

Environmental and Socio-economic Feasibility of Biochar Application for Cassava Production in the Bimodal Rainforest Zone of Cameroon

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Abstract— The benefits of the use of biochar in improvement of soil properties and crop growth have been dominating scientific debates in efforts to include biochar in policy and regulatory frameworks. The study incorporated a semi participatory methodology involving farmers to gain an on-farm-view assessment of the challenges, environmental feasibility, economic profitability and socio-cultural soundness of biochar production and use. Biochar produced from cassava stems, ricehusk and corncobs using an Elsa pyrolyser were applied at 16kg/plot on 8m² experimental plots during the 2016/2017 cropping season in Nkolbisson, Cameroon following a complete randomised design with three replications. Cassava plant growth parameters were measured at 3, 6 and 9 months after planting while yields were obtained at harvest. Cost benefit analysis was used to evaluate the total costs and revenue returns. Fifteen farmers participated in the trial and semi-structured questionnaires and interviews were used to elucidate farmer's assessment of biochar. Results showed that, farmers using ricehusk biochar encured more profits with net benefits of 1.44 million fCFA and marginal rate of return (33.06%) compared to the control (583267fCFA) with MRR of 12.33% and corncob biochar (353436 fCFA) with MRR of 7.80%. Additional revenue (34.95%) was gained from the use of ricehusk biochar market price for CO₂ offset at (\$60). The use of ricehusk biochar was found to be socio-economically and environmentally feasible. However, national sensitization on biochar production could help create awareness, generate a huge leap in livelihoods as well as get the attention of the government for policy drive.

Keywords— Biochar; Food security; Livelihoods; Socio-economic feasibility; Environmental management.

I. INTRODUCTION

Meeting the global challenge of food and nutrition security for a steadily growing population using sustainable agricultural practices is inevitable [16,25]. This particularly applies to the bimodal rainforest area of the Centre Region of Cameroon with persistent shortfalls in agricultural productivity resulting in poverty and increasing rates of malnourishment [26, 27]. Food insecurity in this area is driven by declining soil fertility and access to nutrient inputs which limits access to nutrient rich foods [27]. Cameroon encompasses a rich and stable source of food crops supplied through the sustainable management of more than 20.39 million ha⁻¹ of arable land in five different agroecological zones [27, 29]. In the smallholder farming systems, cassava (*Manihot esculenta* Crantz) is one of the priority food crops cultivated after maize (*Zea mays*) and rice (*Oryza sativa*) alongside vegetable such as amaranth (*Amarantus cruentus*) to enhance nutrition and diversify income [26, 28].

Consequently, 20-30% waste are generated annually from these food crops and are openly burnt in the field or abandoned to rot around processing units [2]. Some of these crop waste materials include; sorghum and millet stovers, corn cobs, groundnut haulms, rice husk, cowpea and cotton stalks and coffee husk. Previous studies had demonstrated that the return of crop waste to the soil increases soil organic matter, essential nutrients and improvement of soil structure [16]. The production of biochar mobilises nutritive

elements from non-usable form in the crop waste (organic) to usable form (inorganic) through thermochemical processes[14,3]. In spite the contribution of crop wastes as feedstock (starting material) for biochar production, their use has not been fully exploited in the humid forest agroecological zone of Cameroon.

Biochar potentially raises crop yields through soil quality and nutrient retention effects (22,1). For example, decreased soil density may enhance water retention and high surface area can facilitate nutrient sorption and delayed release. It also may have synergistic effects with other farm management inputs such as compost, animal manure and inorganic fertilisers[9, 15, 20]. As farmers use organic/inorganic amendments within a social and economic context[25] there is a need to evaluate how biochar fits into farmers' holistic farm management practice. This includes critically assessing farmer's perception of how biochar is produced and its performance on the field before wide spread dissemination.

Most studies in literature focus typically on the environmental and economic profitability of biochar for bioenergy and carbon sequestration [5, 9, 15,]. These studies all found that the economic desirability varies and depends on the pyrolysis technology and the type of feedstock used to produce biochar [5, 6]. Also very few studies have assessed the economic profitability of biochar for cassava production or the socio-cultural soundness of the innovation. Thus it was worthwhile addressing the question whether is it environmentally and socio-economically feasibility to produce and use biochar for food cassava production in the bimodal rainfall area of Cameroon?

