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Research article

Is investment in Climate-Smart-agricultural practices the option for the future? Cost and benefit analysis evidence from Ghana

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ABSTRACT

A majority of smallholder farmers in sub-Saharan Africa (SSA) countries depend to a large extent on agriculture for food security and income. Efforts aimed at improving farm-related profitability are therefore important to improving livelihoods among smallholder farmers. In Ghana, for example, smallholder farmers that depend on agriculture face serious risks especially those related to climate change and variability and soil degradation. Notwithstanding these dangers, evidence of the published literature on how best to tackle these challenges is limited. Over the recent decades, however, there has been advancement by programs channelling resources into Climate-Smart Agricultural (CSA) practices to improving smallholder livelihoods and food security. The interest in advancing investment in CSA practices is a key pathway that has the potential to significantly reduce the negative effect of climate change and variability risks on smallholder farmers livelihoods. Investing in CSA practices is also a key pathway to improving farm yield per unit area. Consequently, smallholder farmers are adopting and implementing CSA practices. Despite that, a gap still exists on the profitability of undertaking such an investment, as this is key in determining the sustainability of CSA practices. On this basis, the present study undertook a detailed cost-benefit analysis (CBA) of seven CSA practices identified with smallholder farmers in the coastal savannah agro-ecological zone of Ghana. A total of 48 smallholder farmers that had adopted these practices were studied. Three CBA indicators namely the net present value (NPV), internal rate of return (IRR) and payback period (PP) were assessed for each of the seven CSA practices. The results showed that out of the seven CSA practices examined, six of them were profitably suitable for adoption and scaling up from the perspective of smallholder farmers as well as the public perspective. The finding from this study, therefore, fill the current information gap in the literature on the costs and benefits of adopting CSA practices on household livelihoods in Ghana. Such a finding is critical to the promotion and scaling up the adoption of CSA practices by smallholder farmers and serve as a basis of formulating appropriate guidelines and policies for supporting CSA practices.

1. Introduction

Smallholder farmers in sub-Saharan Africa (SSA) countries are facing risks associated with climate change in a way that predisposes them to food insecurity and loss of livelihoods (Kumssa and Jones, 2010). However, counteracting risk associated with climate change is challenging especially for smallholder farmers whose farming largely depend on rainfall (Millner and Dietz, 2015). According to experts, agriculture, the main source of livelihoods and income among smallholder farmers is being affected and will continue to be affected by climate change (United Nations Framework Convention on Climate Change (UNFCC), 2011). Unfavourable effects of climate change in agriculture will lead to loss of income and decreased potential to generate employment among smallholder farmers in the rural areas through decreases in crop harvest and livestock products (Traore et al., 2013). Since a majority of smallholder farmers in Ghana depends on horticulture for their income, climate change poses a remarkable danger to the sustenance of livelihoods, food security, and poverty reduction (Beddington et al., 2012).

Evidence of published literature shows that other than climate change and variability related effects, other challenges such as loss of topsoil from agricultural farmers through soil erosion lead to undesirable crop and livestock yield, resulting in loss of income and food insecurity (Pimentel and Burgess, 2013). Between the years 2006 and 2015, for example, land degradation decreased Ghana's agrarian

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income by around US$ 4.3 billion representing about a 5% increase in poverty (Diao and Sarpong, 2011). Such occurrences are exacerbated by deforestation caused by charcoal production (Chidumayo and Gumbo, 2013), leading to a decline in rainfall and frequent droughts (Badejo, 1998; Pimentel and Burgess, 2013). Soil degradation often leads to a decline in harvested yields through hardening, compression of soil particles into smaller particles and diminished ability to hold water (Nearing, 2013). All these challenges present a hurdle to the achievement of sustainable food security, improved livelihood among smallholder farmers and the capacity to adapt to climate-related risks (Connolly-Boutin and Smit, 2015). To reduce the negative effects, some adjustments to the implemented agricultural practices are required to improve profitability. Such adjustments, however, need to take into account the costs and benefits that farmers may experience to make informed investment choices (Bhave et al., 2016; Williams et al., 2020).

The Coastal Savanna Agro-ecological Zone (AEZ) of Ghana is an important area for smallholder farmers because horticulture flourishes well (MoFA, 2013) and the potential for farmers to improve on their livelihood is high (Pimentel and Burgess, 2013). However, farmers still experience a few difficulties, such as diminished crop yields due to soil erosion, land degradation, deforestation and climate change. Professionals, therefore, need to consistently look for innovations (such as CSA practices) which when implemented and adopted can provide smallholder farmers with improved versatility and capacity to adjust to weather changes (Tachie-Obeng et al., 2013). The adoption of CSA practices has been shown by business models to be advantageous to farming communities among many localities (Schroth et al., 2015; Williams et al., 2020). On this basis, therefore, evaluating the costs and benefits of any investment in agricultural practices can help farmers and extension officers in adjusting their decisions and focus on the best techniques for making their adaptation more effective (UNFCC, 2011). Such an undertaking has the potential for (i) assessing and evaluating the impact on adopting and implementing specific CSA practices on time, thereby providing farmers with information on whether it is worthwhile to get the capital needed to successfully implement and maintain a CSA practice until profit is realized and (ii) advising the smallholder farmers on the potential for CSA practices to pay back the invested capital.

Evidence of published literature shows that some agricultural practices have a higher potential for reducing greenhouse gases emission (e.g., through carbon sequestration), improving food security (e.g., through higher productivity) and hence the ability to sustain household livelihoods (FAO, 2012). CSA can deliver environmental benefits that help households to adapt to the effects of climate change and variability (Scherr et al., 2012). Selection of the CSA practices is key in achieving larger benefits at the least cost. This, however, depends to a large extent on the benefits that can be perceived by the farmers. Perception of benefits will influence farmers decision on the acquisition of loan to invest in new technologies. Cost-benefit analysis (CBA) is, therefore, important as it provides farmers with valuable information on the benefits that are likely to be accrued after investing in specific CSA practices. These benefits, when compared to the costs, provides smallholder farmers with the duration required to achieve a break-even point. The present study aims at evaluating seven CSA practices that smallholder farmers perceive to have the largest impact on food security, productivity and mitigation in the coastal savannah AEZ in Ghana. Since farmers are the ones that bear the investment cost and directly appreciate the economic benefits of adopting CSA practices, the analysis presented in this paper is from a farmer viewpoint, as compared to the public viewpoint.

The main objectives of this paper are to:

1. Assess the costs and benefits associated with adopting seven CSA practices that are considered Climate-Smart, and
2. Estimate the value of externalities associated with implementing the seven CSA practices

This paper is organized as follows: Section 2 describes the study, explains how the seven CSA practices were chosen and ranked, the data collection and analysis. In section 3 the main findings are presented. The discussion is contained in section 4 while section 5 concludes.

2. Materials and method

2.1. The study site

Ghana is situated in West Africa and lies between latitudes 4° and 11^0N and longitude 4° W and 2° E. The country is divided into 10 regions that cover six agro-ecological zones (AEZ). They include Sudan Savanna, Strand and Mangrove, Rain Forest, Moist-semi deciduous forest, Guinea Savanna and Coastal Scrub and grassland (Figure 1). The data used in this study was obtained from Coastal Savannah AEZ, the area spanning from the lower end of Akwapin -Togo ranges in the east through Accra city to the west of the country. Its widest part is approximately 8 km and occupies approximately 4500 km^2. Rainfall in Coastal Savannah AEZ is bimodal in distribution and ranges from 600mm to 1200 mm annually. Long rains are received between June and July while short rains occur in September and October. The average temperature ranges between 18 °C and 29 °C. The altitude ranges from 1240 to 2000 m above sea level. The main crops include maize, rice, cassava, cowpea, tomatoes, shallot, millet, coconut and pineapples. The main livestock is cattle and shoats. The average farm size is two hectares.

2.2. Ranking and selection of the studied practices

The practices were ranked based on the Climate-Smart Agricultural Prioritization Framework (CSA-PF) (Corner-Dolloff et al., 2014). The CSA-PF process aimed to identify CSA practices and investment portfolios that are of interest to different users in a given area and context. This framework does this by taking into account the financial and economic benefits to ascertain (i) the feasibility of scaling practices already implemented by farmers in a given area, and (ii) new practices whose implementation can be scaled up in the Coastal Savannah AEZ as a part of Ghana's adaptation and mitigation strategies to climate risks. Eighteen CSA stakeholders, including specialists from the Council for Scientific and Industrial Research (5), department of agriculture (1), non-governmental organization[1] (4), Ghana national association of farmers and fishermen (1), Ministry of Food and Agriculture (MoFA) (3), Climate Change Agriculture and Food Security (CCAFS) program (1), national development planning commission (1) and farmers (2) were engaged in the CSA_PF workshop (Table A1). In terms of Gender, the composition comprised 14 men and 4 women.

