Integrating Biochar with Solar Drip Irrigation Technology for Smallholder Vegetable Farming in South-Eastern Ghana Yields Profitable Returns

ABSTRACT

Ghana's agricultural sector faces significant challenges, characterized by low productivity and a heavy reliance on unpredictable rainfall and outdated farming practices, with limited use of modern agricultural inputs. This research investigates the potential profitability of integrating biochar and solar drip irrigation technologies for smallholder vegetable farming in Ghana, a country withsub-Saharan African agricultural conditions. The study employs gross margin and net farm income approaches to estimate profitability, providing a robust financial analysis of the proposed agricultural innovations. The results reveal a substantial mean gross margin of GH¢35,021.25 and a net farm income of GH¢48,786.50 per ha across the study area during the dry season from 2017-2020. These findings underscore the economic viability of biochar and solar drip irrigation, demonstrating significant financial benefits for smallholder farmers. The study concludes that adopting these technologies can markedly enhance agricultural productivity and profitability. It is recommended that smallholder farmers adopt biochar and solar drip irrigation to improve their farming outcomes, thereby contributing to sustainable agricultural development in the region.

Keywords: Biochar, Solar, Irrigation, Technology, Smallholder, vegetable, farming, Profitable

1. INTRODUCTION

In Africa, close to 60% of the economically active population are engaged in smallholder subsistence food crop farming and depend on the agricultural soils for their livelihoods. Food crop production is mostly through shifting cultivation where farmers do “slash and burn” on a piece of land, grow food crops for some years and leave it to fallow to help soil regain fertility overtime[1]. The progressive reduction in the fallow period as a result of increasing population pressure however makes it unlikely for these soils to regain their full fertility levels before reuse ([1], [2], and [3]). Ghana’s agriculture characterized by low productivity and highly dependent on an erratic rainfall pattern and outdated agricultural practices with low application of appropriate inputs. Soil which is one of the critical factors in agricultural production is plagued with fertility degradation by plant nutrient use, erosion and soil leaching coupled with low application of fertilizers, which has been identified as one of the constraints to food security in Sub-Sahara Africa (SSA)([2] and [3]). [4] for instanceindicate that huge proportions of agricultural lands in SSA are acidified to extremely high levels, compromising on the fertility of the soils for optimum crop growth. In recent times, however, discussions have focused on reasons for declines in crop yields; and soil acidification has been identified as a major contributing factor [5]. Application of organic matter, lime and the use of acid tolerant crop and agroforestry have been proffered as some of the management practices engaged by farmers in curbing this problem. The use of organic materials has been established to improve soil fertility and the capacity to reduce soil acidity ([6] and [7]).

Average yields of some selected food crops and vegetables in Ghana are below the achievable levels under rain-fed conditions. For instance, 10t/Ha of tomato, 8.0t/Ha of garden eggs and 15.0t/Ha of pepper are produced currently under rain-fed conditions instead of 20.0t/Ha, 15.0t/Ha and 30.0 t/Ha respectively [8] which means, there is high potential and wide catching up to do if Ghana wants to be a positive net producer of vegetable bracket to contribute to food security status of Ghana.

Ghana commits almost 10% of her annual budget into agriculture [3] placing the country on top of the list of investors in this sector in Africa. However, food crop yields in Ghana have shown disappointing growth in the past years and this is thought to be as a result of low soil fertility coupled with low application of appropriate agricultural inputs.Though this low fertility problem can be corrected using both inorganic and organic fertilizers, the major drawbacks of inorganic fertilizers are their costs and high inaccessibility to poor farmers ([9]) and their low efficiency in highly weathered soils ([10]) making the amount and efficiency of inorganic fertilizer use in the country less effective. For example,[11] found from their study on fertilizer adoption and use among smallholder farmers in Northern Ghana that income of household head among others contribute significantly to fertilizer use intensity and that use of fertilizer has been low. Among the technologies used to curb nutrient loss to plants due to weathering and soil erosion is a soil amendment agent 'Biochar', which is said to hold plant nutrients in solution over time, thereby, increasing the nutrient resident time so as to make these plant nutrients available and accessible to plants [12]. Biochar is charcoal produced under high temperatures and anaerobic conditions [13], a process called pyrolysis, and is used for soil amendment [14]. Its carbon-negative effect [15]. is essential in reducing the environmental impact of farming. It has the ability to improve soil fertility as well as other ecosystem services and also mitigate climate change [16-19]. The effect of biochar on soil fertility is due to a pH increase in acid soils and soil nutrient retention ([20], and [21].). Biochar is also known to change soil biological community composition and abundance [22-27The indirect economic benefits resulting from yield increases due to the use of biochar have been confirmed (28-33)

Biochar use with irrigation system has proven to increase plant growth and development for increased yield in locations in Ghana [34]. Solar drip irrigation uses solar energy to power water pump to lift water into a reservoir tank for onward delivery to a field through driplines for plant growth and development. This technology is cheaper [34] compared to others because of the use of locally available materials, and the abundance of solar energy in Africa. Preliminary field experiments using biochar and solar drip irrigation in Kade a town in Eastern region of Ghana led to an increased yield of okra with positive gross margin and net farm income on these technologies([34]). Gap analysis revealsthe need for long-term studies on the impact of reduced fallow periods and comparative analyses of various soil fertility restoration techniques, including biochar, in different agro-ecological zones. Research on the socio-economic barriers to fertilizer use and the long-term effects of biochar on soil health, particularly microbial communities, is limited. Additionally, understanding smallholder farmers' perceptions and adoption rates of new technologies like solar drip irrigation combined with biochar is crucial for developing effective agricultural strategies.