II. MATERIALS AND METHODS

Study location

The field study was carried out at Nkolbisson in the bimodal rainforest area of the Centre Region in Cameroon. The average rainfall was received in a bimodal pattern and was between 1100-1200 mm. Average daily temperatures ranged between 20 to 29°C while the humidity level was generally low throughout the region. The climate of the area is equatorial type with two seasons of dry spells between November to March and July and August. The months of April to June and September to October received very heavy rains of up to 1.200 mm. The soils are generally acidic (pH: 5.6) and are classified as rhodic ferralsol.

Experimental design, data collection and analysis

The field experiment design using a completely randomised (CRD) design consisting of four treatments with three replications. The experiment involved 15 farmers from different age groups. A focus group meeting was conducted with the farmers to identify the availability of different potential sources of biochar feedstock (crop waste) and their alternative uses. From the focused group meeting, cassava wastes which include the peelings, stems and tubers abandoned on the farm after the usable part has been harvested, ricehusk and corncobs was adopted for use in the experiment. After that, the farmers went around town and actually see how easy it was to get those different feedstocks, by recording time, effort, labour and cash costs.

Biochar production

Then, biochar was collectively produced from the various feedstocks; cassava stem and roots (CSb); ricehusk (RHb); and corncob (CCb) using a modified ELSA barrel in a process known as pyrolysis [1]. The barrel consisted of a 250 liter metal cylinder opened on one end with a removable circular steel plate (Figure 3). The open end was perforated in-order to supply secondary air required for the combustion. The perforations were made with 3cm L-shaped holes separated with spacing of 3cm. Equally 3 cm plus mark rows of holes were perforated on the closed end of the barrel for supplying primary air. The removable steel plate was also perforated with additional brass fittings for chimney. Semi-circular metal arms were fixed on both sides of the barrel to facilitate the transportation. The crop wastes (Figure 13) were packed in the metal barrel depending on the density of the (crop waste) feedstock. The fire in the barrel ignited from the top of feedstock using a glowing match stick on a dry starter material so that the top lights uniformly. Once the top layer was lit, the circular steel plate and the chimney were placed on the opened end of the barrel.

Due to the low the low oxygen in the system, the feedstock was partially burned to produce volatile gases and biochar via the process of carbonization. This was detected through a thin colourless smoke coming out of the chimney, red pyrolysis flame illuminating and biochar particles falling off through the plus marking holes at the bottom of the closed end. The process ended when all the crop waste was converted to biochar. The biochar was then poured out of the barrel immediately cooled with water before applied on the farm or stored in sacks for future use.

Semi-structured questionnaires were used to elicit the farmer's perception of the time and effort used to produce biochar taking into account differences between the crop wastes. The time was determined by measuring the time the

barrel was lit and the time the barrel was emptied of the biochar Temperature was monitored using a HANNA HI-935005 k-thermocouple from the surface of the barrel. The quantity and volume of crop waste used and the resultant biochar produced were measured using an electronic balance in 60 litter capacity bucket. Thensamples (500g) of each biochar wereanalyses in the laboratory using standard procedures to detect the quality (organic matter, total nitrogen and carbon, pH, CEC and exchangeable complexes).

Biochar application and planting

The experimental field site was divided in to three sections of 2 km apart following a soil fertility gradient from the higher elevated, moderately elevated and flat fields. Then 4m x 2m subplots were plotted out in each section. Thus each section had four plots of 8m² giving a total of 12 plots for entire study.Sixteen (16) kg eachofthe different biochars

were added randomly to the 4m x 2m subplotsand incorporated into the soil using a hand hoe. Then healthy cuttings from an improved cassava variety 8034 with at least 4-5 nodes were planted in each plot at a rate of 1 plant per m²(10000plants ha⁻¹) on 30cm high ridges constructed in the plots. Thus, each plot had 8 cassava plants presumably enough for cassava canopy.

