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The economics of soil organic carbon

Multi-benefits from sustainable land management for smallholders in Western Kenya

Imprint

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The Economics of Land Degradation (ELD) Initiative is a global initiative at the interface of science, policy, and practice that works to make the values of land count in decisions to inform, promote, and scale land solutions for transformative change.
Available from **www.eld-initiative.org**

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List of acronyms

ac	Acre
AF	Agroforestry
AFOLU	Agriculture, Forestry and Other Land Uses
C	Carbon
CA	Conservation agriculture
CH4	Methane
CO_2	Carbon dioxide
CO_{2e}	Carbon dioxide equivalent
COP 15	United Nations Climate Change Conference in 2015
CTRL	Control Group
ELD	Economics of Land Degradation
FAO	Food and Agriculture Organization of the United Nations
FSA	Farming system approach
FYM	Farmyard manure
GAP	Good Agricultural Practices
GHG	Greenhouse gases
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GtC	Giga tonnes of carbon
ha	Hectare
ICVCM	Integrity Council for the Voluntary Carbon Market
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
ISFM	Integrated Soil Fertility Management
K	Potassium
KES	Kenyan Shilling
LDC	Least Developed Country
Mt	Mega tonnes 1,000,000 t
N	Nitrogen
N2O	Nitrous oxide
NGO	Non-governmental organisation
NIR	Near Infra-Red
NPV	Net Present Value
P	Phosphorus
ProSoil	GIZ Global Programme Soil Protection and Rehabilitation

PPM	Push Pull Method
SLM	Sustainable Land Management
SOC	Soil organic carbon
SOM	Soil organic matter
SV BoDeN	Sector Program Soil Protection, Desertification, and Sustainable Land Management
SWC	Soil and Water Conservation
t	Tonne
TLU	Tropical livestock unit
UNFCCC	United Nations Framework Convention on Climate Change
VCM	Voluntary Carbon Market
VCS	Voluntary Carbon Standard
WKCP	Western Kenya Carbon Project
yr	Year

Executive Summary

The farming system of Western Kenya is characterized by small-scale subsistence agriculture, with low inputs, low yields, and rapid loss of soil fertility. This leads to soil degradation which makes soils less productive, as well as reduces food and income security. Healthy and productive soils are not only vital for food production, but also play a crucial role for carbon sequestration: Soils are the largest carbon reservoir of the terrestrial carbon cycle and store more carbon than all terrestrial vegetation and the atmosphere together. Soil organic carbon (SOC) sequestration can contribute to climate change mitigation, by taking atmospheric CO_{2e} and converting it into soil carbon. Sustainable Land Management (SLM) has gained significant attention over the last years because of its potential to contribute to climate change mitigation and adaptation by SOC sequestration.

Extension services to increase implementation rates of SLM among smallholder farmers though often lack financing. To enable long-term financing for extension services, a new and innovative approach comprises the use of the revenues of agricultural carbon credits to support SLM. The study analyses the impact of adopting SLM practices on the household income of smallholder farmers in Western Kenya as well as the carbon sequestration potential of SLM practices, namely Conservation Agriculture (CA) and Integrated Soil Fertility Management (ISFM).

The study applies the 6+1 step approach advocated by the Economics of Land Degradation (ELD) Initiative and combines household surveys to assess socio-economic parameters with soil samples to measures SOC and bulk density on 64 small-scale farms in Siaya county located in Western Kenya. The sample is composed of 22 farmers practicing CA, 21 farmers practicing ISFM and 21 conventional farmers as control group (CTRL farmers). The study focusses on Western Kenya which makes the results not transferable to other agroecological zones and farming systems, as they may differ in productivity and opportunities to diversify production or adopt SLM practices.

The study results show significant differences in the economic performance of CA and ISFM farmers compared to CTRL farmers. The income from farming activities of CA and ISFM famers was twice that of the CTRL farmers: CA farmers gained 1,083 USD per household and year and ISFM farmers gained 1,085 USD per household and year, whereas CTRL farmers gained only 324 USD per household and year. The different average farm sizes of the farm types lead to different profits per ha: The profit per year of 1 ha of cultivated land is 1,732 USD per ha and year for CA farmers, 1,443 USD per ha and year for the ISFM and 555 USD per ha and year for the CTRL farmers. The income results thus show that the adoption of SLM practices leads to economic benefits for farmers compared to business as usual. The revenues for CA and ISFM farmers were not only higher, but their production was also more diversified over different farming activities. Especially fruit production and other products took a larger share within ISFM and CA farms.

Compared to the control group, the carbon storage in the topsoil (0–30 cm) of CA farmers is 13,86 tCO_{2e}/ha and 2,35 tCO_{2e}/ha for ISFM farmers. The higher carbon sequestration at CA farms is because the CA farmers produce more biomass with the cultivation of cover crops than ISFM farmer provide by applying farmyard manure. Depending on the adoption time of the SLM practices and based on the carbon sequestration rates from above, the annual sequestration rate is expected to reach in average 1,98 t/ha/year for an implementation period of 20 years.

CA and ISFM farmers had more soil microbial communities compared to the farmers practicing business as usual. The SLM practices including using organic inputs, crop diversification and rotation, and mulching and cover crop management improve soil structure and soil fertility. The resulting improved growth performance of crops constitute a larger energy source for bacteria and fungi, which contributes to their increased abundance on SLM farms.

Overall, the study provides clear evidence for the benefits of adopting SLM practices in smallholder farming systems in Western Kenya. It is though difficult to demonstrate the specific impact of a single SLM practice, since the SLM practices for every farming system are highly diversified and interconnected. Nevertheless, it is obvious that SLM practices combined with diversified agricultural production increase the potential for additional income and create additional benefits for the environment.

The following key findings can be summarized:

- Extension services on SLM practices contribute significantly to the adoption of SLM practices by smallholder farms in Western Kenya.
- Implementing SLM practices leads to an improvement of the economic performance of the smallholder farmers by increased and diversified income: While farmers practicing conservation agriculture and integrated soil fertility management gained in average 1,587 USD per ha and year, farmers practicing business as usual gained 555 USD per ha and year.
- Not only agroforestry for carbon sequestration in biomass should be included in agricultural carbon projects, but also carbon sequestration in soils by implementing SLM practices should be promoted. They provide crucial co-benefits for the farmers by increased yields.
- Carbon sequestration rates used in soil carbon projects in agriculture verified by certification bodies are estimated conservatively. Actual carbon sequestration in projects may be much higher than the sequestration certified by the issued carbon credits.
- SLM practices provide the opportunity to sequester large amounts of carbon in agricultural soils. To ensure the necessary long-term financing of SLM extension services for smallholders, selling the sequestered carbon as carbon credits is a viable opportunity which should be made use of.

01
Introduction

Soils are the largest carbon reservoir of the terrestrial carbon cycle and store more carbon than all terrestrial vegetation and the atmosphere together. Globally, soils store 1500 Gt of carbon to a depth of 1 m and 2400 Gt to a depth of 2 m (Batjes, 2014). At the same time, the global agri-food system contributes up to one third of total greenhouse gas (GHG) emissions (Rosenzweig et al., 2020): 21 – 37 % of the total anthropogenic GHG emissions are caused by the food system from energy use, supply chain and consumption activities. Also,18 – 29 % of the global total GHG emissions, including deforestation and peatland degradation, are related to Agriculture, Forestry and Other Land Use (AFOLU) alone. It is defined that within farm gate crop and livestock production, including methane from ruminant animals and nitrous oxide from fertilizers, 10 % of GHG emissions derive from agricultural production.

The International Panel on Climate Change (IPCC) highlights the role of AFOLU in its 2022 Report on Climate Mitigation and finds "***robust evidence and high agreement*** that agriculture needs to change to facilitate environment conservation while maintaining and, where appropriate, increase overall production" (IPCC, 2022, p. 796). The IPCC considers various Sustainable Land Management (SLM) practices to be most relevant to reduce emissions and sequester carbon. To structure the diverse agricultural approaches and practices promoting SLM, the IPCC considers four farming system approaches. These demonstrate how Agroecology, Conservation Agriculture, Integrated Production System and Organic Agriculture influence emission reduction and carbon sequestration (see ► Table 1). Some of the management practices (indicated in the right-hand columnon of the table) are used in most farming system approaches such as crop rotation, cover crops, reduced tillage, input of organic matter from plant residues and livestock manure and compost.

At the United Nations Climate Change Conference in 2015 (COP 21) the conservation and the sequestration of CO_2 in soil in agricultural land became a priority to the political discourse. The 4p1000 initiative was one of the outcomes from COP 21. Meanwhile carbon programmes for agriculture have been implemented on a large scale or will be launched in future. At present, the expected revenue per tonne of CO_2 is between USD 5 – 20, as the market is volatile, among other factors (GIZ, 2023). However, leaders of the International Monetary Fund and the World Bank pledge for an international price of USD 25 for low-income countries, USD 50 for middle income countries and USD 75 for high income countries per tonne CO_2 reduced or stored as the target for national and international trade of CO_2 credits (International Monetary Fund, 2019). Carbon credits are considered an opportunity for developing countries to pay off their debts.

TABLE 1 Farming systems and mitigation potential

Source: adopted from (IPCC, 2022)

Farming System Approaches	Management practices	
	REDUCED EMISSIONS	CARBON SEQUESTRATION
Agroecology	› Limited synthetic fertiliser inputs › Improved N use efficiency (from improved soil quality – promoting nutrient cycling)	› Diverse crop rotations › Cover crops › Crop residue/livestock manure/ green manure/mulch/compost inputs to soil › Inclusion of agroforestry
Conservation Agriculture	› Improved N use efficiency (pro-moting nutrient cycling and cover crops – preventing N leaching) › Reduced machinery operations › Reduced SOM oxidation (from reduced tillage)	› Minimum/zero tillage › Diverse crop rotations › Cover crops › Crop residue/mulch inputs to soil
Integrated Production System	› Reduced fertiliser inputs › Improved N use efficiency (from rotation design and improved soil quality) › Reduced emissions intensity per unit of milk/meat (from improved livestock diets) › Reduced deforestation (from increased agricultural production per unit of area, facilitating re-duced LUC)	› Grass leys in arable systems › Diverse crop rotations › Agroforestry/alley cropping › Livestock manure/mulch/compost › Land sparing for afforestation (from increased agricultural pro-duction per unit of area)
Organic Farming	› No synthetic N fertiliser inputs › Reduced N loading and improved N use efficiency (from lower livestock stocking rates, reliance on biological N fixation and use of cover/catch crops)	› Diverse crop rotations › Cover/catch crops › Crop residue/livestock manure/ green manure/compost inputs to soil

To tap on the potentials of SLM practices for climate change mitigation and adaptation along with development benefits, GIZ Kenya supports the transition to Conservation Agriculture (CA) and Integrated Soil Fertility Management (ISFM) in the counties Siaya, Kakamega, and Bungoma in Kenya. Conservation Agriculture (CA) is based on minimal soil disturbance. Main CA principles are no or minimum tillage and permanent soil cover (mulch, crop residues), combined with increased crop diversity and crop rotation. ISFM involves the combination of nutrients from organic and inorganic sources alongside improved germplasm, while addressing local constraints such as soil water availability and acidity/alkalinity that impede expected nutrient use efficiencies. ISFM thus promotes measures such as liming of acidic soils, demand-oriented fertilization, and applying compost and farmyard manure.

After successful implementation of sustainable agriculture in Western Kenya, GIZ and partners built on these SLM practices at a local scale to design a voluntary carbon certification scheme. The Western Kenya Soil Carbon Project (WKCP) aims to provide incentives to farmers in form of extension services, in return for the removal of carbon dioxide (CO_2) through agroforestry and carbon sequestration on crop land. From a farmer's perspective economic benefits will be the primary motivation to adopt SLM. Most ecosystem services that create healthy soils, such as CO_2 sequestration, greenhouse gas reduction, biodiversity conservation, and water retention, yield minimal long-term financial returns. However, they are essential elements that keep the earths energy balance intact, which ultimately contributes to the wellbeing of societies and the global community.

The **main objective of this study** is to assess the impact of adopting SLM practices on the household income of smallholder farmers as well as to analyse the carbon sequestration potential of these practices. Specifically, CA and ISFM practices in Western Kenya are compared to conventional farming. Results can be used for the development of carbon projects in agriculture such as the Western Kenya Soil Carbon Project (WKCP) and for policy recommendations acknowledging the importance of SLM practices for climate mitigation.

The structure and content of the study report

► Chapter 2 focuses on the background and the scientific work on the topic, with an emphasis on the dynamics of soil organic carbon in crop land, the potential for carbon sequestration and the development of voluntary carbon markets.

► Chapter 3 outlines the methodology applied in this study.

► Chapter 4 describes the results of the study comparing farm households implementing CA and ISFM with farms using conventional farming practices that serve as control group.

The report closes with a discussion of the results for future decision making and action (► Chapter 5).

02
Background information

This chapter provides the context of the study focussing on SOC and the impact of SLM practices on SOC content and the voluntary carbon market. The technical background on measuring and modelling of carbon removals in agricultural crop land is outlined. The case study area is also described referring to some historical data base and relevant research.

2.1 Land degradation, SOC and SLM

SLM is defined as "*the use of land resources – including soils, water, vegetation, and animals – to produce goods and provide services to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions*" (WOCAT[1]). There are different types and a large variety of SLM practices. Land degradation due to non-adapted land management practices is accompanied by a loss of SOC and depletion of nutrients, which results in less productive soils. The Intergovernmental Technical Panel on Soils (ITPS) defines soil health as "*the ability of the soil to sustain the productivity, diversity and environmental services of terrestrial ecosystems*" (FAO & ITPS, 2020). This definition shows the shift from an anthropocentric definition, strongly focuses on soil as a source for food production, to a more comprehensive approach, incorporating the role of soil for biodiversity and other ecosystem services, such as climate mitigation, climate adaptation, water purification, or combat erosion. The ITPS states that decarbonisation programmes together with integrated Nitrogen (N) management are key to overcome the dilemma of food security on one side and soil degradation and GHG emis sions on the other side. Nitrous Oxide (N_2O) with a CO_2 equivalent of 300 times of CO_2, whereas Methane (CH_4) has a CO_{2e} of 28, need to be balanced against the increase of SOC in soils (FAO & ITPS, 2021).

2.1.1 Relationship between soil organic matter and carbon

Soil organic matter (SOM) includes all carbonaceous and silicified materials, earthworms, insects, faecal materials, plant debris larger than 2 mm, root bits and pieces, leaf matter that has been partially chewed by small insects or ants, fungal hyphae, glomalin and sticky secretions from roots bacteria or earthworms. SOC constitutes the main component SOM with app. 57 %. Thus, SOC is a vital indicator to assess and mon-

1 World Overview of Conservation Approaches and Technologies (WOCAT) is a global network on Sustainable Land Management (SLM) that promotes the documentation, sharing and use of knowledge to support adaptation, innovation and decision-making in SLM.

tor soil degradation. SOC stock and the potential to increase the SOC in croplands depends on various factors such as soil texture, precipitation, temperature, or the distance to the homestead (Tittonell et al., 2008). SOC stocks can only be maintained or increased through SLM practices, which have a positive carbon balance, where inputs of biomass exceeding the decomposition of SOC and the losses of SOC by erosion (Corbeels et al., 2019). Therefore, the input of biomass through cover crops, plant residues, compost and farmyard manure (FYM) is key to maintain or increase SOC stocks.

The terrestrial ecosystems including croplands, can sequester substantial amounts CO_2 from the atmosphere and thus contribute to climate change mitigation, since 1 t of SOC equals to 3.7 t CO_2 (IPCC, 2006, p. 394). Reversely the decomposition of SOM results in the CO_2 emissions. The exploitation of SOC from natural soils was the basis for the increase of food production by changing former grassland and forestry to cropland. Since 1850 the total loss of SOC is estimated at almost 20 % of the original (natural) total SOC (FAO, 2016).

Organic soils such as Chernozem are the most productive soils since the reservoir of SOM is very high, reaching up to 16 %. Most mineral soils have a much lower SOM content of 0.5 – 3%, which declines rapidly if measure to balance the SOM are not implemented. Worldwide more than two thirds of maize and wheat are produced on soils with SOC less than 2% (Oldfield et al., 2019).

The storage capacity and the availability of the most important plant nutrients like Nitrogen (N), Phosphorus (P) and Potassium (K) are strongly linked to the SOC content. N is important for leaf growth of the plant, P effects root growth as well as flower and fruit development and K is relevant for the overall plant functioning.

Chemical fertilizer can compensate for the loss of SOC to some extent and over a period. If there are no measures taken to balance or increase SOC stocks, this though will result in a loss of soil fertility and reduced availability of plant nutrients, causing severe reduction of yields and farmer's income.

In general, the matter of SOC stock has become an important issue of international cooperation and plays a role in implementing the United Nations Convention to Combat Desertification (UNCCD), the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention for Biological Diversity (CBD).