Biochar with solar drip irrigation technologies has been used over two years in three separate areas in South-eastern (Eastern, Central and Volta Regions) Ghana in some selected communities to ascertain their profitability. The objectives of this study therefore is to identify the major soil management practices and labour use and their understanding and perceptions of farmers on biochar with solar drip irrigation technology as well as the profitability for vegetable production activities.

1.1 Conceptual Framework of Technology package

Figure 1 shows the conceptual framework of biochar production from diverse sources such as plants, animals, and others, utilizing both high and low-temperature methods, each with distinct economic implications. Biochars produced at temperatures exceeding 1000°C are primarily aimed at mitigating climate change effects, whereas those produced at around 500°C are designed for soil enhancement to improve plant growth (Fig. 1).

The adoption of low-temperature biochar alongside drip irrigation systems by farmers can vary, categorized as early adopters, late adopters, or laggards, influencing their respective outcomes.

The Water, Energy-from-Biomass, Soil, Organics, and Crop (WEBSOC) technology and its economic analysis revolve around these biochar production methods. Key considerations include evaluating the economic advantages and determining farmers' readiness to invest in this technology.

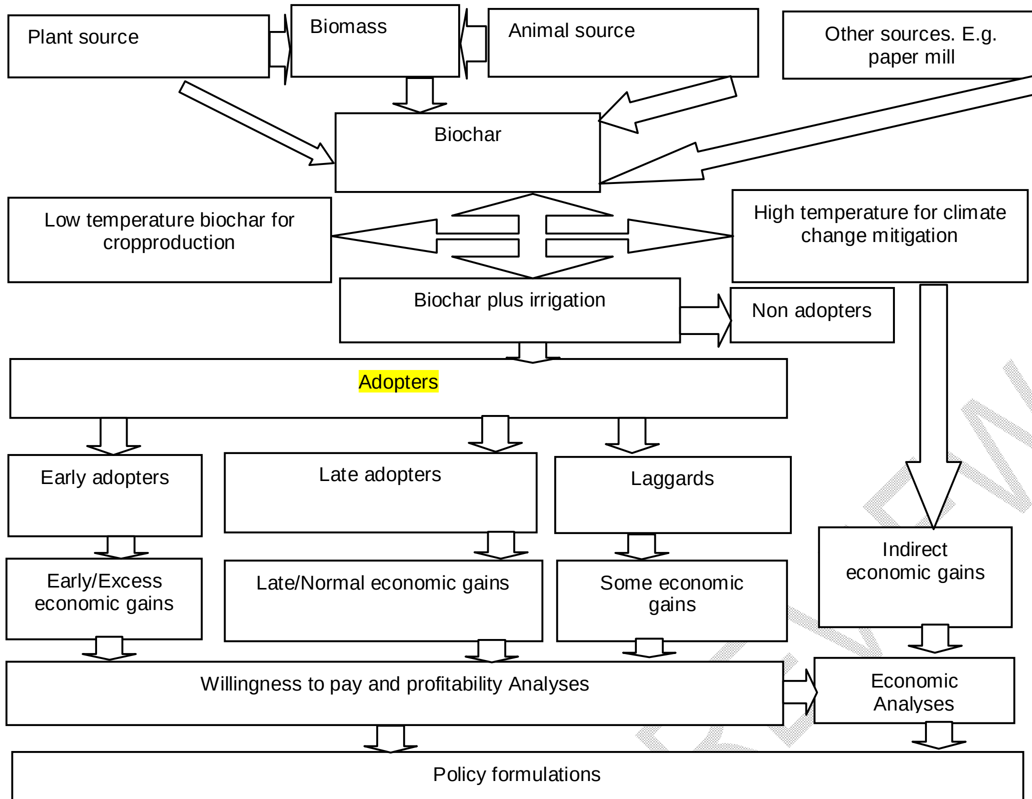


Fig. 1. Conceptual Framework of Technology package

Source: Authors' construction

2. MATERIAL AND METHODS

Rice straw biochar was prepared under standard conditions in the laboratory through fast pyrolysis at a temperature of 500^0.C to make the biochar recalcitrant and hence does not release any nutrients to the soil because it is not easily broken down by soil microbes [35]. This biochar was chosen for the study because of its availability in the study area. The biochar was spread evenly on 0.0018 Ha area and close to the centre of the farmers' 0.05 Ha field and mixed thoroughly to incorporate into the soil. This area was irrigated with the solar drip irrigation technology made of a siphon apparatus assembled from polyvinyl chloride (PVC) pipes and installed in a 220 Litre tank. An area of 0.05 Ha was connected to the tank which habours the siphon and water is lifted into the tank by a low capacity 12 V pump powered by a 50 W solar panel.

