Climate Services 26 (2022) 100287

Contents lists available at ScienceDirect

Climate Services

journal homepage: www.elsevier.com/locate/cliser

Comparative profitability and relative risk of adopting climate-smart soil practices among farmers. A cost-benefit analysis of six agricultural practices

Bwema Ombati Mogaka [a,b,*], Stanley Karanja Ng'ang'a [b], Hillary Kiplangat Bett [a]

[a] *Department of Agriculture Economics and Agribusiness Management, P. O. Box 536-20115 Egerton, Kenya*
[b] *The Alliance of Bioversity International and the International Centre for Tropical Agriculture (CIAT), P. O. Box 6247 Kampala, Uganda*

ARTICLE INFO

Keywords:
Climate-smart soils
Deterministic cost-benefit analysis
Profitability
Relative risk
Sensitivity analysis

ABSTRACT

The adoption of climate-smart soil (CSS) practices among farmers have the potential to rehabilitate and protect the soil. Proponents have not fully addressed factors such as; profitability and the relative risk that farmers face during the adoption and implementation of these CSS practices. These factors determine the adoption and sustainability of these practices. This study assessed the comparative profitability and relative risk of implementing CSS practices among farmers in Kakamega, Siaya, and Bungoma counties in Western Kenya. The prioritization of these CSS practices (agroforestry, intercropping, liming, organic manure use, inorganic fertilizer, and improved hybrid seeds) was based on the climate-smart agriculture (CSA) pillars (production, adaptation, and mitigation) and their benefits. A deterministic cost-benefit analysis model that incorporates sensitivity and scenario analysis assessed these factors. The findings showed that agroforestry was the most profitable having a net present value of US$ 16,071 ha^{-1}, followed by intercropping (US$ 10,487 ha^{-1}), and the use of improved hybrid seeds was the least profitable (US$ 881 ha^{-1}). In terms of relative risk, all the practices were more sensitive to the product price and output than the lifespan, discount rate, and labour cost. The result implies that exposure of these practices to climatic and economic shocks will result in high-profit risk. Therefore, national and county governments should place micro-credit loans with minimum interest, input subsidies, and skilled personnel to promote increased adoption of agroforestry and intercropping. Agricultural extension officers should also demystify farmers' mentality that improved hybrid seeds can guarantee increased productivity.

Practical Implications

The effects of climate change continue to affect the livelihoods of many people across the globe. Many catastrophes ranging from severe heatwaves, torrential rains, floods, increasing water levels, and prolonged droughts have become common in the recent past. The agricultural sector supporting the livelihoods of many people in developing countries is the most hit putting the economy and food security systems at stake. Thus, instituting sustainable approaches that improve agricultural productivity, protect the environment and mitigate the cause of climate change is necessary, especially when the world is experiencing a population increase. In Western Kenya, a soil rehabilitation and protection programme by the German Agency for International Development (GIZ) promoted six practices, agroforestry, intercropping, application of soil lime, inorganic fertilizer, organic manure, and improved seed variety. These climate-smart soil (CSS) practices have the potential to rehabilitate and protect the soil, thereby increasing agricultural productivity, sequestering and minimizing the release of greenhouse gas (GHGs) that are the primary cause of climate change. This paper looks at the comparative profitability and relative risks (droughts, floods, erratic rainfall, fluctuation of output prices, inflation, change in discount rates) of adopting these practices since they major in farmers' efficiency during adoption. Farmers are rational decision-makers who are driven by private interests. Therefore, knowing the profitability and the risk associated with adopting a CSS practice will enhance long-term adoption and minimal regrets. The following implications of the findings are observed:

- Compared to other practices, agroforestry was the most profitable, while improved hybrid seeds were the least. This is because agroforestry has low implementation and maintenance costs compared to improved hybrid seeds.
- Agroforestry, improved hybrid seeds, intercropping, and inorganic fertilizer were sensitive to changes in product price,

---

* Corresponding author.

https://doi.org/10.1016/j.cliser.2022.100287
Received 30 July 2021; Received in revised form 18 February 2022; Accepted 8 April 2022

output, and the discount rate compared to soil liming and organic manure, which was sensitive to changes in the lifecycle.

To further enhance a sustained adoption of the CSS practices to achieve long-term goals, the following recommendations are put forward:

- Development practitioners, policymakers, and other stakeholders need to understand how these factors influence the adoption of CSS among farmers to help them make better choices when settling for a given practice.
- Sensitization programs regarding profitability and relative risks associated with the CSS practices should be advocated during the implementation stage.
- Further, to increase the adoption rate of CSS practices among farmers, the national government, through financial institutions, needs to put in place financially friendly policies such as micro-credit loans with minimum interest to enable farmers to access credit.
- The county government and other stakeholders need to demystify the farmers' mentality that having improved hybrid seeds are guaranteed increased profitability. The national government needs to have strategic grain reserves to ensure price stability, hence cushioning farmers against production and price risks.
- Institutions offering agricultural insurance, irrigation services, and credit should have attractive and pocket-friendly packages. Such packages may incentivize farmers to borrow credit for implementing CSS practices, including those with long lifecycles.

1. Introduction

Climate change continues to occur across the globe, and the magnitude of its effects is projected to increase if efforts to curb greenhouse gases (GHGs) emissions are not fast-tracked (Tollefson, 2018). The livelihoods of many people, particularly farmers in developing countries, are the most threatened (Dube et al., 2016). Thus, the need to uptake of climate-smart soil (CSS) practices that aim to rehabilitate and protect soils offers a holistic approach for achieving multiple benefits – mitigating the adverse effects of climate change and maximizing agricultural productivity is essential (Mogaka et al., 2021; Visser et al., 2019). These practices include agroforestry, intercropping, liming, organic manure applications, inorganic fertilizers, and the use of improved hybrid seeds. Farmers in sub-Saharan Africa (SSA) apply them as integrated soil fertility management (ISFM) practices. They are used to address rural poverty and natural resource degradation (Vanlauwe et al., 2015), improve land productivity and increase yield (Mponela et al., 2016), and enhance the resilience of farming systems (Martey and Kuwornu, 2021) (Table 1).

Table 1
List of CSS practices prioritized in Western Kenya for economic assessment and evaluation.

CSS practices	Practice description
Agroforestry	Land management involves the deliberate introduction of trees, shrubs, or fodder crops such as grevillea tree (*Grevillea robusta,* A.Cunn. ex R.Br.), Brachiaria (*Brachiaria plantaginea,* Hitchc), Calliandra (*Calliandra calothyrsus,* Meisn), Robusta coffee (*Coffea canephora,* Pierre ex A. Froehner) around or among crops or pastureland.
Intercropping	It involves multiple cropping practices of complementary crops such as maize and beans in proximity or simultaneously.
Use of organic manure	Use of organic nutrient-based components to improve soil fertility with but not limited to animal droppings, e.g., poultry, cows, sheep, and goats. Application of about 2.5 tonnes per hectare.
Inorganic fertilizer	Use of mineral substances such as phosphates to improve soil fertility. For example, di-ammonium phosphate (DAP) and Urea. Application of about 125 kg per hectare.
Use of improved hybrid seed	Introduction of improved seed varieties for increased crop productivity. For example use of improved maize variety (20–25 kg per hectare)
Liming	Application to the soil of calcium-and magnesium-rich materials to neutralize soil acidity, e.g., calcium carbonate ($CaCO_3$) (1.2 tons per acre)

Through soil rehabilitation and protection, these CSS practices form part of the climate-smart agriculture (CSA) approach that offers sustainable options for improving food security, increasing resilience among vulnerable farmers, and minimizing GHGs. In contrast to business as usual[1] (BAU), CSS practices integrate soil rehabilitation and protection, improve agricultural productivity, and reduce GHGs, to simultaneously enhance adaptation opportunities and mitigation efforts (Sain et al., 2017). This approach aims to; efficiently utilize limited economic resources to address agricultural productivity and curb the causes of climate change. To make well-versed investment decisions among policymakers, farmers, and other development practitioners, a methodology that empirically quantifies or assesses the benefits, trade-offs, and risks related to these CSS practices is essential (Florio et al., 2016; Ng'ang'a et al., 2017; Watkiss and Cimato, 2016).

An economic assessment of these CSS practices will help farmers understand their potential benefits and sustainability when practicing them on their farms (Ng'ang'a et al., 2017). Determining the timeframe to begin accruing benefits, profitability, and the associated relative risk will influence a given practice's adoption decisions. Thus, a deterministic cost-benefit analysis (CBA) that incorporates sensitivity and scenario analysis provides a range of values that indicates how sensitive the net present value (NPV) is under different scenarios (i.e., pessimistic and optimistic).