FIGURE 1 Biomass input by cover crops (left), compost (right)

2.1.2
Soil organic carbon and ecosystem services

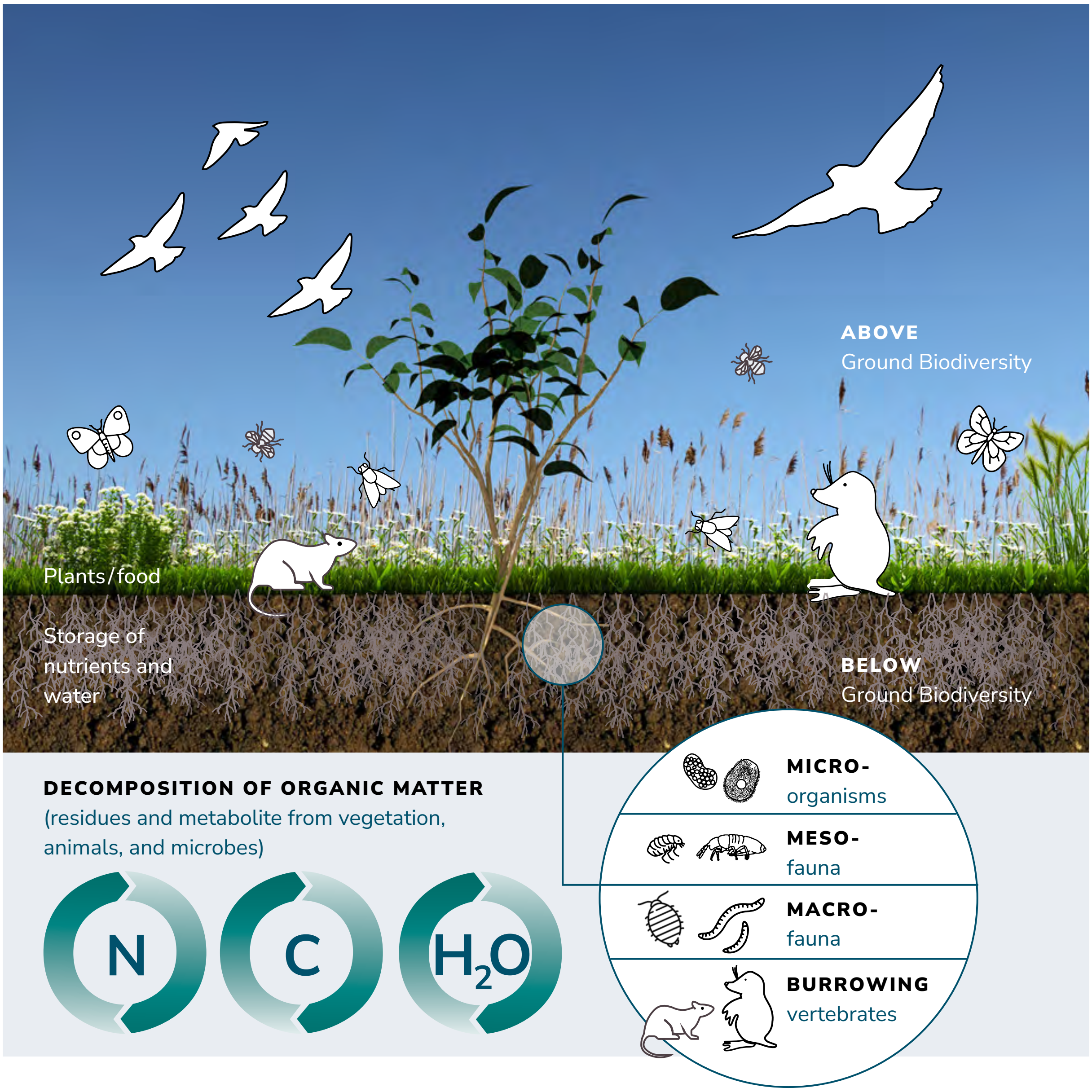
Organic matter (OM) is not only key to healthy and fertile soils and therefore to the provisioning of food, but also contributes to many other ecosystem services relevant for life on earth such as water retention and reduction of erosion and floods through increased water holding capacity of soils rich in OM.

Terrestrial biodiversity depends on healthy soil and a well-functioning food web. It is also central to food security and production, and therefore for overall human wellbeing (Koeninger et al., 2022; Kopittke et al., 2022; Laban et al., 2018a). It hosts millions of organisms, which are the origin and the starting point of the whole below ground and above ground terrestrial food chain.

Soil provides a wide range of ecosystem services (Reicosky, 2020) including supporting, pro-

FIGURE 2 Above and below ground biodiversity

Source: adapted from Laban et al., 2018b



visioning, cultural and regulating services. ► Table 2 gives an overview of the ecosystem services of healthy soil, with the ones being the core interest of this study marked in bold letters.

TABLE 2 Ecosystem services of soils

Source: adopted from Reicosky, 2020

Ecosystem Services	Specific services	Ecosystem services	Specific services
Supporting	› **Photosynthesis** › **Biomass production** › Atmospheric oxygen › **Soil formation and retention** › **Nutrient cycle**	Cultural	› Cultural services › Recreational services › Cognitive services
Provisioning	› **Food production** › Clean water › **Habitat and biodiversity**	Regulating	› **Climate control** › **Biological control** › Hydrological control › Filtering of contaminations › **Waste recycling**

The challenge of documenting and measuring ecosystems services of soil from an economic perspective is to assign a value to each of the indicators used to determine the costs and benefits. Measuring the soil ecosystem services of small holder farming systems is additionally challenging, as these farming systems are complex by nature.

A diversified agricultural production system, ranging from grassland management involving animal husbandry to the production of cereals and vegetables or perennial cultivars, such as fruits, coffee, or tea, need a comprehensive economic model (Sinclair, 2020a), looking at the total farm household.

While this study focuses on carbon sequestration in the context of SLM practices, the need for an in depth-analysis on farming operations is necessary to consider the interrelation of multiple agricultural activities. This includes the socio-economic impacts of SLM on households, and especially food security, as most small holders consume a large part of their productions within their social environment.

2.1.3 Greenhouse gas mitigation potential of sustainable land management

The global agri-food system contributes to GHG emissions with up to one third of the total GHG emissions (Rosenzweig et al., 2020).

- 21 – 37 % of the global anthropogenic GHG emissions are caused by the food system from energy use, supply chain and consumption activities contribute.
- 18 – 29 % of the global GHG emissions, including deforestation and peatland degradation are related AFOLU alone.
- 10 % of the global GHG emissions derive from agricultural production, if defined as within-farm-gate crop and livestock production, including CH_4 from ruminant animals and N_2O form fertilizers.

At the same time, agriculture has a high potential to mitigate GHG emissions: It is estimated that the total technical annual mitigation potential of agriculture until 2050 will be 11.2 (1.6 – 28.5) Gt CO_{2e}/year in total. Thereby, **carbon sequestration could contribute with 85 % and the reduction of CH_4 and N_2O emissions could contribute with 15 %**. Much lower figures are considered realistic regarding prices of one t CO_{2e}. The total potential of AFOLU, including terrestrial ecosystems, is estimated at 28.4 Gt Co_{2e}/year, with a realistic potential between 3.8 and 13.6 Gt CO_{2e}/year, depending on carbon prices between USD 20 and 100 per t CO_{2e}.

2.1.4 The potential for carbon sequestration in crop production

The potential of carbon sequestration in cropland is controversially discussed in the scientific community.

An example is the 4p1000 Initiative launched at COP21 in Paris. When the Initiative was founded in 2015, the name was a statement for the potential of carbon sequestration by an annual sequestration rate of 0.4%. This objective has been questioned by many scientists arguing, that it is too ambitious and that many barriers must be overcome to achieve the goal (Rumpel et al., 2020). On the other side, there are also scientists supporting a sequestration rate of 0.4%, referring to existing scientific results and findings (Soussana et al., 2019).

Other authors (Amundson & Biardeau, 2018) argue, that the rate of 0.4% is an elusive figure, due to the conservative nature of farmers and the manifold barriers, hindering the implementation of necessary farming practices, e.g. no-till, crop rotation and cover crops. Runck et.al. (2020) consider the upscaling of cover crop seeds for biomass production as a controversy to the cultivation of cash crops and therefore a hidden land use cost (Runck et al., 2020), which needs attention by politics and science.

Powlson et al. (2008) discuss the potential for carbon sequestration referring to the SOC stock of the natural vegetation before clearing to establish cropland. Under tropical conditions, the authors estimate a loss of more than 50% of SOC within a period of 10 years, whereas SLM practices, such as returning crop residues, applying FYM or including periods of pasture can raise the value up to 70% of the SOC stock of the natural vegetation (Powlson et al., 2018).

In 2022 Ewing et al. proved that smallholder farms have a much higher potential to increase SOC than estimated by the International Soils Database (ISDA) (Ewing et al., 2022). Soil analysis of 1,160 agricultural fields of small holders in Malawi revealed a potential of 274 ± 14 t/ha SOC on a total of 6.8 million ha of surface soil suitable for agriculture versus the estimation of the ISDA which was 178 t/ha SOC. The authors proved a gap of the potential of 4.42 ± 0.23 t/ha SOC stock to the depth of 20 cm higher than the ISDA figures, with some areas going up to 10 t/ha. Furthermore, the authors stated, the 25% of the high-value sites for carbon sequestration contribute more than 50% of the carbon gap.

More recently, several publications highlighted the limits of mitigating climate change with carbon sequestration in soils for various reasons. Moinet et al. argue that carbon sequestration is conflicting with the increase of yield and thus food security (Moinet et al., 2023). SLM practices such as CA, which are considered to increase SOC, seem to have limited impact on the increase of yields (Corbeels et al., 2020). A global study on the effects of land management changes on SOC stock concludes that evidence-based recommendations are difficult due to missing data and/or the complexity of the matter (Beillouin et al., 2022).

Several research papers conclude that regarding the impact of SLM on carbon sequestration, there is need for in-depth analysis, which is contextualised to the local conditions by considering many factors such as precipitation, temperature, soil texture and residue retention. Furthermore, agriculture must consider other objectives such as food security, diversification of the diets and food nutrition values, biodiversity and many other ecosystem services for neighbouring natural and semi-natural agricultural landscapes.

2.2 Voluntary Carbon Market and Carbon Certification Standards

SLM practices, building up SOC on agricultural crop land receive increasing attention from the political level and the private sector, as service, which can be compensated by financing mechanisms for CO_2 removal. There are already voluntary and governmental carbon sequestration mechanisms in place or in the process of development. Carbon credits and carbon certificates thereby provide the opportunity to generate incentives or additional income for farmers, who implement SLM.

Various certification standards have been established and platforms for carbon credits are available. Even the UNFCCC has set up a United Nation Offset Platform[2] for the voluntary carbon market. Most of the certificates on the voluntary carbon market are traded directly business to business.

Article 6 of the Paris Agreement provides international rules and guidelines for the trade of carbon credits between countries. These guidelines support countries to meet the Nationally Determined Contributions (NDCs) for the reduction and the removal of GHGs from the atmosphere.

The Integrity Council for the Voluntary Carbon Market (ICVCM) has drafted the Core Carbon Principles (CCPs) and Assessment Framework, which are intended to provide reliability and accountability for carbon credit programmes (ICVCM, 2022). The CCPs are related to the requirements for carbon-crediting programs, requirements of the types of carbon credits and requirements related to attributes, which a caron project must possess.

2 https://unfccc.int/climate-action/united-nations-carbon-offset-platform

TABLE 3 Core Carbon Principles of the Integrity Council for Voluntary Carbon Market

Source: ICVCM, 2022

I Requirements for carbon-crediting programs
1 Program Governance 2 Robust Quantification of Emission Reductions and Removals 3 Robust Independent Third-Party Validation and Verification 4 No Double-Counting 5 Registry 6 Mitigation Activity Information 7 Sustainable Development Impacts and Safeguards
II Requirements relating to types of carbon credits
8 Additionality 9 Permanence 10 Robust quantifications 11 Transition towards net-zero emissions
III Requirements relating to attributes
12 Attributes
IV Issues related to Paris Agreement Alignment
13 Alignment with Paris Agreement

More details on the methodology of accounting of carbon sequestration and the reduction of GHG in agriculture cropland and grassland are described in the VM0017[3] (VERRA, 2011a) for Sustainable Agricultural Land Management practices on crop land. The VCM AFOLU is a market, where buyers can purchase CO_{2e} certificates from projects and individuals, which can prove, that they implement SLM, which potentially removes CO_2 or reduces GHG emissions.

The certification of SLM in crop land in Africa is still at the beginning, facing difficulties to apply the VCS VM0017 (VERRA, 2011a) for Sustainable Agricultural Land Management practices on crop land or the VCS module VMD0021 (VERRA, 2012) on the estimation of stocks in the soil carbon pool. The small size of farms and the diversified farming system together with more general constraints of carbon sequestration on crop land make the certification of carbon credits in agricultural crop land difficult (ACMI, 2022, p. 22). However, recent experience from the Western Kenya Soil Carbon Project (WKCP) shows that this is feasible (GIZ 2023).

The price of AFOLU carbon credits is highly variable. The price has dropped from USD 16 in January 2022 to USD 4 in January 2023 (CarbonCredits, 2023). The average price of agriculture CCs rated in 2020 at USD 10.38 and in 2021 at USD 8.81.

The demand for African CCs has increased at a rate of 35 % annually from 2016 to 2021 but is still at a low level of USD 123 million, with approximately 22 Mt CO_{2e} traded in 2021. It is estimated that Africa has a potential of 2,200 Mt CO_{2e} in 2030, with agriculture having a significant share in this figure.

3 Verra announced that VM0017 (VERRA 2011) will be closed in March 2023 in favour of method VM0042 (VERRA 2023).

The voluntary carbon market of Kenya has reached a volume of accumulated 2020 45,778 kt CO_{2e} with a target of 101,4670 kt CO_{2e} in 2030[4]. Kenya had Carbon Market projects certified by the Gold Standard (GS), VERRA/Voluntary Carbon Standard (VCS) and Plan Vivo in 2020. SLM practices are certified mainly by VERRA with a focus on agroforestry. But still most VCC activities are implemented in the non-agricultural sectors.

INFO

The Western Kenya Soil Carbon Project (WKCP)

GIZ and partners tested a voluntary carbon project on the areas where SLM practices have been implemented since years by small-scale farmers. Within the frame of the WKCP, a climate certification scheme for soil conservation measures in connection with the VCM is developed. The project measures the climate impacts of SLM according to the Verified Carbon Standard on 10,000 ha (once fully rolled out 32,000 ha) of smallholder farms in Western Kenya. The local coordination and not-for-profit entity *"Soil-Carbon Certification Services"* (SCCS) coordinates the certification of the climate effectiveness of these soil conservation measures. SCCS manages the MRV system and ensures financing, adoption, and quality of climate resilient SLM through its local extension provider Welthungerhilfe.

The project focuses on smallholder farmers as they are particularly vulnerable to changes in market structures and effects of climate change. Funds generated through the carbon credits are put into community and extension services. Before the project was established, extension services were not readily available and, if provided at all, only on an ad-hoc basis for a short period and mostly donor funded. By participating in the WKCP, the farmer families are entitled to bi-annual extension services on SLM practices for the next 20 years at no cost. About 27,000 farmer families (each with five members in average per household) participate in the carbon project and profit from these services. Through the introduced SLM measures, farmers in the project have 30 – 50 % higher climate risk-adjusted yields. Further benefits for the farmers are diversification of their income streams through assisted farm development and reduction of their dependency of artificial fertilizers with all associated cost reductions.

2.2.1 Beyond carbon – the assessment of SOC projects

SOC projects in agriculture need to consider not only the GHG balance of the farming system, but also other ecosystem services when contributing to the agroecological transition of the agriculture and food system. Food security as a basic human right as well as the impact on biodiversity and the other ecosystem services need to be accounted for.

4 Eastern Africa Alliance on Carbon Markets and Climate Finance, 2021. Carbon Market Profile: Kenya

The increase of SOC by implementing SLM practices contributes not only to carbon offsetting, but also to food security and other ecosystem services such as protection of biodiversity and water resources.

The 4p1000 initiative describes safeguarding, direct, indirect and cross-cutting criteria relevant for the assessment of SOC projects, in a 4-step assessment approach which is described in the following:

Step 1: Safeguarding Criteria are used to ensure that actions to increase SOC do not restrict human rights, or negatively affect land rights and poverty alleviation.

Step 2: Direct Reference Criteria are used to assess the direct effects of projects on i) SOC stocks and land degradation neutrality (SDG 15), ii) climate change adaptation, iii) climate change mitigation (SDG 13), and iv) food security (SDG 2).

Step 3: Indirect Reference Criteria are used to assess indirect effects of projects on a range of other economic, social and environmental dimensions, including welfare and well-being (SDG 12), biodiversity and ecosystem services (SDG 15), water and nutrient cycles (SDG 6), etc.

Step 4: Cross-cutting Dimensions of projects will be reviewed using cross-cutting criteria, including training and capacity building, participatory and socially inclusive approaches.

For each criterion, a set of default indicators and method of assessments are provided.

TABLE 4 4p1000 indicators and associated method principles for SOC project assessment Source: 4p1000 Initiative, 2021a

Step	Type	Criterion	SDGs
1	Safeguards	1.1 Human rights	1, 5, 16
		1.2 Land tenure rights	1, 16
		1.3 Poverty alleviation	1
2	Direct	2.1 Soil conservation/improvement and land restauration	15
		2.2 Soil organic carbon stock increase and maintenance	15
		2.3 Climate change mitigation	13
		2.4 Climate change adaptation	13
		2.5 Food security	2
3	Indirect	3.1 Biodiversity	15
		3.2 Water resources	6
		3.3 Welfare and well being	3, 8, 12
4	Cross-cutting	4.1 Includes and participatory approach	12, 17
		4.2 Training and capacity building	4, 17

2.2.2 Governmental carbon taxes and emissions trading schemes

Carbon Taxes and Emissions Trading Systems (ETSs) are considered the two instruments, which provide the necessary driving forces to reduce CO_2 emissions on one side and offsetting CO_2 from the atmosphere on the other side (Parry et al., 2022).

Carbon taxes are easy to administer and can be applied at the easiest point of tax such as coal, gas, and oil producers. ETSs require a more complex administration and need a sophisticated accounting system. In many countries, including e.g., Denmark, Finland, France, Ireland, and Norway, carbon taxes and ETSs are implemented simultaneously. The use of carbon revenues for the general state budget or the allocation to specific CO_2 reduction schemes is a political decision under consideration of the associated administrative burdens. The International Monetary Fund (IMF) finds that developing countries with a weak administration will face difficulties to administrate ETSs. The use and distribution of the carbon tax revenues as well as the allocation of ETSs are challenging the efficiency of CO_2 emission reduction and CO_2 offsetting.

Public investments can be popular with green investment especially preferred in climate concerned countries, whereas tax and deficit reduction bare the least of administrative burdens (see ▶ Table 4). Transferring carbon tax revenues to vulnerable households are assessed as having a low efficiency but a high political feasibility.