Assessment of the economic feasibility of biochar

Cost-benefit analysis (CBA) analyses was used to evaluate the total field costs of the increasing the yield of cassava using biochar [10]. The cost of biochar production and yields of the 8034 cassava tuber harvested from all plots were adjusted to achieve the actual yields scenarios per hectare. The total field cost (TFC) was calculated following methods of Homagain *et al.*[6]as the cost encured during the production and application of biochar (Table 1).

Table.1: Field Cost encured during the production and application of biochar.

	Description of cost information	Unit cost
1	Cost of pyrolyser (CP): Cost of construction of the pyrolysis unit which includes purchase of metal drum and welding	30000/ pyrolyser
2	Cost of collection (CC): Cost of feeling the sacs with ricehusk, corncobs, coffee husk; and harvesting cassava waste from the farm	1000/sac
3	Cost of transporting the waste to the pyrolyser (CT)	1000/km
4	Cost of processing the crop waste (CPr): This includes grinding or pelleting, drying and storage before carbonisation	
5	Labour cost of producing biochar (CL): This includes the skilled labour in loading crop waste in and biochar out of the barrel	6000/day
6	Cost of applying biochar on the farm (CA)	6000/day
	Total Field Cost (TFC)= CP + CC + CT + CPr + CL + CA	

Determination of field benefits /revenue returns

Total field benefits or revenue returns refer to the marketable yields of the cassava tuber harvested [25]. The field benefits /revenue return (fCFA) was calculated from the sales of cassava tuber yield multiplied by its market price. Based on market analysis obtained from interviewing five cassava buyamsellams (vendors) in the Nkolbisson market during the study period, the average market price of 1kg of cassava tuber was 250fCFA kg⁻¹. This was multiplied by the adjusted yield (t.ha⁻¹) to obtain the gross field benefits from the sales of cassava tubers.

Where TRv: Total revenue return; Ry: Cassava Root yield; Mp: Market price

Similarly, the price value for a ton of CO₂ stored in the biochar obtained from literature was estimated at 60 dollars

(Robert *et al.* 2010; Homagain *et al.* 2016). This also was multiplied by the ton of biochar produced to obtain the gross field benefits from carbon offsets. The two gross field benefits were then summed up to obtain the total gross field benefits per treatment as demonstrated in the results section.

Net benefit/ revenue return was calculated by deducting the total cost of cultivating cassava with biochar from the total revenue return obtained from the sale of the cassava tubers.

Where NRv: Net revenue return; TFC: Total cost of cultivating cassava with biochar; TRv: total revenue return
The marginal rate of return was also assessed to determine the most economically efficient crop waste biochar. The marginal rate of return (MRR) gives information on the extra benefits encured as a result of moving from the

current practice (control) to the new option (biochar) [13]. It was calculated as the ratio of net benefit over the cost of biochar application.

III. RESULTS AND DISCUSSION

Economic Feasibility of Biochar in Cassava Production

Increase in cassava tuber yield in the biochar plots was solely assumed to be due to biochar application. Table 2

Where NRv: Net revenue return; TFC: Total cost of cultivating cassava with biochar; TRv: Total revenue return. The social benefit was measured as benefits accruing from the reduction of atmospheric CO₂ emissions [6].

presentsthe cost and benefits of increasing the yield of cassava in one hectare using biochar issued from crop waste.

Table.2: Economic feasibility of cassava production using biochar issued from crop waste

Treatment	Root yield (kg ha ⁻¹)	Cassava tuber (price/kg)	Revenue from cassava (fCFA)	Total field cost (fCFA)	Total field cost of biochar (fCFA)	Net benefit (fCFA)	Rate of Return (%)
Control	16133	250	4033250	3729344	-	303906	8.14
CSb	18666	250	4666500	-	5299145	-632645	-11.93
CCb	20533	250	5133250	-	4529914	603336	13.32
RHb	23200	250	5800000	-	4358974	1441026	33.06

CSb: Cassava biochar; CCb: Corncob biochar; RHb: Ricehusk biochar

Results from Table 2 show that, farmers using ricehusk biochar encured more profit with net benefits of 1.44 million fCFA and marginal rate of return (33.06%) compared to corncob biochar (603336 fCFA) with MRR of 13.32% and the control (303906fCFA) with MRR of 8.14%. The values of the marginal rate of return (Table 11) depicts that it will be more profitable to use biochar issued from ricehusk to improve soil fertility and increase cassava yields than corn cobs biochar (13.32%). This implies that every cost spent in increasing the yield of cassava was recovered 33.06 times using ricehusk biochar and 13.32 times using corncob biochar. Tarlaet *al.*[25] observed a net economic return of 2.40 million fCFA/ ha⁻¹ and a marginal rate of return of 15.20 when the same active ingredients were used against huckleberry.