The CSA-PF exercise involved: (a) participatory identification of the study site, the production system, and 17 CSA practices in the study area; (b) prioritization of the 17 CSA practices using eleven indicators of the CSA goals (i.e. productivity, resilience, and low-emission development) to develop a shortlist of seven high-priority CSA practices (Table 1); (c) conducting a CBA on the seven CSA practices; and (d) selection of CSA investment portfolios with the stakeholders in a final workshop. This paper focuses on the results from step (c) above, providing a detailed economic case of the seven high-priority CSA practices. For a more detailed explanation of how the CSA practices were ranked and the criteria used (see Mwongera et al., 2016).

The workshop participants identified the coastal savannah agro-ecological zone as the area for the assessment of the seven CSA practices (other details discussed during the workshop are provided in Appendix 1). This was achieved by evaluating the CSA practices in terms of the suitability of adoption and implementation by farmers. The selected

[1] Non-governmental organization comprised Food and Agriculture organization (FAO), Ghana Farmers Wives association and Women in Agriculture Development.

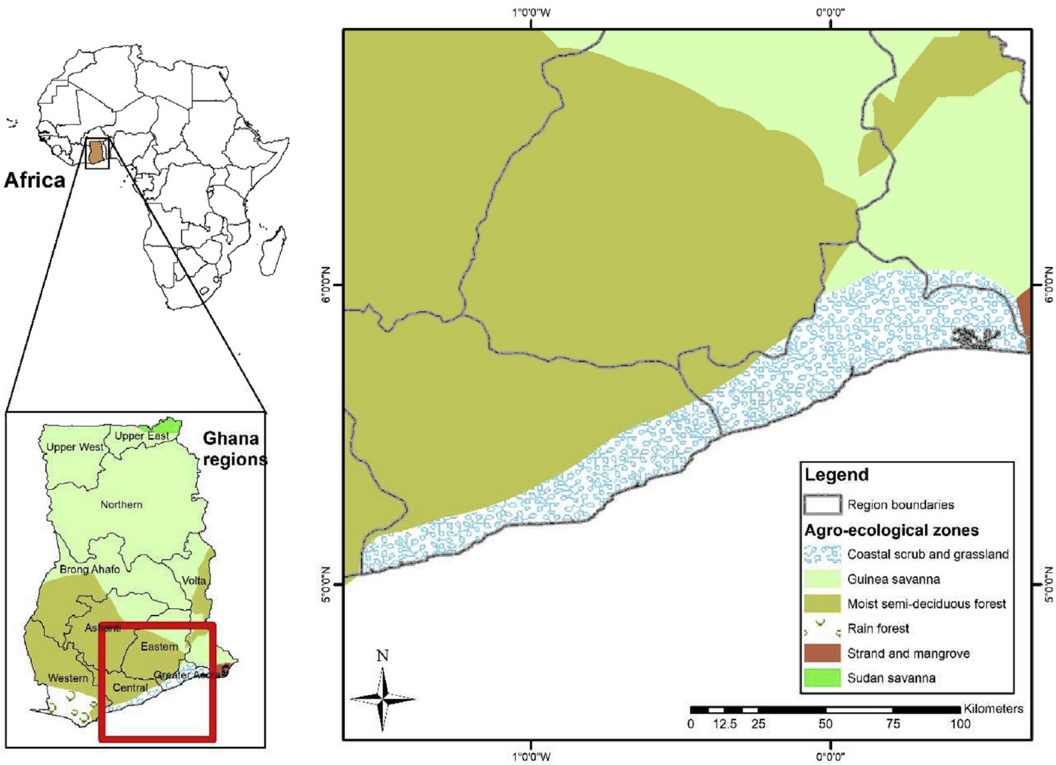

Figure 1. A map of Ghana showing the main agro-ecological zones.

Table 1. Summary information for the prioritized Climate-Smart Agricultural practices studied.

Practice	Description
Minimum tillage	The reduction in the frequency of tilling the land to minimise the interruption of the soil surface, and is sometimes achieved by reducing the use of machines such as tractor or plough on farms
Supplemental feeding	Refers to the extra feeding of animals with residues from agriculture and waste from food industries and sometimes with residues from agriculture and food industry
Crop rotation	Can be described as the growing of crops that are of different species (i.e., cereal, legumes, vegetables etc.) on the same plot of land on different seasons sequentially (i.e., one following each other by seasons). It is aimed at inhibiting the build-up of pest and diseases and also improving soil structure and quality.
Improved livestock housing	Can be described as the construction of animals shelters so that they are not exposed to all the extreme (warm or cold) weather conditions during the day and at night. It allows kraaling of manure
Improved varieties	The use of hybrid seed instead of local or recycled seeds. The usage of other inputs such as fertilizer, labour and management remains unchanged
Mixed cropping	Growing of different (different varieties and/or species) crops in the same season together in a given plot. It is sometimes practised to increase efficiency. For example, when legume is intercropped with maize. The maize benefit from the fixed nitrogen.
Integrated nutrient management	Are activities that farmers implement on their farms to deliberately improve the soil productivity through for example reduction in soil erosion through mulching, soil bund, contour, agroforestry etc.

CSA practices were discussed by the participants in terms of the length of time that each has been in operation since its implementation. The main commodities associated with the seven CSA practices include cereals (i.e. maize *[Zea mays]* and sorghum *[Sorghum bicolor]*), legumes (i.e. cowpeas *[Vigna unguiculata],* Bambara beans *[Vigna subterranea],* groundnuts *[Arachis hypogaea]*, and soya beans *[Glycine max]*) and small ruminant (sheep *[Ovis aries]* and goats *[Capra aegagrus hircus]*).

2.3. Data sources and collection

The data were obtained from a household survey that was conducted between July and August 2016 among 48 key resource farmers. Key resource farmers as used in this study allude to farmers that had successfully incorporated at least one of the seven CSA practices on their farms and had been practising it over a period of not less than 5 years before this study. Survey data was gathered using a structured questionnaire that captured data on (a) general information about the farm area, (b) the specific CSA practice(s) that farmers had implemented, (c) the benefits associated with implementing CSA practices, (d) changes in yields associated with CSA when compared with BAU practices, (f) implementation, maintenance and operations costs linked to the CSA and BAU practices (g) crops and livestock yield for BAU practice, (h) the price per unit received by the farmer for crop and livestock output. The questionnaires used for collecting information for each of the CSA practices are provided in Appendix 2, Appendix 3, Appendix 4, Appendix 5, Appendix 6, Appendix 7 and Appendix 8). More detailed information about the survey is also available at =https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/Q6BO6Q.

Six enumerators were trained on how to conduct the survey, by asking the respondent questions and recording the responses while at the same time observing that the respondent does not become lethargic as this may compromise the quality of data. The questionnaire was originally written in English after which it was translated into the local language – Akan and Ewe – that is spoken by a majority of the households. A pre-test was then carried out among 12 farmers. This allowed each enumerator to interview at least two farmers so that the extent to which the interviewee understood the questions can be assessed and to point out questions that needed to be paraphrased for ease of understanding. The pre-test also helped the research team to study the provided responses, to compare how well they captured the required information and the quality for ease of getting the required narrative during analysis. Consequently, during the pre-test, every unclear issue and gaps in the questionnaire were identified and rectified in the final questionnaire. This study comprises experimentation on human participants, consequently, approval by the International Center for Tropical Agriculture (CIAT) ethic committee was sought before conducting the research. The approval was provided by CIAT's Institutional Review Board (IRB) that this experiment was conducted as per the established guidelines and regulations and that informed consent was obtained from the survey participants.

The use of the seven CSA practices was not very widespread in the study area. Consequently, locating the target farmers that had implemented any of the seven CSA practices using a probability sampling method was a challenge. In light of this, sample farmers were selected through snowballing technique (Christopoulos, 2009; Naderifar et al., 2017). Both the community leader and agricultural extension officer in the area were requested to provide a list of farmers in the study area, which then acted as the sampling frame. The researcher then randomly selected seven seed[2] farmers, from the sampling frame, who had satisfied the targeted criteria of having implemented at least one of the seven CSA practices in the cereal-legume small ruminant farming system for a period of at least two to five years. The selected farmers were then asked to identify other farmers that fit the selection criteria. This process was repeated in four waves[3] to attain the required sample size. The identified farmers were then contacted regarding their accessibility and availability for an interview. A total of 48 farmers (either household head or their spouses) were interviewed. To minimise the bias associated with snowballing recruitment, a Peer Esteem Snowballing Technique (Heckathorn, 2002) was applied (see Appendix 9 for more details). This ensured that the captured sample was a true representation of farmers practising the seven CSA practices cereal-legume small ruminant system in the coastal savannah AEZ (Figure 1). Moreover, this approach enabled us to get farmers that had a thorough understanding of the seven practices, an important requirement when carrying out a CBA study. Conducting CBA presupposes that the physical impacts are well understood for them to be included in an economic appraisal (Atkinson and Mourato, 2015).

