5.14	2.27	34.7	0.06	0.81	1.39	0.62	4.45	0.84	1.29	0.15	0.8
		Treated	5.51	1.91	37.56	0.08	1.02	1.75	1.93	4.64	1.09	1.88	0.14	1.1
Wasa	Topsoil	Control	4.37	1.35	204.3	0.12	1.53	2.63	5.07	2.24	0.04	0.6	0.12	0.91
		Treated	4.97	2.85	7.74	0.13	1.78	3.06	5.81	3.84	0.26	1.26	0.12	1.35
	Subsoil	Control	4.09	1.22	32.53	0.14	1.37	2.36	2.93	2.86	0.02	0.79	0.22	1
		Treated	4.82	2.84	23.3	0.13	1.68	2.89	0.76	3.22	0.34	1.34	0.21	0.9

4.4.3 Nutrients found in Biochar Applied and Control Soils

Biochar increased soil nutrients at different levels, Soil pH increased from extremely low to moderately high acidic of 4.09 pH to 5.68 pH in topsoils of Wasa and Ihombe due to increase of Mg and Ca. Biochar increased SOC and SOM to a medium level due to acidic functionality and presence for significant iron (Fe) that lowered carbon in the soils.

Biochar increased CEC from very low in control soils (2.24 CmolK^{1}) in Wasa to low in treated soils (6.7 CmolKg^{-1})in Ikuti due to low pH and moderate organic matter contents especially in Ikuti. Biochar increase TN from very low 0.08% in control soils to low in treated soils 0.16 % this is due to low carbon input from biochar, and crops that could not compensate the N-losses. The study revealed that, Phosphorous P increased in treated soils recording 15.43(mg/kg) in Ihombe and low with 0.76(mg/kg) in Wasa compared with the control.

Finding shows that, Potassium (K) was at medium level, the K values were 1.35cmolc/kg in Wasa, and the lowest was 0.54 cmolc/kg in Ikuti. The K values were higher in treated soils than in control soils. Findings revealed that, Calcium (Ca) and Magnesium (Mg) were at medium level and adequate for crop production, especially on the treated soils. Fe, Zn, and Na maintained low because high zinc and iron in the soil would result into toxic content in crops that has challenges in human health, Na has no impact on plant growth.

Generally, treated topsoils (20-40cm), recorded higher nutrients than treated subsoils(20-40cm) and controls. This finding corresponds to Laird *et al.,* (2010), and Lehmann *et al.,* (2014) that biochar can amend and increase soil nutrients for agriculture production.

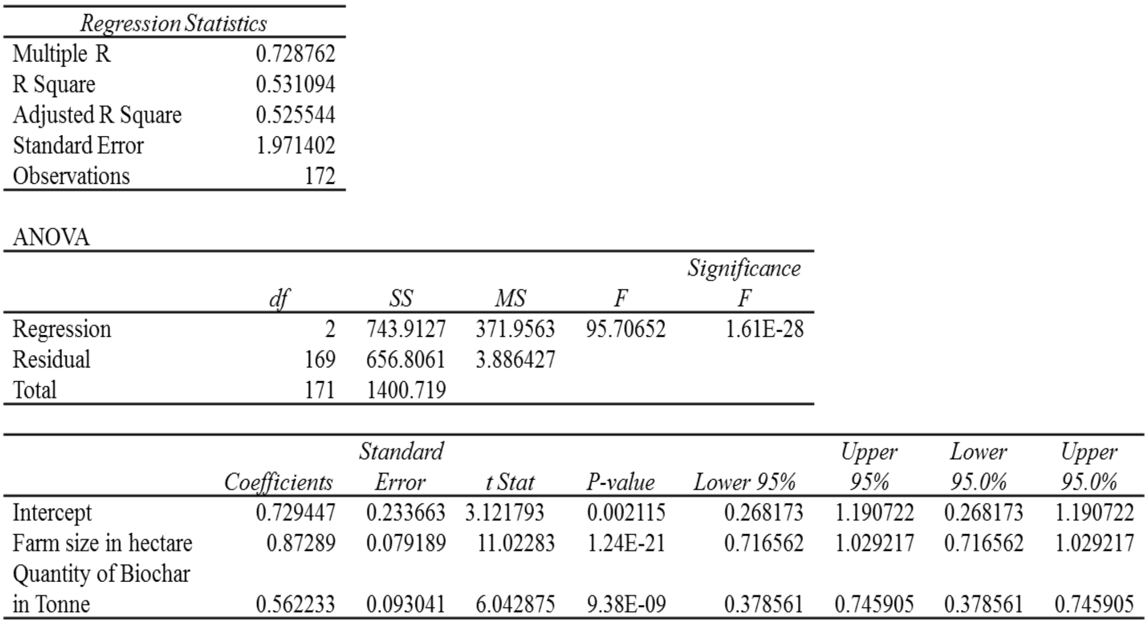
4.4.4 Social Economic Benefits, Challenges and Opportunities for Biochar adoption