The negative value of -632645 fCFA and MRR (-11.94%) indicates that the farmer incurred losses with the use of cassava biochar (Table 2). Despite the higher yield of cassava biochar compared to the control treatment, the economic loss observed was mainly due to the high cost

production of cassava biochar. This also shows that some biochars may not be economically feasible because of the high cost of production [10,9].

Cassava planted in the ricehusk biochar plots showed an average increase in yield (23.22t.ha⁻¹), while those planted in the cassava and corncob biochar plots only saw an average increase in yield of 18.67t.ha⁻¹ and 20.53t.ha⁻¹ respectively(Table 4).The farmers involved with the trials were very pleased with the results and noted that the biochars were more friable and porous and allowed for root penetration and better water flow to the soil very soon after application. The changes observed with soil color from red to dark brown and black showed that organic matter was increased and soil acidity reduced according to the farmers.

Economic Feasibility of Biochar in Carbon Sequestration

Table 3 shows the quantity of carbon dioxide gas stored in the biochar, the price per ton, the income obtained from selling cassava and generating carbon offsets in one hectare in the study area.

Table.3: Economic analysis of biochar cassava production and carbon offsets

Biochar types	Ton of CO ₂ stored of biochar (t/ha ¹)	Price/ton of CO ₂ (fCFA)	Revenue from CO ₂ offsets (fCFA)	Gross revenue cassava and offsets (fCFA)	field from CO ₂	Net benefit (fCFA)	Rate of return (fCFA)
CSb	3.33	36000	119880	4786380		-512765	-9.68
CCb	0.98	36000	35280	4918630		388716	8.58
RHb	2.29	36000	82440	5882440		1523466	34.95

As indicated in table 3, ricehusk and corncob biochars had higher marginal rates of return of 34.95 and 8.58% respectively. This shows that there was an additional revenue gain from the use of these biochars when the prevailing market price of CO₂ offset was US\$60/ton and therefore economically feasible. The data in Table 3 further reveals that the use of biochar pyrolysed from crop waste could be more profitable if a potential carbon offset market exists and the market price for avoided C emissions was high enough so that the farmers could incur a positive return. Also, the use of biochar issued from ricehusk was environmentally feasible since less CO₂ was discharged to the environment. Several life cycle analysis studies have shown that CO₂ emissions could be reduced during the production of biochar from crop waste [17, 22, 6, 5, 9].

Farmers perception of biochar production and utilisation

Pyrolysis is the thermochemical decomposition of organic materials in the absence of oxygen [23, 15]. In this study biochar was produced from crop waste using a pyrolysis technique with temperatures ranging from 400-700 °C and carbonisation time of 40-50 min [6]. The pyrolyser had an intake capacity of 5 kg/hour yielding ~3 kg/hour of biochar depending on the density of the crop waste. The main constraints that hindered the production of biochar were:

Lack of knowledge and skills in producing and applying biochar

According to the farmers (20%), if a farmer does not have accurate and precise knowledge on how to produce and apply biochar, the investment of using biochar becomes more uncertain, thereby lowering the application and expected benefits. Based on the interviews with farmers on-farm training of farmers could motivate a higher production and application rate.

Cost of collection and transportation of crop waste

The use of crop waste as starting material for biochar requires various on and off-farm operations including collection, packing, transportation, storage, processing and pyrolysis [6]. Also, the bulky nature of the crop waste

makes them expensive to transport even for short distances as stipulated by 55% of the farmers.

Funds to purchase equipment

Forty percent (40%) of the farmers reported that the pyrolysis process was the most costly item incurred during the life cycle of biochar production and has been estimated to account for 40 % of the total cost. Kulyk, [10] posits that the size and scale of the biochar production system influences the cost and economic viability. The inefficiencies and difficulties for farmers to access credit in fair conditions, propagates a significant credit constraint, that not only hinders the production of biochar but further increases the effective cost that farmers would face, in case they required finance to purchase equipment to produce biochar [18].