The adoption of the seven CSA practices had occurred in an irregular interval of between two to five years, making it a challenge to compare the yields from CSA and BAU over the lifespan of the practice. To overcome this challenge, we adopted a CBA that took both ex-ante and ex-post character for data analysis. The ex-ante approach was necessary because of the practices that had been implemented recently, implying that the farmers were yet to experience consistent and reliable yields over time. For recently implemented CSA practices, there was the uncertainty of how the yield varies from one year to the next and the impact of these practice on ecosystem services. Therefore, for recently introduced CSA practices, the researchers relied on the experts, via focus group discussion (see Appendix 10 for details) for information such as the magnitude of the change in yield per hectare, the length of time it takes for the optimal yield to be achieved since implementation of the CSA practices, and the lifespan.[4]

2.4. Cost-benefit analysis (CBA)

A cost-benefit analysis methodology was used for evaluating the implemented CSA practices over their lifespan. Such evaluations call for an approach that is both robust and easily implemented and yet provide results that are vigorous enough and that can be easily applicable and critical in informing investment decisions (i.e., by government planners, development partners, non-government organizations and farmers) now and in the future. CBA is a method that determines whether the benefits (both tangible and intangible) for a project, practice or policy outweighs the costs (and by how much) over a given duration. In the past CBA has been applied to both the private and public sectors (Atkinson and Mourato, 2015). A critical task in CBA involves the definition of alternatives and quantifying their impacts on the objective in question (Morimoto and Hope, 2004).

In the literature, two types of CBA methodologies are commonly used: the deterministic and the probabilistic. A probabilistic CBA methodology was selected as the most appropriate for the analysis contained in this paper. The CBA was implemented by accounting for all the costs and benefits accrued to the farmers and members of society when CSA practice was implemented and for the duration of CSA practices. To evaluate the cost and benefits of the seven CSA practices, three indicators are used: the net present value (NPV) and internal rate of return (IRR) and the Payback Period (PP). The NPV accounts for the time value of money and calculates the present value of the benefits and costs. In this study, NPV captures the time value of incremental benefits generated by CSA practices when compared to the business as usual over the lifespan of the practice. The IRR is the discount rate that makes the NPV of a project equal to zero. Consequently, the IRR does not take into account the cost of capital – an advantage in its estimation. After the estimation of IRR, however, it is common practice to compare it with a range of probable values to determine the profitability of each practice or project under diverse scenarios. A project is considered worth investing in if its IRR is greater than the opportunity cost of the money. The payback period (PP) refers to the time that a specific CSA practice takes to reach the break-even point. The PP was calculated by dividing the projected total costs of the CSA practice by the projected total revenues. In this study, a discount rate of 26% was applied as it the commonly used estimate for opportunity costs of money by the Bank of Ghana (Bank of Ghana, 2016).

As opposed to deterministic CBA that uses the average or mode values of the variables in the computation of IRR without measuring variability and uncertainty (Brent, 1996), the probabilistic approach used in the present study incorporates measurement of variability and uncertainty in the resulting IRR. Variability and uncertainty are attached to the resulting IRR to avoid underestimation of risks taken by farmers when implementing a practice. This has been incorporated by allowing a range of value for each variable and by assigning a measure of probability for the occurrence of these values. As such the approach used in this paper produces a cumulative distribution function (CDF) of the resulting NPV and IRR. By so doing, the CDF of the IRR provides the likelihood of the implemented CSA practice being profitable to the farmer. The

[2] The seed farmers in this study refers to the first set of farmers that were selected randomly from the provided sampling frame.

[3] Heckathorn (2002) offers a statistical probability proof that, within three to four waves, most heterogeneous population snowballs sampled through random seeds elicits a sample with characteristic representative of the target population.

[4] A lifespan, as used in this study, refers to the time duration since when a CSA practice was implemented up to such a time when the practice is stopped and overhauled or replaced by a new practice.

[5] Sequestration of carbon occurs when the carbon in the atmosphere is absorbed and stored in the soil.

[6] In the US minimum reduces soil erosion by more than one-third, (from 1.3 tons to 1.9 tons) between 1982-1997 (Claassen, 2013). In India soil erosion under minimum tillage was 5%–40% less compared to conservation agriculture (Bhatt and Khera, 2006).

[7] https://www.greenlife.co.ke/11-advantages-of-minimum-tillage-zero-tillage-systems/.

probabilistic CBA was carried out using Monte Carlo simulation using the @Risk (Palisade Corporation, 2013) so that the CDF of the IRR is attained by sampling from the probability distribution simulations associated with the random variable included in the analysis.

2.5. The CBA model

The analysis contained in this paper was done from the farmers' point of view. This is because this paper evaluates the profitability of the farmers that had implemented the CSA practices. This type of analysis is important for priority setting and a rationale for ensuring that the implemented CSA practices are sustainable. In addition to the consideration of farmers profit, public interest was also considered by considering externalities (such as on-farm biodiversity, carbon sequestration, soil biodiversity, social impact and reduction in soil erosion) in the CBA calculation. The value associated with the externalities was, however, computed separately from private profitability, as critical elements that are important for the evaluation of economic trade-off by the decision-makers. The private profitability was calculated by estimating the flow of changes in the Net Benefits (Eq. (1)) per hectare because the BAU is being replaced by a CSA practice. This CBA model has been used in other studies (Sain et al., 2016; Ng'ang'a et al., 2017; Williams et al., 2020) The estimation of the flow of private profitability indicators over the lifespan of the CSA practices per hectare, therefore, was calculated by deducting incremental costs flow from the Incremental Gross Benefit (IGB) flows. The IGB was calculated by multiplying the market price of the product by the increase in crop yield.

$$\Delta NetBenefits_t^{CSA} = \sum_{t=1}^{T} \frac{1}{(1+r)^t} \left\{ \left(\sum_{n=1} \text{Price}_{nt} * \Delta Y_{nt}^{CSA-BAU} \right) - \left(\sum_{n=1} \Delta C_{nt}^{CSA-BAU} \right) \right\} \quad (1)$$

Where $Price_{nt}$ represents the price of commodity n in time t; $\Delta Y_{nt}^{CSA-BAU}$ represents the annual change in yield for n for CSA compared to BAU; $\Delta C_{nt}^{CSA-BAU}$ represents the annual change in the cost of implementing CSA compared to BAU; r is the discount rate.

2.5.1. Model assumptions

To account for the effect of implementing CSA practice on the crop yield, we assumed that the implemented CSA practices would provide a positive social impact on the society, improve the soil (via for example reduction in soil erosion, increased soil biodiversity, carbon sequestration and on-farm soil biodiversity) at the farm level. CSA practices that are associated with these effects are likely to have an indirect impact on crop yield through improved crop yield per hectare, thereby improving adaptation and resilience to climate change (FAO, 2010). The physical response to yield following their implementation, however, may take a long time subject to an initial level of soil deterioration. To physically model how the physical response to crop yields would look like when CSA practices are implemented, we assumed that the response function would start with a lag period immediately after the implementation of CSA practices, which would last until when the yields start to be realized from the practice (Figure 2). Figure 2 is a Liebig production function that has been widely applied in the biological field to aid the process of modelling following the law of minimum (see Beattie and Taylor, 1993 for more details).

Figure 1 is characterized by (i) lag period (t0 and t1), (ii) time at which the visible physical response kicks in (t1) up to when it reaches attain its maximum and (t2), (iii) period following when the visible physical response curve reaches the optimal and flattens to form a plateau until the lifespan of the practice comes to an end (t2 to T). In other words, the physical response affects lag periods. During the lag period (i.e., t0 to t1) there is no visible effect of the yield associated with the CSA practice. The CSA practice impact on the crop yield is represented by the difference between t2 and t1. Yf represents the highest yield attainable from crops under the CSA practice (i.e., the increment). T stands for the lifespan period.