4.4.5 Social Economic Benefits of Biochar in the study area

Findings show, smallholder farmers who applied biochar (n=44), 41 respondents=93% agreed biochar increased crop production. Maize increased from 1t ha^{-1} to 3t ha^{-1} which is 200% increase. This may improve food security, income due to high price offered to organic crops while serving input costs. Moreover, (n=44) 39 respondents=88.6% agreed that biochar increased employment by transporting feedstocks, kilns, and biochar. This finding corresponds to reports by Gwenzi *et al.,* (2015), Cornelissen, *et al.,* (2013), Aslund, (2012), Cosmidis & Siwingwa, 2017, and Kimetu *et al.,* (2008) that, biochar offers social economic benefits to small scale farmers in Kenya,, Zimbabwe, Zambia, Tanzania and Rwanda etc.

The study found significant indication that, farm size and biochar had a significant relationship with crop production since $p<0.05$. The relationship was through a multiple regression analysis. A model of $Y=\beta0+\beta1xi_1+\beta2xi_2+\ldots..+\beta px_i+\epsilon$ was used to find the relationship. The significant relationship with coffee p=0.002115, maize was p=0.00565

Table 1: The relationships between coffee against biochar and farm size



Regression Statistics	
Multiple R	0.728762
R Square	0.531094
Adjusted R Square	0.525544
Standard Error	1.971402
Observations	172

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	743.9127	371.9563	95.70652	1.61E-28
Residual	169	656.8061	3.886427		
Total	171	1400.719			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.729447	0.233663	3.121793	0.002115	0.268173	1.190722	0.268173	1.190722
Farm size in hectare	0.87289	0.079189	11.02283	1.24E-21	0.716562	1.029217	0.716562	1.029217
Quantity of Biochar in Tonne	0.562233	0.093041	6.042875	9.38E-09	0.378561	0.745905	0.378561	0.745905

Table 2: The relationships between Maize against biochar and farm size

Regression Statistics	
Multiple R	0.539831945
R Square	0.291418528
Adjusted R Square	0.283032949
Standard Error	3.080638542
Observations	172

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	659.623	329.811	34.7523	2.3E-13
Residual	169	1603.87	9.49033		
Total	171	2263.49			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.023583448	0.36514	2.80329	0.00565	0.30277	1.7444	0.30277	1.7443999
Farm size in hectares	0.615666777	0.12375	4.97524	1.6E-06	0.37138	0.85995	0.37138	0.8599541
Quantity of Biochar	0.812286766	0.14539	5.5869	9.1E-08	0.52527	1.0993	0.52527	1.0993037

4.4.6 Challenges Facing Biochar Production and Application

70% of respondents agreed that feedstocks have alternative usage i.e. they are used for cooking, animal feed, compost making, mulching, making local mats, and ironing clothes. There is lack of biochar awareness by 70.8% in Wasa, 61.3% in Ikuti, and 44.4% in Ihombe. 84.1% of respondents agreed that kilns are affected by rust, and there is application of industrial fertilizers by 51%.

4.4.7 Opportunities for Promoting and Adoption of Biochar

Farmers agreed that, there is abundance of feedstocks i.e. maize cobs by 73.8% in Wasa, 77.4%in Ikuti, and 100.0% in Ihombe. And 70.0% farmers agreed that the biochar system may fit in the society without disturbing cooking and farming practices. This finding corresponds to Singh *et al.,* (2015), Brown, (2013), and Kloss *et al.,* (2012

4.4.8 Contribution of the study to the body of knowledge

The socio-economic factors may influence farmers’ decision toward biochar production and application. Biochar may amend the soil by improving nutrients availability. Biochar may increase crop production and contribute toward food security, employment and income generation despite challenges which can be addressed.

4.4.9 Recommendation, It is essential to add biochar quantity per hectare (over 3 t ha^{-1}) for potential nutrients increase in the soil. More education and awareness campaigns is needed to improve farmers and understanding of the biochar system, and the government involvement is essential for sustainable biochar production and application. The use of Tropical Products Institute (TPI) kiln design which is cheap, robust, ease of operation, maximum efficiency for developing countries.

4.5 Areas for further research

More research on feedstocks, test of food produced by biochar, and soils deficiency of specific areas. More research on carbon sink, Carbon trade and air quality, more research on human health during biochar application.

4.6 Conclusion

The study concludes that, the socio-economic factors may affect farmers' decision to apply biochar in their farms. The study concludes that, biochar may increase soil pH, CE C, SOM, P, TN, Mg, Ca, K, mostly on topsoils than in subsoils. Moreover, Iron, and Zinc and Na are maintained low since are not needed in large quantity by plants. The study concludes that, biochar production and application may have socio-economic benefits to the community, challenges, and has opportunities to grow and reach many people due to availability of feedstocks and the ability to fit in the society.