2.1 The Study Area

The study was done in three Regions of Ghana; namely; Eastern, Central and the Volta Regions. These places were selected based on previous trials done on biochar for vegetable production. In Eastern Region, Kwaebibirem district was purposively selected as the study area.In the Central Region Region, Cape Coast was also purposively selected for the study area and Angloga also selected for Volta Region. These regions like the rest of Ghana, has a tropical climate, characterized by moderate temperatures between 21^0 C-32^0C for most of the year and has two rainfall regimes between March and October. Annual rainfall figures is between 1,168 mm and 2,100 mm. The vegetation zones include grassland and deciduous forests.

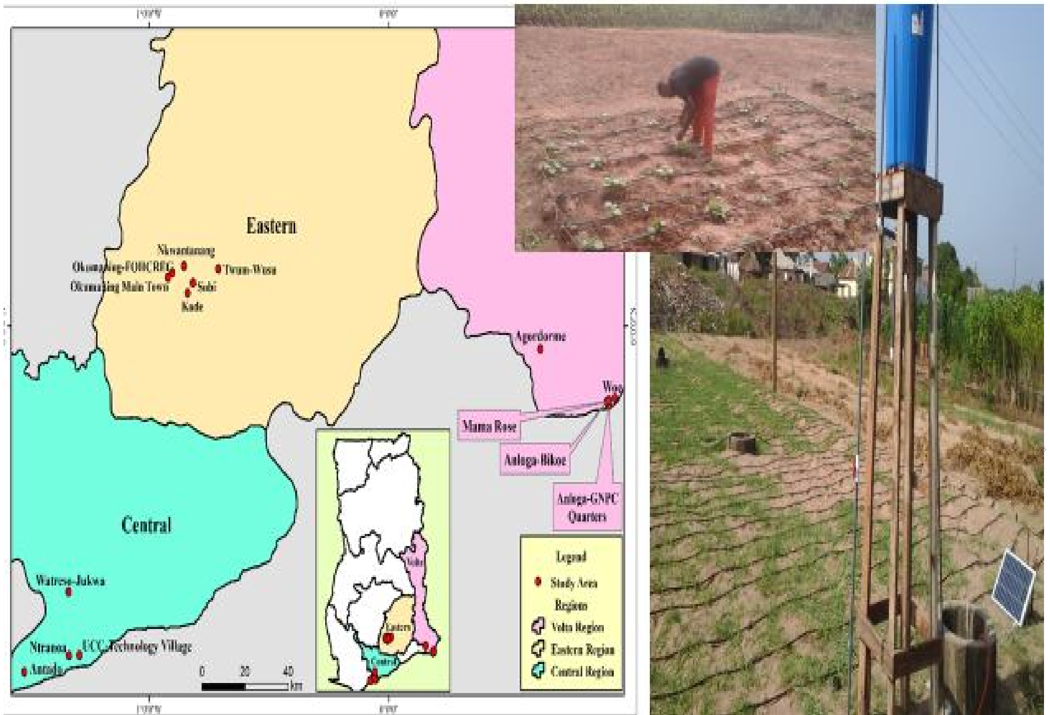


Fig 2 A map showing the Study Communities and Package

<u>2.1.1 Data Collection Approach</u>

Total samplesize of three hundred and twelve (312) farmers was drawn from fifteen (15) communities (Fig. 2). Data was collected with structured questionnaire on information such as farmers' characteristics, production activities and perception about biochar with solar drip irrigation technology after they have observed an on-farm demonstration from their neighbours' farm.A multistage sampling technique was used for the collection of 312 vegetable farmersfrom the study communities using the formula:

$$n = \frac{N}{[1+(N)\gamma^2]} \quad (1)$$

where n = Sample size; N = size of the population; γ= significance level (0.05 for this study).

In the first stage of sampling, Eastern, Central, and Volta Regions were purposively selected based on climatic and vegetation factors and vegetable production volumes. In the second stage, Kade and Anloga Districts and Cape Coast Metropolis in the Eastern, Volta, and Central Regions respectively were again purposively selected. In the third stage, on-station experiments were set up in these towns, and farmers from all the areas were invited to observe the demonstrations. Five contact farmers were purposively selected in each town. In the fourth stage, on-farm experiments were established in the contact farmers' farms as demonstration sites for neighboring farmers to observe. These contact farmers kept a notebook of visiting farmers, from which visitors were randomly selected by lottery.

For profitability assessment, data was collected from fifteen contact farmers, covering variables such as weeding costs, chemical costs (fertilizers and insecticides) and their application costs, seed costs, and yield. The data was analyzed using descriptive statistics including frequencies, percentages, mean, standard deviation, tables, and graphs with the aid of SPSS version 20, Excel, and Stata version 12 statistical software. Data collection was conducted using an internet-based open data kit (ODK) to Excel, then imported to SPSS and Stata for cleaning and analyses.