The main objective of this paper is to determine the comparative profitability and relative risk of adopting CSS practices among farmers. The study hypothesizes that the CSS practices do not differ in profitability and relative risks among the farmers adopting them. Understanding these factors will help farmers make informed decisions when selecting CSS practices to minimize setbacks (regrets) during adoption.

During the implementation of these practices, the main costs incurred by farmers include the installation, maintenance, and operational costs (Ng'ang'a et al., 2017). Most at times, these costs differ from one practice to another. Some CSS practices have higher implementation and maintenance costs while others are low, eventually influencing profitability. In addition, there are relative risks associated with adopting these practices. For example, economic shocks such as fluctuation of output prices, changes in discount rates, inflation, and climatic shocks such as droughts and floods also impact the profitability of any CSS practice. Seasons of increased harvest, farm produce supply increases while demand decreases, leading to poor prices. At the same time, the converse is true when farmers experience climatic shocks such as irregular and erratic rainfall, floods, and droughts. Farmers, therefore, should be aware of these risks to take mitigation measures and avoid losses.

Therefore, rational farmers must know any CSS practice's private benefits, risks, and associated trade-offs before adoption. CSS practices with higher implementation costs may increase the farmers' financial burden hence becoming reluctant to adopt the technology (Khatri-Chhetri et al., 2016). Despite efforts to promote the adoption of these practices, existing literature and climate adaptation programs lack information on profitability and relative risk surrounding these practices, which can influence adoption. Empirical evidence on profitability and relative risk for preferred CSS practices aim to support farmers and other

---

[1] Business as Usual refers to farmers practicing their day-to-day soil fertility management practices with a sole purpose of increasing productivity.

key stakeholders to make informed decisions when adopting and rolling out these soil-based climate change programs to optimize agricultural planning.

1.2. Theoretical foundation of CBA

Economic theory postulate that scenarios with scarce resources often call for trade-offs. Farmers are rational beings motivated by private interests. Hence, they require a methodology that helps them know which CSS practice can maximize their benefits with the resources at their disposal. The economic tool needs to have a rational basis for selecting a CSS practice. For example, if the benefits of agroforestry are more than intercropping is the proper criterion for selecting CSS practices among farmers. The economic tool needs to determine the economic efficiency of the CSS practices adopted by farmers. An analytical methodology evaluates investment decisions by estimating the future flow of benefits and costs of financial resource allocation in present terms. It helps determine the worthiness of given investment activity.

The CBA has three indicators for assessing an investment, and the frequently used include the NPV, the internal rate of return (IRR), and the payback period (PP) (Mutenje et al., 2019; Ng'ang'a et al., 2021). NPV is the difference between the present values of cash inflows and cash outflows over the lifecycle of an investment. It calculates the current value of a future stream of payments. It relies on a discount rate derived from the cost of capital required to invest. The major drawback of using NPV in the analysis is its assumptions about future events like the constant discount rate for the whole project, overstated future cash flow, and unforeseen expenditures when life changes are inevitable. Therefore, to overcome these drawbacks, sensitivity analysis is conducted. IRR indicates the discount rate that makes the NPV of an investment equal to zero (Cruz and Singerman, 2019). The IRR of a given CSS practice is compared with the cost of capital (discount rate) used to implement it to determine its worthiness. The higher IRR, the more desirable the CSS practice undertakes (Sain et al., 2017). A CSS practice is profitable if the IRR is greater than the cost of capital. One of the advantages of the IRR is that it is simple to interpret through visualization as a scientist or a farmer. PP refers to the amount of time to recoup the cost of investing in a CSS practice. The point at which an investment in a given CSS practice reaches a break-even point. CSS practices with shorter paybacks are more attractive compared to longer ones. The study used a discount rate of 12% since it was the lending rate for most commercial banks in Kenya as the opportunity cost of capital.

Therefore, a CBA tool that determines the profitability of a given practice using the benefits and costs by comparing a situation where a farmer has adopted the CSS practice against the traditional soil fertility practices (or business as usual) is best suited. In addition, a more in-depth comparison between CSS practices is possible using deterministic CBA model that incorporates sensitivity analysis for the relative risk determination. It provides a proper criterion for selecting these practices by farmers to adopt them on their farms. One limitation of applying CBA to determine the economic efficiency of CSS practices is the shadow pricing of non-market goods and services. Attaching value to environmental goods and services of these CSS practices to quantify social benefits is challenging (Ng'ang'a et al., 2017b).

2. Materials and methods

2.1. Site description

The study area (Fig. 1) comprises three counties in western Kenya: Kakamega, Bungoma, and Siaya. Kakamega County lies 30 km north of the equator. It is lies about between latitude 00° 28′S and 10° 30′N, and longitudes 340° 20′E and 350° 15′W, and an altitude, of 1,535 m. It comprises nine sub-counties[2] with 1.9 million people (GOK, 2019). The primary economic activity is agriculture. The main crops grown include sugarcane, maize, beans, bananas, tea, and sorghum.

Bungoma County borders Uganda to the northwest, Trans-Nzoia to the northeast, Kakamega to the east and southeast, and Busia County to the southwest. It lies between latitude 00° 28′S and 10° 30′N of the equator, and longitude 340° 20′E and 350° 15′W. It has a land area of 2068 km^2 and a population of 1.7 million (GOK, 2019). Its highest altitude is approximately 4,321 m above sea level (m.a.s.l.). The major soils are loamy. Agriculture is the county's backbone, with many people relying on crop production and animal rearing. The main crops include maize, beans, finger millet, sweet potatoes, Irish potatoes, and African indigenous vegetables.

Siaya County borders Busia County to the north, Kakamega County and Vihiga County to the northeast, and Kisumu County to the southeast. It lies between latitude 00° 26′S to 00° 18′N and longitude 33° 58′E and 34° 33′W. The total land size is approximately 2,496.1 km^2. It has an altitude range of between 1,140 to 1,500 m.a.s.l (CGOS, 2018). It has a population of about 993,183 and an estimated population density of 392.6/km^2 (GOK, 2019). The annual population growth rate is about 1.7%. The main economic activities include farming, livestock keeping, and fishing.

In general, the population of Western Kenya is growing fast. Siaya, Kakamega, and Bungoma counties have an annual population growth rate of 1.7%, 1.2%, and 2.0%, respectively (GOK, 2021). This growth rate is putting much pressure on the farming systems. Economic returns from farming are declining due to reduced soil fertility because of excessive soil mining and increased climate shocks (Mwongera et al., 2017). The farming systems range from small-scale mixed subsistence to large-scale commercial. The mean annual precipitation is between 1,200 mm and 2,206 mm and an annual temperature of 22.5 ℃ (Nyawira et al., 2021). Major soils are Andosols that have a high potential for agricultural production (Food and Agriculture Organization, 2014).

2.2. Ranking/ prioritization process of the CSS practices

A workshop was held for ranking and prioritizing the CSS practices with stakeholders (county government agricultural officials, GIZ representatives, CIAT research team, farmers, and expert groups) present. First, five farm typologies developed by CIAT were presented, and the participants asked if they agreed with the farm typologies and if they would like to add any changes. Secondly, the participants developed a long list of agricultural practices for the local context. They then reviewed, discussed, and described the long list classifying the agricultural practices into (soil, water, crop, and livestock management) in line with the area of interest, production system, and sociological context. The participants also discussed indicators for the CSS practice. The participants came up with a list of 20 practices. Thirdly, the participants identified agricultural practices applicable to the farm typologies in the study area. The stakeholders reviewed and prioritized the long list of agricultural practices at this stage. The participants were divided according to the farm typologies, with the farmers kept separate from the local expert. The groups were then provided with a long list and asked to select only practices relevant to their farm type. Some of the key issues considered included the production system/crop of livestock the practice applies, opportunities and benefits (economic, social, and environmental) accrued from implementing the practice, barriers and challenges, and what is considered when adopting each practice.

Finally, the participants ranked the prioritized practices by pairwise ranking matrix. This process was done first by constructing a pairwise matrix (i.e., each box in the matrix represented an intersection (or

---

[2] Sub counties in Kakamega County include Butere, Mumias East, Matungu, Khwisero, Shinyalu, Lurambi, Ikolomani, Lugari and Malava.