Acknowledgement
Thanks to IRA and CCCS at University of Dar es salaam, and Linkoping University Sweden to facilitate the study.

5.0 Biochar Pilot towards Improving Productivity and Quality in Coffee Farming: Case of Kilimanjaro, Tanzania

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Solidaridad Tanzania

5.1 Background

Solidaridad implements biochar technology under the projects of “The coffee resilience program in East Africa and Sustainable landscape innovation project both implemented in Kilimanjaro and Arusha. The coffee resilience project aims to develop a sustainable, inclusive and robust Climate Smart Agriculture model for coffee producers in Kenya, Tanzania, and Uganda in order to improve coffee productivity and quality, as well as to increase coffee farmers' income. The project is working with 10,000 coffee farmers in Arusha and Kilimanjaro from 12 cooperatives. Whereby the project is working with 60 promoter farmers from Arusha and Kilimanjaro covering 5 districts Meru, Siha, Hai, Moshi Dc and Rombo. And mostly the promoter farmers are youth to ensure sustainability.

5.2 Main objective

Under the coffee resilience project, the main objective was to increase production, quality and income to smallholder farmers, through enhancing capacities of stakeholders to work towards increasing productivity of commodities within a framework of good landscape performance for restoration of ecosystems.

5.3 Methodology

Maize-cobs biomass mobilization was done during dry season as it was a harvesting season and was cheap. 10 drum kilns were made. Training of 60 pioneer farmers and 5 extension officers on biochar production and application was done. Biochar with organic manure was applied in the demo plots which were designed to be learning centers. The application of biochar was done for both matured and young coffee trees.

5.4 Key Results

Both matured and young coffee trees showed positive results

Young coffee trees:

- Increase number of nods for coffee seedlings
- Increase number of leaves
- High growth rate of the coffee seedlings
- Improved health of the coffee tree

Matured trees

- Increased moisture content in the soil
- Improve the capacity of the tree to carry many flowers without falling.
- Healthier trees carrying great number of cherries.
- Speed-up cherry maturity
- Helps in uniformity of cherry ripening
- Increase the weight of the cherries
- Increase the quality of the cherries both by getting higher grades and high cupping score

5.5 Success Story

Demo plots with biochar and manure have shown positive impacts towards productivity and quality of coffee produced. Biochar ns manure improved soil water holding capacity and reduce fertilizer requirements.

5.6 Challenges facing biochar

Moisture content of biomass is not uniform affect pyrolysis process thus affecting the timing and making most dried biomass transforming to ashes thus losing the physical structure. Limitations to up-scaling biochar technology due to limited biomass availability as biomass is utilized for fuel, feed and soil protection, and there is rarely surplus that could be used for biochar. Lack of large-scale production for biochar production, and absence of cheap methods of biochar production.

5.7 Areas for Further research

More research on the uniform dosage of biochar in application, biochar for fuel and by product. More studies on how to enrich biochar through mixing biomass with mineral prior or after pyrolysis. Risk of polluting production methods: to ensure that biochar production does not contribute to air pollution and methane emissions, it is critical that biochar is produced in a facility that captures or combusts the gases released during pyrolysis. More studies and demonstrations on other methods of producing biochar in large scale and more cheap cost.

5.9 Conclusion

Biochar is thus a technology that can simultaneously enhance soil productivity, and contribute to climate change mitigation and sustainable development. It is therefore well-suited as a strategy for sustainable land management and climate smart agriculture.

6.0 Effect of Field Applied Biochar as a Climate Change Mitigation Strategy to Enrich Soil and Improve Productivity of Okra

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ABSTRACT

Vegetables including Okra are an important part of African diet however they are impacted by low soil fertility as aftermath of climate change. A study was conducted at the University of Dar es Salaam, Botany Department Nursery area to evaluate the effect of field applied biochar on soil enrichment and yield improvement of Okra. Okra seeds were directly sown in experimental plots measuring 1m long and 0.45m wide and plants spaced at 30cm between and within rows to make six okra plants per observation. The experiment was laid out as a Completely Randomized Design in split plot arrangement. Soil status with and without NPK or FYM were the main plots and 3 biochar levels were the sub plots giving nine treatments levels: Biochar:Soil(0:0), Biochar:Soil(6.25:0), Biochar:Soil(12.5:0), Biochar:FYM(0:1.5), Biochar:FYM(6.25:1.5), Biochar:FYM(12.5:1.5), Biochar:NPK(0:90), Biochar:NPK(6.25:90), and Biochar:NPK(12.5:90) in 3 replicates. Quantitative data were collected on soil physical-chemical characteristics, plant height and marketable yield. ANOVA was computed using INSTAT3 software while differences between treatments means were computed using Student Keul Test at