TABLE 5 The options for the use of carbon tax revenues

Source: IMF staff (Parry et al., 2022)

Instrument		Economic efficiency	Income distribution	Administrative Burden	Political Feasibility
General Revenue	Public investment	+	+	±	+
	Tax reduction	+	+	+	+
	Deficit reduction	±	±	+	–
Assistance to households	Lump-sum transfer	–	+	±	±
	Cash transfer or social assistance	±	+	±	+
	Assistance to HH energy bill	–	±	±	+

+: advantage ±: neither advantage nor disadvantage –: disadvantage

The revenues and carbon taxes and the ETSs can be used for investments in the reduction of CO_2 emissions and the offset of CO_2 from the atmosphere. The political feasibility of carbon taxes like any other tax depends on a wide consent in the society. ETSs are easier to implement due to their market-oriented nature but have substantial disadvantages regarding the efficiency and the distribution of revenues and the broader pricing of GHGs. ETSs may have less advantages in countries with low administrative capacity. The prices for the compensation of CO_{2e} varies from USD 2 in Japan to USD 10 in South Africa and up to 64 USD in France.

More on the adjustment of agricultural carbon projects to international and host country regulations can be found in the guidebook for project developers (GIZ 2023).

2.3 Case study area and historical data

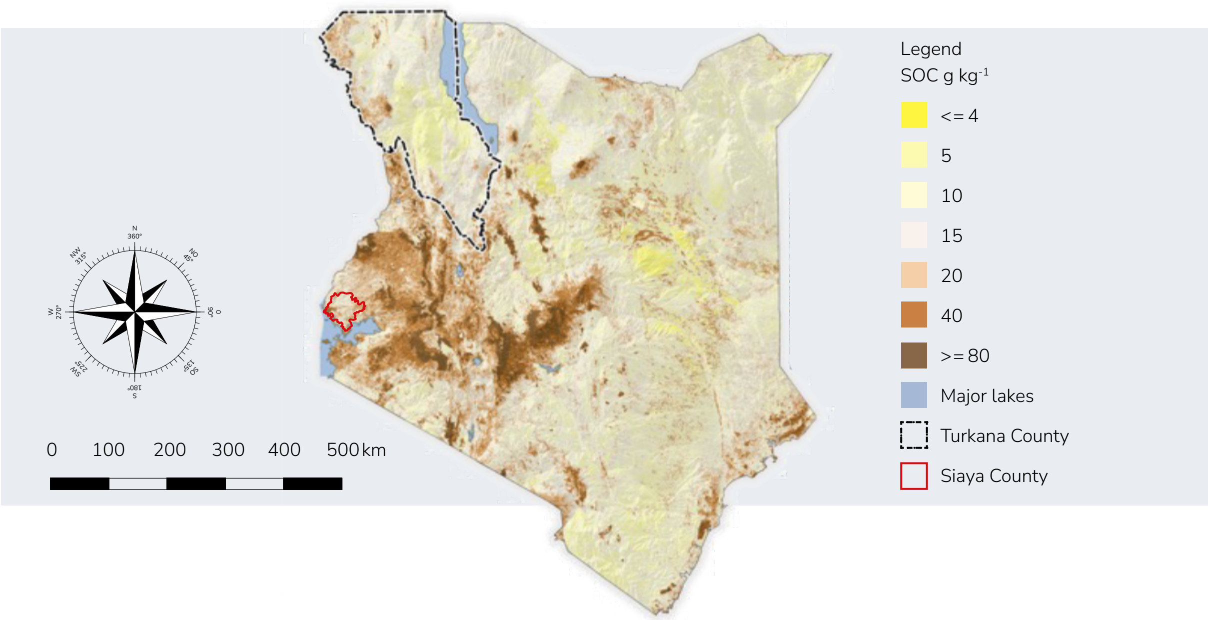
The study area is in Western Kenya and has been chosen in accordance with stakeholders and partner organisations. For the comparison of farm systems, several considerations were made to reduce the variability of natural conditions, such as precipitation, temperature, which would bias the results of comparing farming systems with the specific issue at stake. The study ensured that farming system were homogeneous/similar to extent of farm size with regard to acreage, animal stock, the cultivated crops and even farming practices, apart from the SLM practices implemented by the participating farmers, except the CTRL group. Furthermore, the area was selected because of the reasonable number of farmers, who implemented SLM practices for at least three years.

2.3.1 Soil organic carbon stocks and agro-ecological zones in the study area

In the study area of Siaya county, Vågen et al. indicate a SOC content of up to 40 g/kg in Siaya county. Croplands in many cases were found to be below 20 g/kg (▶ Figure 3) (Vågen et al., 2018a).

FIGURE 3 Carbon stocks in Kenya

Source: (Vågen et al., 2018a), available under Creative Commons Attribution 4.0 International (CC BY 4.0) license



Kibet et al. (2022) report a SOC content of approximately 12 g/kg for cropland cultivated with sorghum and approximately 6 g/kg for maize. Soil bulk density ranged from 1.3 g/cm³ to 1.6 g/cm³, with agroforestry having the lowest and grassland the highest figures of bulk density. The bulk density of plots with maize and sorghum at near 1.5 g/cm³ (Kibet et al., 2022).

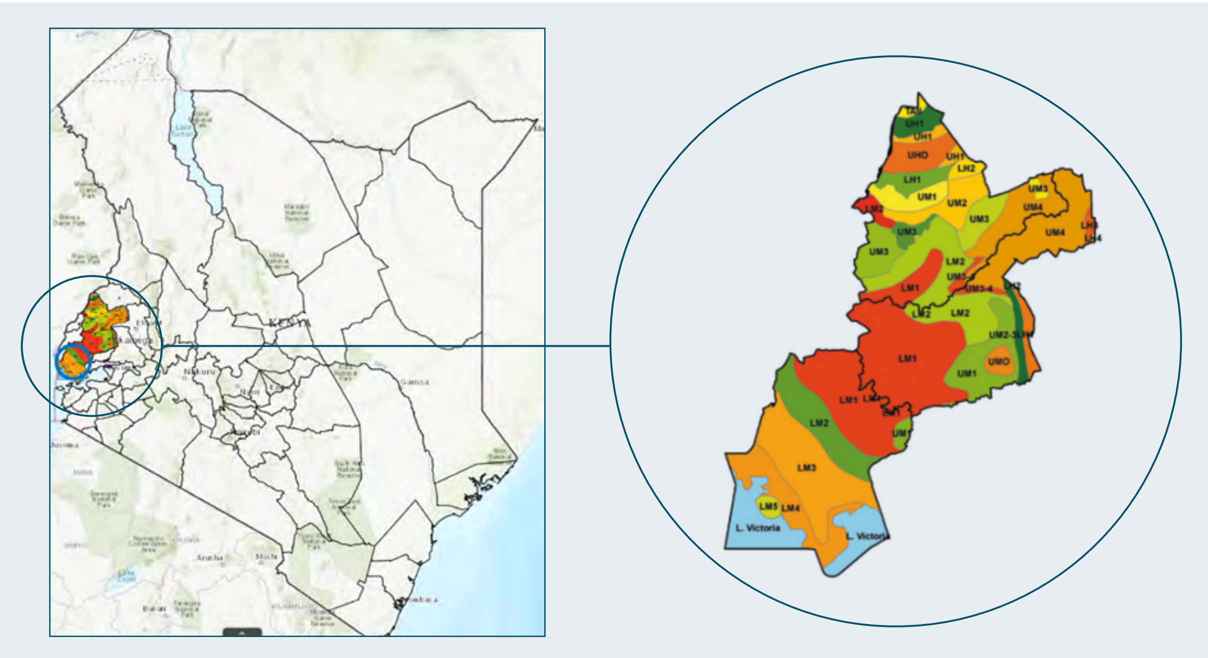
Sommer et al. found significant evidence in Bungoma county, that CA can reduce the loss of SOC stock in agricultural cropland in Kenya compared to the business-as-usual farming systems with a difference of 2.6 t CO_{2e} ha/year. Due to the lack of historical soil data from the same plots, the authors could not prove whether the difference is due to a lower rate of SOC reduction or due to an increase of SOC (Sommer, Paul, et al., 2018). Based on 200 samples the bulk density was at an average of 1.25 g/cm³; SOC at 18 g/kg; Clay and Sand content had a strong influence on SOC content with average of 30% clay (9.4 % min – 51% max) and 57 % (28 % min – 81% max) sand.

LM3 is the predominant agroecological zone of the study area. It is characterized as a semi-humid "Lower Midland Zone" with an annual mean temperature between 21°C and 24°C (Jaetzold, 1987). The left side of ► Figure 4 describes the GIZ ProSoil project area in Western Kenya. The agroecological zones of Siaya, Kakamega and Bungoma are displayed on the right[5] with the blue circle indicating the location of the participating households.

The total annual rainfall of Siaya County is depicted in ► Figure 5.

FIGURE 4 Siaya County in Western Kenya with agroecological zones (AEZ)

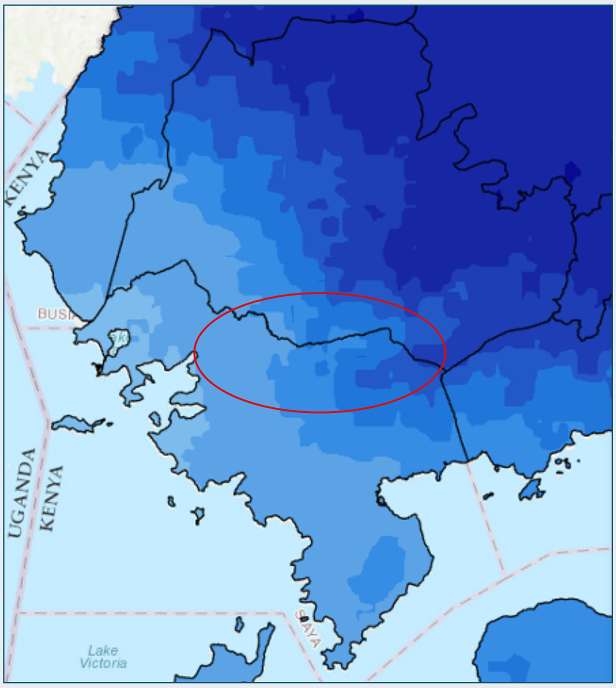
Source, left: Western Kenya Soil Geochemistry, 2022, right: Ministry of Agriculture, Kenya/ German Technical Assistance (GTZ) R. Jaetzold, J. Wieczorek, 2011.



5 Colours and letters distinguish AEZs, "LM" = Lower Midland Zone (annual mean temperature 21 – 24°C), "UM" = Upper Midland Zone (18 – 21°C), "LH" = Lower Highland Zone (15 – 18°C), "UH" = Upper Highland Zone (10 – 15°C).

FIGURE 5 Total annual rainfall in Siaya County

Source: Western Kenya Soil Geochemistry (Copyrights: Open Government License, CC BY 4.0 and CC BY 3,0)



Legend
Western Kenya data
Total annual rainfall (mm)
Value

- < 650
- 650 – 800
- 800 – 950
- 950 – 1,100
- 1,100 – 1,250
- 1,250 – 1,400
- 1,400 – 1,550
- 1,550 – 1,700
- 1,700 – 1,850
- > 1,850
- District boundaries
- Location of households

► Western Kenya Soil Geochemistry with ArcGISWeb AppBuilder

2.3.2 Farming system in the study area

According to the baseline study of Schuh (2015), the most common farming systems in Siaya county in 2015 were crop-based with a total gross margin of almost 200,000 KES/year and a profit of approximately 130,000 KES/year in 2015 with 80 % and 20 % coming from crop production and livestock production respectively (Schuh, C. 2015). ► Table 6 provides some basic figures on the farm system in the study area.

TABLE 6 Socio-economic figures of households in LM3 / Siaya county in 2015

Source: (Schuh, 2015b) (Schuh, 2015a)

Land use	acres
Total land operated	2.9
Crop land cultivated	2.6
Main crops	In %
Maize	30.7 %
Maize and beans	22.9 %
Kale	10.5 %
Sorghum	8.1 %
Cassava	4.2 %
Sugar cane	2.1 %
Permanent grassland	8.4 %

Average no of livestock	No.
Cattle total	5.8
Cows	2.8
Goats	1.9
Sheep	1.3
Chicken	7.3

The yields recorded during the baseline study are highlighted for maize with 492 kg/acre and season. The total annual milk production is approximately 460 litres per lactating cow. More than 80 % of maize, beans and milk is consumed by the household members themselves.

2.3.3 SLM practices promoted by GIZ ProSoil in the study area and impact on GHG mitigation

ProSoil Kenya supports the farmers in implementing SLM in Siaya, Kakamega and Bungoma county. The promoted practices consist of various components, having a potential for climate mitigation in crop production and carbon sequestration. ► Table 7 indicates the various components for the six technology packages. The practices have been documented in various publications, manuals and guidelines (African Conservation Tillage Network (ACT), 2018; FAO, 2007; Idowu & Grover, 2010; Mutua et al., 2014). CA, ISFM, and Agroforestry are the most relevant technology packages to increase SOC. The other packages of Integrated Pest Management (IPM), the Push-Pull method (PP) and the package on Good Agricultural Practice (GAP) are primarily targeting at the productivity of crops. This study focuses on the ISFM and CA packages.

TABLE 7 Technology packages supported by GIZ Kenya

Source: ProSoil Western Kenya 2021

SLM (technology packages)	Components
Conservation Agriculture (CA) (Corsi & Muminjanov, 2019)	› Continuous minimum mechanical soil disturbance › Permanent organic soil cover › Diversification of crop species grown in sequences and/or associations
Integrated Soil Fertility (ISFM) and Integrated Pest Management (IPM) (Fairhurst et al., 2012)	› Soil analyses › Liming of acidic soils › Use of compost and manure › Mineral fertilizer where needed › Bio-pesticides
Soil & Water Conservation (SWC) on- and off-farm	› Cross slope barriers following the contour lines › Direct sowing (no ploughing) › Mulching › Cover crops
Agroforestry (AF)	› Tree nurseries › Multipurpose trees › Fruit trees › Indigenous trees

Push-Pull method (PPM) (ICIPE, 2007)	› Use of trap and repellent plants (Desmodium & Pennisetum/Brachiaria) › Effective against striga weed, stem borer and fall army worm
Good Agricultural Practic-es (GAP)	› Sowing dates and depths › Seed rates › Row spacing › Weed management › Post-harvest management

FIGURE 6 Agroforestry system (top left), Nappia grass grown for the push-pull-method (top right), Maize field with cover crops (bottom left)
Source: GIZ/Wehinger

The technology packages are strongly interlinked and create synergies. Some farmers participating in ProSoil have implemented various components of the SLM practices. Farmers implementing ISFM and CA create synergies by implementing time. The package on GAP is considered a standard IPM and Push-Pull, AF and SWC at the same time. The package on GAP is considered a standard technology package, which require rather little effort, with a significant increase on productivity. ► Figure 7 and ► Figure 8 provide an overviewof the intervention logic of CA and ISFM. The main differences are the focus of no-till and the cultivation of cover crops of CA technology package, whereas ISFM focuses on the increase of soil fertility, with an emphasis to provide the right amount of organic and chemical fertilizer to the demand of each crop applied in the right time and the application of most relevant pest management measures. Both SLM packages target similar impact with food security, income and climate mitigation and adaptation.

FIGURE 7 Intervention logic of CA

Source: adopted from (African Conservation Tillage Network (ACT), 2018)

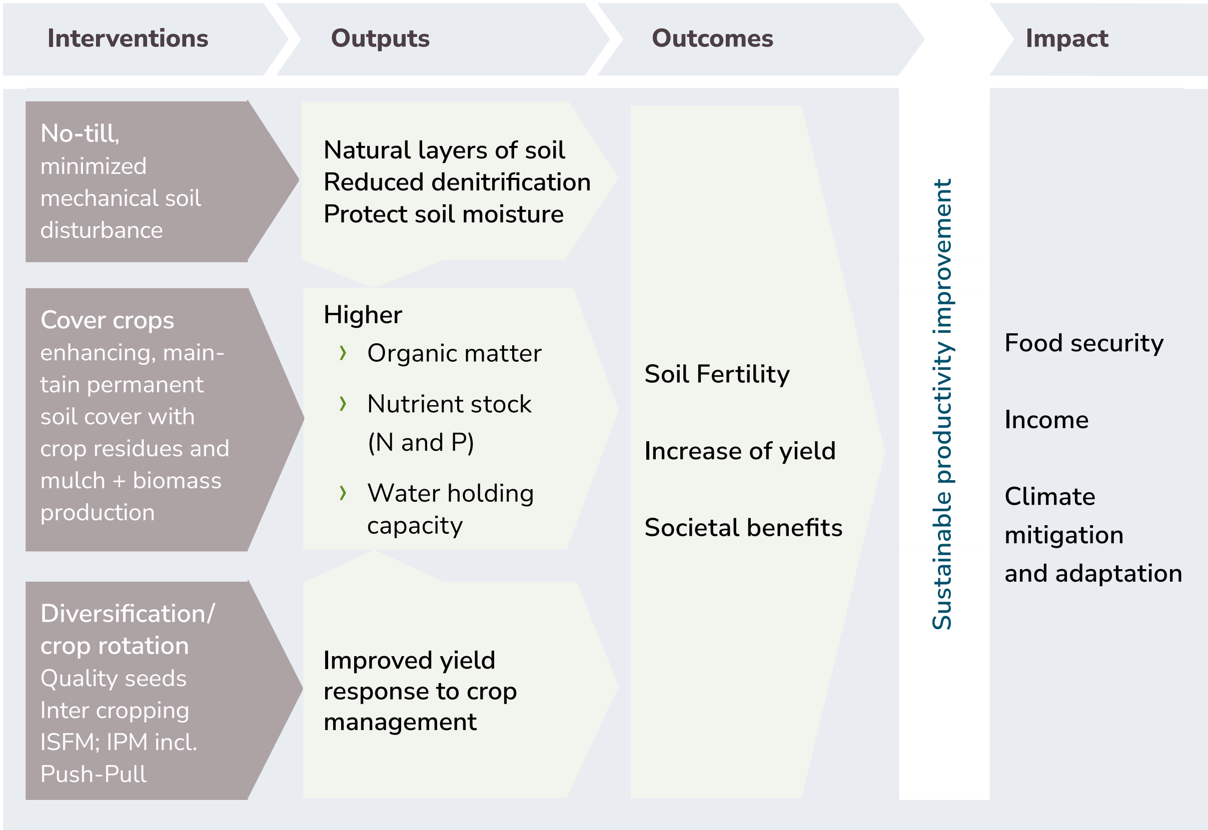
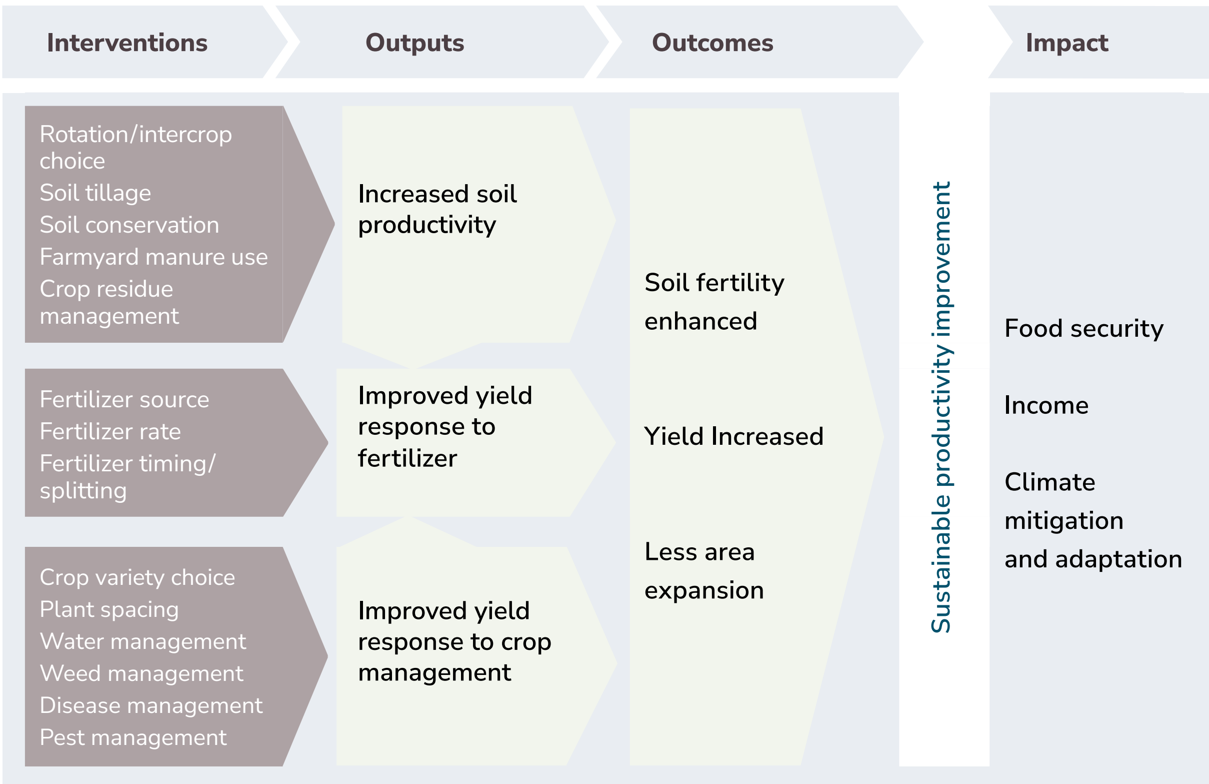