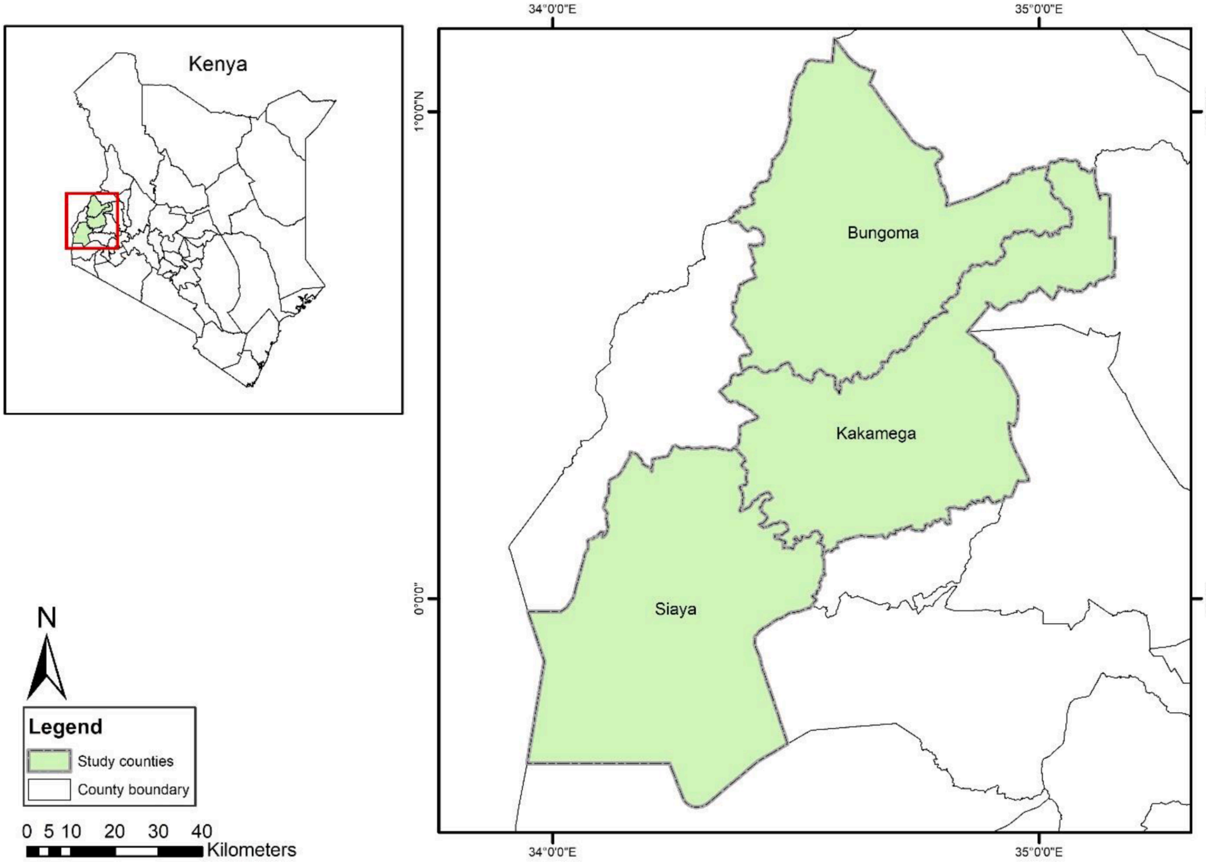

Fig. 1. Study area map: Source: IEBC, 2019.

paired) of two practices). Each pair was ranked whereby the groups adopted a consensus-oriented discussion to determine which preferred two practices. A preferred practice from each pair was identified and written in the appropriate box. The process was repeated until the matrix was complete. Each group noted down the reasons for the preferences. The practices were counted and ranked as the number of times they appeared in the matrix. If there was a tie (i.e., where practices appeared in equal number of times), a preference was given to the one with the higher ranking in the box where they were compared. The results of the pairwise ranking matrix from each group were presented with the reasons for prioritizing the top-ranked six CSS practices.

2.3. Data and data sources

The study used secondary data collected in 2016 with qualitative and quantitative variables. Data collection was done using structured household questionnaires and a literature review to fill gaps. Farmers' data from three counties: Kakamega, Bungoma, and Siaya, were collected. The sampling frame comprised 265 households with different farm typologies. A formula for finite population by Cochran (1977) was used to determine a sample of 96 farmers at a 95% confidence level and an acceptable error of 5% (Mogaka et al., 2021). A proportionate to size formula determined the distribution of the farmers across the three counties. The analysis involved 88 farmers after eight cases were dropped as they missed the main variables of interest (e.g., crop yield, costs, and output prices).

The data consisted of the adoption, implementation, and maintenance costs of six prioritized CSS practices settled on at a CSS prioritization workshop. Before adopting the CSS practices, farmers with BAU practices provided recall data for at least five years. Secondary data collected included inputs (farm and labor), yield quantities, and market prices for all inputs, services, and activities associated with the BAU and the implementation of the CSS practices. Inputs, services, activities, and outputs changes between BAU and CSS practices determined profitability. From the survey that informed the secondary data, most farmers had adopted the CSS practices for at least three years. Thus, implying that many farmers had incurred sunk costs. Many farmers had implemented the CSS practices on their farms and the benefits earned. Hence, the CBA analysis exhibits both an ex-ante and ex-post approaches.

2.4. Deterministic CBA model approach

The basis of economics is the scarce resources allocated among many uses. Thus, economic trade-offs among these scarce resources for specific use become inevitable for rational agents (Balana et al., 2012). Agricultural stakeholders, especially farmers, aim at maximizing their private interests. Thus, economic tools that inform on how to allocate the scarce resources optimally, at the same time avoiding risks, are necessary. A CBA tool was used to assess profitability and the relative risk of alternative CSS practices using benefits flow and different costs over their lifecycles (Ng'ang'a et al., 2017). The main advantage of CBA is that it is relatively simple and provides robust results for decision-makers especially, development practitioners and governments (Sain et al., 2017). The CBA is an evaluation technique for assessing the profitability of alternatives in both public and private sector-ranging from infrastructural, transportation systems, and environmental impacts investments (Beria et al., 2012; Hoogmartens et al., 2014; Sain et al., 2017). This study adopted a deterministic CBA model approach that incorporates sensitivity analysis for more robust results in decision-making and maximizing agricultural investments (Dittrich, 2016). The model was evaluated before applying it in the study area to check its performance (robustness) and whether it suits this case. For instance, the model was tested for sensitivity- changes in the output values that can arise from changes in the input variables. Ng'ang'a et al. (2017b) and

Sain et al. (2017) used the model to conduct a CBA for CSA practices adopted by farmers. Since the farmer characteristics and where the model was applied resembled our study area, it was settled for analysis.

Studies in the past adopted a deterministic approach of CBA solely to calculate indicators such as NPV and IRR. The shortcoming of the deterministic approach alone is that it considers values of the variables calculated at the average or mode without measuring variability or uncertainty associated with the resulting indicator. This approach can result in underestimating or overlooking risks a farmer takes when adopting a given CSS practice on his farm (Oberndorfer et al., 2020). To overcome these limitations, decision-makers have gone further to incorporate sensitivity[3] and scenario[4] analysis to the deterministic CBA approach. The sensitivity analysis has a robust range of values that can ascertain a level of risk given changes in the input variables under different scenarios (i.e., pessimistic and optimistic).

Another alternative to overcoming the shortcoming of the deterministic approach is the use of probabilistic CBA. The probabilistic CBA has a robust analysis with a range value of the indicators and attaches the likelihood of these indicators. The probabilistic approach uses a cumulative distribution function, generating measurable values with a probability to the indicators of economic returns from each CSS practice for analysis. The cumulative distribution function, either the NPV or IRR, gives the probability that the indicator value is below or equal to a given threshold (Sain et al., 2017). However, the probabilistic CBA is not applicable for the study since the data available lacked the maximum and minimum values of crop output obtained by experts' reviews. These values help in the determination of the probabilities for the triangular distribution. Thus, the study settled on the deterministic CBA that incorporates the sensitivity analysis.

2.5. Model specification

The model's specification points out the areas of the analysis for determining the indicators of interest. Determining the benefit and the cost flows enlighten the farmers and other stakeholders on the viability and sustainability of the prioritized CSS practices (Ng'ang'a et al., 2017). In addition, the valuation of the external impacts – the environmental and social benefits – can be determined for the public interest. The social benefits included improved biodiversity, increased carbon sequestration, and water retention. These external impacts are usually determined separately from private profitability calculations to inform decision-making when appraising public economic trade-offs (Sain et al., 2017).