2.2 Theoretical framework underlining the Profitability of the Package

Profitability of a technology has been analysed in different ways using methods such as Net Present Value (NPV), Benefit Cost Ratio (BCR), Internal Rate of Return (IRR). The NPV is expressed by [36]as:

$$\sum_{t=1}^{n} \frac{C_t}{(1+r)^n} - C_o \qquad (2)$$

Where C_o = the capital outlay in GH¢, C_t = the net cash inflow generated by in period t in GH¢, n = the project life, r = discount rate. In this, project with positive NPV are accepted for investment. The IRR is the rate of return that makes the NPV equal to zero. [36] expressed the IRR as:

$$\sum_{t=1}^{n} \frac{C_t}{(1+k)^n} - C_o = 0 \qquad (3)$$

Where k is the IRR. If IRR is higher than the discount rate (r) the project is accepted for investment. The benefit- cost ratio (BCR) is given as:

$$\frac{\sum_{t=1}^{n} B_t/(1+r)^t}{\sum_{t=1}^{n} C_t/(1+r)^t} \qquad (4)$$

Where: B_t= benefit in GH¢ for year t, C_t= cost in GH¢ of year t, t = time period, r = discount rate. The decision rule is to accept projects with BCR greater than one. For this project, Gross margin and Net farm income analyses are employed[37] for short term and NPV for long term profitability. Income generated from the use of the technologies by the fifteen selected contact farmers was computed as the monetary value of total farm output. Costs and returns were calculated on per Ha basis. Variable costs included cost of fertilizer, herbicides, seed and labour, and fixed costs included cost of construction of set up, land rent and costs of hand tools. Depreciated fixed cost for the different components of the technologies was computed using the straight line method with salvage value assumed to be zero after components expire. The gross margin is given as:

$$GM = GI - TVC \qquad (5)$$

$$NFI = GM - TDFC \qquad (6)$$

Where TDFC is given as:

$$TDFC = \frac{Initial\ value\ of\ technology\ component - Salvage\ value\ of\ technology\ component}{life\ span\ of\ technology\ component} \qquad (7)$$

$$NFI\ Ratio\ (NFIR) = \frac{NFI}{GI} \qquad (8)$$

$$Operating\ Expense\ Ratio\ (OER) = \frac{TVC}{GI} \qquad (9)$$

$$Return\ Per\ Cedi\ \ Outlay\ (RPCO) = \frac{NFI}{TC} \qquad (10)$$

To determine the short run profitability of biochar amended soil with solar drip irrigation over two cropping seasons, between 2017 and 2020, Gross margin and Net farm income were estimated as stated above. The increase in okra yield across the selected areas due to biochar amended soils and the solar drip irrigation against the control and multiply by the local market price of okro to express the economic value in monetary terms. The additional costs incurred due to the package, that is incorporation of biochar into the soil and field management among others were also expressed in monetary values. Sensitivity analyses were conducted by simulating a 10% change in input cost and output price in order to ascertain the impacts of possible changes in yields and input costs and output prices on net revenues. A financial cost-benefit analysis was done to assess the payback period of the biochar treatments and prioritized the treatments according to their payback periods. This was also done to determine the cumulative net benefits of treatments that resulted in positive net revenues over a ten-year period. Given the long-term project horizon of at least ten years, costs and benefits occurring at different points in time were discounted to make them comparable in terms of time. For this, a real discount rate r was determined based on interest rate and inflation rate. Sensitivity analyses were conducted to determine the impacts of changes in yields, input costs, output prices and real interest rate on NPV. The project life span was based on studies that evaluated the impacts of organic and clay-based soil amendments on crop yield and soil properties [38-44]. These studies observed similar increases in yield after three to five cropping seasons due to a one-time application of organic and clay-based soil amendments compared to the yield gains in the first cropping season. The results are attributed to the long-term effects of soil amendments like biochar in improving key soil properties such as soil PH, cation exchange capacity (CEC) and major soil nutrients. Thus, it is assumed that the increases in yield due to one-time application of soil amendments remain the same for ten consecutive years given that climatic condition remains the same within this period. To look at the consequences of the possible worst yield scenario, a 10% annual reduction in yield gains was tested on net revenue. To estimate the output price for the years 2017–2020, average inflation rate observed over the last ten years was used.

3. RESULTS AND DISCUSSION

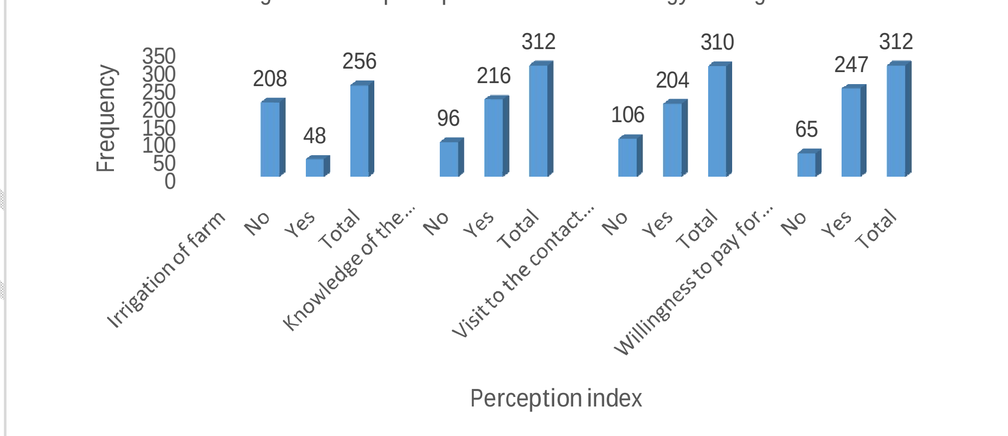
3.1 Socioeconomic characteristics, perceptions, soil management practices and labour use by farmers

This section examines the agricultural practices and technology adoption among farmers based on recent survey findings. The study covers aspects such as engagement with agricultural extension officers, marketing strategies, fertilizer use, and labor practices among farmers in the study area.