FIGURE 8 Intervention logic of ISFM

Source: adopted from (Bationo et al., 2012) licensed under a CC Attribution 3.0



2.3.4
Historical soil data of the study area

▶ Figure 9 and ▶ Table 8 present the characteristics and origins of the relevant soil types in the study area in Siaya County. The characteristics of the soil types are well drained, with a great variability on depth from shallow to very deep, with a fine to medium texture and a fertility ranging from low to high. Although the selected farms are in close vicinity, the soil types show a great variability.

FIGURE 9 Map of soil types near Bond, Siaya County

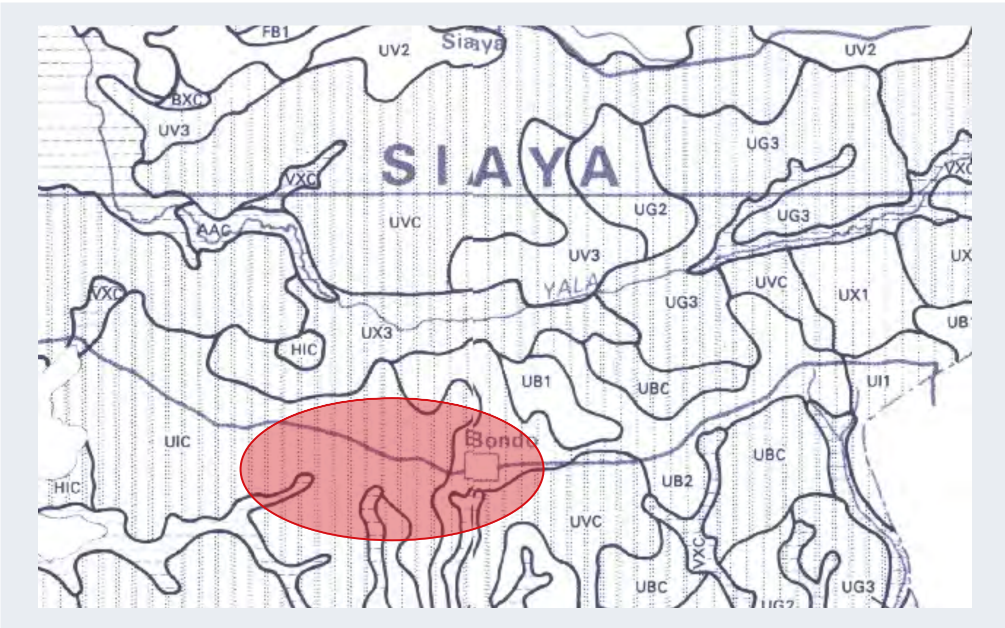


TABLE 8 Characteristics of the relevant soil types in Siaya County

Source: (Enserink, H.J. 1985. Sorghum Agronomy Investigations in Kenya using a Farming Systems Perspective) and Exploratory Soil Map of Kenya (Sombroek et al. 1982)[6]

U	Uplands (alt. 1250-1500 m, gently undulating to rolling, slopes 2–16%					
UB	Soils developed on basic igneous rocks (basalt, nephelinites, dolerites, etc.)					
UB1	Nitisols and Luvisols	w	d-vd	f	m-h	
UB2	Acrisols and Cambisols	w	md-d	f	l	
UBC	Same as UB1 and Lithosols	w	d/sh	f/m	m-h/l	Rock outcrops
UI	Soils developed on intermediate igneous rocks (diorites, andesites, phonolites, etc.)					
UIC	Lithosols, Cambisols and Acrisols	w	sh	m/f	l	Gravelly, rock outcrops
UVC	Lithosols, Luvisols and Arisols	w	sh/md	f	m-l	Gravelly, rock outcrops

6 Classes of soil characteristics indicated in the legend are:
Drainage: excessive (e), well (w), moderately well (mw), imperfect (i), poor (p)
Depth: very deep (vd: +120 cm), deep (d: 80–120), moderately deep (md: 50–80 cm), shallow (sh: 20–50 cm)
Texture: very find (vf), fine (f), medium (m), coarse (c), variable (v)
Fertility: high (h), moderate (m), low (l)

Over the last years various studies on the SOC stock were conducted in Western Kenya. The results are partially not easy to compare, because the methodology and the sampling depth are different.

Sommer et al. (2018) consider CA to account for 7.2 t C/ha higher carbon stock in the topsoil (0 – 20cm) than business as usual (BAU) in crop land in Bungoma county (Sommer, Silva, et al., 2018). The difference of SOC in g C/kg of CA was significant with values of 15 g C/kg for CA plots and approximately 10 g C/kg for BAU plots. Whether this difference is related to reduced carbon loss or carbon sequestration could not be verified, due to the lack of historical data. If the difference was attributed to carbon sequestration, the authors calculated an annual rate of 720 kg C/ha of C or of 2.6t CO_{2e}/ha/year.

Winowiecki et al. (2022) reported a significant increase of SOC (g/kg) of the topsoil (0 – 30 cm) in the plots of farm households participating in GIZ ProSoil from 2015 to 2020 (L. A. Winowiecki et al., 2022). For Siaya county the authors measured an increase in SOC between 2015 and 2020 of 2 g/kg from 15 g/kg to 17 g/kg. In Bungoma and Kakamega county, the absolute numbers are slightly higher.

Soil samples taken from ProSoil farmers[7] in 2018 and 2019 were analysed from different certified soil laboratories using different methodologies: Soil samples had an average 18.4 g/kg SOC (N = 500), and 14.27 g/kg SOC (N=132). Another set of data scanned with a handheld infrared scanner indicated an average of 13.72 g/kg SOC (N = 56).

Results from reviewing literature on SOC contents of agricultural crop land in Western Kenya show that only Sommer et al. have compared the SOC stock of ProSoil farmers with other farms, which do not participate in the programme (Sommer, Silva, et al., 2018).

A more detailed summary on the state of science on SOC in East Africa is summarized in the technical report on the East Africa Soil Carbon Workshop of CIAT in 2018 (Nyawira & Sommer, 2018) and the Policy Brief on including soil organic carbon into national determined contributions: Insights from Kenya by ICRAF (Aynekulu et al., 2022a). Key messages therein include, that the potential of SLM practices to increasing SOC is much higher than many scientists and policy makers are aware of. They emphasize that land degradation and the accompanying loss of soil health and soil fertility through the depletion of SOC is a threat not only to food security but also to other ecosystem services of soils.

TABLE 9 SOC content on agricultural crop land in Western Kenya

Authors / Source	Results on SOC in g/kg
(Sommer, Silva, et al., 2018) 0 – 30 cm	15 g/kg for CA plots / 10 g/kg for BAU plots.
(Winowiecki et al., 2022) 0 – 30 cm	15 g/kg in 2015 and 17 g/kg in 2020 increase at ProSoil farmers in Western Kenya
Welthungerhilfe (ProSoil) 0 – 30 cm	2018 and 2019 18.4 g/kg average over all samples 14.3 g/kg from certified laboratories 13.72 g/kg with a handheld NIR scanner

7 Soil analysis data received from Welthungerhilfe / ProSoil in 2021

03
Methodology

The study follows ELDs 6+1 step approach to assess the economics of land management (ELD 2015). Details of the study design and specific methodology are summarized in ► Table 10 according to the individual steps of the approach.

TABLE 10 Study design according to ELDs 6+1 step

Source: adopted from (ELD Initiative, 2015)

	Description	Tools and methods
Step 1	Inception	Literature review, background and case studies. Stakeholder mapping and cooperation strategy. General socio-economic data on agriculture in the study area. Coordination with CGIAR and ProSoil monitoring unit. Recommendations on data collection and methodology.
Step 2	Geographical characteristics	Characterization of the agro-ecological zones and corresponding agriculture farming systems. Defining typical farming systems based on available socio-economic analysis. The illustration of the geographical characteristics, based on existing data layers on soil erosion, land cover, organic matter was limited to existing maps and figures focussing on the plots and maps of the farms.
Step 3	Types of ecosystem services	Description of the characteristics of the farming systems and the ecosystem services, based on the household survey and the soil analysis.
Step 4	Role of ecosystem services and economic valuation	Economic valuation of the ecosystem services based on a margin analysis, comparing CA farmers and ISFM farmers with CTRL farmers, which had not been involved in any activities of ProSoil up until then. The geographical area was restricted to one single agro-ecological zone, where it was expected to have similar natural conditions with regards to precipitation, temperature, soil parameters and socio-economic features of the households.
Step 5	Patterns and pressures	With the household survey together with the evaluation of the soil samples provides insight in patterns and pressures in favour or against the implementation of SLMs.
Step 6	Cost-benefit analysis and decision-making	The costs benefit analysis is then directly linked to the soil sample data, to provide evidence of the effects of SLM on soil fertility/reduction of soil degradation, while describing the economic benefits/costs.
Step 6+1	Take action: change, adapt and facilitate	After the first round of interviews in August 2022, the farmers received feedback on their soil-analysis with detailed recommendations on how to improve and what actions to take.The results of the study will be presented and discussed after the draft final report was submitted and approved.

The review of existing data, research papers and reports from the project itself in the inception phase revealed a lack of relevant information needed for the study. The following challenges regarding the availability of data for this study were found in step 1 of the ELD 6+1 approach:

- Geo-referenced soil sampling data for the project area was not available.
- Existing mapping of the fields, including field sizes of the farms was not precise enough for calculating potential SOC stock.
- Bulk density measurements had never been implemented and were mostly unavailable from other studies.
- Missing links and correlation of SOC to socio-economic analysis (e.g. household income and soil parameters).
- Household surveys covered the whole of Western Kenya area, having a large variety of soils and different agro-ecological zones. This made it difficult to compare economic data with the effect of SLM practices on carbon content.
- The quality of soil sampling procedures could not be guaranteed due to a lack of documentation.

Subsequently, the study design was revised, and additional soil sampling and soil testing was carried out.

The literature review revealed some general shortcomings of several studies on carbon sequestration and SLM such as:

- Interdisciplinary studies combining soil science or natural science and socio-economic analyses with a specific view at soil carbon are missing. Specifically, no study analysed the correlations of SOC stock on arable land and the economic performance of farm households.
- Studies on SOC including co-benefits on biodiversity or food security (respectively income) for the specific were not available.
- Studies on SLM mainly focused on the increase or decrease of yield of specific crops and considered only some SLM practices.
- On-farm studies with a holistic look at the whole farm are rare (Sinclair, 2020b). The baseline study on economic performance of farms in the project area did not consider the impact of SLM on carbon sequestration or biodiversity.

Based on the review of documents, reports and publications, a set of necessary data was elaborated and translated into the soil sampling design and the soil analysis as well as into an in-depth household questionnaire. The following data was acquired:

Economy of small holder farms
- Total sales and consumption of products of the farm household
- Variable and fixed costs for the operation of the farm
- Farm assets (land, buildings, machinery, livestock's, crops and plants)
- Profit of the whole farm household including self-consumption
- All relevant production units, yields, prices, inputs and sales

Soil Carbon
- SOC
- Bulk density
- General soil data (silt, clay, sand), N, P, K, Mg

Erosion and water management

- Physical infrastructure for the benefit of water harvesting and storage on the farms
- Agro-forestry area and other natural and-semi-natural structures on the farm

Biodiversity

- Indicator on soil biodiversity included soil micro-organisms

3.1 Farming systems approach (FSA) versus single crop analysis

In the past, many studies on SLM practices described costs and benefits of SLM for a single crop, comparing practices like the application of FYM and/or compost and the cultivation of cover crops versus the conventional/ traditional or BAU farming practices. Considering the complexity of SLM approaches, this single crop or value chain approach falls short of a comprehensive impact assessment. SLM analysis must consider the total farm with its various components such as crop production, grass land, animal husbandry, and agroforestry, to understand the dynamics of SOC stocks, soil fertility, yields and income of a single farm household (Sinclair, 2020b). More than that, the FSA is obligatory especially for carbon sequestration schemes for the following reasons:

1. SOC of all agriculturally used plots should be balanced: This is to avoid un-equal allocation of biomass within a farming system, which could result in an increase of SOC in one part of the farm while depleting other parts (VERRA, 2011b).
2. GHG mitigation cannot be limited to carbon sequestration but must consider other GHGs such as CH_4 or N_2O, as well as landscape elements such as agroforestry and hedges. They are related to the farming systems but may not directly influence SOC in cropland (FAO, 2014).
3. The adoption of a holistic management that considers the inter-relatedness of all parts of the farming system should be considered the standard for SLM approaches and basic principle for regenerative agriculture (4p1000 initiative, 2021b).
4. The socio-economic and environmental assessment of smallholder farms is incomplete, unless the most relevant production units are considered, which generate the biggest part of income (Sinclair & Coe, 2019).

This study therefore adopts a FSA, starting from the selection of the area, the choice to compare the complete farm household income including income from home-consumption, and the methodology of soil sampling and measuring SOC.

3.2 Selection of project farms and control group

The findings of literature review and interviews conducted during the inception phase led to the decision to concentrate the study on agro-ecological zones with similar natural conditions (see ► 2.3).

The households to participate in the survey were chosen based on a stratified selection, using the following parameters: The CA, the ISFM and the CTRL farmers comprised each a group of at least 20 individual household farms. All the CA and ISFM farmers had at least 2 acres of land and had practiced CA or ISFM for a minimum of three years on at least 66 % of their cultivated land. The CTRL farmers had similar acreage and were located in the neighbourhood of the CA and ISFM farmers. To ensure gender and age parity, 30 % of the households sampled were female household heads below 35 years of age. The final selection was done in close cooperation with staff members of Welthungerhilfe (WHH), an implementing partner of ProSoil in the county Siaya.

The sample size of 64 households is relatively small. This shortcoming though is countered by the fact that the farmers' answers and thus the results are relatively homogeneous, so that there is a high saturation of the data.

3.3 Household survey and economics of the farming system

The survey data was collected using KoboToolbox software for android devices. In this case a 10-inch, 2022 edition tablet with LTE was used. For the detailed evaluation of the collected data, a standard calculation software was used. The key economic indicators elaborated from the data of the survey were:

General socio-economic data of the household e.g. gender and age of household head, number and age of household members, education level.

Revenues from sale of product and consumption of agricultural products.

Variable costs for the operation of the farming activities, including seeds, organic and inorganic fertilizer, pesticides, pharmaceuticals, etc. – if necessary, with relevant description of their impact on climate mitigation.

Gross margin of the total household income from agricultural activities minus variable costs.

General Costs: General and specific costs of production, investments, resources owned and rented/leased e.g.

- Buildings
- Machinery
- General cost of inputs

Profit/loss per year
Gross margin – General cost = Annual profit

A major part of the household survey was dedicated to the implementation of specific SLM practices.

3.4 Measuring soil carbon and soil health

The assessment of SOC stock was based on soil analysis with a Near Infrared Scanner of Soil care Kenya on the spot. Additional analysis for cross checking the results was foreseen with a midrange infra-red scanner after processing the soil samples at ICRAF in Nairobi. The following guidelines for sampling and processing of the soil were elaborated, based on relevant protocols and with small amendments (Trachtenberg et al., 2021).

3.4.1 Soil sampling

The soil sampling protocol that incorporates geo-referenced data of the plot with a mapping software was used. Priority for the mapping of the fields was given to the existing UNIQUE DATA Collection App, which is used for the "Western Kenya Soil Carbon Project" (GIZ 2023). Samples from households who had not been mapped with the UNIQUE app, were taken using a free software for the mapping of the plots.