To determine the private profitability and relative risk indicators of replacing business as usual (BAU) by a CSS practice, the flow of benefits and costs, are calculated per hectare basis over a given period. To obtain the net benefits, incremental gross benefits calculated as product price multiplied by incremental yield when replacing the BAU practice are subtracted from incremental cost due to adopting a CSS practice over its lifecycle, as illustrated in Eq. (1).

$$\mathrm{NPV}_{\mathrm{J}}^{\mathrm{css-bau}} = \sum\nolimits_{t=1}^{T} \frac{1}{(1+r)^{t}} \left[\sum\nolimits_{\mathrm{j}=1}^{\mathrm{j}} \left\{ \mathrm{P}_{\mathrm{jt}} * \left(\Delta \mathrm{Y}_{\mathrm{jt}}^{\mathrm{css-bau}} - \Delta \mathrm{C}_{\mathrm{jt}}^{\mathrm{css-bau}} \right) \right\} \right] \tag{1}$$

Where, P_{jt} is the product price of the crop affected by the CSS adoption, $\Delta \mathrm{Y}_{\mathrm{jt}}^{\mathrm{css-bau}}$ is the incremental yield, $\Delta \mathrm{Y}_{\mathrm{jt}}^{\mathrm{css-bau}}$ is the change in the cost of implementing the CSS practice per year, r is the discount rate (the cost of capital), and T is the lifecycle of the practice in consideration.

2.5.1. Productivity changes

CSS practices must guarantee soil rehabilitation and protection for sustainable agricultural productivity to maintain its health for optimal performance. When modelling the impacts of these adopted CSS practices on crop output, some assumptions were that the implemented CSS practices would increase soil fertility, increase crop productivity, improve soil structure, water penetration, and soil quality at the farm level (Ng'ang'a et al., 2017b). The crop physical changes, especially on output, reflect the indirect impacts of these CSS practice adoption outcomes. The productivity changes varied across the alternatives due to the nature of the practice itself, soil health, and other biophysical factors such as topography and slope that concentrate agriculture on flatter and fertile lands (Yackulic et al., 2011).

The crop physical response function assumes a linear plateau model (REF _Ref74085058 \h Fig. 2). The linear plateau model borrows from Liebig's law of minimum principle (Beattie and Taylor, 1993), implying that crop yield is directly proportional to the number of essential nutrients provided by soil and increases gradually, reaching a maximum at a given point (Walker et al., 2016). The principle further says that crop performance (growth, health, and productivity) is not only a function of the total amounts of nutrients in the soil but the scarcest. Thus, soil rehabilitation and protection are critical in ensuring the availability of these scarcest nutrients.

Fig. 2 illustrates the different points in the adoption process, starting with the lag period, which is between t0 andt1. At this point, there is no physical response change; ideally, the farmer has begun the adoption process. The second phase starts the physical change response, reaching the maximum at t1andt2. After the farmer has adopted the preferred CSS practice, there are physical changes in productivity until it gets to a point where it reaches the maximum. The final phase is the physical response plateau: where the yield maximizes t2 until the end of the lifespan of the practiceT. At this point, the curve flattens out, indicating that the farmer needs to begin practicing the CSS practice again. Y_{f} represents the optimum yield from the affected crops due to the adoption of the CSS practice. Whereas T represents the lifespan of the CSS practice.

2.5.2. Costs

Costs used in the CBA model can be classified into three categories: installation, maintenance, and operational. Installation costs are incurred during the initial adoption process, such as purchasing agricultural machinery, farm implements, and trees for agroforestry (Ng'ang'a et al., 2017). These costs are incurred only once for the entire lifecycle of the CSS practice. Maintenance costs are incurred for recurrent operations that occur regularly throughout the lifecycle, e.g., weeding, for optimal practice performance. At the same time,

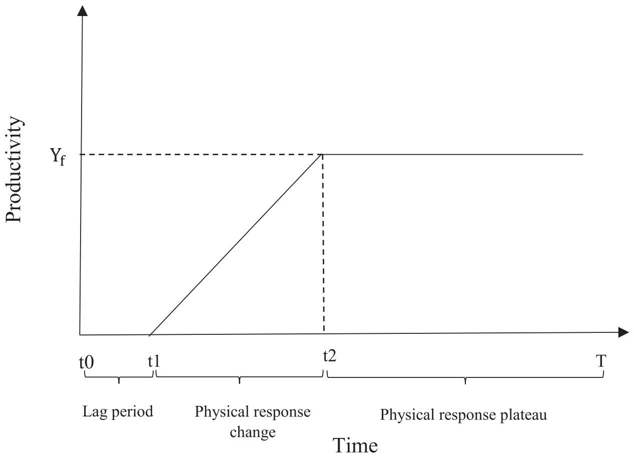

Fig. 2. The assumed shape of the crop physical response function (. Source: Beattie and Taylor, (1993)

---

[3] Sensitivity analysis, which is also known as what-if analysis, refers to how the NPV of a given CSS practice changes with different values of an input variable holding others constant under a given set of assumptions.

[4] Scenario analysis refers to a process of estimating a change in the NPV of a given CSS practice based on the occurrence of different scenarios (i.e., pessimistic and optimistic).

operational costs occur because of introducing a CSS practice. They are associated with the outputs of the CSS practice.

2.5.3. Variables used in the model

The variables used in the CBA are classified into two categories, random and non-random variables (Table 2). Random variables are on a continuous scale and can take any values within the possible values in a given cumulative function. The study modelled many random variables, including installation costs such as machinery and equipment prices, input prices, maintenance costs, crop yield response, time in years when the physical response starts, and the point it reaches a maximum in the practice life cycle. To consider a variable as random, one must look at many factors such as variability of the biophysical factors, household characteristics, and the attributes of preferred CSS practice. The non-random variables are evaluated at the mean, such as output prices and the discount rate. These are variables out of the farmer's control, determined by demand and supply and the monetary policy.

2.6. Private profitability

Taking into consideration the crop response curve after implementation of CSS practices and the linear plateau model adopted for the maize, beans, and bananas, information from survey data and literature review (Table 3) was done to assess practice durations (Ng'ang'a et al., 2017; Ng'ang'a et al., 2021; Sain et al., 2017). The expert review provided the lifespan period for each CSS practice. The survey data provided the base yields (Y_0) for the BAU practices through a recall. After the implementation of the CSS practices, the optimal yield(Y_f) and other data were then collected (Table 4). All the six prioritized CSS practices had a yield response from the second year of implementation(t_2).

A) A quick response cycle, there is no lag, and a plateau is reached in the second year, the lifespan is more than 15 years, B) A quick response, there is no lag, and a plateau is reached in the second year, the lifespan is less than six years, C) A quick response cycle and no plateau is assumed. Productivity increases until the end of the lifespan of the CSS practice.

2.7. Sensitivity and scenario analysis

Sensitivity and scenario analysis are necessary to obtain robust results when performing a deterministic CBA. Sensitivity analysis measures how the impact of uncertainties of one or more input variables can lead to uncertainties on the output variables (Pichery, 2014). The analysis is essential because it improves the model's prediction by studying its response to changes in input variables. The expected values of the various parameters involved can be used to evaluate robustness (i.e., "sensitivity" of the results from these input variable changes and identify the values beyond which results change significantly. On the other hand, scenario analysis predicts a future event like droughts and the consequences. The scenario analysis estimates the change in the profitability of a given CSS practice in a theoretical best-case (optimistic) and worst-case (pessimistic) scenario (Balaman, 2019). The incidence probability and possible impact of a scenario (i.e., in the event of an economic or climate shock) should be considered in tandem to develop a mitigation measure on scenario analysis results. The primary aim of scenario analysis is to analyze the results of the more extreme outcomes (with high probability or severe impacts) to determine the CSS practices investment strategy.

Table 2
Variables used in the CBA model to estimate the indicators used in the CBA model.

Variable	Nature	Rationale
Cost structure (Installation, maintenance, and operational costs)	Random	Reflects the cost of implementing the CSS practice. The costs are random because of variations such as variability in biophysical factors, household characteristics, production technology across farms, and the attributes of the CSS practice.
Crop yield response	Random	Determine the effect of the implemented CSS practice on the farm output. It brings out the degree of uncertainty during implementation.
Output prices	Non-random	Determined by market forces hence minimal variations across farms
Time (lifespan) and discount rate	Non-random	The time of analysis is the CSS practice's lifespan, and financial institutions fix the discount rate. Therefore, they are not under the control of the farmers hence non-random.