$p \leq 0.05$. Soil pH significantly increased (7.8) where experimental plots were treated with Biochar:FYM(12.5:1.5). A significant increase in total Nitrogen (1.37%), available phosphorus (2.71%), cation exchange capacity (71.98), and organic matter (6.07%) were noticeable in plots treated with biochar:NPK(12.5:90). Plots treated with Biochar:NPK(12.5:90) resulted in higher marketable yields (6.87t/ha) compared to other treatments. Control plots Biochar:Soil(0:0) yielded the lowest (0.97t/ha) a response which possibly was associated with conditioning the soil to avail optimal nutrients that steepened differences in Okra yield

6.1 Introduction

Tanzania is characterized by small scale farming which is associated with low productivity due to low capacities in accessing necessary agricultural inputs including both inorganic and organic fertilizers (Winowiccki, 2012). As of 1997 Tanzania produced large amounts of solid agricultural waste to amounting to 100,000MT sisal pulp, 58,860MT coffee pulp, 5,374MT sugar cane bagasse, 5280MT maize straw, 1089MT sorghum, 367MT millet and 39MT wheat straw (Kivaisi, 1997; Magingo, 1998). These are either minimally utilized, burnt or left to rot in big piles where they contribute to environmental pollution. These agricultural wastes however can be transformed to a useful resource known as biochar. Biochar has been shown to offer multiple benefits to soil performance, notably crop nutrient use efficiency, water storage and control of plant disease spread. In this way, biochar has been speculated to improve soil quality invariably leading to increased soil productivity (Laird *et al.*, 2010).

In many developing World including Tanzania, biochar is currently a non-intentional by-product of charcoal making kilns and charcoal distribution centres.In future, this by-product may increase since many institutions, NGO, and individuals are adopting usage of gasifier stoves that are currently being developed. It is against this background that benefits of biochar were tested in this study in attempt to improve okra productivity on less fertile soils.

6.2 Materials and Methods

Experimental design and procedures

The experiment was laid out at University of Dar es Salaam, Botany Department Nursery area situated at latitude 6°46'53.76"S and longitude 39°12'20.41"E. Biochar treatment was compared to non-treated control, inorganic fertilizer NPK and Farm yard manure (FYM). The experiment was laid out as a Completely Randomized Design (CRD) in split plot arrangement whereby, soil status of with and without NPK or FYM were the main plots and 3 biochar levels were the sub plots giving the following nine treatments levels: Biochar:Soil (0:0), Biochar:Soil (6.25:0), Biochar:Soil (12.5:0), Biochar:FYM (0:1.5), Biochar:FYM (6.25:1.5),Biochar:FYM (12.5:1.5), Biochar:NPK (0:90), Biochar:NPK (6.25:90), and Biochar:NPK (12.5:90) in 3 replicate. Biochar was applied at rates of 0, 2.75 and 5.5$\mathrm{ton{\cdot}ha^{-1}}$ by spreading and mixing evenly into the soil to a depth of approximately 15 cm. Prior to mixing in the experimental field, biochar briquettes were ground and sieved to pass through a 2mm sieve. This was done so as to attain larger surface area of the soils. This was followed by watering the pots for about two (2) weeks for biochar activation before the start of the experiment. NPK in the form of 20:10:10 was applied at a rate of 0.36 $\mathrm{ton{\cdot}ha^{-1}}$, FYM was applied at the rate of 5.94 $\mathrm{ton{\cdot}ha^{-1}}$

Okra Seeds were directly sown in experimental plots measuring 1m long and 0.45m wide at a spacing of 30cm between rows and within a row to make six okra plants per experimental observation. This was followed by timely watering to ensure availability of adequate moisture.

Layout of Field Experiment

Parameters assessed included soil analyses for pH, CEC and % Carbon to establish the soil characteristics before biochar application. Plant height was recorded in all treatments from two weeks after sowing and subsequently once per week. Measurement of plant height was measured in centimeter from the ground level to the apex of the plant.

Data analysis

INSTAT3 software was used to accomplish Analysis of Variance (ANOVA) of the data to find means of multiple variables and Newmann-Keul Test was computed to test differences between treatment means at $p<0.05$.

Vegetative parameters namely number of branches per plant, number of leaves per plant, and average leaf area (cm^2)/plant were recorded. Also, yield and yield components namely, number of fruits, number of fresh pods per plant, and fresh weights were recorded bi-weekly.

6.3 Results

General performance

The performance of Okra is mainly determined by yield parameter as the main determinant of the study. The highest fresh okra yield was determined from Okra planted in plots treated with biochar in combination with NPK in the ratio Biochar:NPK (12.5:90). Also, good performance of parameters like average number of fresh pods per plant, number of branches per plant, number of leaves per plant and leaf area per plant were found in Okra plant planted in plots treated with biochar in combination with NPK in the ratio Biochar:NPK (12.5:90). The treatment conditioned the soil with soil nutrients enough to stimulate the performance of the crop.