2.5.2. Costs elements, nature of variables and shape of the random variable

In economic literature, CBA cost structure comprises of two items; implementation (or installation) and maintenance costs. In both of these costs, the main components include materials (i.e. machinery, input, services and labour). Implementation costs comprise the resources that are set aside for the acquisition of equipment, labour and infrastructure required for the establishment of a CSA practice during implementation (Sain et al., 2016). Maintenance costs are resources set aside for the

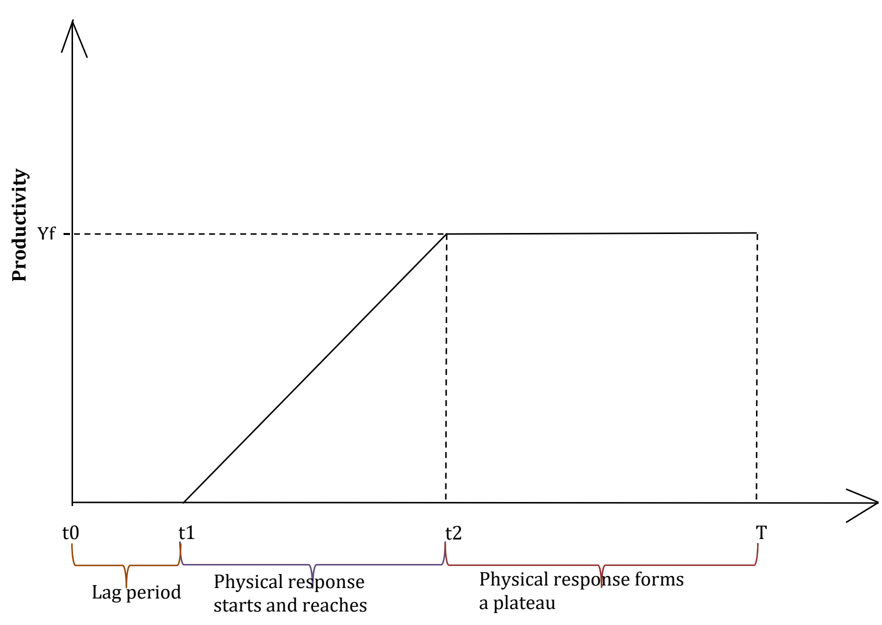

Figure 2. The linear plateau response function (Source: Beattie and Taylor, 1993).

Table 2. Variable used in the simulation model to calculate the NPV of the Net Benefits associated with the CSA practices.

Variables	Attribute	Explanation
Implementation cost	Random	The implementation cost is considered random to capture the variability in production technologies among farmers in the area of study
Maintenance cost	Random	The maintenance cost is considered random to capture the variability in production technologies among farmers in the area of study
Yield price associated with crops (cereals, legumes and vegetables) and livestock (cattle, sheep and goats)	Non-random	Based on the information collected via the household survey, the variation of crop prices per unit had very minimal variation across the farms
The response of yield from the crop (cereals, legumes and vegetables) and livestock (cattle, sheep and goats)	Random	The yield associated with different crops vary across farms and this variation is determined largely by the impact that the adopted CSA have on different crops. It was considered random to capture the large degree of uncertainty around its true value
Practice lifespan, time for physical response parameters (t1 and t2) and the discount rate.	Non-random	The lifespan associated with the CSA practices being studied was provided by the attribute of the practice itself and is therefore nonrandom.

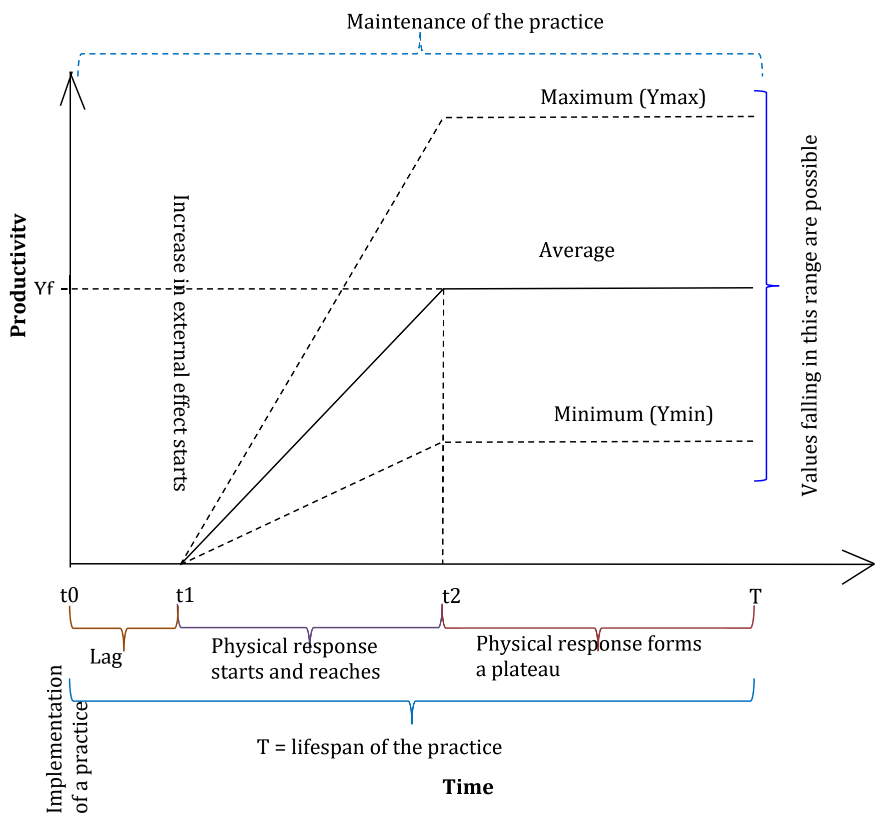

Figure 3. The proposed shape that the physical response function is assumed to take during the lifespan of a CSA practice.

acquisition of equipment, labour, inputs, and services for ensuring that the implemented practice progresses to its completion. Therefore, maintenance costs are incurred annually throughout the lifespan of the practice. In addition to the implementation and maintenance cost, the activity costs were included in the CBA computation. Activity costs are not necessarily incurred yearly and are mostly – but not always – associated with the harvesting (Sain et al., 2016).

To account for the cost items, data on crop and livestock yield prices, costs of inputs (i.e., seeds, fertiliser, veterinary drugs and labour), yield change (i.e., the difference in yield between CSA and BAU), the lifespan of the practices, and the time since the implementation of practice when the physical response begins and reaches the maximum was used. The nature of these variables was then specified as required for probabilistic CBA into random and non-random variables. Random variables are variables considered and evaluated over the entire range of possible values as it relates to CDF (Table 2). Non-random variables were evaluated at the mean.

These variables are considered random because they capture the variation observed across the studied farms. To adopt CSA over BAU most farmer considers the physical response to yield. In this study, random variable comprised of the implementation, maintenance and crop yields (Table 2). The yields harvested varied from one farm to the next demonstrating differences in exposure to farmers. On this basis, yield was considered random. Non-random variables are that does not vary from one farm to the next when the CSA practices being implemented among them is considered. Non-random variables include the costs, yield prices, lifespan period, discount rate and time for physical response parameters (Table 2). These variables are considered non-random because they are largely dependent on the CSA practice being implemented.

In specifying the shape of the random variable to evaluate the uncertainty associated with the physical response associated with the yield for each CSA practices, the researchers assumed that the physical yield response curves take a triangular probability distribution that can be characterized by three parameters: minimum, most likely and the

Table 3. Summary of the external effects associated with seven CSA practices.

	Soil erosion	On-farm biodiversity	Carbon sequestration[5]	Soil biodiversity	Social impact
Minimum tillage	Strengthen the soil structure which resists soil erosion[6,7],	Enhances dramatic build-up of soil organism number of different plants per unit area	Increases the concentration of soil organic carbon (SOC) and N within aggregate in the upper 5–8 cm depth	Enhances the fertility of soil through decaying organic matter	No social impact
Improved genetic varieties	Herbicide-tolerant crops do not need tilling thereby less disturbance to the topsoil	There are few or no-toxic effects on non-target organisms in the soil	Improved crop such as the herbicide-tolerant preserve soil and reduces carbon into the atmosphere	Enhances the soil fertility in that the improved crops have a faster degradation and shorter persistence of plant residues	Minimal effect on labour usage
Improved livestock housing	Decreases loss of soil	Trees tend to be harvested thereby reducing plant biodiversity	Overtime produces long-lived nutrient hotspots.	Enhances the fertility of soil through manure derived from kraaling	Has a positive social impact in that it is labour demanding
Mixed cropping	Reduces soil erosion	Enhances the number of different plants per unit area	Enhances the sequestration of soil carbon through using crop residue as mulch	Enhances the fertility of soil through decaying crop residues	Has a positive social impact
Integrated nutrient management	Decreases loss of soil	Enhances the number of different organism per unit area	Enhances the sequestration of soil carbon via using crop residues as mulch	Enhances the fertility of soil through decaying organic matter	Has a positive social impact
Crop rotation	Decreases loss of soil	Increases the number of different plants per unit area	Enhances the sequestration of soil carbon	Enhances the fertility of soil through decaying organic matter	Has a positive social impact
Supplementary feeding	Reduce grazing pressure and therefore ensure ground cover is maintained	has a positive effect in that it supports the re-introduction of crop species	Reduces the GHG emissions	Enhances the fertility of soil through decaying organic matter	Has a positive social impact

Sources: (Bhatt and Khera, 2006; Carpenter, 2011; Claassen, 2013; Duiker and Myers, 2005; Lal, 2004; Lal et al., 2007; Minten et al., 2009; Miura et al., 2008; Orchard et al., 2017; Riginos et al., 2012; Zurbrügg et al., 2010).

maximum value (Figure 3). This assumption is usually applied to instances where information related to the exact value of the parameters is missing. The minimum (Ymin) and maximum (Ymax) values were derived from the experts. The triangular probability distribution associated with each CSA practice exposes the variability associated with the CSA innovations across farms. The shape of the cost structure was determined by the best fit using @Risk software on the implementation and maintenance cost of the surveyed farmers.