About 19% of the farmers have contact with agricultural extension officers and are advised on the use of agrochemicals for their farming activities, compost and on collective farming. Twenty-six percent sold almost all (90%) of their produce for a living, 9.6% sold 100% of their produce while 15.9% sold 80% to market women.

From the responses, it shows that most of the farmers know about the technologies because they have paid visit to their colleague´s on-farm experimental set up and saw how they work. The resultsof their visit (Fig 3) and knowledge of the package is expressed in high level of willingness to pay because they have good perception about the technology package.
The study revealed that 55.8 % of vegetable farmers use inorganic fertilizer for their farming activities in the three regions. Fertilizers such as NPK 15 15 15, urea, ammonium sulphate, among others, are used by these farmers. Few of them use other soil fertility management practice such as crop residue, animal residue, compost manure, industrial waste, intercropping practice, and crop rotation. There is dominant use of inorganic fertilizers among these farmers and demonstrates potential effect it will have on the use of the technologies especially the biochar, which is known to improve the accessibility of inorganic fertilizers by increasing the resident time after its application to the soils. The farmers also apply weedicides and insecticides for their farming activities. Labour, both skilled and unskilled is one of the key inputs in farming venture with limited technology. For this study, farmers in the study area employ 58.1% mandays of family labour for pesticide application and 66.1% for weedicide application and some hire labour for inorganic fertilizer application. Labour, whether hired or not are mostly adult males and females. In application, children help the adults by fetching water for mixing fertilizers, weedicides, while the adults do the actual application.

Fig 3 Farmers perception on the Technology Package



3.2 Cost Components and cost of the Package

Some of the major components of the package include bicycle tyre inner tube, 10L plastic container, water pump, water hose (1/2 inch), 3/4-inch water hose, flexible wire, 3/4 inch PVC pipe, 3/4 inch PVC elbow, 3/4 Air valve, 1 inch PVC elbow, PVC T Connector. The others are solar panel, poly ethylene (PE) filter, one inch PVC pipe, one-inch filter connector, plastic container (220L), polyethene pipe, driplines and 0.05 Ha land. The mean cost of establishing the technologies in the Eastern region is **GH₵2361.37**. The highest cost of the Package was recorded in the Volta Region (**GH₵2564.36**) due to the differences in the construction of reservoir platform and proximity to sources of water. In the Eastern and Central Regions, locally available materials were used and employed the services of the farmers in raising the platform but in the Volta Region artisans were employed for the construction of the platform. The minimum and maximum costs were both recorded in the Eastern Region due to diversity in the availability of local materials for the building of the Package.

3.2.1 Profit and Loss estimation for the Package (Short Term Profitability)

The short-term profitability of the Package was computed after it has been used in the minor season for three communities from September to November 2017 and dry season from December 2017 to March 2020 crop growing seasons. Due to the erratic nature of rainfall the amount of water needed by okra was supplemented [45] with the solar drip irrigation in these communities in the minor season and fully irrigated in the dry season. Gross income, gross margin, net farm income and return per Cedi outlay [46] for both biochar and no biochar plots show remarkable differences. The results show that biochar plots have higher returns [47] in all the study communities for minor and dry seasons than without biochar, though the total cost of the biochar plots is relatively higher compared to the no biochar plots (Tables 1and 2). More so the operating expense ratio [48] for the biochar plots is lower with higher return on Cedi outlay compared to the no biochar plots in all the three study communities who use the technologies.The significance of biochar combined with solar drip irrigation resulting in higher returns on partially and fully irrigated systems compared to the rainy period can be attributed to several factors. Biochar improves soil fertility and water retention, which enhances crop yields, especially during minor and dry seasons when water availability is limited. Solar drip irrigation provides a consistent and efficient water supply, reducing water stress on crops and optimizing nutrient uptake. Despite the higher initial cost of biochar plots, the increased productivity and yield during periods of limited rainfall lead to higher overall returns. This demonstrates the effectiveness of biochar and solar drip irrigation in enhancing agricultural output in water-scarce conditions. In all the three communities, there was no statistically significant difference [49] between the yields for the biochar and no biochar plots in the minor season except the Okumaning community where yields and the incomes for the two plots show a statistically significant difference ($p < 0.5$), which may be attributed to the presence of biochar, good maintenance of the farm and prolonged harvest. This justifies that soil amended with biochar tends to give a better plant growth and development and ultimately higher yield than without biochar [50].[32], [51]. Tables 1 and 2 show summary of the profitability of the use of the Package for three communities in the study area.