Effect of Biochar on physical-chemical properties of soil

Biochar application resulted in significant changes of physico-chemical properties of the soil notably pH and CEC and phosphorus when compared to the physico-chemical properties of the same soils before mixing-in the biochar, farm yard manure and NPK in different ratios as shown in the experimental plots.

Physical-chemical properties of Soil and Biochar before mixing

Soil type	pH	EC (mg/L)	TN (%)	$PO4^-$(%)	CEC	OM (%)
Field soil	6.72	130.53	0.32	0.17	59.62	0.61

Biochar	7.93	10.11	1.49	2.23	130.22	30.69

EC=Electrical Conductivity, TN=Total Nitrogen, PO=Phosphate, CEC=Cation Exchange Capacity, OM=Organic Matter

The pH value (7.8) significantly increased when the experimental plots were treated with biochar and farm yard manure in the ratio of Biochar:FYM (12.5:1.5). The significant increase in total Nitrogen (1.37%), available phosphorus (2.71%), Cation Exchange Capacity (71.98), and organic matter (6.07%) was mostly noticeable in soils from the experimental plots treated with biochar and NPK in the ratio of biochar:NPK (12.5:90) (Table 2). On the other hand, lowest electrical conductivity was observed in experimental plots where biochar and low FYM were applied (EC=108.94mg/L).

Physical-chemical properties after mixing Soil with Biochar, FYM, and NPK

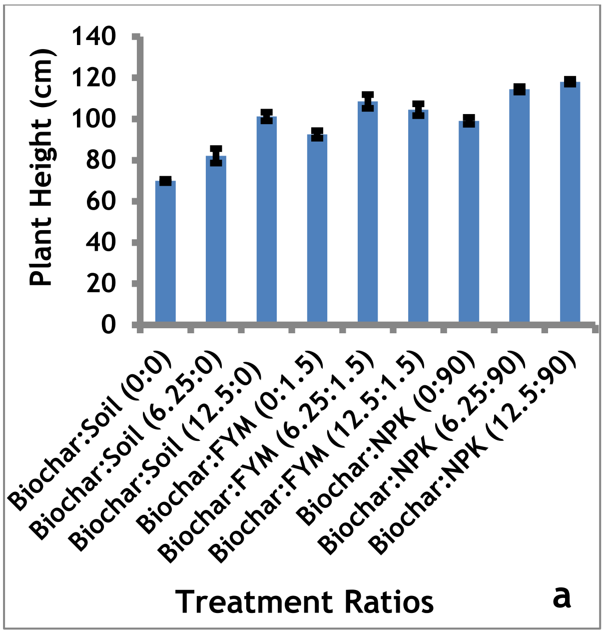
Treatment ratios	pH	EC (mg/L)	TN (%)	PO4^{-}	CEC	OM (%)
Biochar:Soil 0:0	6.72	130.53	0.32	0.17	59.62	0.61
Biochar:Soil 6.25:0	7.37	115.31	0.59	0.64	65.63	5.12
Biochar:Soil 12.5:0	7.76	110.37	0.68	0.67	66.65	5.45
Biochar:FYM 0:1.5	7.01	119.23	0.47	0.18	54.57	5.93
Biochar:FYM 6.25:1.5	7.79	114.41	0.98	1.21	61.47	5.98
Biochar:FYM 12.5:1.5	7.8	108.94	1.23	1.63	70.53	6.11
Biochar:NPK 0:90	6.35	120.21	0.79	0.83	64.84	1.73
Biochar:NPK 6.25:90	6.89	116.11	1.11	2.37	69.72	5.26
Biochar:NPK 12.5:90	7.02	110.33	1.37	2.71	71.98	6.07

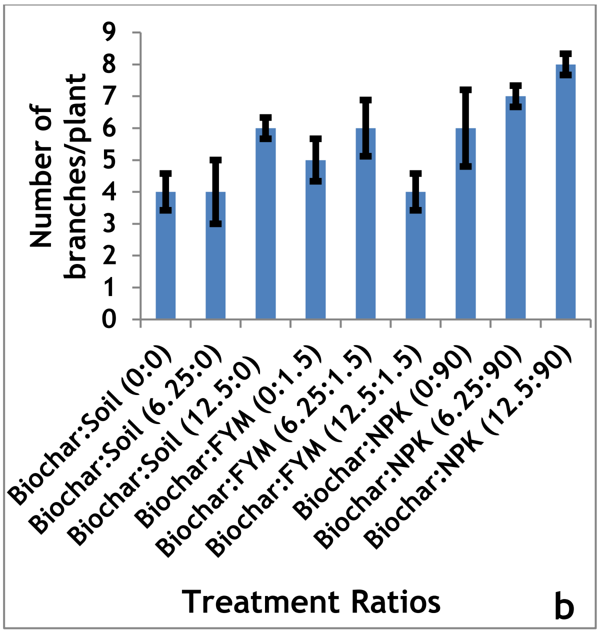
EC=Electrical Conductivity, TN=Total Nitrogen, PO=Phosphate, CEC=Cation Exchange Capacity, OM=Organic Matter
NPK=Nitrogen, Phosphorus, and Potassium, FYM=Farm Yard Manure