The samples for SOC were taken from three levels of 0–30 cm, 30–60 cm and 60 –100 cm. The samples for the bulk density test were taken from 0–30 cm, 30–60 cm and 60 –100 cm.

For the actual soil sampling, detailed instructions were elaborated. Together with the collection of relevant information and a unique sample ID the data collection was most accurate. For each plot, a sampling pattern was designed to collect nine subsamples, each with one single georeferenced centre point. This design was used to make sure it can be easily applied with little technical equipment and repeated in the future.

Instructions for the sampling were elaborated in detail and provided to the field staff with handouts and during a training unit before starting the sampling exercise. The household survey team and the soil sampling team worked hand in hand to make sure that mapping, sampling and assessment of the relevant SLM practices as well as economic parameters corresponded.

FIGURE 10 Mapping the plots with smartphone Apps

Source: Google Play Store and app developer (UNIQUE, StudioNoFrame)

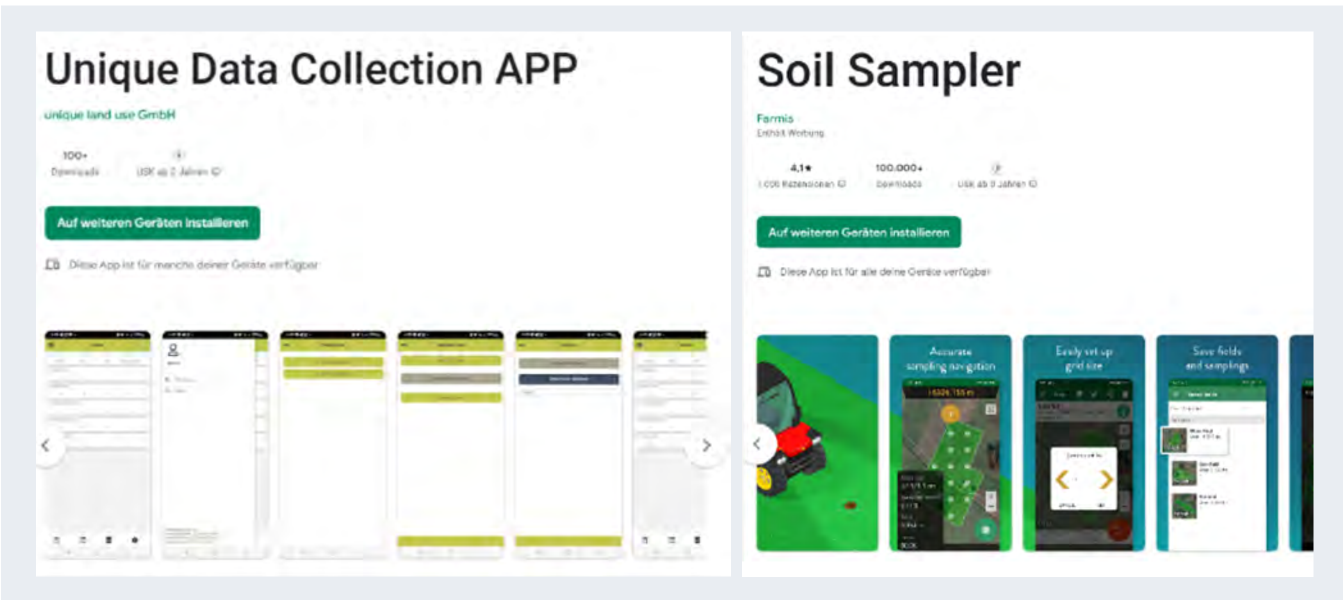
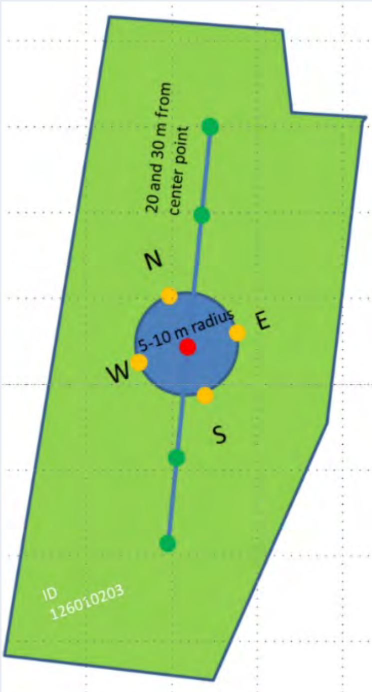


FIGURE 11 Soil sampling design and instructions



Step 1. Centre point (GPS)
A point at the centre of the field was chosen to document the GPS data.

Step 2. Satellite points
A sample was then taken at 5 to 10 meters from the centre point North, South, East, West.

Step 3. Parallel points
An imaginary line was drawn parallel to the longest side going through the centre point. Another 2 samples were taken at each side at a distance of 20 up to 30 meters from the centre point.

Step 4: Mix and divide
All subsamples were mixed well. The final sample was put in a bag for analysis

FIGURE 12 Soil sampling process

Source: GIZ/Wehinger

3.4.2
Soil processing

Soon after collection, soils were processed and dried at the Kenya Forestry Research Institute

(KEFRI) located in Maseno subcounty. After drying, the samples were crushed and sieved with a 2 mm sieve at the premises of WHH in Siaya town.

3.4.3
Soil analysis

The soil analysis was implemented on-site with a handheld NIR scanner. For additional validation of the results approximately 60 % of the samples were sent to the soil lab at World Agroforestry ICRAF in Nairobi for further analyses.

3.4.4
Most relevant equations for CO_{2e} stock

The commonly used equation for the calculation of the SOC stock causes an error, if the SOC content is measured at a fixed soil depth (e.g. 0 – 30 cm), because SOC changes lead to a change of Bulk Density (BD) (Fowler et al., 2022).

The following equation to calculate the SOC stock of a specific area was used:

SOC stock

$$SOCstock = SOCc \cdot BD \cdot D \cdot Area$$

SOC stock = SOC in t/ac (4046.87 m^2)
SOCc = SOC content as a % or g/kg soil mass
BD = Bulk Density (g/m^3)
D = Soil surface depth [m] of the sampling depth
Area = surface of the plot to be accounted for

FIGURE 13 Instructions for sample processing

Source: Own depiction

CO_{2e} stock

The equation for CO_2 sequestered in soil was based on CO_2 equivalents (CO_{2e}), which is used to balance other GHGs against each other.

CO_{2e} stock = SOC stock · 44/12 or (3,67)

SOC stock = Stock of SOC as mentioned above
44 = Molecular weight of Carbon
12 = Molecular weight of Oxygen

The sampling depth is usually the same with 0 – 100 cm, taking samples from the top soil from 0 – 30 cm, subsoil 30 – 60 cm and the lowest level from 60 – 100 cm. Measuring SOC change in lower soil levels usually was not applicable, because soil sampling below 100 cm is extremely costly.

Increased SOC content lowers bulk density. This results in a bias of the above-mentioned equation, causing an underestimation of the SOC stock. Therefore, the equivalent soil mass (ESM) approach for the calculation of the new BD and an adjusted soil depth was used.

Equivalent Soil mass (ESM) approach

SOCstock=BDn · Da · SOCn

SOC stock = SOC in t/ac (4046.87 m^2)
BDn = New bulk density (g/cm^3) based on the mineral soil mass
Da = Adjusted soil surface depth [m]
SOCn = New SOC as a decimal percent [%]

Equation for mineral soil mass

The mineral soil mass was calculated to overcome errors by different soil organic matter (SOM) content. As mentioned above, the soil organic matter corresponds to the SOC content with a factor of 1.9 (former 1.724) and vice versa with a relation of SOC = 0.52 (0.58) · SOM (Minasny et al., 2020).

Mm=Mt · (1 – k · SOCc)

Mm = Mineral soil mass
Mt = Total soil mass
K = 1.9
SOC = SOC content as a decimal percent [%]

Adjusted soil surface depth

To correct for the mistake in SOC stock calculation with a fixed depth of sampling the following equation was used for the adjusted soil depth:

Mn = Mi
Da · BDn · (1-k · SOCn)=Di · BDi · (1 – k · SOCi)
$Da = Di \cdot {}^{BDi}/_{Bdn} \cdot {}^{(1-k \cdot SOCi)}/_{(1-k \cdot SOCn)}$

Mi = Initial mineral soil mass per area [t/ac]
Mn = New mineral soil mass per area [t/ac]
Di = Initial depth (cm)
Da = Adjusted soil surface depth [cm]
BDi = Initial bulk density [g/cm^{-3})]
BDn = New bulk density [g/cm^{-3})]
SOCi = Initial SOCc as a decimal percent [%]
SOCn = New SOCc as a decimal percent [%]

The most relevant take away from the mathematical section on the equation to calculate the SOC stock is the **complexity of solid and accurate SOC stock accounting**. Furthermore, BD is the parameter which is most difficult to measure in the field due to high costs. Great efforts were made to use pedotransfer functions to overcome this obstacle. Since soil testing becomes more efficient using Near Infrared (NIR) or Mid Infrared scanners, which can detect the soil texture, the accounting of SOC stocks may become easier and more accurate.

3.5 Limitations and shortcomings of the methodology

SOC measurements were made on all farms, with the majority of 117 samples taken at 0 – 30 cm depth. 47 samples were taken from 30 – 60 cm and 12 samples from 60 – 90 cm (100) cm. Due to the available tools for soil sampling, the measurement of SOC in lower levels were partly not possible. Rocks and high BD restricted the implementation of the sampling scheme.

The measurement of BD was limited to the sampling depths of 0 – 30 cm and 30 – 60 cm. Due to the effort needed for BD measures, the measures were limited to 71 BD samples. Unfortunately, the sampling team took only 3 BD measures from only one farm of the CTRL group at 30 – 60 cm. The bulk density of the lowest level from 60 – 100 cm had to be estimated, based on the other levels and literature.

The average SOC content for one farm was calculated based on the average SOC content of all plots on the farm, thus being summarized in one single value per farm, although CA and ISFM farmers implemented the SLM practices only on parts of the farm. The SOC contents of the three groups (CA/ISFM/CTRL) could be compared.

Extreme values, which were way out of the range from other values, were eliminated from any equation e.g., CEC with 400 – 500 mmol+/kg versus the average of app. 150 mmol+/kg. Possibly, the SOC stocks were also underestimated because most samples which were taken from below 30 cm soil depth were dried before scanning. This may have resulted in low SOC values, since the NIR scanner is programmed to measure moist samples. Since the values of SOC of CA (9.58 g/kg), ISFM (9.60 g/kg) and CTRL (9.55 g/kg) farmers are in a very close range the error is considered to be very little.

04

Results

This chapter presents the results of the household survey and the SOC analysis regarding the impact of SLM on SOC, soil biodiversity and the economic performance of the households. The results show the differences and similarities of the CA and ISFM farms compared to the CTRL farms.

4.1 Results of the household survey

A total of 64 (n = 64) small-scale farmers were interviewed using semi-structured questionnaires. This involved 22 farmers practicing CA, and 21 farmers practicing ISFM. To effectively compare the changes resulting from the two interventions, 21 farmers, who were practicing neither CA nor ISFM – the "control group" (named CTRL) were interviewed.

SLM	No. of household	Location	No. of household
CA	22	Bondo	46
ISFM	21	Rarieda	9
CTRL	21	Alego-Usonga	9

Source: household survey 2022

4.1.1 Socio-economic parameters describing the households

More than half of the households (54.7 %, n = 35) were male headed with an average size of four members. Majority (71.9 %, n = 46) of the household heads were middle aged. The results further show that very few (9 %, n = 2) CA respondents had post-secondary education compared to 23.8 % (n = 5) and 19 % (n = 4) of the ISFM farmers and the CTRL farmers respectively.

Gender by household	Interview partner	Other household members
Male	35	142
Female	29	126
Age of the household members	**Interview partner**	**Other household members**
< 15	0	70
15–35	12	103
36–60	34	70
> 60	18	25

Source: household survey 2022

The level of education of the interview partners was almost the same for all three groups – outlined in Table 11, with one having a degree and six having a diploma.

TABLE 11 Education of the interview partner
Source: household survey 2022

	Interview partners			Other members
	CA	ISFM	CTRL	
Primary	9	8	10	112
Secondary	11	8	7	97
Certificate	1	2	1	19
Diploma	1	3	2	28
Degree	0	0	1	12

TABLE 12 Attended trainings by CA and ISFM farmers
Source: household survey 2022

Attended Trainings	Farmers attending	Ø Duration in days	Ø Relevance
CA	17	2.7	4.9
ISFM	29	2.3	4.6
Agroforestry	17	2.8	4.8
Cover crops	7	2.5	4.6
Vermicompost	21	2.9	4.8
Compost and manure	18	2.9	4.8
Push Pull	4	3.0	4.7
Tree nursery	13	2.6	4.6
Crop production	11	3.4	4.6
Vegetables	3	3.0	4.3
Animal husbandry	6	3.4	4.9
Financial literacy	3	3.0	5.0
others	11	2.9	4.8

Trainings received

Farmers from the CTRL group stated that they have not received any training whatsoever. All respondents from the CA (100 %, n = 22) and ISFM (100 %, n = 21) had attended at least one of the trainings on farming and SLM practices. The farmers were mainly trained on ISFM (34.9 %, n = 15), CA (20.9 %, n = 9), agroforestry (6.9 %, n = 3), and composting and organic farming (25.6 %, n = 11). All trainings were rated as highly relevant (average score = 4.7/5) by those (n = 43) who attended the SLM trainings.

4.1.2 The farming system and agricultural activities

Owned and cultivated area

All respondents owned the land they farm with a mean farm size of 2.6 acres (1.1 ha) reflecting the small-scale nature of farms surveyed. Most farmers reported to have cultivated only parts of their owned land with a mean value of 1.55 ac (CA), 1.86 ac (ISFM) and 1.44 ac (CTRL) cultivated land. The other area is not cultivated. The following paragraphs therefore relate to the cultivated land of the farmers.

More than half (n = 37) of the respondents reported to have cultivated two plots. Only 6 farmers (with 3 CA, 2 ISFM and 1 CTRL) reported to cultivate 3 or more different plots. Most farmers grow various crops on one single parcel.

TABLE 13 Owned and cultivated land of the participating farmers

Source: household survey 2022

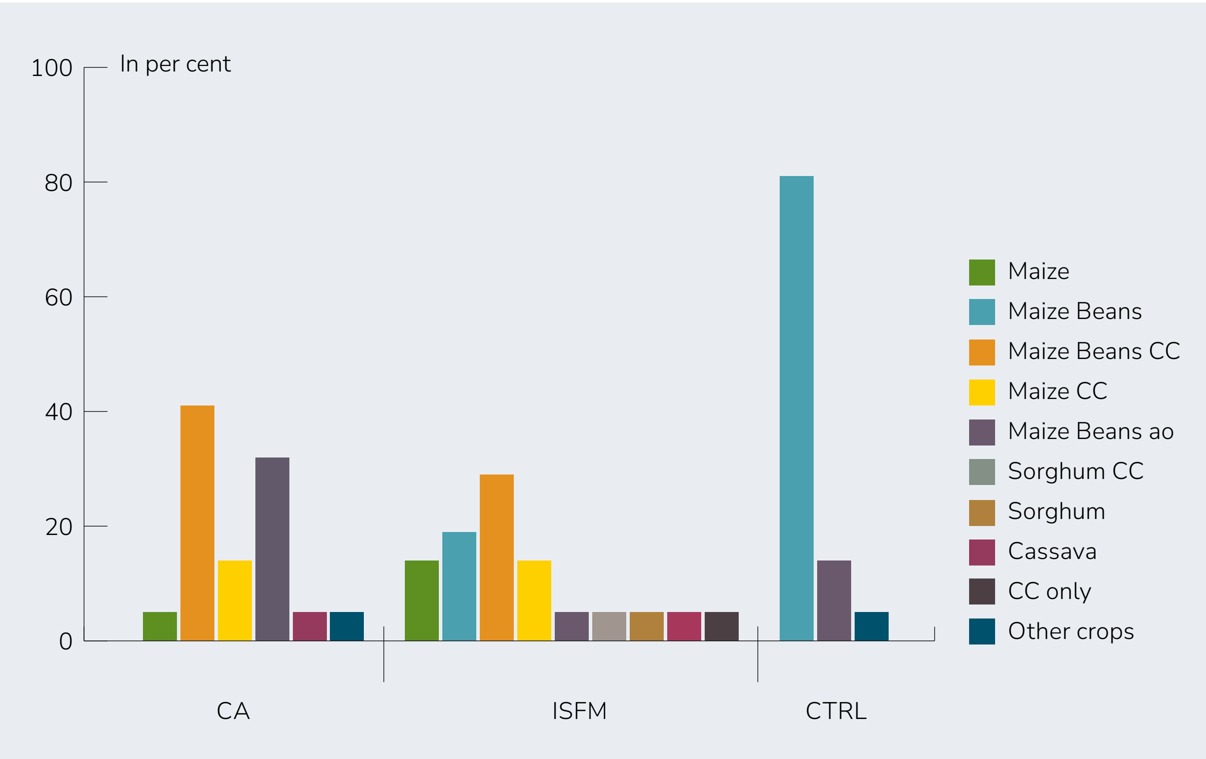
	Total owned area	Cultivated area	Other area	Number of plots per farm		
	ac	ac	ac	1 plot	2 plots	3 or more plots
CA	2.70	1.55	0.89	22	14	3
ISFM	2.88	1.86	0.95	21	12	2
CTRL	2.27	1.44	0.83	21	11	1

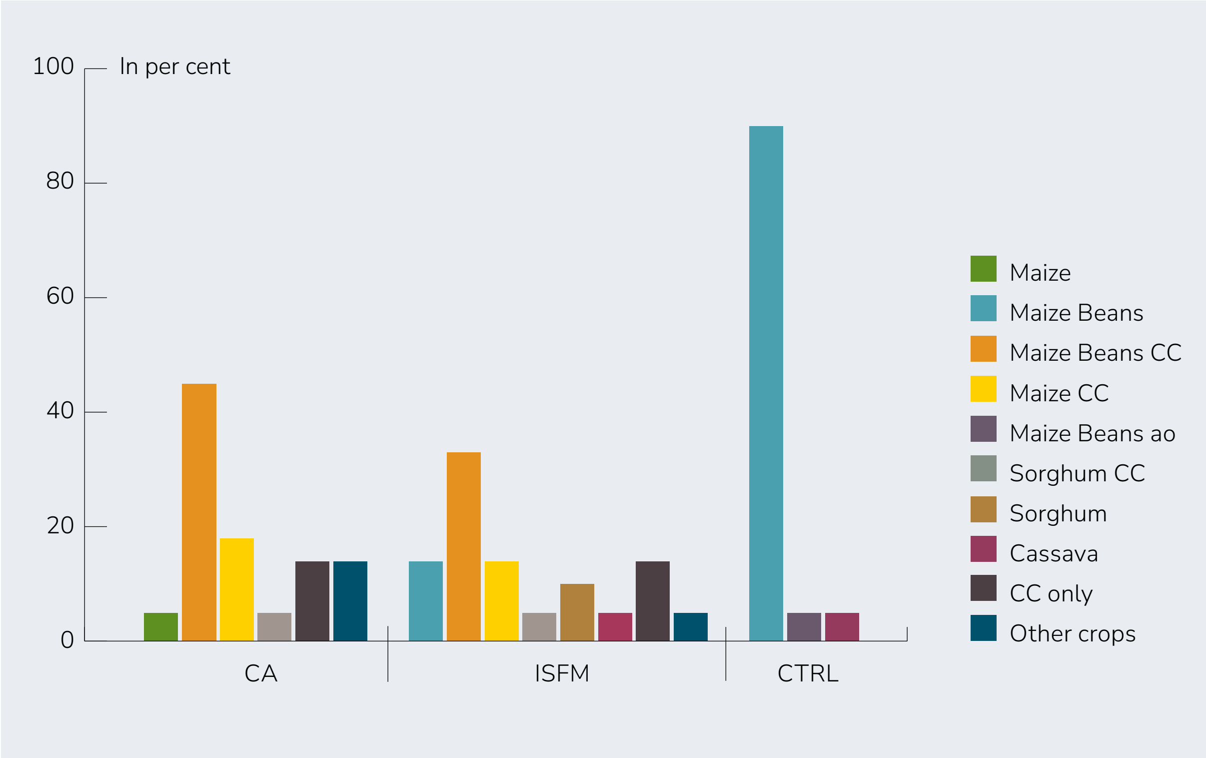
Crop production

► Figure 14 describes the crops produced by the surveyed households. Maize and beans were the most grown crops (75 %, n = 48). These crops must be considered the main source of nutrition for the households. The crops produced by the CTRL farmers are dominated by maize and beans and a small number of other crops, whereas CA and ISFM production is much more divers.