Table 1 Profitability per Ha of Okro for three Communities in the Minor season

Community	Nkwantanang		Ntranoa		Okumaning Camp	
Variables	Biochar	No biochar	Biochar	No biochar	Biochar	No biochar
TC in GH₵	48526.60	47326.60	51519.80	52719.80	44662.60	43462.60
TVC in GH₵	4580	6200	6200	2800	2800	4580
GI in GH₵	26500	25415	45555.60	36630.80	65500	42899.40
GM=GI-TVC in GH₵	21920	20834	39355.60	30430.80	62700	40099.40
DFC in GH₵	5568.8	5488.80	5868.6	5788.60	6871.60	6791.60
NFI=GM-DFC in GH₵	16351.2	15346.20	33487	4642.20	55828.40	33227.80
NFIR=NFI/GI	0.75	0.74	0.74	0.67	0.85	0.065
OER=TVC/GI	0.21	0.22	0.160	0.169	0.042	0.065
RPCO=NFI/TC	0.34	0.32	0.64	0.48	1.2	0.72

Source: Author's computations from Survey data (2021)

Table 2 Profitability per Ha of Okro and Cabbage for four Communities in the Dry Season

Community	Subi		Jukwa		Sogakope		Okumaning Camp	
Variables	Biochar	No biochar	Biochar	No biochar	Biochar	No biochar	Biochar	No biochar
TC in GH¢	48564	47364	48842	47642	60829	59629	61749	60549
TVC in GH¢	3200	3200	4480	4480	11900	11900	4200	4200
GI in GH¢	39000	27000	49583	35306	22578	18919.6	28924	25437
GM in GH¢	35800	17957	45103	30826	7018	10678	24724	21224
DFC in GH¢	5923	5843	5702.20	5622.20	5745.80	5665.80	6175.80	6095.80
NFI in GH¢	29877	17957	43881	25204	98640	5665	22748	15141.20
NFIR=NFI/GI	0.77	0.67	0.89	0.71	0.47	0.07	0.78	0.60
OER=TVC/GI	0.08	0.12	0.13	0.09	0.53	0.63	0.68	0.70
RPCO=NFI/TC	0.61	0.38	0.53	0.89	0.18	0.12	0.37	0.25

Source: Author's computations from Survey data (2021)

Where TC = total cost, TVC = Total Variable Cost, GI = Gross Income, DFC= Depreciated Fixed Cost, GM= Gross Margin, NFIR= Net Farm Income Ratio, OER= Operating Expense Ratio and RPCO = Return per Capital Outlay.

For long term profitability of the Package, a cash flow was developed to determine the cumulative net benefits of the biochar treatments within a particular region that had positive net revenues over project period. Given a proposed project life span of ten years, costs and benefits occurring at different points in time were discounted using a real discount rate r determined from nominal interest rate and inflation rate from 2007 to 2017 data. An average interest rate of 22.9% and an inflation rate of 12.9% was calculated from the data given in Table 3, therefore r = 8.9% was used as the real interest rate to discount the cash flows of the respective years. The real interest rate was calculated using:

$$r = {i - \pi}/{1 + \pi} \qquad (11)$$

Tables4 show some communities who used the package for dry season okra production in three different regions of the study area with investment cost, operating cost and corresponding benefits derived from the use of the Package. These values are projections from a 0.05 Ha area used by the contact farmers' experimental plots during the dry season. This is for only biochar-amended plots. It is assumed that the 10 tons per Ha biochar applied to the soil remain for ten years based on the average useful life of the technologies. It is also assumed that all other factors remain constant for the ten-year period with components of the Package which have outlived their useful life replaced and that the operating costs in the respective areas also remain constant. Cash flow was developed based on these.

The net present values of application of the Package for okro production for towns in Volta, Central and the Eastern Regions during the dry season is summarized in table 5. The results show that it is most profitable implementing the package in Central Region though all have positive net present values. These generally mean it is worth implementing in the study area even when the operating cost was increased by 10% and the benefit reduced by the same percentage point for the soils amended with biochar and the solar drip irrigation.

Table 3 Average Interest and Inflation rates for the Year 2007-2017

Variable	Year									Average
	2007	2008	2009	2010	2011	2012	2013	2016	2017	
Inflation(%)	10.7	16.5	19.3	10.9	8.7	9.2	11	17.8	11.8	12.9
int.rate(%)	22	22	23	20.5	21	22	24	26	26	22.9

Source computed from https://tradingeconomics.com/ghana/interest-rate

Table 4 Selected Communities with cost and Average useful Life of Package *per Ha*

Community	Variable			
	Invst. Cost in GH¢	Operating cost in GH¢	Benefits in GH¢	Useful life
Sogakope	9671.9	11900	22578	8.7
J Watreso	9321.9	4480	49583	8.6
K Camp	9221.9	4200	28924	9.2

Source: Authors computations (2021)

Table 5 Summary of Net Present Values per Ha

Town	Normal NPV	NPV at 10%
Sogakope (Volta Region)	23374.71	13337.28
Okumaning (Eastern Region)	29743.62	23703.59
JukwaWatreso (Central Region)	72491.85	64285.92