2.6. External effects and their valuation

Besides the private benefits associated with the implementation of CSA practices, they provide ecosystems benefits that are beyond farms and communities, such as on-farm biodiversity, carbon sequestration, soil biodiversity, reduction in soil erosion and greenhouse gases (GHG) emission (Irvine et al., 2003). CSA practices also provide a positive social impact on society through, for example, creating employment. Though it is known that most of the CSA practices have the potential for generating varied effects, five external effects were identified as relevant and feasible to value given the study parameters, stakeholders expertise and preference (Table 3) (details of the tool used for collating externality related information for each CSA practice are provided in Appendix 11). The value of the external effects associated with a reduction in soil erosion, social impact, soil biodiversity, carbon sequestration, and on-farm biodiversity (explained in details in section 2.8.1) was estimated by assessing the change in the external effects due to the introduction of the CSA practices and their associated shadow price when compared to the BAU (e.g. Sain et al., 2016). A shadow price is an approximate monetary value used as a proxy for the market price that represents a marginal value that the society is willing to pay for the externality. Several methods have been suggested in the literature for estimating the shadow price, and they vary based on the type of external effect in question (e.g. Pearce, 1993). Details of the methods used are explained in Sections 2.8.1 to 2.8.5. When the range of variation in shadow prices associated with the seven CSA practices was large, it was considered a random variable for which a simulation was conducted using @Risk. By so doing, the model was able to capture the large degree of uncertainty associated with the true value of the variables. The @Risk was used to perform risks analysis using Monte Carlo simulation to provide many possible outcomes of our model and inform our result of the likelihood and risks associated with any given outcome (Wafula et al., 2018). This enabled us to judge which risk is worth taking thus allowing for the best decision under uncertainty. Monte Carlo simulation was used to express the value associated with random variable subject to the prevailing risks (further details on how the @Risk software was used to run Monte Carlo is provided in Appendix 12).

2.7. Private profitability values

To capture the physical response curve following the implementation of CSA practices in line with the linear plateau, the model adopted for the yield response is as shown in Figure 3. Information about the lifespan of the CSA practices (Table 4) was derived from the experts. The initial yields (Y_0) for the BAU practice (Table A2) were derived from survey data. Following the implementation of the CSA practices, the most likely, final yield (Y_f), minimum (Y_{min}) and maximum (Y_{max}) characterizing the triangular distribution were derived from the experts. About five CSA practices initiated their yield response from the second year (t2) (Table 4). The implementation of CSA practices increased the yield for most CSA practices as compared to BAU practices except for maize in mixed cropping and minimum tillage, and cassava, okra, tomatoes and pepper in minimum tillage (Table A2).

The costs were considered random due to their variation in farms. Consequently, @Risk software was used in determining the best fit distribution of the implementation and installation costs (Table 5) to reveal

Table 4. Actual values that were used to estimate the physical yield response to the adoption of the Climate-Smart agricultural practices.

Climate-Smart agricultural practice	Parameters			Assumed Shape
	t1 (Years)	t2 (Years)	T (Years)	
Crop rotation	1	2	3	A
Mixed cropping	1	2	3	A
Minimum tillage	1	2	3	A
Improved genetic resources	1	2	6	B
Improved Nutrient Management	1	2	3	A
Supplementary feeding	1	4	8	D
Improved housing	2	4	6	E

NB: A = A quick physical response cycle, there is no lag and the plateau is attained in the second year, and the lifecycle is three years; B = A quick physical response cycle, there is no lag and the plateau is attained in the second year and the lifecycle is six years; C = A quick physical response cycle, there is no lag and the plateau is attained in during the third year and the lifecycle is five years; D = A quick physical response cycle, there is no lag and the plateau is attained in during the fourth year and the lifecycle is eight years; E = There is a one year lag A quick physical response cycle, there is no lag and the plateau is attained in during the fourth year and the lifecycle is six years.

Table 5. The distribution of cost structures and parameter values.

CSA practices	Incremental cost	
	Implementation costs (US$/ha)	Maintenance costs (US$ha^{-1}year^{-1})
Crop rotation	Lognormal (595, 121)	Uniform (817,490)
Mixed cropping	Lognormal (143, 334)	Uniform (19, 117)
Minimum tillage	Lognormal (151, 285)	Uniform (77, 264)
Improved genetic resources	Lognormal (140, 319)	N/a
Improved nutrient management	Lognormal (102,22)	Uniform (49,299)
Supplementary feeding	Lognormal (39, 99)	Uniform (150, 1050)
Improved livestock housing	Lognormal (579, 524)	Lognormal (512, 643)

NB: To establish the distributions, @risk software was applied to the survey data.
N/a represents not applicable.

Table 6. Summary of parameters used in the CBA model.

Parameter	Distribution	Parameter representing	Source
T, t_1 and t_2	Non-random	The response function	Expert survey
Y_{i0}	Non-random	Yield for Business as usual practice	Household survey. The mean of observation with business as usual practice before CSA is adopted
Y_{imax}	Random triangular	Maximum yield associated with the CSA practice	Expert survey.
P_i	Non-random	Market price per unit at the farm level	Household survey. The mean price received by farmers
(implementation cost)$_j$	Random best fit the data	The implementation cost of CSA practice j	Household survey
(maintenance cost)$_j$	Random best fit the data	The maintenance cost of CSA practice j	Household survey. The annual maintenance cost associated with each practice
Increases in external effects	Non-random	Quantity of external effect produced by the implementation of CSA practice	Expert survey
Shadow prices	Random uniform	Estimation of the value of one unit of the external effects affected by the implementation of CSApractice	Expert survey

NB: To establish the distributions, @risk software was applied to the survey data.
N/a represents not applicable.

the variability of the adopted CSA practices. The model parameters and the source of information about the parameter are presented in Table 6 (a detailed example explaining how the parameters in Table 6 are related to each other graphically is provided in Appendix 13).

2.8. Externalities parameters

As discussed briefly in Section 2.6, the economic valuation incorporated the value associated with changes in on-farm biodiversity, carbon sequestration, soil biodiversity, reduction in soil erosion and social impact associated with implementing the seven CSA practices.

2.8.1. On-farm biodiversity

The adoption of CSA practices such as crop rotation, integrated nutrient management (INM) and mixed cropping tends to improve on and below ground agrobiological diversity (Tiemann et al., 2015). Strategies for estimating agrobiological diversity are not common (von Haaren et al., 2012). Methods of estimating biodiversity suggested in the

Table 7. A summary simulated results of the benefits associated with the externalities.

Externalities	Distribution	Average (US$ ha^{-1})	5% Percentile (US$ ha^{-1})	95% Percentile (US$ ha^{-1})	Stdev
On-farm biodiversity	ExtValue (48,18)	59	28	102	23
Carbon sequestration	Triangular (0.6; 90; 90)	15	3	29	5
Soil biodiversity	Uniform (2, 27)	15	3	27	8
Social impact	Risk Laplace (55, 48.5)	275	9	668	242
Reduction in soil erosion	Risk Uniform (5,61)	33	8	58	16

NB: 10,000 for Monte Carlo simulation (n = 10,000).