FIGURE 14 Crop production plot 1 in spring season (above) and fall season (next page) in 2021

Source: household survey 2022





CTRL farmers did not cultivate cover crops. 18 CA (81.8 %) and 14 ISFM (66.7 %) farmers had cover crops on their plots, which shows that the cultivation of cover crops is part of both SLM approaches. The most common cover crops used by the CA and ISFM farmers include the *Desmodium intortum* (tick clover), *Mucuna pruriens* (Velvet Bean), *Canavalia Ensiform* is (Jack Bean), *Crotalaria juncea* (Hemp), and the *Dolichos lablab* (Egyptian Bean).

Other crops grown include sorghum, cassava, and potatoes. The other plots are cultivated with the similar crops, with only very little variability from plot No. 1.

Vegetable production

More than half of the respondents (59.4 %, n = 38) grew vegetables. The average area used for vegetable production was approximately 600 m² (CA), 500 m² (ISFM) and 700 m² (CTRL). Thus, the differences in vegetable production between CA, ISFM and CTRL farmers are small. The most grown vegetables included collard greens, kales, sukuma wiki and spider plant, cultivated on app. 70 % of the vegetable plots. The other 30 % of the vegetable plots are cultivated with a variety of local indigenous vegetables. Only one CA farmer produces pumpkins, which seemed to thrive very well.

Animal husbandry

In terms of livestock, indigenous poultry are among the most widely reared livestock (95.3 %, n = 61), providing valuable disposable income for the households. Chickens are kept on free-range to scavenge and look for food. Modern drugs are rarely used to address diseases and pests. On average, households keep 19.94 chicken in average with the ISFM farmers (23.9), CA famers (21.5) keeping relatively more chicken compared to the CTRL farmers (14.5). There are several threats to market competitiveness for chicken, which are though general to the sector: Market competition from exotic birds, diseases, pests and predation, as well as costs of drugs and general bird mortalities, leading to low value for the local chicken due to low prices. The general market organization is weak and less determinable. No selective breeding is apparent, and/or practiced.

Respondents also keep cattle, goats and sheep as a source of household food and income. On average, households keep an average of 3.6 cows. The mean cow herd size for the CA, ISFM and CTRL farmers was 3.6, 4.5, and 2.7, respectively. Cattle breeds consist of a mixture of indigenous breeds and crossbreeds. The indigenous cattle are well adapted to the local conditions, although crossbreeding with higher yielding breeds was an increasingly common practice. To conveniently quantify a wide range of different livestock types and sizes in a standardized manner, tropical livestock units (TLU) are used, where one cattle with a body weight of 250 kilograms is considered one TLU. The results show that the ISFM farmers (TLU = 10.6) and CA (TLU = 8.9) farmers had relatively more tropical livestock units compared to the CTRL (TLU = 6.9).

Results on the sale of livestock and livestock products show that very few respondents sell their livestock. Market timing for live animals is influenced by the availability of pasture and water, an animal's optimum body condition, as well as household's cash needs. Generally, livestock productivity is very low. Milk is the most important livestock product. However, few households (10.9 %, n = 7) get sufficient milk from indigenous local cattle breeds for consumption and for sale. The production of milk is not market-oriented and only a minor portion of the locally produced milk enters the commercial sector because of marketing constraints and lack of processing techniques suitable for smallholder dairies. Milk and milk products are channelled to consumers through the informal market which involves direct delivery of fresh milk by producers to consumer in the immediate neighbourhood.

TABLE 14 Livestock production in 2021

Source: household survey 2022

Livestock production of households		Hens	Cows	Cattle young	Calves	Goats adult	Goats young	Sheep adult	Sheep young	Bee-hives
Average per household	CA	23	4	3	1	5	5	5	5	40
	ISFM	26	5	5	2	6	0	6	1	5
	CTRL	12	3	3	0	7	11	5	0	8
Household with livestock	CA	20	18	12	1	21	5	8	5	1
	ISFM	21	17	4	1	13	0	7	1	1
	CTRL	20	12	5	0	11	2	5	0	2
Total no. of animals	CA	461	65	15	1	49	10	26	8	40
	ISFM	541	77	3	2	50	0	22	1	5
	CTRL	243	33	3	0	42	11	15	0	15
Tropical Livestock Unit (TLU)	**CA**	**8.9**								
	ISFM	**10.6**								
	CTRL	**6.9**								

4.1.3
SLM practices implemented on the farms

The most common SLM practices implemented by the CA farmers include minimum mechanical soil disturbance (72.7 %, n = 16), permanent organic soil cover (68.2 %, n = 15) and diversification of crop species (86.4 %, n = 19). For soil and water conservation, both the CA and the ISFM farmers implemented different practices such as the cross-slope barriers along the contour lines (60.5 %, n = 26) and mulching (76.7 %, n = 33). Results show that only the CA farmers sow directly without ploughing (63.6 %, n = 14).

Results also show that for integrated pest management, the CA and ISFM farmers used compost and/or organic manure (90.7 %, n = 39), limed acidic soils (76.7 %, n = 33), and conducted routine soil analysis (46.5%, n = 20). Only the CA farmers use vermijuice (62.5 %) as a biopesticide and the push pull method (56.4 %) which involves the use of trap crops such as Bracharia or Nappier grass and repellent plants such as Desmodium.

The common SLM components of GAP implemented by both the CA and ISFM farmers include proper row spacing (76.7 %, n = 33), weed management (76.7 %, n = 34), and post-harvest management (55.8 %, n = 24).

Only 39 % (n = 25) of the respondents practice agroforestry on their farms, of which 48 % (n = 12) were CA farmers, 40 % (n = 10) were ISFM farmers and only 12 % (n = 3) were from the CTRL farmers. Almost half of the trees (48 %, n = 12) used in the agroforestry plots were Grevillea robusta trees, which is mostly used for timber, fuelwood and poles or posts. Grevillea robusta is also employed for biological nitrogen fixation.

The figures of ► Table 15 indicate that the majority of CA (20) and ISFM (20) farmers are implementing a wide range of SLM practices, whereby most CA farmers implement almost all SLM practices to some extent.

► Table 16 shows that SLM practices implemented by CA and ISFM farmers are limited to the use of compost and manure (N = 20) and to some extent bio-pesticides (N = 5). Soil analysis and the use of mineral fertilizer are only used by one farmer. The other practices implemented on the farm are indicated by the percentage of cultivated land. The numbers show that CA farmers are implementing SLM practices on most parts of their land, with focussing on permanent soil cover on 77 %, cover crops on 74% and cross slope barriers on 61% of their cultivated land.

TABLE 15 Implemented SLM practices

Source: household survey 2022

	Good Agricultural Practice (GAP)	Integrated Soil Fertility Management (ISFM)	Push Pull Method (PPM)	
CA	19	21	16	
ISFM	15	20	8	
CTRL	3	0	0	
	CA	**SWC**	**AF**	**None**
CA	20	18	18	1
ISFM	12	19	11	1
CTRL	0	3	1	16

TABLE 16 Details on the implementation of SLM practices

Source: household survey 2022)

No. of farms implementing practices of ISFM and IPM package on their farm

ISFM and IPM					
	Soil analysis	Limimg acidic soils	Use of compost and manure	Mineral fertilizer	Bio-Pestcides
CA	0	0	**20**	0	5
ISFM	1	0	**20**	1	5
CTRL	0	0	**0**	0	0

Practices of SLM packages applied on X % on culivated land

Good agricultural practices (GAP)					
	Sowing depth	Seed rate	Row spacing	Weed management	Post harvest management
CA	66 %	61 %	70 %	70 %	40 %
ISFM	37 %	43 %	61 %	43 %	25 %
CTRL	0 %	5 %	5 %	4 %	0 %
Push-pull method (PPM) – Use of trap and repellent plants					
CA	61 %				
ISFM	28 %				
CTRL	0 %				
Conservation agricultural (CA)					
	Minimum soil disturbance	Permanent soil cover	Diversification of crops		
CA	30 %	77 %	27 %		
ISFM	20 %	48 %	7 %		
CTRL	0 %	0 %	0 %		
Soil and water conservation (SWC)					
	Cross slope barrieres	Direct sowing	Mulching	Cover crops	
CA	61 %	23 %	25 %	74 %	
ISFM	74 %	18 %	50 %	45 %	
CTRL	9 %	0 %	9 %	0 %	

The results in Table 16 further show that:

- CTRL farmers implemented few or no SLM practices.
- Almost all CA (n = 20) and ISFM (n = 20) farmers used compost or/ and manure.
- GAP measures were implemented by CA farmers on 61 % to 70 % of their land, and ISFM farmers on 37 % to 61 % percent.
- ISFM and CA farmers implemented cross slope barriers on more than 60 % of their cultivated land.
- ISFM farmers and CA farmers used cover crops on 45 % and 74 % of their land respectively.
- The Push-Pull-Method was implemented by 61 % of the CA farmers and 28 % of the ISFM farmers.

The figures show that decisions to implement SLM practices were based on individual preferences and capacities. CA farmers seemed to be more advanced in implementing these practices than ISFM farmers.

4.2 Profit loss analysis comparing CA, ISFM and CTRL group farmers

The analysis considered revenues, costs and income for the whole farm and not for a single plot or a single crop. The implementation of the farming systems approach was explained in detail in ► chapter 3.

4.2.1 Revenues from farming activities

► Chapter 3 outlines the revenues of the participating farmers from crop, fruits and animal production plus other income from other activities e.g., seed production, sales of vermicompost and other agricultural inputs such a biopesticides and manure. Donations were considered as revenue though they were insignificant. Farmers reported that these donations were mainly provided through seeds and other small amounts of inputs for the implementation of SLM practices.

Some farmers provided agricultural services such as ploughing, transport of machines and farm labour. The income from crop productions differed significantly between CA farmers (KES 97,600) and ISFM farmers (KES 74,300) and the CTRL group farmers (KES 37,600).

It has a share of approximately 49% (ISFM), 64 % (CA) and 60 % (CTRL) of total revenues. ISFM farmers generated relatively more income from fruit sales (KES 24,600) compared to CA (KES 12,200) and CTRL farmers (KES 1,500) respectively.

The share of revenues from animal production to total revenues ranged from 18,7 % (KES 28,000) for CA farmers to 25.4 % (KES 39,000) for ISMF farmers and 37.7 % (KES 22,000) for CTRL farmers.

Comparing the total revenue from farming activities, CA (USD = 1,266) and ISFM (USD = 1,265) farmers made almost the same amount of money which is 58.9 % more than what the CTRL farmers (USD = 520) made from farming activities. Other products had a share of approximately 9 % of the total revenues for CA and ISFM farmers with KES 14,000. Donations contributed less than 0.3 % to total household revenues.

Total revenues of the households of the CA farmers (KES 151,940 equivalent to USD 1,266) were almost the same as the ISFM farmers (KES 151,851 equivalent to USD 1,265) but more than twice as high as the CTRL group farmers (KES 62,412 equivalent to USD 520). CA farmers had much higher revenues per acre of cultivated land than ISFM and CTRL farmers with 819 USD/ac versus 681 USD/ac of ISFM and 361 USD/ac of the CTRL farmers.

4.2.2 Variable costs

The variable costs are almost the same for all farmers ranging from KES 16,200 (ISFM) to KES 17,100 (CA) and KES 18,500 (CTRL). They are primarily from the farm inputs such as seeds, seedlings, and fieldworks such as ploughing, harrowing, harvesting and transport. Due to very different numbers on revenues, these variable costs constitute different shares of total revenues: CA and ISFM farmers had variable costs of 12 % revenues, whereas CTRL group farmers had variable costs of almost 20 % of their revenues.

The costs incurred for seeds by the CA and ISFM farmers are relatively higher compared to the cost incurred by the CTRL farmers. This is because ISFM (85.7%, n= 21) and CA (90.9%, n = 20) farmers used certified seeds from agrovets which are slightly more expensive compared to uncertified seeds used by most (66.67%, n = 14) of the CTRL farmers.

Costs for fruit seedlings were much higher for CA and ISFM farmers compared to CTRL farmers. This indicates that, unlike CTRL farmers, CA and ISFM farmers have been involved in the fruit tree value chain development programme of WHH. The CA and ISFM incurred additional costs on cover crop seeds which was not the case for the CTRL farmers.

FIGURE 15 Total revenues from farming activities incl. home consumption

Source: household survey 2022

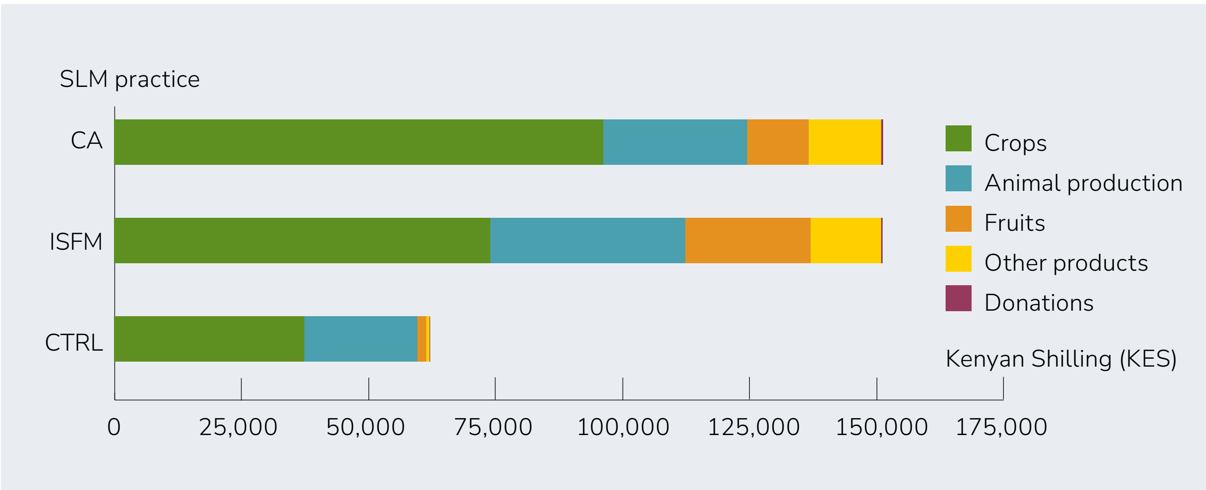
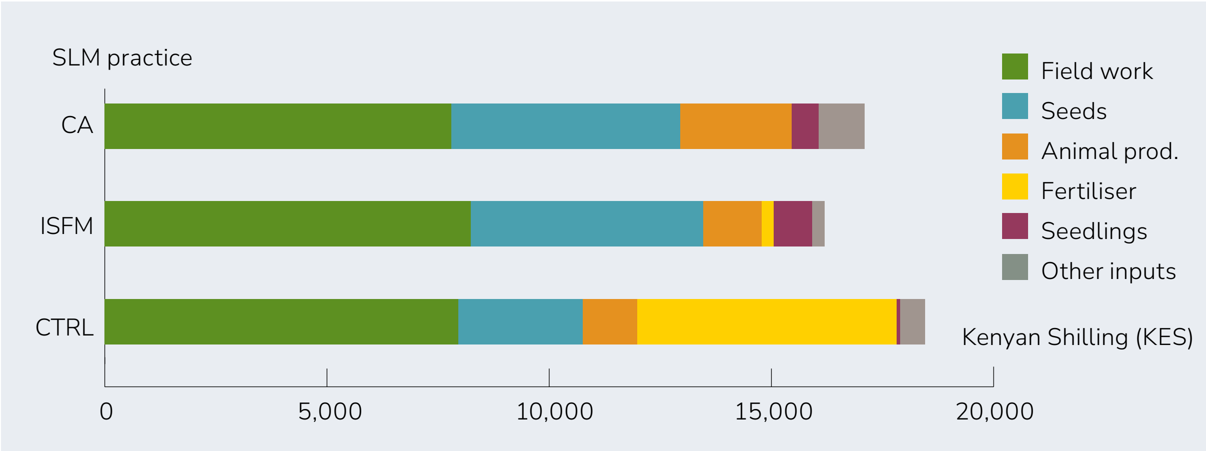


FIGURE 16 Variable costs of the farm household

Source: household survey 2022



For all CTRL farmers (100 %, n = 21) and few (9.5 %, n = 2) ISFM farmers, there incurred additional costs for chemical fertilizers such as Diammonium Phosphate (DAP), Nitrogen, Phosphorus, and Potassium (NPK) and Calcium Ammonium Nitrate (CAN). None of the CA famers used chemical fertilizers.