Labour

The collection, preparation and transportation of the large amounts of crop waste materials was relatively labour intensive and further increased the cost [8, 22]. Also, cassava and corncobs biomass were pelletised/chopped in to smaller pieces to ease drying and loading in the barrel. After the pyrolysis, the charcoal was further milled before applying on the field. This did not only increase the cost of production but also increased the labour cost as well, the reason for the higher field cost incurred for cassava and corncob biochar [11]. In addition to labour cost, farmers also identified the small quantity of biochar produced by the Elsa technology as a major limitation to the use of biochar.

Willingness of men to produce and use biochar

The major motivation of farmers to produce and apply biochar on their farms was the improvement of soil properties and crop growth. All the farmers interviewed were motivated to produce and apply biochar due to the increase in yield observed from the ricehusk biochar plots. Although factors such as the use of the improved variety might have contributed to the yield increases of cassava in the studied site, it may be possible to conclude that the use of biochar contributed a significantly higher percentage of the benefits compared to the gains obtained without using biochar. Results further indicate that most (80%) of the

farmers aged between 20-50 years with 40-50 years forming higher percentage.

The elderly farmers (>40 years old) were more willing to use biochar in their farms because, in the study area, farmers of 40-60 age group owned land, control the major family resources especially the cash resources and engage more in farming activities. Tata *et al.* [26] also reported that older farmers (>40 years old) in most rural communities have larger farms and are probably richer and thus have the extra economic and labour capacity to invest in farming activities. Contrary, the younger farmer (<30 years old), were not willing to use biochar. This was because they perceived investment in biochar production as disincentive. The collection, transportation of starting material, carbonisation and pelletizing was perceived laborious and time consuming to bear before they realize any benefit from their investment. Though applying biochar to marginalised soils offsets carbon emissions for a long-term sequestration, thus the carbon credit accrued from carbon sequestration may ultimately offset this cost in the long run [24], they would rather opt for other farm management options that may remunerate immediate returns to investment rather than biochar.

Willingness of women to produce and use biochar

Generally, agricultural activities in the study area are gender-based. The most difficult tasks such as clearing of forestland or fallows, felling of trees or maintaining cash crop farms are executed by men while women's activities are more oriented towards household food crop production with revenue received from the sales of cassava and cassava products such as *garri*, and *miondo*. Another important source of revenue is the collection and selling of non-timber forest products, such as *Njangsang* or *Ezezag* (*Ricinodendron heudelotii*), *Okok* (*Gnetum africanum*), *Kome* (*Coula edulis*) and *Andog* (*Irvingia gabonensis*). But similarly to the younger men, the high levels of investment of the biochar technology and the associated development was a major drawback for women participation as advanced by Agrawal [14].

Cultural norms and beliefs

Some of the farmers (30%) acknowledged they would rather buy the already produced biochar and apply in their farms than produced biochar on their own because they considered producing biochar or charcoal as lowering their status in the community.

Social feasibility of biochar application

The implication of biochar application considered in this study included: Employment, reduced poverty; increased food security and Health and safety.

Employment

Crop waste (feedstock) collection, processing, and transportation and the application of resultant biochar to soil was labour-intensive and thus presents an opportunity to create employment according to 60% of the farmers interviewed. Direct employment would result from the construction, operation and management of pyrolyser [17]. Furthermore, the production and application of biochar could diversify and increase the income and thus contributed to the local economic development.

Health and safety risks

Potential health and safety risks of biochar production and application include:

- The high temperatures and volatile gases generated from equipment during biochar production pose human health and safety risks [11, 17, 19]. Biochar or.
- Inhaling dust particles during biochar application could lead to respiratory ailments. Using protective masks could help reduce health risks, while mixing it with water or manure could mitigate the risk of heat, fire and dust during production, transportation and application [17, 19].