Table 3
Actual values that estimated the physical yield response to the implementation of the CSS practices.

Climate-Smart soil practices	Parameters			Assumed Shape
	t1 (years)	t2 (years)	T (years)	
Agroforestry	1	2	15	A
Intercropping	1	2	17	A
Liming	1	2	6	B
Improved hybrid seeds	1	2	2	C
Use of inorganic fertilizer	1	2	2	C
Use of organic manure	1	2	5	B

Table 4
Summary of parameters used in the CBA model.

Parameter	Distribution function	Description	Information source
T, t1, t2	Non-random	The physical response function	Expert survey
Y_0	Non-random	The base yield obtained from BAU practice	Household survey 2016. The average of observations with BAU before CSS practice adoption.
Y_{max}	Random triangular	Maximum yield associated with the CSS practice	Expert survey
P_i	Non-random	Market price per unit of output at farm level	Household survey 2016. The mean price received by farmers for the affected crops
$(\text{implementation cost})_j$	Random best fit the data	Cost for implementing CSS practice j	Household survey 2016.
$(\text{maintenance cost})_j$	Random best fit the data	Cost for maintaining CSS practice j	Household survey, 2016. Maintenance of each CSS practice per year

3. Results

3.1. Comparative profitability

All the CSS practices analyzed were profitable (Fig. 3). This is indicated by the positive NPV and an IRR, larger than the discount rate (12%), over their lifecycles. Agroforestry was the most profitable among all the CSS practices, with an NPV of US$ 16,071 ha^{-1}, with an IRR of 1046% and a PP of one year. Intercropping, liming and use of organic manure followed in that order with an NPV of US$10,487 ha^{-1}, US $6,173 ha^{-1}, and US$3,497 ha^{-1} and an IRR of 454%, 2210%, and 169%, respectively. In contrast, inorganic fertilizer and the use of improved hybrid seeds were the least profitable, with an NPV of US$

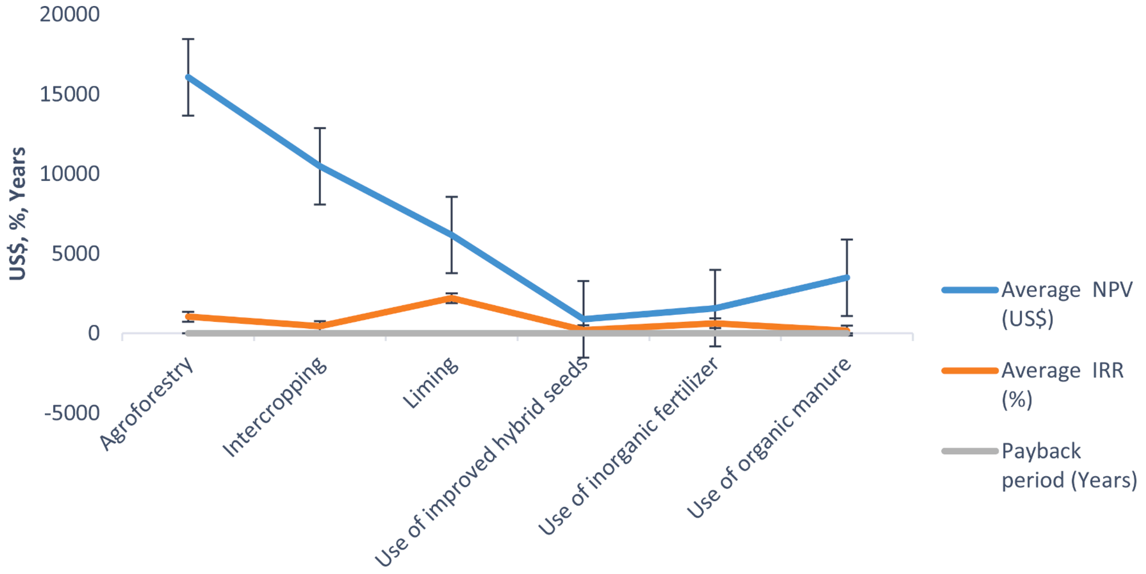

Fig. 3. Average values of profitability indicators of the adoption of CSS practices.

1,576 ha^{-1} and US$ 881 ha^{-1} and an IRR of 634% and 204%, respectively. Except for organic manure, all the CSS practices had a one-year short payback period. This suggests that the practices are profitable, and farmers are likely to recoup their investment capital after one year.

Some CSS practices such as agroforestry required little investment cost, resulting in high NPV values and a short PP to start experiencing returns. The low NPV for the use of improved hybrid seed (US$ 881 ha^{-1}) can also be associated with high investments costs (i.e., the cost of purchasing the seed, transportation, and planting) and a possibility of farmers using counterfeit seeds with poor yields. The use of hybrid seeds and inorganic fertilizer shows a significant profit-risk due to the high installation costs and the short lifecycles as their recovery period is limited.

The costs vary across the CSS practices (Fig. 4). Installations costs were high for those farmers who practiced organic manure and the least for those who preferred liming. Maintenance costs were high for those farmers who preferred intercropping and the least for those who practiced liming. Operational costs were high for agroforestry, while zero cost for the liming practice. Generally, intercropping incurred the highest costs per annum, with liming incurring the least. Although intercropping had high installation, maintenance, and operation costs, it was more profitable (US$10,487 ha^{-1}) than soil liming, use of organic manure, inorganic fertilizer, and improved hybrid seed. This result is associated with the benefits of intercropping, where farmers plant complementary crops. The practice itself can protect the soil from nutrient losses, increase water infiltration, and improve the soil structure (Thierfelder et al., 2017). Soil liming was relatively profitable (US $6,173 ha^{-1}) than the use of organic manure, inorganic fertilizer, and improved hybrid seeds because of its low installation, maintenance, and operation costs. The use of organic manure was low in profitability (US $3,497 ha^{-1}) due to its high installation costs compared to all other CSS practices.

3.2. Relative risk

The input variables used for sensitivity analysis include the product

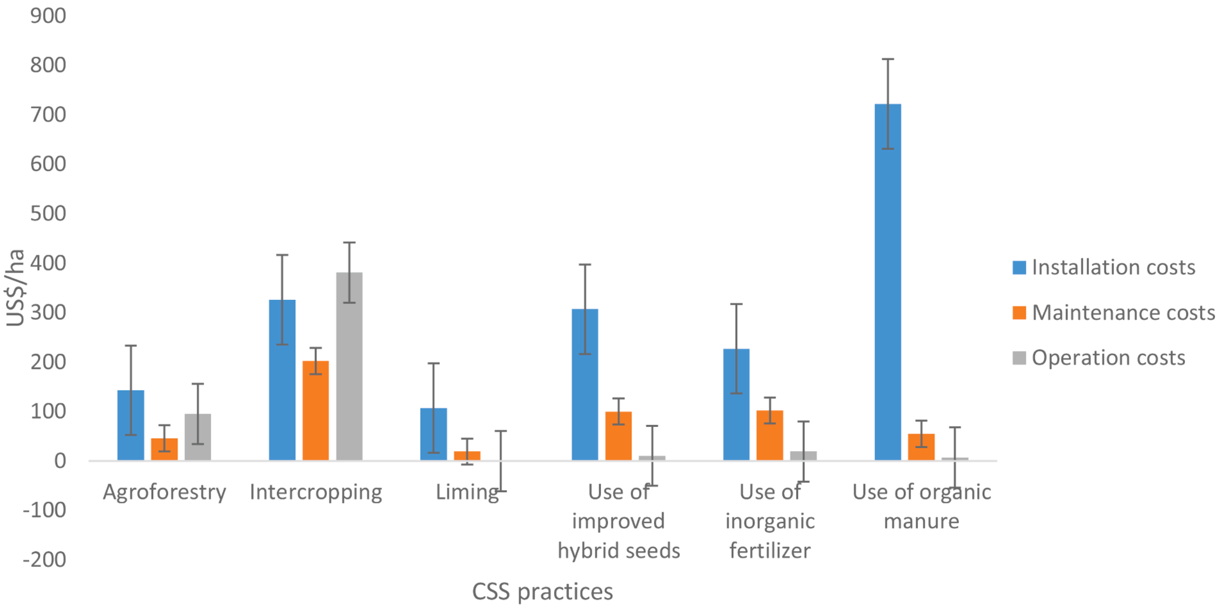

Fig. 4. Summary of installation, maintenance, and operation costs.

price captured as price per bag[5] of maize, output as yield per hectare, labour cost per annum, discount rate, and the life cycle (years). The two scenarios- pessimistic (-10%) and optimistic (+10%) were used to determine how sensitive the NPV was to changes in the input variables. The scenarios were used to determine the changes in CSS practices' benefits (profits) under different exposure. The relative risk helps us answer the probability of having more or less profits with an exposure of a CSS practice to different scenarios. First, these input variables in both scenarios across the CSS practices significantly changed the incremental NPV value except for the annual labour cost that had the least change. Secondly, all the input variables positively changed the net benefits except the discount rate with a negative NPV. Among the input variables used for sensitivity analysis, the CSS practices were highly sensitive[6] to output, followed by the product price, moderately sensitive to the discount rate, and least sensitive to annual labour cost.