Further costs for all farmers incurred from field works such as ploughing, harrowing, harvesting and transportation. Farmers buy these services from "service providers" or neighbours. Arising costs were comparatively similar with app. KES 8,000, constituting a share of app. 40 % of total variable costs.

The costs on seedlings for fruits, animal production and other inputs (farm labour) have a small share of below 20 % of all variable costs.

Overall, total variable costs are composed of 30 – 40 % input costs for crop production, 40 – 50 % costs for field works, and remaining 10 – 20 % for other variable costs.

4.2.3 Profit / Income

The analysis of the annual margin of CA, ISFM and CTRL farms show that ISFM farms had greatest annual gross margins (USD 1,130.5), followed by CA farms (USD 1,123.6). CTRL farms (USD 366.3) had the least annual gross margins.

Considering general annual costs, the CA farms (USD 40.5) have the least costs compared to ISFM (USD 45.6) and control farms (USD 42.8).

This means that annual on-farm profit for ISFM (USD 1,083.2) is almost equal to that of CA (USD 1,084.8). The CTRL farms have the lowest annual on-farm profit (USD 323.5).

Results for the margins per acre show that CA farmers make margins of USD 727 per acre while ISFM and CTRL farmers make USD 609 per acre and USD 254 per acre, respectively.

CA farmers (USD 701) make 16.7 % more profit per acre than the ISFM farmers (USD 584) and 67.9 % the CTRL farmers (USD 225).

Off-farm income includes income from sources other than farming, including employment wage, casual farm wage, casual non-farm wage, and self-owned nonfarm business income. Summary statistics show that off-farm income was higher among the ISFM (USD 732) and the CTRL farms (USD 651) than the CA farms (USD 436).

FIGURE 17 Overview of on-farm income (USD per ha and year)

Source: household survey 2022

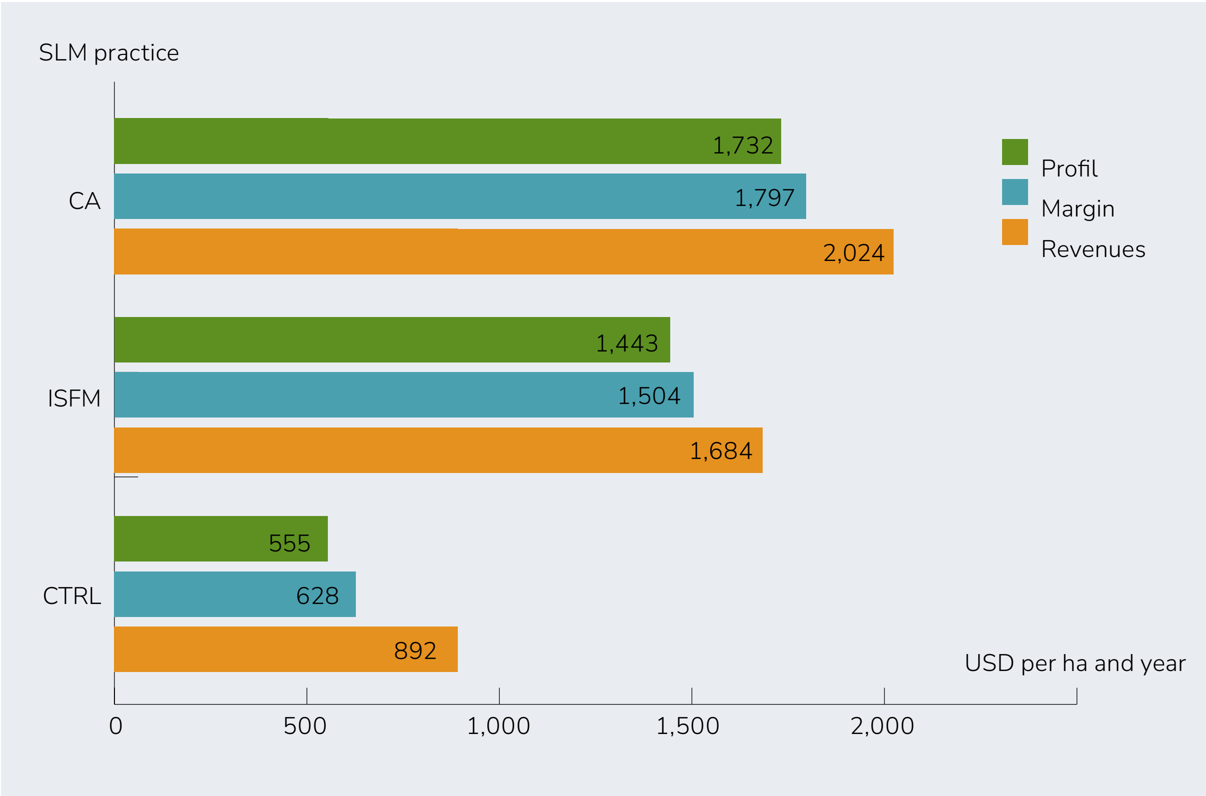
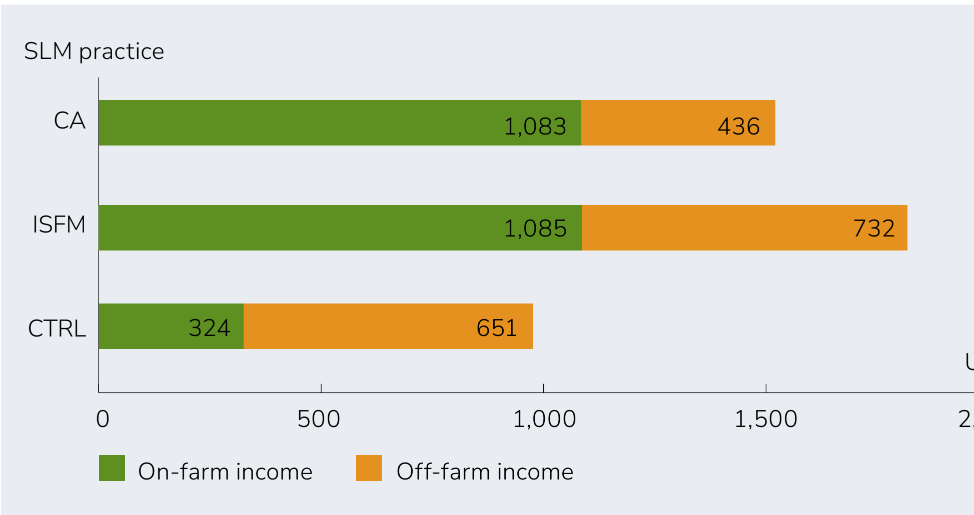


FIGURE 18 Household income by source

Source: household survey 2022



Cultivated land	ha
CA	0,63
ISFM	0,75
CTRL	0,58

4.3 Results of the soil analysis for SOC and BD and other indicators

In this paragraph, findings on carbon sequestration potential of SLM practices through increasing SOC on crop land of the participating households are elaborated. Firstly, the results of all soil samples for the various soil depths are compared. They show the distribution of SOC stock in the soil and how relevant parameters such as SOC content, SOC stock, BD and CO_{2e} stock change. Thus, they are key reference parameters for carbon credit projects. For easier reading, the following abbreviations are used for the different soil layers/levels: L1 = 0 – 30 cm, L2 = 30 – 60 cm, and L3 = 60 – 100 cm. To determine the changes of soil parameters related to SLM, the results of the soil analysis of the topsoil (0 – 30 cm) between the different groups of farmers (CA, ISFM, CTRL) were compared.

4.3.1 CO_{2e} stocks on different soil levels

The mean value of SOC in all samples taken on following three different levels was used to calculate the total CO_{2e} stock: L1 (0 – 30 cm), L2 (30 – 60 cm), and L3 (60 – 100 cm). The total stock of CO_{2e} was 199 t/ac (492 t/ha). Of these, 37.2 % were found in L1, 33.2 % in L2 and 29.4 % in L3 (see ► Table 17).

To describe the soil in the area more detailed, various boxplots of the most relevant parameters are outlined in ► Figure 19. The mean value of SOC content in g/kg drops from 12.6 g/kg at L1 to 9.6 g/kg at L2 and 5.9 g/kg at L3. The boxplots also show the variance of the upper quartile (UQ) of 15.3 g/kg and the lower quartile (LQ) of

TABLE 17 Stock of CO_{2e} at different depth levels

Source: own samples and equations

Levels of soil sampling		L1	L2	L3	
Depth	cm	0 – 30	30 – 60	60 – 100	0 – 100
Depth in cm	cm	30	30	40	
Number of HH with samples	**N**	**62.00**	**26.00**	**12.00**	
Bulk density	t/m³	1.32	1.56	1.68	
Volume of the soil	m³	1,214	1,214	1,619	
Total to weight of soil	t/ac	1,600	1,894	2,721	
SOC	g/kg	**12.61**	**9.22**	**5.87**	
SOC in %	%	1.26 %	0.92 %	0.59 %	
SOC stock	t/ac	20.18	17.46	15.97	54
CO_{2e} **stock**	%	**37.6 %**	**32.6 %**	**29.8 %**	**100.0 %**
CO_{2e} **stock**	t/ac	**74**	**64**	**59**	**197**
	t/ha	183	158	145	486

FIGURE 19 Boxplots for SOC, BD, N, and CEC for all samples

Source: own samples and equations

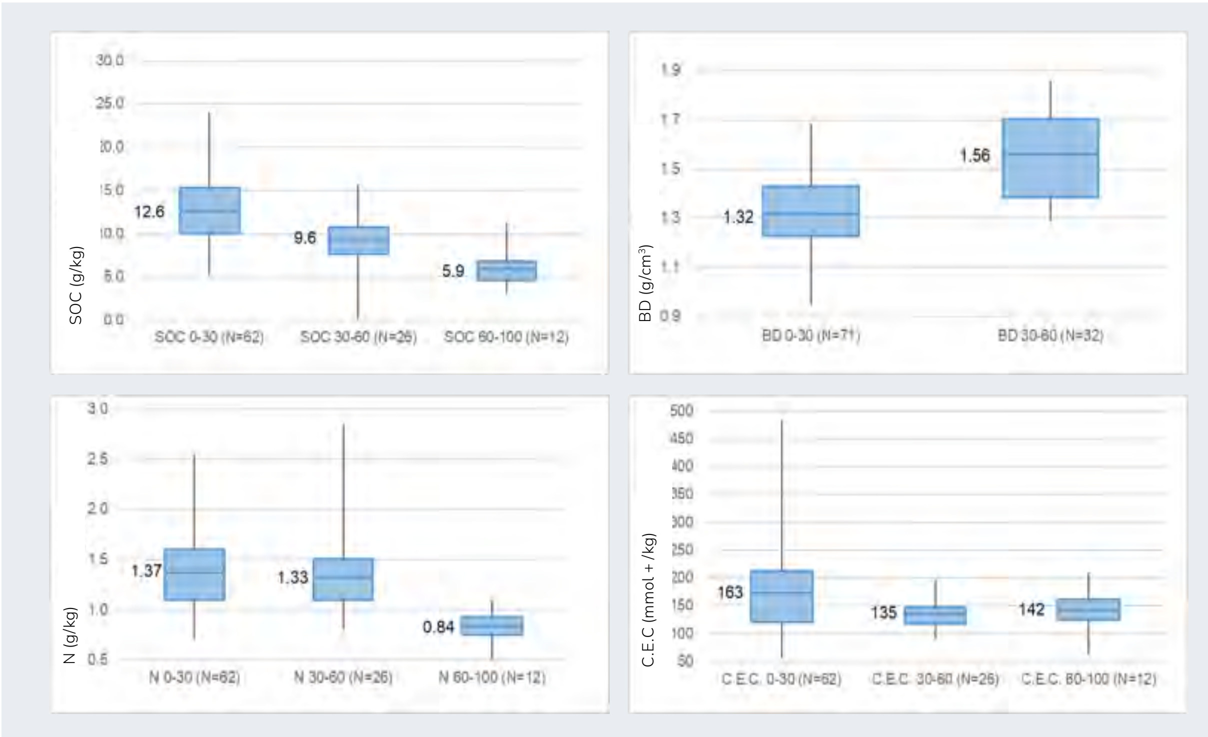
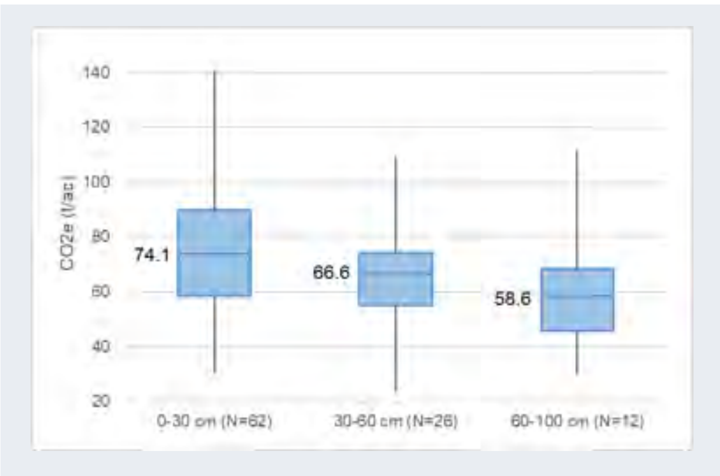


FIGURE 20 Boxplot of CO_{2e} stock at different depth levels

Source: own samples and equations



10.0 g/kg, indicating a difference of 5.3 g/kg or approximately 50 %.

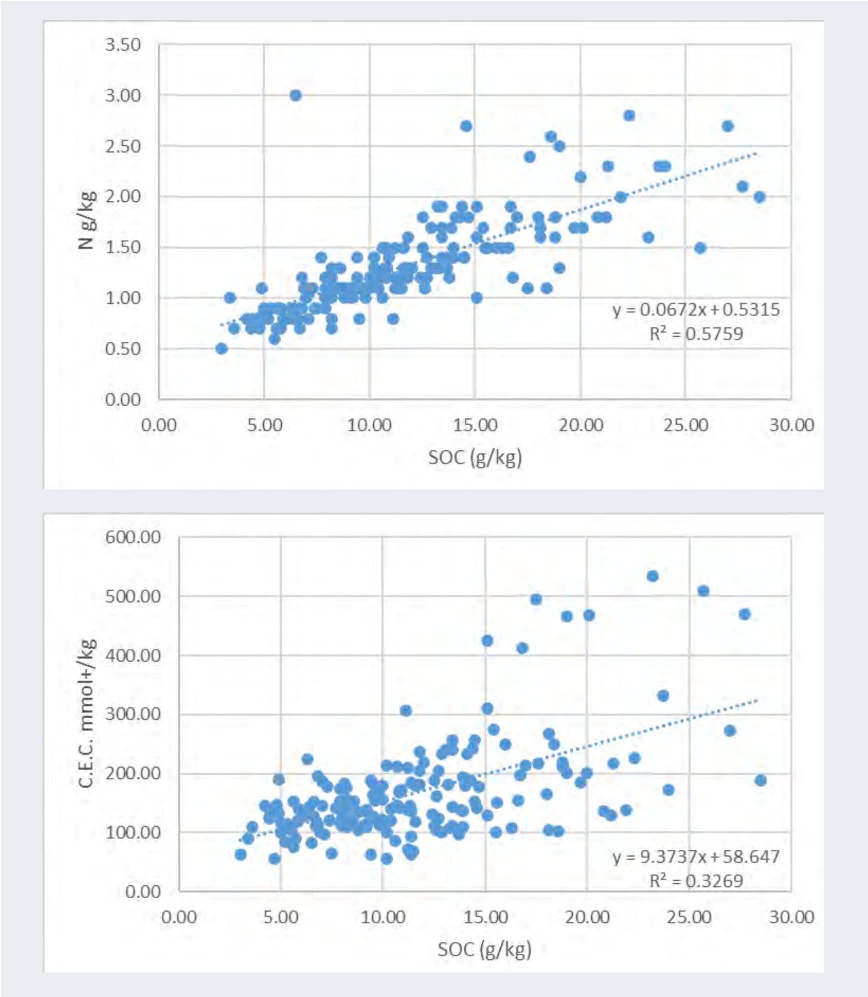
The bulk density differs from 1.32 at L1 and 1.56 at L2. Bulk density tests from L3 were not possible, due to the lack of heavy tools and machinery. Nitrogen in L1 was 1.37 g/kg, in L2 1.33 g/kg and in L3 with 0.84 g/kg, being the lowest value.

The Cation Exchange Capacity (CEC) was high at L1 with 163 mmol+/kg, 135 mmol+/kg at L2, and 142 mmol/kg at L3.

The stock of CO_{2e} was measured in t/ac with mean values of 74.1 t/ac at L1, 66.6 t/ac at L2 and 58.6 t/ac at L3. The values of the quartiles show a range of approximately 20 %, which can sum up to a difference in CO_{2e} stock of approximately 40 t/ac. Extreme values are indicated with the straight lines in the graph (► Figure 20).

FIGURE 21 Regression of SOC to N and SOC to CEC

Source: own data



N and CEC are considered parameters which indicate to some extent the productivity of soils and correlate with the SOC content. The regression of all soil samples (see ► Figure 21) allows to confirm this very often cited finding. The regression between SOC and N is positive with $R^2 = 0.57$, whereas SOC and CEC are less strongly correlated with $R^2 = 0.33$.