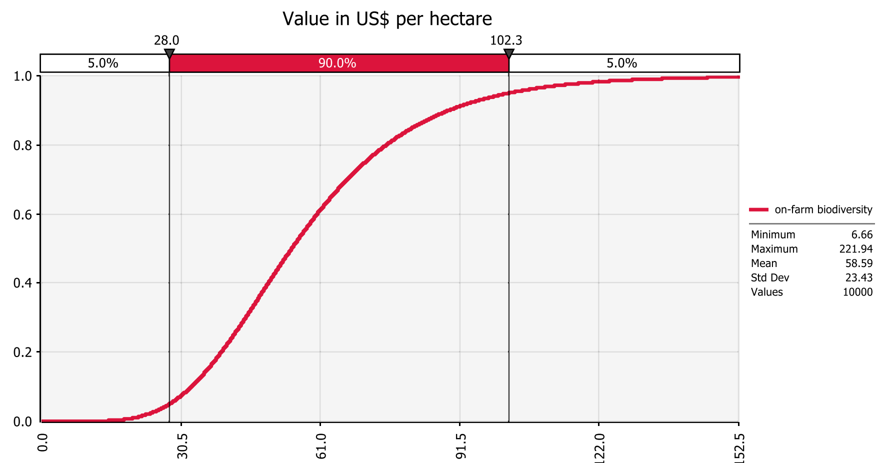

Figure 4. Cumulative distribution of the value per unit change in on-farm biodiversity per hectare per year.

literature depend on the context (Gabel et al., 2018). On-farm biodiversity, for example, is assessed by assigning different scores to land uses types. A land-use covered wholly by vegetation was allocated a high score because it provides more ecological benefits while a practice such as a monoculture was assigned a score of zero. (Henry et al., 2009. In this study, on-farm biodiversity was assessed using sustainability monitoring and assessment routine (SMART) farm tool (see Schader et al., 2016 for more details) where biodiversity is reflected as a theme that encompasses other sub-themes (e.g., species-diversity) (Gabel et al., 2018). Consequently, indicators related to the on-farm biodiversity were estimated as the change in the number of plants and organisms by types that were present under CSA practices as compared to the BAU. This was done on a score of zero to one while the value per score was estimated as the maximum values that the experts were willing to pay (Hanley and Barbier, 2009 Pg. 188). To take into account the risk inherent in these values, a Monte Carlo simulation (n = 100,000) was performed using @Risk. The results that fitted in a uniform distribution (Table 7) showed that the maximum willingness to pay value per change in biodiversity score ranged from US$ 28 to US$ 102/unit/year with a mean of US $59/unit/year (Figure 4). The value of the total change in the on-farm biodiversity score was then derived by multiplying the change in score to get the change of on-farm biodiversity. The value associated with on-farm biodiversity for the seven CSA practices varied from US$ 6/ha to US$ 40/ha with a mean of US$ 24/ha (Table 8).

2.8.2. Carbon sequestration

Carbon sequestration is the conversion of carbon dioxide (CO_2) to other uninterrupted pools (Henry et al., 2009). Carbon sequestration can be classified as either a private or public process that aims at raising carbon content in the soil (Lal, 2008). On the one hand, carbon sequestration improves the soil structure, texture and water holding capacity. On the other hand, it improves the quality of the air (Farage et al., 2007). Considering that the biomass for most crops is stored for a very short time as compared with the woody biomass (e.g., Nowak and Crane, 2002), the estimates for carbon sequestered by the CSA practices being evaluated were derived from published literature in sub-Saharan Africa (SSA) countries. The quantity of carbon sequestered, as derived from the literature, was assumed to be a good approximation of the actual carbon sequestered in Coastal Savannah AEZ. According to Farage et al. (2007), the quantity of carbon sequestered through crop cultivation and/or livestock keeping is about 0.08Mg/Cha/year. However, to avoid overestimating the quantity of carbon sequestered, we assumed that 50%

Table 8. A summary of the simulated estimation of external benefits (US$/ha) associated with the seven CSA practices.

Externalities	Crop rotation	Mixed cropping	Minimum tillage	Improved varieties	Integrated nutrient management	Supplementary feeding	Improved livestock housing
On-farm biodiversity	23.40	32.28	30.67	12.91	19.37	6.45	40.00
Carbon sequestration	3.00	10.00	3.00	3.00	27.00	30.00	25.00
Reduction in soil erosion	32.50	87.50	90.00	20.00	56.00	50.00	80.00
Soil biodiversity	18.00	24.00	25.00	5.00	10.00	10.00	15.00
Increased biodiversity	8.00	15.00	11.00	8.00	29.00	40.00	38.00
Social impact	80.00	55.00	0.00	50.00	120.00	160.00	100.00

NB: 1 US$ was equal to 4 GHC$ at the time of the survey (June–August 2016).

(i.e., 0.04Mg/Cha/year) of what is published by Farage et al. (2007) as the quantity sequestered by all the CSA practices that had incorporated some crops and/or livestock, but which the experts had indicated as significantly enhancing the sequestration of carbon. This supposition was based on the fact that some benefits are associated with the sequestration of soil carbon that is derived from domesticated animals – due to animal waste that is used as manure (or fertilizer) on the farms. For inclusion in the CBA computation, the sequestered carbon was first converted into carbon equivalent. The derived value was then multiplied by US$ 8/ha/year (Gordon et al., 2018), and by the number of years that each CSA had been practised.

2.8.3. Soil biodiversity

To compute the change in soil biodiversity associated with introducing the seven CSA practices, we first sought to understand the different soil function and services such as regulating, supporting and provision, all of which are interlinked (Pascual et al., 2015; Plaas et al., 2019). Then following the total economic framework (e.g. Pascual et al., 2015), a change in soil biodiversity was estimated as the sum of the change in expected returns to crops production as a result of intensification including the natural insurance for example (as compared to the variability of crop yield) due to improvement on soil biodiversity associated with the seven CSA practices. The value of increased return associated with soil biodiversity was captured via a survey by assessing the opportunity cost of the avoided yield loss as a result of implementing CSA practices when compared to the BAU over the lifecycle of the practices. Taking into account the uncertainty of the value provided, the value of the soil biodiversity ranged from US$ 5/ha to US$ 25/ha with a mean of US$ 15/ha (Table 8).

2.8.4. Social impact

Social interaction among community members is important to the implementing of CSA practices. This is because it facilitates continuous learning from each other and may create demand for extra labour which culminates in social impacts on employment. Evidence of the literature shows that those households that possess extensive network (formal or informal) are likely to receive new ideas of how to implement specific technologies (Aguilera, 2002) including attracting the technical know-how as may be needed (Khatri-Chhetri et al., 2019). In this paper, our focus is on the social impact that relates to the implementation of CSA practices that lead to the creation of employment. It was assumed that the implementation and maintenance that is done annually may require extra labour compared to what is required under BAU. Survey data was used to calculate the increase in labour during implementation and maintenance. Therefore, the change in social impact was estimated by multiplying the average daily rate of labour in coastal Savannah AEZ

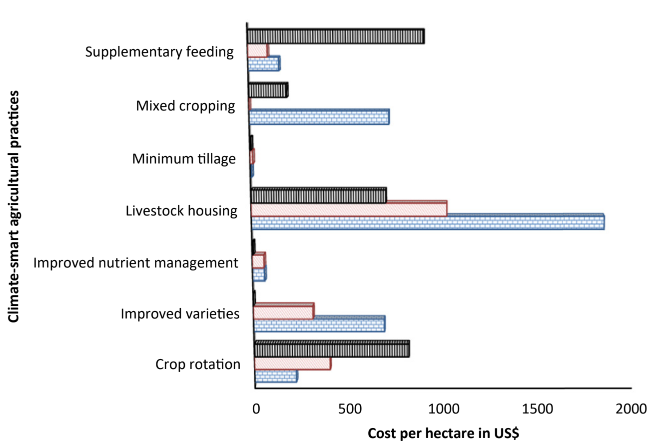

Figure 5. Installation, maintenance and operation costs for the studied climate-smart agricultural practices.

(approximately US$ 5/person/day). The total value of social impact associated with the seven CSA practices varied from US$ 0 to US$ 160 per hectare per year with a mean of US$ 80 per hectare (Table 8).

2.8.5. Reduction of soil erosion

One of the notable effects of implementing CSA practices over the BAU is that CSA practices improve the sustainability of farm production by decreasing soil erosion (One Acre Fund, 2015). The reduction in soil erosion promotes biodiversity, improves soil fertility and crop yield (Marta-Pedroso et al., 2007). Moreover, a reduction in soil erosion also improves water quality (Kremen and Miles, 2012). We used the opportunity cost for soil erosion as estimated by the experts, where the estimated value of soil loss by erosion was between US$ 0.20/ton to US$ 0.90/ton with a mean of US$ 0.60 per ton. Taking into account the uncertainty of the value provided for the seven CSA practices, the amount of soil erosion that could have occurred in the absence of the seven CSA practices ranged from 9 tons per hectare to 95 tons per hectare with a mean of 58.59 tons per hectare. The value of soil erosion reduction was estimated by multiplying the average value of soil with the quantity of soil erosion that has occurred in the absence of the CSA practices. These values ranged between US$ 20 to US$ 90/ha and an average of US$ 59/ha (Table 8).