The CSS practices were highly sensitive to price captured as price per bag. The use of inorganic fertilizer was highly sensitive to changes in the product price (i.e., a 10% change in the input price resulted in a more than 10% change in the NPV), followed by the use of improved hybrid seeds, intercropping agroforestry, and liming as the least sensitive (i.e., a 10% change in the input price resulted in a less than 5% change in the NPV). The practices were also highly sensitive to the output, and the order sensitivity was as follows: the use of inorganic fertilizer was highly sensitive, followed by the use of improved hybrid seeds, organic manure, intercropping, liming, while agroforestry was the least sensitive. The practices were least sensitive (i.e., an average change of 0.85%) to the annual labour cost. In terms of the discount rate, agroforestry and intercropping were highly sensitive (i.e., an average change of −11.6%), the use of organic manure and liming were moderately sensitive (i.e., an average change of −5.5%), while the use of improved hybrid seed and inorganic manure was the least sensitive (i.e., an average change of −3%). Concerning the lifecycle, the use of organic manure and liming were highly sensitive; agroforestry and intercropping were moderately sensitive (i.e., an average increase of NPV by 7.9%), while using improved hybrid seeds and inorganic fertilizer was not sensitive.

4. Discussion

Generally, farmers prefer profitable practices for which they start experiencing net economic returns within a short time (Lan et al., 2018). Therefore, conducting a CBA that considers the important factors during an investment, time lag, and associated risk is of the essence. The six practices were profitable on average when all costs and benefits associated with them were taken into account. In addition, the CBA results indicated that all the CSS practices had a short PP of one year except for the use of organic manure that had two years. The result implies that farmers can repay within one year if they have access to credit to implement these practices.

Agroforestry and intercropping were the most profitable compared to other prioritized CSS practices. The results corroborate the findings of (Kay et al., 2019; Phimmavong et al., 2019; Sereke et al., 2015). Phimmavong et al. (2019) illustrated that agroforestry and intercropping systems that integrate food and trees in the Lao Peoples Democratic Republic (PDR) had higher economic returns for rural development. Sereke et al. (2015) also indicated that Swiss farmers who practiced agroforestry, particularly those linked to innovative market of farm produce and receiving payment on ecosystem services, found it more profitable than BAU. At the same time, Kay et al. (2019) showed that the financial value of the Mediterranean agroforestry system's outputs was more significant than the corresponding agricultural system (BAU) after accounting labour and machinery costs. The finding was attributed to reduced nutrient and soil losses and carbon capture and storage benefits.

Although the high costs of implementing the practices influenced the NPV values, intercropping was still very profitable (US$10,487 ha^{-1}) compared to soil liming, use of organic manure, inorganic fertilizer, and improved hybrid seeds. Generally, the practice is more labour-intensive, and specifically-designed mechanization is rare (Hong et al., 2019). The result implies that farmers who intercrop complementary crops despite incurring high implementation costs still profit from the practices. The findings of a study by Ngwira et al. (2020) in Mangochi corroborated our results that farmers who intercropped maize with pigeon pea got the most significant net returns.

Soil liming also ranked third after agroforestry and intercropping in terms of profitability. The results is associated with low implementation costs compared to organic fertilizer, inorganic fertilizer and improved hybrid seeds. Organic fertilizer was fourth in profitability with an NPV of US$3,497 ha^{-1}. Despite the practice having high installation costs, it had low maintenance and operation costs.

Improved hybrid seeds and inorganic fertilizer are the CSS practices preferred but were least profitable. The findings can be associated with the high proliferation of counterfeit agricultural inputs, estimated to be over 40–60% in SSA (Masso et al., 2017). The findings of Masso et al. (2017) further indicate that soil fertilization centered on nitrogen, phosphorus, and potassium with little regard to micro-nutrients, soil amendments, and liming. Therefore, this can result in low yields and poor profitability for the CSS practice. Thus, farmers adopting these practices need coping measures due to the high climate risks. The low returns in inorganic fertilizer and the use of improved hybrid seed may be attributed to the poor quality and low adoption of these inputs (Bold et al., 2015). The study found that fertilizer purchased in local markets had 30% nutrient missing, and hybrid maize seed contains less than 50% genuine seeds leading to poor returns among farmers in Uganda. Having these counterfeit inputs sold to farmers, the probability of having poor profits among farmers who adopt these practices is high.

With the increased economic and climatic shocks, a risk assessment during the implementation of the CSS practices is essential to ascertain expected changes in the profitability when input variables change. By knowing the level of risk involved in adopting the different CSS practices, farmers will be able to make wise decisions and minimize losses. This assessment offers ways of helping farmers manage these risks and optimizing agricultural planning to policymakers and other stakeholders. A sensitivity analysis that involves adjustment of inputs variables under two scenarios- pessimistic and optimistic- lets us know how profitability changes under risky conditions. Under the optimistic scenario, adjusting input variables had incremental NPV except for the discount rate, and the converse is true.

Practices such as improved hybrid seeds and inorganic fertilizer had a high profitability risk due to the high sensitivity to the product price and output changes. The results resonate with Mather et al. (2016) finding that fertilizer use is marginally profitable for smallholder farmers in the southern highlands in Tanzania to compensate for production and market price risk when yields fall. The findings were associated with infrequent fallowing and lack of extension services to complement National Agriculture Input Voucher Scheme (NAIVS). Some of the recommendations to minimize the profitability risk associated with changes in the product price and output were effective dissemination of information to sustainably increase productivity through appropriate fertilizer use, improvement and stabilizing maize prices, and reduction of fertilizer costs (Mather et al., 2016). Intercropping, agroforestry, and the use of inorganic manure were moderately sensitive to changes in the product price. This result can be associated with low investment costs, especially for agroforestry and the use of organic manures. Thus, changes in the product price will have a moderate effect on the profitability of these practices. Farmers who preferred liming had a low profitability risk since it was less sensitive to the product price.

---

[5] The bag used to measure output weighed approximately of 90 kg.

[6] Highly sensitive implies that a change in input variable results in a significant change in NPV (i.e. a 10% change in an input results in a more than 10% change in the NPV), high profit risk under pessimistic scenario and the converse holds.

Improved hybrid seeds and inorganic fertilizer were highly sensitive to output changes. This finding implies that farmers who prefer these practices are at a higher profit-risk during the pessimistic scenarios. The results resonate with Mather et al. (2016) that a sustainable increase in productivity requires improving profitability among smallholder maize farmers in Tanzania. Intercropping, the use of organic manures, and liming were moderately sensitive to changes in output implying, that changes in output will have a marginal effect on the profitability. Farmers who preferred agroforestry were less prone to risk, as the practice was less sensitive to changes in the output. This result implies that low investment costs and a longer agroforestry lifecycle improve its resilience.

Agroforestry and intercropping were highly sensitive to changes in the discount rate. This finding suggests that farmers who preferred these practices are at higher risks of losing their profitability during the optimistic scenario. This result is due to the long lifecycles for these practices, which implies long repayment periods, increasing the cost of capital. The farmers who preferred organic manure and liming experienced a moderate effect on the profitability, as the practice was moderately sensitive to changes in the discount rate. Improved hybrid seeds and inorganic fertilizer were less sensitive to discount rate changes. This finding implies that farmers who preferred these practices were likely to have minimal changes in profitability due to changes in the discount rate.

All the CSS practices were least sensitive to changes in the annual labor cost. The result implies that changes in labor cost had insignificant changes in the profitability of practices. Despite changes in labour showing no significant change in profitability, the effects of climatic shocks such as soil erosion can adversely affect labour productivity, thus low agricultural profits. A study by Giannakis and Bruggeman (2018), who explored labour productivity of agricultural systems across European regions, indicated that soil erosion affects productivity negatively. The study illustrates that for every ton/ha in modelled soil erosion rates, the probability of achieving higher labour productivity decreased by 28%. Hence, farmers can experience low profitability risk to changes in annual labour costs if all factors are constant. However, there is a higher probability of decreased agricultural profits for every labour unit invested in implementing the CSS practices in scenarios of increased climatic shocks.