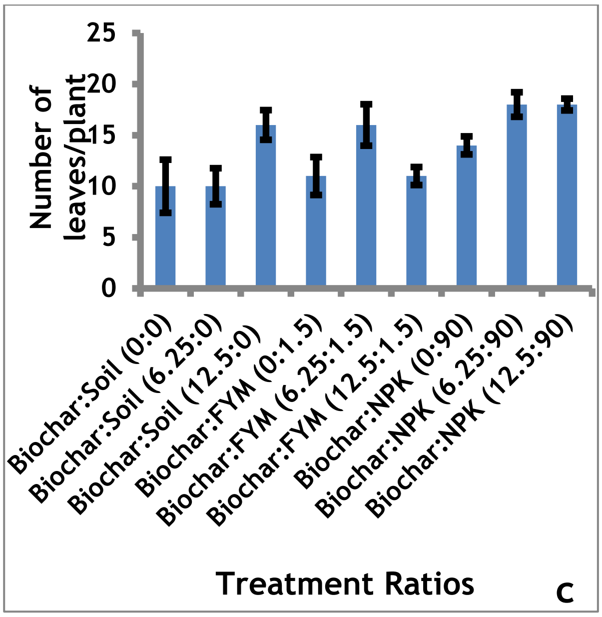
Effect of Biochar on Okra plant growth and yield

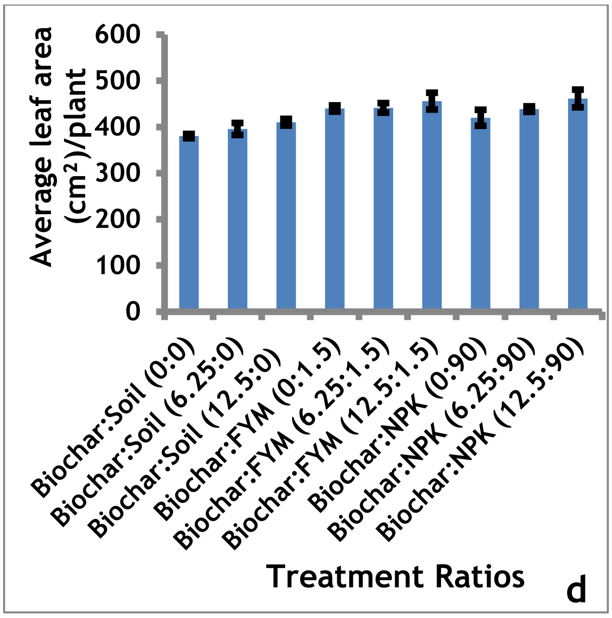
Plant growth in terms of plant height was significantly highest where biochar was mixed into the planting field plots as well as where additional fertilizer in the form of NPK was applied. Okra planted in plots treated with Biochar:NPK (12.5:90) produced significantly highest mean height(118.1cm), mean number of branches per plant (8), average number of leaves per plant (18), and average leaf area (cm^2)/plant (461.7cm^2) than Okra planted in other treatments.

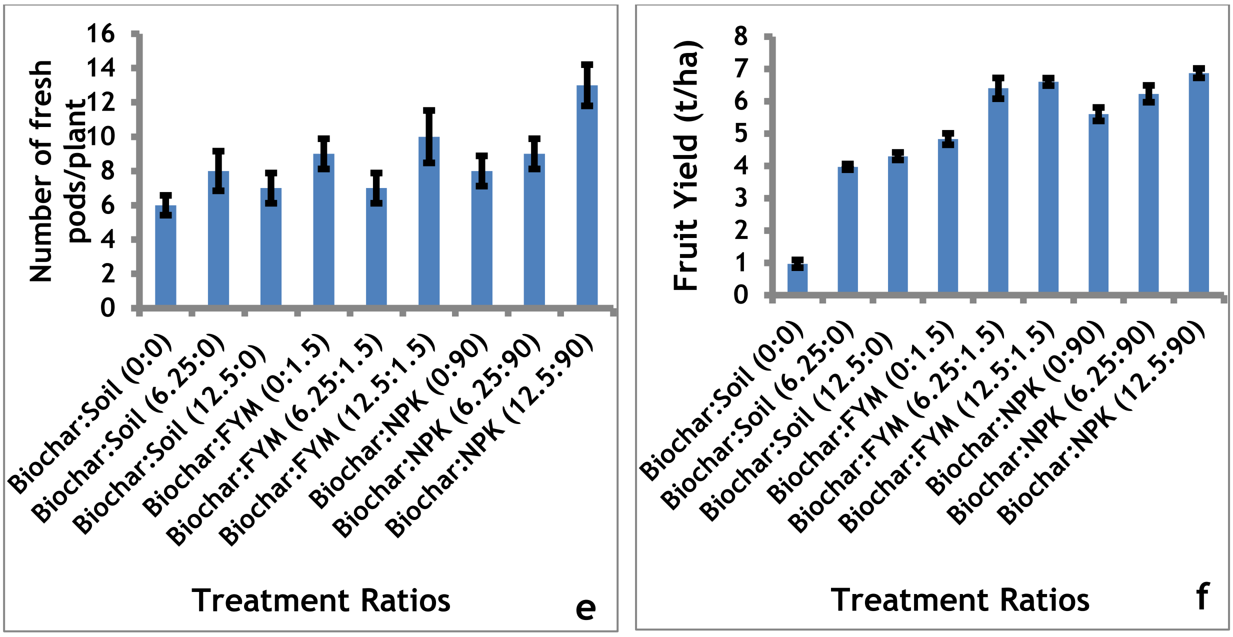
Likewise, the average number of fresh ponds per plant (13) and Okra yield in terms of marketable weight per hectare (6.87t/h) was significantly highest in plots which were treated with Biochar:NPK(12.5:90) than in non-treated plots which produced the lowest mean number of fresh pods per plant (5) and yield of only 0.97t/h