Reducing poverty and increasing food security

Healthy soils deliver important agroecological functions to many of the rural poor especially those that depend on soils for a secured food supply. Land degradation and soil fertility decline poses tremendous challenges to increasing agricultural productivity and economic growth. The resulting crop productivity decline limits local opportunities in striving for food security, development and self-reliance. The study however found that the use biochar could make meaningful contributions in addressing problems of poverty and food insecurity if strategically promoted [17, 18, 19]. The effective use of biochar applied alone or in combination poultry manure, compost or mineral fertilizer in smallholder farmlands has the potential to arrest decline in soil fertility, which could potentially improve resilience of the land resources and enhance crop productivity [28]. Biochar thus could play a major role in addressing the global food security challenge for the future.

Environmental benefits of biochar in crop production

The key feature to the potential solution of climate smart agriculture is the effective recycling and efficient use of agricultural and agro-industrial biomass in an environmentally and socially sustainable manner [11, 17]. Biochar leverages locally available agricultural and agro-industrial wastes such as cassava waste cuttings, coffee husks, corn cob, and ricehusk which otherwise are a public

health hazard and polluting waterways [7, 11]. The study also looks to reduced air pollution both at the farm and milling station where efforts to burn the dry pulp could cause significant pollution. Biochar also offers a unique value of liming, supply of critical plant nutrients such as potassium, phosphorus and calcium thus enhancing soil fertility and crop productivity. Furthermore, the proven capacity of biochar to sequester carbon in soil and reduce non-CO₂ GHG emissions for long periods could provide added benefits by contributing mitigate climate change [19].

Biochar Production and Forest Conservation

The application of biochar produced from organic biomass to soil has great agricultural and environmental potentials but controversies related to its utilisation exist, especially when timber forest products are exploited for use as a biochar starting material. If timber is primarily exploited for biochar production, this could lead to deforestation and subsequently threaten climate change and biodiversity [17]. This could also compromise food security since rainfall and fertile soils are critical for agricultural production. Also air, water and land pollution could be avoided if biochar is produced essentially from waste material such as waste wood (saw dust) and crop waste (rice husk, corncob, groundnut husk and empty fruit bunches) instead of openly burning, or dumping in along river banks. Slash and char stores up to 50% of the carbon in a highly stable form [2]. Thus biochar production from crop wastes should therefore be encouraged to avoid the overexploitation of forests resources.

Strategies for promoting the use of biochar in cassava production

The above results have shown that decline in the yields of cassava which was caused in part by soil fertility decline due to heavy leaching of soil nutrients could be solved by the use of biochar issued from crop waste.

Multi-locational and on-farm trials using fast track participatory approach

This strategy focus on the demonstration of biochar as a soil amendment to enhance sustainable farm management as such, will involve the following activities:

- Demonstration of biochar in comparison with other organic amendments and mineral fertilisers;
- Promote alternative formulations of biochar such as mixing biochar with manure, compost and mineral fertilizer and applied at different rates; and
- Demonstration of biochar as a strategy to reduce pollution (eutrophication and GHG emissions) and wastage of nutrient resources.

Indigenous knowledge and capacity building

Using participatory approaches such as training of trainers [3] will go a long way to enhance capacity building that blends local and technical knowledge on soil fertility management thus providing the relevance, credibility and legitimacy dimensions required for adoption of improved soil management practices such as biochar.

IV. CONCLUSION

Majority of farmers involved the study could produce and apply biochar using the Elsa technology. The main willingness to apply biochar from farmer's point of view was the improvement of soil properties and cassava growth. Ricehusk dust biochar was the most easy to produce biochar and would therefore allow for the large scale use. The economic gain from the sales of cassava exemplifies the significant improvements that smallholder farmers can obtain when biochar is used in their farms. Barriers to the production and application of biochar include funds to purchase equipment, labour and the small quantity of biochar produced using the Elsa technology. Based on the above mentioned points, the study found that the production and application of biochar in the humid tropical forest soils is socio-economically and environmentally feasible. Benefits from increased crop yields due to the soil amendment of biochar could contribute to increased food security. The collection of crop wastes (feedstock) represents an opportunity for creating job employment. The income resulting from sales of food crops and carbon offsets could contribute to reduce poverty and increase livelihoods. However, given the high dependency of farmers in the bimodal rainforest area on agriculture national sensitization on biochar production could help create awareness, generate a huge leap in livelihoods as well as get the attention of the government for policy drive.

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