Source: *Authors computation from survey data (2021)*

Table 6 Cost of installation of the Package per Ha for some communities in the study area

#	Cost components	Qty	UC (GH¢)	(SKP)	Qty	UC (GH¢)	(OKC)	Qty	UC (GH¢)	(WSO)	Qty	UC (GH¢)	(SBI)	Qty	UC (GH¢)	(NTR)	Qty	UC (GH¢)	(NKG)
1	Bicycle tube	3	5	15	3	5	15	3	5	15	3	5	15	3	5	15	3	5	15
2	10L Plastic container	3	5	15	3	5	15	3	5	15	3	5	15	3	5	15	3	5	15
3	Twine	3	5	15	3	5	15	3	5	15	3	5	15	3	5	15	3	5	15
4	Water Pump	3	60	180	3	60	180	3	60	180	3	60	180	3	60	180	3	60	180
5	Water hose (1/2 inc)	30m	2.6	78	30m	2.6	78	30m	2.6	78	30m	2.6	78	30m	2.6	78	30m	2.6	78
6	3/4 inch Water hose	144	2.6	374.4	144	2.6	374.4	144	2.6	374.4	144	2.6	374.4	144	2.6	374.4	144	2.6	374.4
7	Flexible wire	60	0.29	17.4	60	0.29	17.4	60	0.29	17.4	60	0.29	17.4	60	0.29	17.4	60	0.29	17.4
8	Cellotape	3	2	6	3	2	6	3	2	6	3	2	6	3	2	6	3	2	6
9	3/4 inch PVC (6m)	16m	2.3	36.8	16m	2.3	36.8	16m	2.3	36.8	16m	2.3	36.8	16m	2.3	36.8	16m	2.3	36.8
10	Wooden pegs	1	0.10	10	100	0.20	20	100	0.20	20	100	0.15	15	100	0.20	20	100	0.20	20
11	¾ inch PVC elbow	9	2	18	9	2	18	9	2	18	9	2	18	9	2	18	9	2	18
12	¾ Air valve	3	14	42	3	14	42	3	14	42	3	14	42	3	14	42	3	14	42
13	1 inch PVC elbow	15	1.5	22.5	15	1.5	22.5	15	1.5	22.5	15	1.5	22.5	15	1.5	22.5	15	1.5	22.5
14	Inch T connector	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3
15	Solar Panel	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3
16	Half inch Filter	3	11.9	35.7	3	11.9	35.7	3	11.9	35.7	3	11.9	35.7	3	11.9	35.7	3	11.9	35.7
17	One inch PVC pipe	9m	2.1	18.9	9m	2.1	18.9	9m	2.1	18.9	9m	2.1	18.9	9m	2.1	18.9	9m	2.1	18.9
18	filter connector	3	11.5	34.5	3	11.5	34.5	3	11.5	34.5	3	11.5	34.5	3	11.5	34.5	3	11.5	34.5
19	reservoir (220mls)	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3
20	Reservoir platform	8hrs		20	8hrs		20	8hrs		20	8hrs		20	8hrs		20	8hrs		20
21	PE main	60m	1.72	103.2	60m	1.72	103.2	60m	1.72	103.2	60m	1.72	103.2	60m	1.72	103.2	60m	1.72	103.2
22	Driplines	10000m	0.56	5600	10000m	0.56	5600	10000m	0.56	5600	10000m	0.56	5600	10000m	0.56	5600	10000m	0.56	5600
23	Wooden support	40		5	40		5	40		5	40		5	40		5	40		5
24	Twine	20	1	20	20	1	20	20	1	20	20	1	20	20	1	20	20	1	20
25	500m2 area	20	500	10000	20	500	10000	20	500	10000	20	500	10000	20	500	10000	20	500	10000
26	land preparation	20	25	1000	20	25	800	20	25	800	20	25	600	20	25	800	20	25	800
27	Installation cost	20	300	6000	20	300	6000	20	300	6000	20	300	6000	20	300	6000	20	300	6000
28	Biochar (Kg)	50	20	1000	50	20	1000	50	20	1000	50	20	1000	50	20	1000	50	20	1000
29	Applying biochar	12 hrs	50	100	10 hrs	40	80	12 hrs	30	60	12 hrs	25	50	10 hrs	30	60	12 hrs	30	60
30	Biochar transport	20	10	200	20	10	200	20	10	200	20	10	200	20	10	200	20	10	200
31	PVC glue	1	15	15	1	15	15	1	15	15	1	15	15	1	15	15	1	15	15
32	Hark saw blade	1	15	15	1	15	15	1	15	15	1	15	15	1	15	15	1	15	15
33	PVC thread tape	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
34	Hhammer	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
35	Measuring tape	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
36	PVC pipe for bell	3	24	72	3	24	72	3	24	72	3	24	72	3	24	72	3	24	72
37	Two inch end cup	3	5	15	3	5	15	3	5	15	3	5	15	3	5	15	3	5	15
38	Metal weight	3	10	30	3	10	30	3	10	30	3	10	30	3	10	30	3	10	30
39	Metal file	1	0.33	0.33	1	0.33	0.33	1	0.33	0.33	1	0.33	0.33	1	0.33	0.33	1	0.33	0.33
40	Drilling machine	1	114	114	1	114	114	1	114	114	1	114	114	1	114	114	1	114	114
41	Pair of pliers	1	2	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2	2
42	Mosquito net	1	30	30	1	30	30	1	30	30	1	30	30	1	30	30	1	30	30
43	Screw driver	1	0.33	0.33	1	0.33	0.33	1	0.33	0.33	1	0.33	0.33	1	0.33	0.33	1	0.33	0.33
44	Well	1	250	250	1	250	250	1	250	250	1	250	250	1	250	250	1	250	250
	Total			**25523.06**			**25313.06**			**25293.06**			**25078.06**			**25243.06**			**25293.06**