Plant Height (cm)
0
20
40
60
80
100
120
140
Biochar:Soil (0:0)
Biochar:Soil (6.25:0)
Biochar:Soil (12.5:0)
Biochar:FYM (0:1.5)
Biochar:FYM (6.25:1.5)
Biochar:FYM (12.5:1.5)
Biochar:NPK (0:90)
Biochar:NPK (6.25:90)
Biochar:NPK (12.5:90)
Treatment Ratios
a


Number of branches/plant
0
1
2
3
4
5
6
7
8
9
Biochar:Soil (0:0)
Biochar:Soil (6.25:0)
Biochar:Soil (12.5:0)
Biochar:FYM (0:1.5)
Biochar:FYM (6.25:1.5)
Biochar:FYM (12.5:1.5)
Biochar:NPK (0:90)
Biochar:NPK (6.25:90)
Biochar:NPK (12.5:90)
Treatment Ratios
b


Number of leaves/plant
0
5
10
15
20
25
Biochar:Soil (0:0)
Biochar:Soil (6.25:0)
Biochar:Soil (12.5:0)
Biochar:FYM (0:1.5)
Biochar:FYM (6.25:1.5)
Biochar:FYM (12.5:1.5)
Biochar:NPK (0:90)
Biochar:NPK (6.25:90)
Biochar:NPK (12.5:90)
Treatment Ratios
c


Average leaf area (cm²)/plant
0
100
200
300
400
500
600
Biochar:Soil (0:0)
Biochar:Soil (6.25:0)
Biochar:Soil (12.5:0)
Biochar:FYM (0:1.5)
Biochar:FYM (6.25:1.5)
Biochar:FYM (12.5:1.5)
Biochar:NPK (0:90)
Biochar:NPK (6.25:90)
Biochar:NPK (12.5:90)
Treatment Ratios
d



Effect of Biochar treatment on Okra plant (a) height (b) number of branches per plant (c) number of leaves per plant (d) average leaf area (cm²)/plant (e) number of fresh pods per plant (f) yield (t/ha)

Biochar has been shown to improve soil fertility, crop nutrient use efficiency and enhancing soil moisture content for okra productivity. The combination of Biochar with farmyard manure, and NPK was found to improve soil physical-chemical properties which on the other hand enhanced Okra productivity. The combination of biochar and NPK in the ratio Biochar:NPK (12.5:90) was found to have increased total Nitrogen (TN=1.37%), available phosphorus (2.71), Cation Exchange Capacity (CEC=71.98), and organic matter (OM=6.07%). The application of biochar and its combination with farmyard manure and NPK improved soil physical-chemical properties to enhance okra productivity.

The treatment ratio of Biochar:NPK (6.25:90) promoted highest plant height (118.1cm), mean number of branches per plant (8), average number of leaves per plant (18), average leaf area (cm²)/plant (461.7cm²) than Okra planted in other treatments.

According to an extensive study on yield done by Weinberger and Msuya (2004) and Lotter et al., 2014, the average Okra yield in most Okra growing areas in Tanzania was found to be 5.92±ton/ha. In the current study, Biochar:NPK (6.25:90) promoted the highest okra yield (6.87t/h) than other treatment ratios, hence showing the effectiveness in promoting yield potential of the Okra.