3. Findings

3.1. Costs of installation, maintenance and operations

All the affected practices had a lifespan of between three and eight years, and the implementation of the seven CSA practices affected either crops or livestock or both (Table A3). The result also showed that except for livestock housing, the cost of implementation for all the CSA practices was less than US$ 500 per hectare (Figure 5). Similarly, the cost of maintenance and operations for all the studied CSA practices were less than US$ 1,000 per hectare. The cost of installing livestock housing was about 300 and 29 times larger than what is required to install minimum tillage and integrated nutrient management (Figure 5). The maintenance cost was larger for livestock housing (US$ 1,017) followed by crop rotation (US$ 400) and improved varieties (US$ 313). The operation costs was larger for supplementary feeding (US$ 900) followed by crop rotation (US$ 817) and livestock housing (US$ 700). Minimum tillage had the lowest implementation, maintenance and operation costs followed by improved nutrient management. The implementation and maintenance costs for integrated nutrient management was almost similar (Figure 5).

3.2. Financial profitability associated with adopting the seven CSA practices

The findings showed that of the seven CSA practices, six were privately profitable because they had a positive NPV and a larger IRR than the discount rate for their lifespan (Table 9). Minimum tillage is the only CSA practices that had a negative NPV and a lower IRR than the discount rate. The IRR for the six practices with positive NPV ranged between 62.56% and 227% (Table 9). Of the six CSA practices with positive NPV, mixed cropping had the lowest IRR (i.e. 62.56%) while integrated nutrient management (INM) had the highest IRR (i.e. 227.67%). For the six practices with positive NPV, there was a 95% confidence interval that the NPV, IRR and PP ranged between US$ 842 to US$ 10,167, 41%–292% and 0.89–3.31 years respectively. The high IRR for integrated nutrient management practices was due to the low implementation cost at the start (Figure 5) as well as the short period between implementation and when the effect of CSA on the yield starts to be noticed. Minimum tillage had a negative NPV and IRR (Table 9), and this could be due to a decline in the yield from crops (i.e. watermelon) compared to the BAU on farms where it had been implemented (Table A2). Consequently, minimum tillage had the lowest impact (in terms of income and yield) on

Table 9. Summary information on net present value (NPV), internal rate of return (IRR) and the payback period (PP) for the seven CSA practices studied.

CSA practice	The probability distribution of Net Present Value			Internal rate of return (IRR)			Payback period (Years		
	Mean NPV (in US$)	90% confidence interval (US$)		Mean (%)	90% confidence interval		Mean	90% confidence interval	
		min	max		min	max		min	max
Crop rotation	2,646.00	842	4,589	70.69	41	110	1.0	1.70	2.30
Mixed cropping	364.35	147	594	62.56	46	82.7	1.0	1.90	2.10
Minimum tillage	(3,958.00)	(4,734)	(-3348)	(287.00)	(274)	(299)	-	-	-
Improved varieties	1,372.37	935	1917	107.53	89	131	2.0	1.80	2.10
Improved Nutrient Management	2,467.00	1,966	2,585	227.67	206	292	1.0	0.89	1.10
Supplementary feeding	5,520.00	3,915	7,720	265.97	246	289	3.0	2.68	3.32
Improved livestock housing	7,193.04	4906	10,167	120.13	101	142	2.0	1.89	2.10

NB: The discount rate = 26%.

Table 10. Summary information about the profitability of CSA practices and the likelihood of returns falling below which investment in them is considered unprofitable.

	Summary of the probability distribution of IRR results
Crop rotation	The practice is profitable and IRR is about 71% with a 95% probability of falling between 41 and 110%.
Mixed cropping	The practice is profitable. The IRR is above 26% with a 7% probability of falling below the prevailing discount rate
Minimum tillage	This practice is unprofitable
Improved varieties	The practice is profitable and IRR is above 26%.
Improved Nutrient Management	The practice is profitable, its IRR is above 26% and has no likelihood of falling below 26%. This practice has a 5% probability for IRR being greater than 270%
Supplementary feeding	The practice is very profitable because there is a 100% probability that IRR will be above 26%
Improved livestock housing	The practice is profitable and only shows a 3% probability that the IRR will fall below the prevailing discount rate

NB: The prevailing discount rate in the market at the time of the survey (July 2016) was 26%.

farmers' livelihood. This could be the reason why most of the studied farmers in the Coastal Savannah AEZ showed no interest in implementing it for a period of four years before the present study. The main impacts on implementing CSA practices among farmers were realized in terms of economic benefits (e.g., Akudugu et al., 2012). Among the seven CSA practices that were evaluated, crop rotation, mixed cropping and INM had a PP of one year, while improved varieties and improved livestock housing had a PP of two years (Table 9). Supplementary feeding is the only CSA practice that had a PP of three years. In summary, therefore, all the seven CSA practices studied, except for minimum tillage, constitute a basket of promising climate-smart agricultural technologies that could be adopted for implementation and scaling up in the Coastal Savannah AEZ in Ghana. This is because these practices yield positive net benefits, have an IRR that is greater than the discount rate, and a break-even point of three years or less. Besides, the 95% confidence interval that the IRR for six practices was larger (41%–292%) than the prevailing discount rate (26%) provides compelling results to justify government promotion of these CSA practices.

Table 10 shows the probability distribution summaries of the profitability of the seven CSA practices studied. The risk associated with the seven CSA practices are depicted by the cumulative distribution function (CDF) for the internal rate of return being lower or equal to the prevailing discount rate. All of the six practices with a positive NPV, except mixed cropping, were generally profitable and carries minimum risk (Table 10), meaning that these practices could be implemented by farmers with a low likelihood of losing invested capital. Farmers who had implemented mixed cropping had a 7% likelihood of unprofitable results.

Table 11. The Social net present value (SNPV) and social internal rate of return (SIRR) associated with the seven CSA practices.

CSA practice	SNPV (US$/ha)	SIRR (%)
Crop rotation	3,072.00	76
Mixed cropping	680.00	94
Minimum tillage	466.00	236
Improved varieties	1,952.00	173
Improved nutrient management	3,388.00	324
Supplementary feeding	5,697.00	272
Improved livestock housing	6,042.00	129

NB: The discount rate used = 26%.

3.3. Environment and social benefits associated with adopting the seven CSA practices

The adoption implementation[8] of the seven CSA practices studied was also associated with some external effects (Table 3). Figure 4, shows the results from the Monte Carlo simulation using the @risk software indicating the average value of benefits that are associated with the increase in on-farm biodiversity. Considering the uncertainty of the values used, the average value of biodiversity ranged between 6.66 and 222 ha^{-1} with an average of about US$ 60 ha^{-1}. The average estimated value of sequestered carbon, reduction in soil erosion, soil biodiversity and social impact due to the implementation of CSA practices were about US$ 15 ha^{-1}, US$ 33 ha^{-1}, US$ 15 ha^{-1} and US$ 275 ha^{-1} respectively (Table 7). These values were then considered across all the seven practices for each year starting with when the practice is implemented for the entire lifespan of the practices. All the seven practices studied had positive environmental and social benefits to society, quantified as social net present value (SNPV) (Table 11). SNPV is a summation of the private NPV and the benefits associated with the externalities across the seven studied CSA practices, the SNPV ranges between US$ 466 to US$ 6,042. The respective social internal rate of return (SIRR) ranges from 76% to 324% for crop rotation and improved nutrient management respectively. All seven CSA practices had a positive impact on society and the environment (Table 11).

[8] Implementation and installation cost have the same meaning. Consequently, these two terms have been used interchangeably throughout the manuscript.

4. Discussion

In most cases, the development practitioners and the policymakers propose actions that aim at contributing to the improvement of agricultural production by proposing investment in strategic agricultural activities and practices or innovations. Most of the activities and practices proposed are mainly based on two things (i) the potential impact that the proposed action is likely to bring about on the livelihood of the smallholder farmers and (ii) the impact of the adopted practice on the society or community at large. The benefit of implementing CSA practices to the society could be through job creation, increased food security, improved adaptation to climate change and/or improved infrastructures. Against this background, the evidence provided by the present study provides a sound basis upon which sustainable policies can be initiated and developed (van Wee and Börjesson, 2015). In the present study, CBA was used to evaluate the profitability of seven CSA practices implemented in the Coast Savanah agro-ecological zone of Ghana. Evidence of this study could be used as the basis by which the Ministry of Agriculture (MoA) in Ghana can advocate for the adoption and upscaling of CSA adoption among farmers. CBA studies are important to the development and adaptation process because they provide evidence against which governments, non-governmental and development partners may use to strategically direct investment funds to improve the livelihoods of smallholder farmers (Boardman and Forbes, 2011; Birol et al., 2010). In the past CBA has been applied to evaluate viability under climate-change-related investment decision on levels such as a plot, farm, watershed, landscape, region, etc. (Dietz and Hepburn, 2013; Nassopoulos et al., 2012). CBA has also been used to evaluate the suitability of government policies relating to taxation, private projects, transport and infrastructures (van Wee and Börjesson, 2015; Boardman and Forbes, 2011). CBA is, therefore, very important when making decisions relating to investments – of either private or public importance (Birol et al., 2010; Luedeling et al., 2015). Nevertheless, the value estimates provided by CBA studies are not without shortcomings and uncertainties as it relates to the expected impact of climate change and the discount rate used (Baum, 2009). Despite such challenges, actions based on evidence are still needed by the farmers, investors and government to make informed and urgent planning and investment decisions. A sound policy prescription, investment plans and decision are outcomes of a rigorous and robust evaluation. CBA is a suitable approach that is capable of providing evidence-based advice for future investment plans that are profitable and sustainable (Scrieciu et al., 2011). It is, therefore, important for the researcher to acknowledge and communicate challenges encountered in CBA computation as well as all the assumption made transparently.