Organic manure use and liming were highly sensitive to changes in the lifecycle compared to other prioritized practices. Therefore, there are higher risks for farmers who prefer these practices if the lifecycle changes. These changes in CSS practices lifecycles can result from poor management, increased soil erosion due to heavy rains, use fake inputs for the case of inorganic fertilizer, improved seeds, and soil lime. Agroforestry and intercropping were moderately sensitive to lifecycle changes, which means that farmers who preferred these practices had low risks involved when there were changes in the lifecycle. Improved hybrid seeds and inorganic fertilizer were not sensitive to changes in their lifecycle since they were short compared to other practices. This finding implies that the profitability of CSS practices was less likely to be affected by changes in the lifecycle.

The CBA analysis focus on the private profitability and relative risks associated with a given CSS practice by the farmer. All the CSS practices analyzed in this study were profitable and had an average PP of one year. The result helps policymakers, development practitioners, and county governments to rank these prioritized practices, enabling them to allocate resources optimally towards the most profitable CSS practices (Lan et al., 2018). They will also promote these practices and help farmers make better choices when adopting these CSS practices. Stakeholders should also have an attractive package of incentives for farmers, such as input subsidies in scenarios where the sustainability of these CSS practices is a challenge. The national government should also provide strategic grain reserves and attractive insurance packages to help farmers overcome fluctuations in prices and output. By doing this, practices like improved hybrid seeds and inorganic fertilizers with a higher profitability risk can be sustainable. Financial institutions should also offer loans with minimum interest to promote CSS practices such as agroforestry with long lifecycles.

5. Conclusions and policy recommendations

Assessing comparative profitability and relative risk of adopting preferred CSS practices is necessary to ensure farmers' sustainability. The CSS practices have different installation, maintenance, and operation costs, making them differ in profitability. CSS practices with high implementation costs are less profitable than those with low costs. The relative risk differs across all the CSS practices, as indicated in the results negating the hypothesis. Therefore, we reject the hypothesis that the CSS practices do not differ in profitability and relative risks among farmers.

All the CSS practices were more sensitive to changes in output prices, yield per hectare, and discount rate than labour cost and lifespan, which also influence profitability. Inorganic fertilizer and improved hybrid seeds were highly sensitive to output prices and yield changes. Therefore, intervention policies such as minimum procurement prices and temporary storage programs are essential to guarantee profitability during climate and economic shocks. Therefore, development practitioners, policymakers, and other stakeholders need to understand how the CSS practices compare (i.e., profitability and relative risk) to help farmers make better choices when settling for a given practice.

This study recommends putting in place sensitization programs regarding profitability and relative risks associated with the studied practices. Further, to increase the adoption rate of CSS practices among farmers, the national government, through financial institutions, needs to put in financially friendly place policies such as micro-credit loans with minimum interest to enable farmers to access credit (Mogaka et al., 2021). Through these initiatives, farmers can access more credit and invest in CSS practices. The county government and other stakeholders need to demystify the farmers' mentality that having improved hybrid seeds are guaranteed increased profitability. The national government needs to have temporary grain reserves to ensure price stability, hence cushioning farmers against production and price risks. There is also a need to enforce the sale and distribution of quality input to curb counterfeit ones. Institutional offering services such as agricultural insurance, irrigation facilities, and credit should have attractive and pocket-friendly packages. Such packages may incentivize farmers to borrow credit for implementing CSS practices, including those with long lifecycles.

Although the adoption of CSS practices can guarantee improved soil health, increase agricultural productivity, and mitigate the adverse effects of climate change, upscaling adoption of these CSS practices is imperative to sustain these long-term goals. Thus, future studies should consider having a more in-depth economic assessment that can forecast the probability of these CSS practices being profitable in the future and the extent of adoption. Additionally, incorporating expert reviews, market dynamics, and more climate uncertainties is necessary for more robust results that broaden information that farmers require for efficient selection of CSS practices for adaptation. This approach will increase adoption levels, thereby enhancing long-term food security and climate change goals.

CRediT authorship contribution statement

Bwema Ombati Mogaka: Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Stanley Karanja Ng'ang'a:** Conceptualization, Funding acquisition, Software, Investigation, Methodology, Supervision, Validation, Writing – review & editing. **Hillary Kiplangat Bett:** Supervision, Validation, Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We acknowledge with gratitude the support from the International Centre for Tropical Agriculture (CIAT) for allowing us to use their secondary data to carry out and support this study. We also acknowledge GIZ (Contract No. 81206681, 2018) and the African Economic Research Consortium (AERC) (AE/TG/19-02 (Award 1310)) for funding this work, the farmers who made this data availability possible, extension officers, and the enumerators who supported primary data collection. Our much gratitude also goes to Mr. Wilson Nguru Maina for his contribution to the study area map for this paper.

References

Balaman, Ş.Y., 2019. Chapter 5—Uncertainty Issues in Biomass-Based Production Chains. In: Decision-Making for Biomass-Based Production Chains. Academic Press, pp. 113–142.

Balana, B.B., Muys, B., Haregeweyn, N., Descheemaeker, K., Deckers, J., Poesen, J., Nyssen, J., Mathijs, E., 2012. Cost-benefit analysis of soil and water conservation measure: The case of exclosures in northern Ethiopia. Forest Policy Econ. 15, 27–36. https://doi.org/10.1016/j.forpol.2011.09.008.

Beattie, B.R., Taylor, C.R., 1993. The Economics of Production. Krieger Publishing Company.

Beria, P., Maltese, I., Mariotti, I., 2012. Multicriteria versus Cost Benefit Analysis: A comparative perspective in the assessment of sustainable mobility. Eur. Transp. Res. Rev. 4 (3), 137–152. https://doi.org/10.1007/s12544-012-0074-9.

Bold, T., Kaizzi, K., Svensson, J., Yanagizawa-Drott, D., 2015. Low quality, low returns, low adoption: Evidence from the market for fertilizer and hybrid seed in Uganda. Centre for Economic Policy Research London, England.

CGOS, 2018. County Government of Siaya strategic plan. https://siaya.go.ke/county-integrated-development-plan-2018-2022-workshop/.

Cochran, W.G., 1977. Simple Random Sampling. Third Edition. John & Wiley Sons, Sampling Techniques.

Cruz, J., Singerman, A., 2019. [FE1060] Understanding Investment Analysis for Farm Management. EDIS 2019 (4), 4.

Dittrich, R., 2016. Top-down and bottom-up decision-making for climate change adaptation. An application to flooding. Thesis (PhD). School of Geosciences, University of Edinburgh, Edinburgh, Scotland.

Dube, T., Moyo, P., Ncube, M., Nyathi, D., 2016. The impact of climate change on agro-ecological based livelihoods in Africa: A review 9 (1), 256–267. https://doi.org/10.5539/jsd.v9n1p256.

Florio, M., Forte, S., Pancotti, C., Sirtori, E., Vignetti, S., 2016. Exploring cost-benefit analysis of research, development and innovation infrastructures. An evaluation framework.

Food and Agriculture Organization, 2014. World reference base for soil resources 2014: International soil classification system for naming soils and creating legends for soil maps. FAO.

Giannakis, E., Bruggeman, A., 2018. Exploring the labour productivity of agricultural systems across European regions: A multilevel approach. Land Use Policy 77, 94–106. https://doi.org/10.1016/j.landusepol.2018.05.037.

GOK, 2019. Kenya Population and Housing Census: Volume II i. https://www.knbs.or.ke.

GOK, 2021. Kenya National Bureau of Statistics (Website). https://www.knbs.or.ke.

Hong, Y.u., Berentsen, P., Heerink, N., Shi, M., van der Werf, W., 2019. The future of intercropping under growing resource scarcity and declining grain prices-A model analysis based on a case study in Northwest China. Agric. Syst. 176, 102661. https://doi.org/10.1016/j.agsy.2019.102661.

Hoogmartens, R., Van Passel, S., Van Acker, K., Dubois, M., 2014. Bridging the gap between LCA, LCC and CBA as sustainability assessment tools. Environ. Impact Assess. Rev. 48, 27–33. https://doi.org/10.1016/j.eiar.2014.05.001.

IEBC, 2019. Independent Electoral and Boundaries Commission. https://www.iebc.or.ke/resources/?Boundary_Delimitation.