6.4 Conclusion

The physical chemical properties of the experimental field were improved upon application of biochar in combination with NPK. The applied ratio of Biochar:NPK (6.25:90)brought a significant effect on improving Nitrogen (TN), available phosphorus, Cation Exchange Capacity (CEC), and organic matter (OM). Soil pH value significantly increased on application of biochar and farm yard manure in the ratio of Biochar:FYM (12.5:1.5).Yield of Okra plant cultivated in plots treated with biochar in combination with NPK in the ratio Biochar:NPK(6.25:90) was higher than other combination treatments. The treatment sufficiently supplied the required elemental nutrients to increase Okra yield and improving the health status of the plant. The treatment ratio further improved plant growth and development in terms of plant height, number of branches per plant, number of leaves per plant, average leaf area (cm²)/plant, and number of fresh pods per plant compared with Okra cultivated using other treatments. The study revealed that biochar offers an opportunity of supplying elemental nutrients available for plant depending on the feed-stock used for crop production. Hence, biochar improves soil physical chemical properties and could be considered as an important agronomic practice that increase the growth and yield of plants and can be used as a soil conditioner in infertile soils including those which are impacted by climate change.

7.0 CONCLUSION, WAY FORWARD

7.1 CONCLUSION

Recent researches and projects on Biochar in Tanzania have been allocated in areas with considerable high precipitation. More research and or projects should be directed to other regions which experience low rainfall. Also effectiveness of biochar on other crops need thorough investigation due to its capability in modifying the soil status.

Based on studies and projects presented, it was concluded that

- Biochar is not a fertilizer. What biochar does is to improve soil physical and chemical characteristics such as water holding capacity, nutrient mobilization. It is therefore a soil amender. biochar is potential in climate change mitigation, food security, soil amendment, and reduction of inputs costs to farmers when efficiently explored.
- Biochar itself does not provide significance change in crop productivity unless it is applied together with other fertilizer materials like Urea, NPK, CAN. Best result is recorded when biochar is applied together with Farm Yard Manure(FYM).
- Biochar has a tendency to improve soil moisture content in the soil. This attribute is essential when planning agricultural activities in arid and semi areas where water is always scarce. Areas such as central zone and some parts of northern Tanzania, can adopt the use of Biochar in farming systems.
- Its ability to amend the soil by improving nutrient availability, makes Biochar be used for increased crop production and contribute toward food security, employment and income generation among smallholder farmers.
- To facilitate Carbon sink. It was concluded that when biochar is applied to the soil, increases Leaf Area Index which implies that, photosynthetic part of plants increases leading to increased ability of the plant to manufacture their own food through photosynthesis process.
- Climate Change regulation is also enhanced when Biochar is applied to the soil because of its role in terrestrial and geological carbon sequestration. It reduces emissions from biomass and fossil fuels. Studies found that net carbon withdrawn from the atmosphere is about 20% which means it helps in reducing carbon dioxide from the atmosphere.
- Further studies should be done in order to determine the economic threshold of using biochar.
- Biochar has an ability to reduce methane and di-nitrous oxide emissions in the soil
- It was noted that biochar has a tendency of increasing soil pH to a level that is not suitable for some plants.

7.2 WAY FORWARD

- Members agreed that biochar is not a soil fertilizer, it is an amendment that improves soil condition and enhance nutrients availability in the soil for plant consumption.
- Members agreed that The Workshop agreed that continue the relationship between CCCS (UDSM) and the invited organizations i.e. SCAAP, Solidaridad, Naliendele, Sokoine University of Agriculture and Muhimbili University Health Science and Allied Science. Action plan taken was to create a Whatsapp group and group email.
- Members agreed that, the workshop secretariat should write the workshop proceedings and circulate to members.
- Members agreed to continue grouping the findings and when reach 15 findings Prof. Yanda will help to ask for a special issue in journal to publish the findings.
- Members agreed to publish the workshop proceedings and standalone paper in a journal.
- Members agreed to write a biochar project proposal focusing on Climate change mitigation, Food security, emission reduction, and adaptation.
- Members agreed that, there will be series of meetings both via email and virtual.
- Members advised organizations such Solidaridad to include research in their projects to have scientific agreed reports that may help the growth of the organization.

It was agreed that team of experts (multidisciplinary) be formed and devote time to come up with ideas/Concept Notes for further research.

Areas for further Research be conducted on the following topics and others

- Assess the role of biochar in climate change adaptation and mitigation
- Characterize different source of biochar
- The role of Biochar in arid and semi-arid areas of Tanzania
- Interactions among biochar, soil and plants to develop methods applicable for end-users.
- Methods and costs of applying biochar to soils.
- Linking biochar and climate resilience in arid and semi-arid areas with a focus on energy, food security and sovereignty.
- Examine taste of various food crops produced after applying biochar whether are organic or non-organic.
- Determination of application rate of biochar in relation to the biomass used biochar preparation.
- Assess the contents of biochar produced from selected source of biomass for biochar preparation.
- The role of Biochar on soil reaction (pH).