In recent times, CBA has been used in evaluating the potential for agricultural practices to improve production under the uncertainties associated with climate change and variability (e.g., Daigneault et al., 2016; Mishra and Rai, 2013; Sain et al., 2016). The present study also focuses on seven CSA practices that are preferred by smallholder farmers in the Coastal Savannah AEZ in Ghana. The preference for the seven practices is based on their potential to help smallholder farmers in overcoming challenges associated with climate change, soil erosion and land degradation in the cereal-legume small ruminant farming system of Ghana. A close examination of these practices through CBA is likely to provide policymakers with key inputs to shape their thinking when making policies. At the same time, this information is useful to farmers, especially when making strategic changes in investment or future investment decisions (Atkinson, 2015). The seven CSA practices evaluated in this study comprise alternatives that produce social-economic benefits to society now and in the future, irrespective of whether climate change continues to occur or not. Therefore, the seven CSA practices comprise what Dittrich et al. (2016) refer to as “no-regret options”, meaning that no assumptions were made on them concerning climate change.

In any CBA study, the duration of practice from implementation to when it starts yielding benefits – whether private or public is important. This is because the realization of benefits, to farmers, largely depends on how fast the investment achieves a break-even point. In this study, except for minimum tillage, all CSA practices had a relatively short PP – ranging between one and three years – and were privately profitable (Table 9). However, since a majority of the studied are smallholder farmers, a PP of three years taken by practice such as supplementary feeding could be too long. Meaning that resource-constrained smallholder farmers may consider not implementing a practice that takes several years to swing around profitability. To increase farmers interests in investing in CSA practices with a long PP, some kind of support (e.g., in terms of capital and technical skills) is key as a way of improving the environment and enabling investment opportunities. Other enabling condition such as the provision of credit, improving the extension service, and improving the land tenure security could also help ease the implementation and adoption of CSA practices, especially those with a long PP. Practices with a PP of two years or less, such as improved varieties, mixed-cropping, improved livestock housing, crop rotation, and improved nutrient management, provides a much better option of farmers to invest in. CSA practices with shorter PP are appealing to smallholder farmers because benefits are realized shortly after implementation.

Agriculture provides food and many other products, thereby affecting ecosystem services (Ludeling and Shephered, 2016). To ensure the completeness of our CBA study, some of the externalities associated with the seven CSA practices were considered and evaluated. Failure to take externalities into account in CBA studies has the potential for putting doubt on the findings (Ackerman and Heinzerling, 2002). This is because failure to take cognizance of the externalities may lead to an oversight of other potential benefits that emanate from the installation of the CSA practices being studied. Accounting for the externalities is also important as it shifts the assessment beyond the private profitability aspects (Chaudhury et al., 2016; Sain et al., 2016; Williams et al., 2020). In this study, the studied CSA practices are beneficial to society. Estimation of externalities is, however, not without challenges and is highly debatable, because they are not traded in the market (Scrieciu et al., 2011). The assessment of externalities was based on expert information. The findings showed that the seven CSA practices studied had a positive impact on the ecosystem through reduction of soil erosion, increased soil biodiversity, increased on-farm biodiversity, improvement of soil carbon through carbon sequestration and social impact (Table 8). The social impact was higher for supplementary feeding due to the increased labour demand for livestock feeding resulting in a higher impact through employment. Supplementary feeding had a relatively higher impact on carbon sequestration compared to other CSA practices because of the dietary manipulation which reduces the GHG emissions (Michigan State University, 2016). While the purpose of this study was to evaluate the seven CSA practices and to advise on the most suited CSA practices for scaling up based on private profitability and hence their sustainability. The incorporation of the externalities associated with each of the seven CSA practice helps to harness the knowledge that can strengthen the case of CSA adoption and implementation (Ludeling and Shephered, 2016).

Challenges related to the uncertainties of the values used for evaluation (UNFCC, 2011), were encountered. To minimize errors in the estimation of private profitability, we used primary data collected from a representative sample of farmers within the coastal savannah AEZ. The errors associated with the estimation of values associated with externalities were minimized by relying on information collected from experts, as they were familiar the externalities. The definitions of the terms such as BAU and CSA were well defined and discussed by all the workshop participants during the CSA-PF to ensure that they were well understood. A thorough understanding of the BAU by the farmers enabled them to provide detailed responses of the incremental costs and benefits associated with implementing CSA practices when compared to BAU. To account for the inconsistencies that may arise as a result of using a different discount rate, a 14 year average rate of 26% from the Bank of Ghana was used in the analysis. The prices of products harvested from the seven CSA practices were assumed to be constant but adjusted to inflation – based on market dynamics – on the lifespan of the practices. Finally, the results contained were validated by the stakeholders in January 2017 as a step toward moving these findings to the broader participatory process of making a decision based on sound and validated evidence.

4.1. Advantages, disadvantages and limitations

This CBA study is critical to helping investors and farmers to understand the costs, benefits and payback period associated with the CSA practices, and facilitates the evaluation of the financial feasibility associated with investing in different CSA practices. The value of the present work can also be seen is by looking at the accuracy of the data revealed by comparing the results of ex-ante (forecasting the likely benefits of the future) and ex-post (conducting further analysis in order to inform decision being made) CBA for the adopted CSA practices. The use of ex-post is less common nowadays than the use of ex-ante appraisal as in the present study. Like any CBA, we encountered challenges such as those associated with uncertainty and valuation. Uncertainty arising from data measurement was addressed by using a representative sample size of smallholder farmers that have implemented the seven CSA practices. Further, we cross-checked the survey results with the information received from focus group discussions. To reduce the uncertainty, the BAU was well defined and discussed with the stakeholders (qualified through dialogue) to ensure that what would happen on the farms under BAU and with CSA was well understood by farmers. The farmers were, therefore, able to use the BAU (as their baseline) when providing the costs and benefits associated with the CSA practices. The design and the process of CBA, took into account the objectives, information available, needs and perception of stakeholders as transparently as possible, hence providing results that are robust enough and that are based on quality data.

5. Conclusions

For a targeted investment of CSA practices by smallholder farmers, there is a need for a detailed evaluation to understand the cost, benefits, and payback period associated with each of the seven CSA practices. Such an evaluation may end up having a large impact on the decision relating to their scaling up, their sustainability and food security. The present CBA evaluate CSA practices that have been shown to constitute best-bet options as it relates to the adaptation to climate risks, financial return, the required implementation costs, and the probability of losing the invested money. The results from this study, therefore, provides critical information that can help farmers to re-evaluate their investment decisions. The Ministry of Agriculture of Ghana could use this information on priority setting in the agricultural sector and in projects where decision outcomes on how to adapt are not very clear. The results from this study provide insights on the externalities and social benefits associated with the studied CSA practices, and this is critical to helping all the stakeholders to understand the true potential associated with each of the studied practices from the public perspective (including creating employment for the women and the youth). The studied CSA practices if adopted would lead to positive environmental and social impacts and help in the achievement of the three CSA goals of food security, adaptation and mitigation. The consideration of externalities in economic valuation is important and needs to be included in the economic analysis of adaptation options to ensure a robust economic evaluation in future studies. Such consideration would support decision making during the selection of CSA options and guide the efficient allocation of scarce resources in the future. The value of externalities considered in this study was determined using Monte Carlo simulation and future studies could benefit from considering the dynamics associated with evaluating such values. Such a holistic approach may help to broaden information required for the selection and investment of appropriate CSA practices, and also enhance future planning and decisions.

Declarations

Author contribution statement

Stanley Karanja Ng'ang'a: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Vail Miller: Performed the experiments; Wrote the paper.

Evan Girvetz: Conceived and designed the experiments; Wrote the paper.

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Data availability statement

Data associated with this study has been deposited at =https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/Q6BO6Q.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

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