Source: Authors computation from survey data (2021)

Qty = Quantiy of items needed, UC = unit cost of item, SKP = Sogakope, OKC = Okumaning Camp, WSO = Watreso, SBI = Subi, NTR = Ntranoa and NKG = Nkwatanan

4. CONCLUSIONS

Based on the results and discussions it can be concludedthat:
Few farmers have contact with agricultural extension officers, indicating limited access to professional guidance on advanced farming practices and the use of agrochemicals. The majority of farmers sell a substantial portion of their produce, highlighting a high dependency on farming for livelihood. There is a predominant use of inorganic fertilizers among farmers, which might affect the adoption of biochar technologies that can enhance fertilizer efficiency. Family labour is heavily relied upon, especially for pesticide and weedicide application. Children often assist adults, indicating a family-centric approach to labour in farming.

The package involves various materials such as bicycle tyre inner tubes, plastic containers, water pumps, and solar panels. These components are essential for setting up the irrigation and biochar system. The establishment costs vary by region, with the highest costs recorded in the Volta Region due to the need for artisans to construct platforms. In contrast, the Eastern and Central Regions used locally available materials, resulting in lower costs.

Biochar plots consistently show higher gross income, gross margin, and net farm income compared to no-biochar plots across various communities, indicating better short-term profitability despite higher initial costs. Biochar plots exhibit a higher net farm income ratio (NFIR), suggesting more efficient conversion of income into profit. The operating expense ratio (OER) is also lower for biochar plots, reflecting better cost management. In the Okumaning community, biochar plots showed statistically significant higher yields and incomes in the minor season, while in other communities, the differences were not statistically significant but still favorable towards biochar. Over a ten-year period, biochar plots are projected to remain profitable, with all communities showing positive net present values (NPVs). The Central Region, in particular, demonstrates the highest profitability, making it the most viable region for implementing the package.

4.1 RECOMMENDATIONS

To enhance the socioeconomic conditions, soil management practices, labour use, and overall profitability for farmers the following recommendations are made based on the findings from recent studies on biochar and solar drip irrigation technologies.

Few farmers currently have contact with agricultural extension officers. To address this, the reach and availability of extension services must be expanded. Providing farmers with guidance on advanced farming practices and the effective use of agrochemicals can significantly improve productivity and sustainability.

Biochar has been shown to enhance fertilizer efficiency and improve soil health. Education and outreach programs should be established to inform farmers of these benefits. Demonstrating the long-term profitability of biochar will encourage its wider adoption.

Encouraging the use of organic fertilizers and other soil fertility management practices, such as composting and crop rotation, is essential. Offering subsidies or incentives for organic farming inputs can facilitate this transition, reducing reliance on inorganic fertilizers.

Family labour, particularly child labour, is heavily relied upon for pesticide and weedicide application. Introducing labour-saving technologies and training programmes can improve efficiency, reduce reliance on family labour, and enhance overall productivity.

The cost of establishing biochar and irrigation systems varies by region. Identifying and promoting the use of locally available materials can help reduce these initial costs, making the package more accessible to farmers. In regions with higher costs, leveraging local artisans for construction can also lower expenses.

To assist farmers with the initial costs of adopting new technologies, financial assistance such as low-interest loans or grants should be provided. Emphasizing the long-term profitability of these investments will make them more attractive to farmers.

Tailored strategies should be developed for different regions based on their specific cost structures and resource availability. This approach ensures that the most effective methods are employed, taking into account local conditions and materials.

Continuous investment in research to improve biochar and irrigation technologies is necessary. Additionally, providing ongoing training for farmers on best practices for implementation and maintenance will support sustained productivity improvements.

A system for monitoring and evaluating the impact of biochar and irrigation technologies on farm productivity and profitability should be established. This data will be crucial for refining and optimizing the agricultural package over time.

Encouraging collective farming and community-based approaches to implement and maintain biochar and irrigation systems can lower costs and ensure better resource utilization. This approach also facilitates knowledge sharing among farmers.

Implementing these recommendations can significantly improve farming practices, increase yields, and enhance overall profitability for farmers. By addressing key areas such as extension services, biochar adoption, labour efficiency, and financial support, farmers can achieve better socioeconomic outcomes in the long term.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that generative AI technology(ChatGPT)has been used to update some of the references and editing of some part of the manuscript.

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