Kay, S., Graves, A., Palma, J.H.N., Moreno, G., Roces-Díaz, J.V., Aviron, S., Chouvardas, D., Crous-Duran, J., Ferreiro-Domínguez, N., García de Jalón, S., Măcicăşan, V., Mosquera-Losada, M.R., Pantera, A., Santiago-Freijanes, J.J., Szerencsits, E., Torralba, M., Burgess, P.J., Herzog, F., 2019. Agroforestry is paying off–Economic evaluation of ecosystem services in European landscapes with and without agroforestry systems. Ecosyst. Serv. 36, 100896. https://doi.org/10.1016/j.ecoser.2019.100896.

Khatri-Chhetri, A., Aryal, J.P., Sapkota, T.B., Khurana, R., 2016. Economic benefits of climate-smart agricultural practices to smallholder farmers in the Indo-Gangetic Plains of India. Curr. Sci. 1251–1256.

Lan, L.e., Sain, G., Czaplicki, S., Guerten, N., Shikuku, K.M., Grosjean, G., Läderach, P., Loor, J.J., 2018. Farm-level and community aggregate economic impacts of adopting climate smart agricultural practices in three mega environments. PLoS ONE 13 (11), e0207700. https://doi.org/10.1371/journal.pone.020770010.1371/journal.pone.0207700.t00110.1371/journal.pone.0207700.t00210.1371/journal.pone.0207700.t00310.1371/journal.pone.0207700.t00410.1371/journal.pone.0207700.t00510.1371/journal.pone.0207700.t00610.1371/journal.pone.0207700.t00710.1371/journal.pone.0207700.t008.

Martey, E., Kuwornu, J.K.M., 2021. Perceptions of Climate Variability and Soil Fertility Management Choices Among Smallholder Farmers in Northern Ghana. Ecol. Econ. 180, 106870. https://doi.org/10.1016/j.ecolecon.2020.106870.

Masso, C., Nziguheba, G., Mutegi, J., Galy-Lacaux, C., Wendt, J., Butterbach-Bahl, K., Wairegi, L., Datta, A., 2017. Soil fertility management in sub-Saharan Africa. In: Sustainable agriculture reviews. Springer, pp. 205–231. https://doi.org/10.1007/978-3-319-58679-3_7.

Mather, D., Minde, I., Waized, B., Ndyetabula, D., Temu, A., 2016. The profitability of inorganic fertilizer use in smallholder maize production in Tanzania: Implications for alternative strategies to improve smallholder maize productivity.

Mogaka, B.O., Bett, H.K., Ng'ang'a, S.K., 2021. Socioeconomic factors influencing the choice of climate-smart soil practices among farmers in western Kenya. J. Agric. Food Res. 5, 100168. https://doi.org/10.1016/j.jafr.2021.100168.

Mponela, P., Tamene, L., Ndengu, G., Magreta, R., Kihara, J., Mango, N., 2016. Determinants of integrated soil fertility management technologies adoption by smallholder farmers in the Chinyanja Triangle of Southern Africa. Land Use Policy 59, 38–48. https://doi.org/10.1016/j.landusepol.2016.08.029.

Mutenje, M.J., Farnworth, C.R., Stirling, C., Thierfelder, C., Mupangwa, W., Nyagumbo, I., 2019. A cost-benefit analysis of climate-smart agriculture options in Southern Africa: Balancing gender and technology. Ecol. Econ. 163, 126–137. https://doi.org/10.1016/j.ecolecon.2019.05.013.

Mwongera, C., Mwungu, C. M., Kinyua, I., Karanja Ng'ang'a, S., 2017. Prioritizing climate-smart agriculture practices in Western Kenya.

Ng'ang'a, Stanley Karanja, Miller, Vail, Girvetz, Evan, 2021. Is investment in Climate-Smart-agricultural practices the option for the future? Cost and benefit analysis evidence from Ghana. Heliyon 7 (4), e06653. https://doi.org/10.1016/j.heliyon.2021.e06653.

Ng'ang'a, S.K., Notenbaert, A., Mwungu, C.M., Mwongera, C., Girvetz, E., 2017. Cost and benefit analysis for climate-smart soil practices in Western Kenya. Kampala, Uganda.

Ng'ang'a, S.K., Owuso Essegbey, G., Karbo, N., Ansah, V., Nautsukpo, D., Kingsley, S., Girvetz, E.H., 2017b. Cost and benefit analysis for climate-smart agricultural (csa) practices in the coastal savannah agro-ecological zone (aez) of Ghana. https://hdl.handle.net/10568/83464.

Ngwira, A.R., Kabambe, V., Simwaka, P., Makoko, K., Kamoyo, K., 2020. Productivity and profitability of maize-legume cropping systems under conservation agriculture among smallholder farmers in Malawi. Acta Agriculturae Scandinavica, Sect. B—Soil Plant Sci. 70 (3), 241–251. https://doi.org/10.1080/09064710.2020.1712470.

Nyawira, Sylvia S., Hartman, Melannie D., Nguyen, Trung H., Margenot, Andrew J., Kihara, Job, Paul, Birthe K., Williams, Stephen, Bolo, Peter, Sommer, Rolf, 2021. Simulating soil organic carbon in maize-based systems under improved agronomic management in Western Kenya. Soil Tillage Res. 211, 105000. https://doi.org/10.1016/j.still.2021.105000.

Oberndorfer, S., Sander, P., Fuchs, S., 2020. Multi-hazard risk assessment for roads: Probabilistic versus deterministic approaches. Nat. Hazards Earth Syst. Sci. 20 (11), 3135–3160. https://doi.org/10.5194/nhess-20-3135.

Phimmavong, Somvang, Maraseni, Tek Narayan, Keenan, Rodney J., Cockfield, Geoff, 2019. Financial returns from collaborative investment models of Eucalyptus agroforestry plantations in Lao PDR. Land Use Policy 87, 104060. https://doi.org/10.1016/j.landusepol.2019.104060.

Pichery, C., 2014. Sensitivity Analysis. In: Wexler, P. (Ed.), Encyclopedia of Toxicology, Third Edition. Academic Press, pp. 236–237. https://doi.org/10.1016/B978-0-12-386454-3.00431-0.

Sain, G., Loboguerrero, A.M., Corner-Dolloff, C., Lizarazo, M., Nowak, A., Martínez-Barón, D., Andrieu, N., 2017. Costs and benefits of climate-smart agriculture: The case of the Dry Corridor in Guatemala. Agric. Syst. 151, 163–173. https://doi.org/10.1016/j.agsy.2016.05.004.

Sereke, F., Graves, A.R., Dux, D., Palma, J.H., Herzog, F., 2015. Innovative agroecosystem goods and services: Key profitability drivers in Swiss agroforestry. Agron. Sustainable Dev. 35 (2), 759–770. https://doi.org/10.1007/s13593-014-0261-2.

Thierfelder, C., Chivenge, P., Mupangwa, W., Rosenstock, T.S., Lamanna, C., Eyre, J.X., 2017. How climate-smart is conservation agriculture (CA)?–its potential to deliver on adaptation, mitigation and productivity on smallholder farms in southern Africa. Food Security 9 (3), 537–560. https://doi.org/10.1007/s12571-017-0665-3.

Tollefson, J., 2018. IPCC says limiting global warming to 1.5 C will require drastic action. Nature 562 (7726), 172–173. https://doi.org/10.1038/d41586-018-06876-2.

Vanlauwe, B., Descheemaeker, K., Giller, K.E., Huising, J., Merckx, R., Nziguheba, G., Wendt, J., Zingore, S., 2015. Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation. Soil 1 (1), 491–508. https://doi.org/10.5194/soil-1-491-2015.

Visser, S., Keesstra, S., Maas, G., De Cleen, M., 2019. Soil as a basis to create enabling conditions for transitions towards sustainable land management as a key to achieve the SDGs by 2030. Sustainability 11 (23), 6792. https://doi.org/10.3390/su11236792.

Walker, Tom, Hash, Tom, Rattunde, Fred, Weltzien, Eva (Eds.), 2016. Improved Crop Productivity for Africa's Drylands. Washington, DC: World Bank.

Watkiss, P., Cimato, F., 2016. The economics of adaptation and climate-resilient development: Lessons from projects for key adaptation challenges. Centre for Climate Change Economics and Policy.

Yackulic, C.B., Fagan, M., Jain, M., Jina, A., Lim, Y., Marlier, M., Muscarella, R., Adame, P., DeFries, R., Uriarte, M., 2011. Biophysical and socioeconomic factors associated with forest transitions at multiple spatial and temporal scales. Ecol. Soc. 16 (3).