4.3.2 Comparing CO_{2e} stock between CA – ISFM – CTRL group farmers

SOC per acre is calculated by using soil organic carbon and bulk density values under consideration of the plot size. The samples were taken from at least two plots from each CA and ISFM farms, since CA and ISFM farmers implemented the SLM practices only on a part of their plots. This partial implementation could lead to an increase of SOC on the fields with SLM practices, but a decrease of SOC on the other fields due to an unproportional allocation of FYM or compost (so-called "leakage"). It was thus necessary to take soil samples from all cultivated land. Non-cultivated land, which would be used for grazing, is left fallow or is used by other family members, was not considered. On the CTRL farms, 20 samples were deemed as sufficient, because it was assumed that the same farming practices are used on all plots.

For the analysis of the SOC stocks of the participating households, 117 samples composed of 9 subsamples each plot were taken from 0–30 cm depth. The samples were all scanned on-site or immediately after sampling in the office of WHH in Siaya.

The boxplots of ▶ Figure 22 show a wide range of SOC for ISMF plots, namely from 5.2 g/kg to 28.5 g/kg. 50 % of the CA plots' SOC content range between 8.6 g/kg to 17.4 g/kg. The values of the ISFM farmers are similar. Values of the CTRL plots range from 7.5 g/kg to 14.0 g/kg. These values overall indicate more variability within the group of CA and ISFM farmers than within the CTRL farmers.

The analysis of bulk density is based on 71 samples. The final figures to compare the groups represent the average of all samples for each farm. Unfortunately, only three samples from one farmer of the CTRL group were taken, why this figure is not representative. Due to the lack of other figures, the numbers are still included. The bulk density decreases from 1.41 g cm^{3-1} of the CTRL group farmers to 1.34 g/cm^3 of ISFM and 1.29 g/cm^3 of CA farmers.

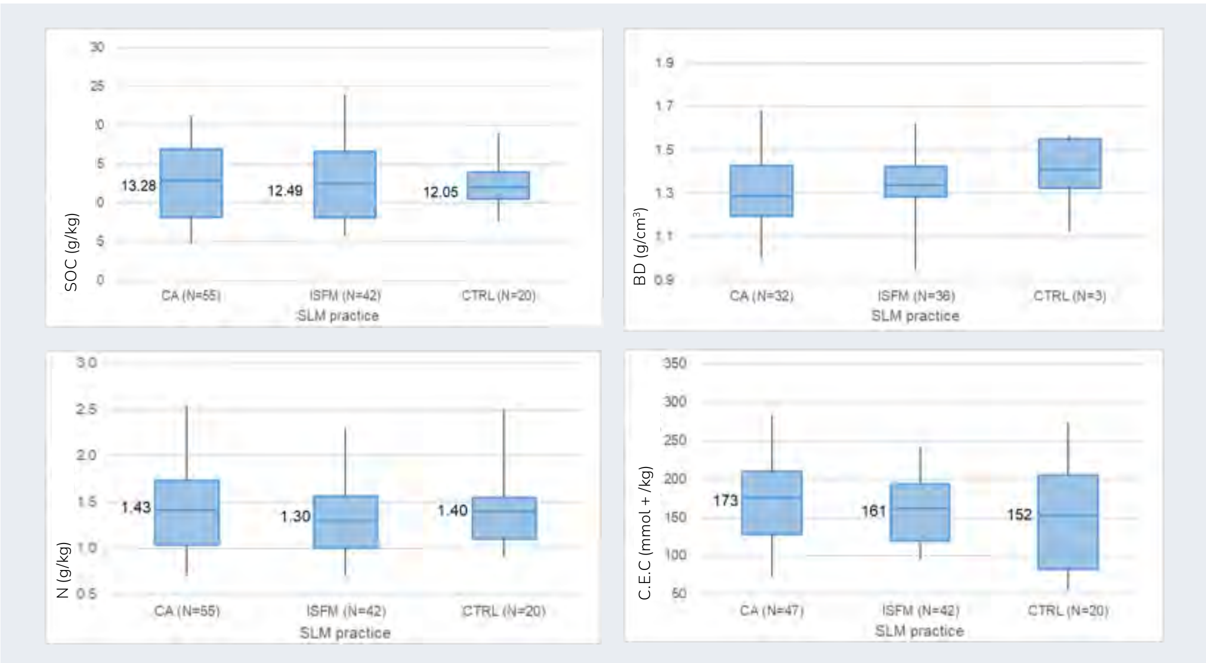
The N-content o of semi-natural soils usually correlates with the SOC content of soil. For the CA farmers, their N-value of 1.43 g/kg is only slightly higher than N-valued of 1.40 g/kg of CTRL farmers, whereas the difference to ISFM farmers is app. 10 % (1.31 g/kg). The almost similar content of N-content of CA and CTRL farmers could result from the use of synthetic fertilizer.

The CEC differs almost 10 % between CA and CTRL farmers, with the CEC-values of ISFM farmers in-between.

The results indicate a SOC increase of 12.05 g/kg in the CTRL group, 12.49 g/kg in the ISFM group and 13.28 g/kg in the CA farmer group (see ▶ Table 18). Based on these mean values and with a correction of the mineral soil mass as well as an

FIGURE 22 Boxplots for SOC, BD, N , and CEC analysis at the depth of 0–30 cm

Source: own samples and equations



adjusted soil depth, the calculated difference of topsoil CO_{2e} stock is 5.61 t/ac (13.86 t/ha) for CA farmers and only 0.95 t/ac (2.35 t/ha) for ISFM farmers. Assuming that the farmers started to implement SLM practices once they registered as "ProSoil"– farmers[8] , the implementation period of the SLM practices of CA farmers is 4.1 years and that of ISFM farmers 5.29 years.

Dividing the total increase of CO_{2e} stock by the years of implementation, the annual sequestration rate amounts to 1.37 t/ac/year (3.38 t/ha/year) for CA farmers and 0.18 t/ac/year (0.44 t/ha/year) for ISFM farmers.

► Table 19 describes the total CO_{2e} stock in soil to the depth of 100 cm if the distribution of SOC equals the figures in ► Table 17, which is 37.17 % of total CO_{2e} stock at 0 – 30 cm, 33.41% at 30 – 60 cm and 29.42% at 60 – 100 cm depth. Total CO_{2e} stock is approximately 218 t/ac (539 t/ha) for CA farmers, 206 t/ac (508 t/ha) for ISFM farmers and 203 t/ac (502 t/ha) for CTRL farmers.

Since having started the implementation of SLM practices, CA farmers have sequestered 15.09 t/ac (37 t/ha) more than CTRL farmers. ISFM farmers record a plus of 2.56 t/ac (6 t/ha) compared to CTRL farmers.

TABLE 18 CO_{2e} stock value at 0 – 30 cm of CA, ISFM and CTRL

Source: own data

Levels of soil sampling		CA	ISFM	CTRL
Depth	Unit	0 – 30	0 – 30	0 – 30
Sampling depth		0.30	0.30	0.30
Depth correction		0.31	0.31	0.30
Number of HH with samples	**N**	**21.00**	**21.00**	**20.00**
Average year of SLM implementation	yr	4.10	5.29	1.00
Area (acre in m)	m²	4,047	4,047	4,047
Bulk density	t/m³	1.25	1.34	1.41
Volume of the soil	m³/ac	1.255	1.255	1.214
Total soil mass (original)	t/ac	1.574	1.679	1.708
New mineral soil mass (Mn)	t/ac	1.665	1.667	1.708
SOC	**g/kg**	**13.28**	**12.49**	**12.05**
SOC in %	%	1.33 %	1.25 %	1.20 %
SOC stock in t/ac and t/ha	t/ac	22.10	20.83	20.57
	t/ha	54.61	51.47	50.83
CO_{2e} stock	**t/ac**	**81.10**	**76.44**	**75.49**
	t/ha	**200.41**	**188.89**	**186.54**
Difference of CO_{2e} stock at 0 – 30 cm	**t/ac**	**5.61**	**0.95**	
	t/ha	**13.86**	**2.35**	
CO_{2e} sequestered per year since start of SLM	t CO_{2e}/ac/year	1.37	0.18	
	t CO2e /ha/year	3.38	0.44	

8 The year of registration of the farmers as "ProSoil" farmers, which implement SLM practices is based on the records of WHH Siaya.

TABLE 19 Total CO_{2e} stock in 100 cm soil depth

Source: own data

		CA	ISFM	CTRL	
CO_{2e} stock (0 – 30 cm)	**t/ac**	**81.10**	**76.44**	**75.49**	**37.17%**
CO_{2e} stock (30 – 60 cm)	**t/ac**	72.89	68.70	67.85	33.41%
CO_{2e} stock (60 – 100 cm)	**t/ac**	64.18	60.49	59.74	29.42%
Total CO_{2e} stock (0 – 100 cm)	**t/ac**	**218**	**206**	**203**	**100.00%**
	t/ha	539	508	502	
Difference in CO_{2e} stock of CA and ISFM against CTRL	**t/ac**	**15.09**	**2.56**		
	t/ha	**37**	**6**		

4.3.3 Scenario for the potential of carbon sequestration and "Carbon credits"

There is an overwhelming list of scientific papers on the potential of carbon sequestration for GHG removal. Some of these papers argue that increasing SOC in a specific area may be limited by the equivalent of the carbon stock of natural vegetation, respectively natural forests. In Western Kenya, the pristine forests of the protected areas could be considered a natural maximum benchmark of up to 80 g/kg for the accumulation of SOC (Vågen et al., 2018b).

To increase SOC of crop land, having SOC contents of 10 – 16 g/kg, to the level of natural vegetation is no realistic assumption for future scenarios. It is even uncertain to reach the annual sequestration rate of CA farmes of 1.37 t/ac/year (3.38 t/ha/year) of CO_{2e} (outlined in ► Table 18), since the ISFM farmers have a much lower sequestration rate of only 0.18 t/ac/year (0.44 t/ha/year). It is also very likely the sequestration rate will decrease over time due to the saturation of SOC.

Though, due to the rather low level of SOC of agricultural land, the potential to increase SOC and thus to sequester carbon can be considered significant. This becomes especially evident when considering that 50 % of all farmers, referring to the upper quartile (Q) have a SOC content of 15.30 g/kg whereas the lower quartile has a content of only 9.97 g/kg (see ► Table 20). The mean value is 12.61 g/kg. These SOC contents result in a CO_{2e} stock of 88 t/ac (218 t/ha) of the upper Q versus a CO_{2e} stock of only 57 t/ac (142 t/ha) of the lower Q and a median value of 73 t/ac (180 t/ha). This big difference of the CO_{2e} stock between the upper and the lower Q indicates a high potential for carbon sequestration especially for farmers, which have a low CO_{2e} stock, assuming that the natural soil parameters, precipitation, and other natural conditions are similar.

► Figure 23 shows the CO_{2e} in t/ha for different soil levels for the upper quartile, median and lower quartile across all participating farmers. It indicates the large difference between soil depths and also within the soil levels.

TABLE 20 Potential CO_{2e} sequestration in the topsoil (0–30 cm)

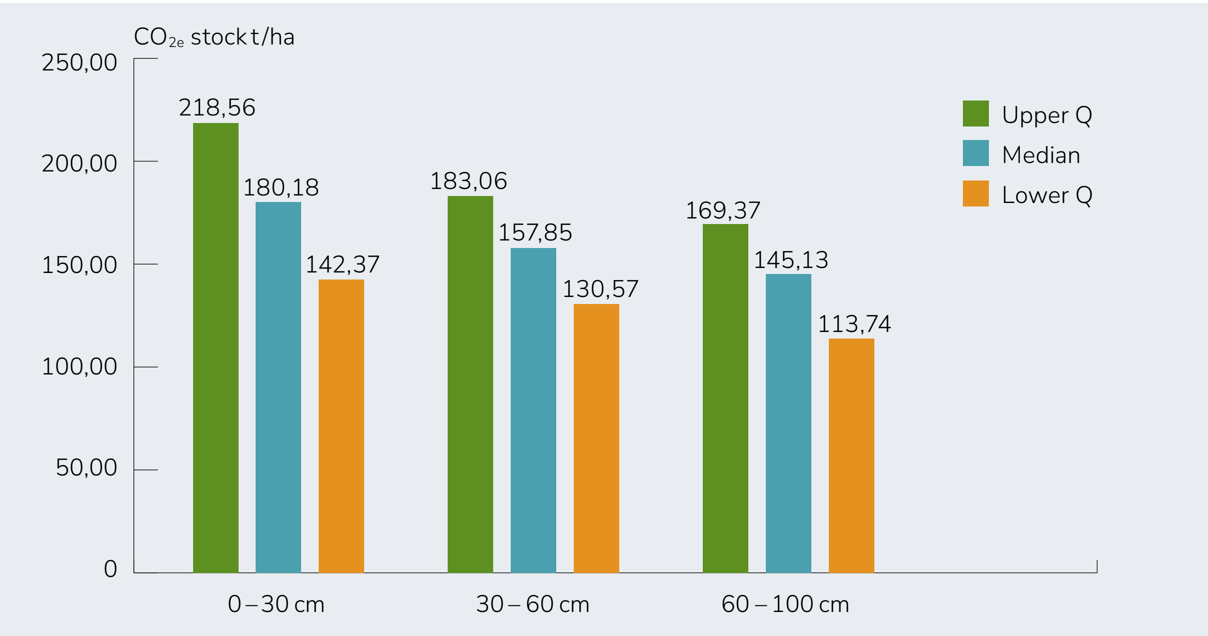
Source: own data

All HH	Unit	0–30 cm
Bulk density	g m^{3-1}	1.30
Total weight of soil	t/ac	1,575
Mean initial SOC stock		
SOC	%	1.26 %
SOC	g/kg	12.61
SOC stock	t/ac	19.87
SOC stock per ha	**t/ha**	**49.10**
Conversion factor SOC to CO_{2e}	3,67	
CO_{2e} **(*3.67) stock**	t/ac	72.92
	t/ha	**180.18**
Upper quartile		
SOC	g/kg	15.30
SOC stock	t/ac	24.10
CO_{2e} **(*3.67) stock**	**t/ac**	**88.45**
	t/ha	**218.56**
Lower quartile		
SOC	g/kg	9.97
SOC stock	t/ac	15.70
CO_{2e} **(*3.67) stock**	**t/ac**	**57.62**
	t/ha	**142.37**

The following scenario considers the potential of carbon sequestration in the top soil (0-30 cm) only, because the WKCP uses the changes of CO_{2e} stock in the top soil for the estimation of Verified Carbon Units. With this constraint the WKCP follows a rather conservative approach to calculate the future carbon sequestration, as there are missing in-depth studies of the dynamics of carbon stocks in the project area. Once a full monitoring system for carbon stock verification is established the estimation may need revision. The carbon stored in biomass from agroforestry, which accounts for approximately 60 % of the overall carbon stored in the WKCP, is not considered in the following calculations, as only carbon stored in soils are considered within this study.

FIGURE 23 CO_{2e} stock of all farmers (with or without SLM implemented)

Source: own data



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The calculated depth and sampling depth according to VMD0021 (VERRA, 2012)

The VCS module VMD0021 describes guidelines for defining the calculated and the sampling depth. It considers the sampling depth for measuring SOC should be set at a level, where at least 90% of the change in soil carbon resulting from project activities is expected. A depth of 100 cm should be considered a starting point, from where a reduction or an increase of the soil depth might be necessary. In 2022 VERRA has commissioned a study on a new soil carbon standard, which will be introduced in future VCS.

In the request for proposals on the "Development of a VCS tool for soil sampling, processing and analysis to determine soil organic carbon stock changes" it is stated:

"A key component of these ALM (Agricultural Land Management) methodologies is the procedures used to estimate SOC stock changes when SOC is directly measured, from land stratification to soil sampling to laboratory analyses. SOC stocks are unevenly distributed across landscapes and depend on mineralogy, topography, climatic conditions, and land use, among others. Therefore, effective strategies for direct measurement of SOC should capture this variability to reduce uncertainties and allow for science-based estimations of SOC stock changes attributable to project interventions. Furthermore, the physical sampling of soils and subsequent laboratory analyses, require adherence to established procedures linked to the selected sampling and analytical approaches." (VERRA, 2022)

To estimate the potential for soil carbon stock change, currently a focus is set on the topsoil with a depth of 0 – 30 cm. In future research, a more in-depth study of soil organic carbon dynamics at a depth of 30 – 100 cm should be considered.

The following estimate of the increase in CO_{2e} stock and thus soil carbon sequestration rate is based on the following assumptions:

1. 50 % of farmers (upper Q) increase their SOC stock by app. 15 % compared to the measured CO_{2e} stock in 2022.
2. 50 % of farmers (lower Q) have the highest sequestration potential with an estimated increase of 30 % of the level of CO_{2e} stock in 2022.
3. The farmers will introduce SLM with an emphasis on the increase of biomass using cover crops, compost and manure. No-till practice is implemented wherever the machinery and technology are available.
4. All farmers will extend the implementation of the SLM practices on their farmland to all cultivated land.
5. Extension services and the provision of key inputs, financed by the revenues of the carbon credits, encourage a high adoption rate of participating farmers.

Based on these assumptions the total weighted increase of CO_{2e} is estimated at 37.75 t CO_{2e}/ha (see ► Table 21). The increase of the farmers in the upper quartile is 16.4 t CO_{2e}/ha and in the lower quartile 21.4 t CO_{2e}/ha. The assumptions consider the fact that the farmers with the lower stock have a much higher potential to increase the CO_{2e} stock (see ► Figure 24).

The estimated increase of CO_{2e} stock corresponds to a SOC increase from 15.30 g/kg to 17.60 g/kg for the upper quartile, and from 9.97 g/kg to 12.96 g/kg for the lower quartile respectively (see ► Table 22).

The annual sequestration rate depends essentially on how long the SLM practices are comprehensively practiced. The annual sequestration rate is expected to reach 3.77 t CO_{2e}/ha/year in 10 years, declining then to 1.98 t CO_{2e}/ha/year in 20 years (see ► Figure 25).

TABLE 21 Target stock of CO_{2e} (0 – 30 cm)

	t CO_{2e}/ha	+ %	t CO_{2e}/ha	% of household	weighted increase
Farmers (upper quartile)	**218.56**	15%	32.78	50 %	16.39
Farmers (lower quartile)	**142.37**	30%	42.71	50 %	21.36
Total Increase of CO_{2e}				**t/ha**	**37.75**

FIGURE 24 Estimated CO_{2e} stock for the upper Q (+15%) and the lower Q (+30)

Source: own calculations

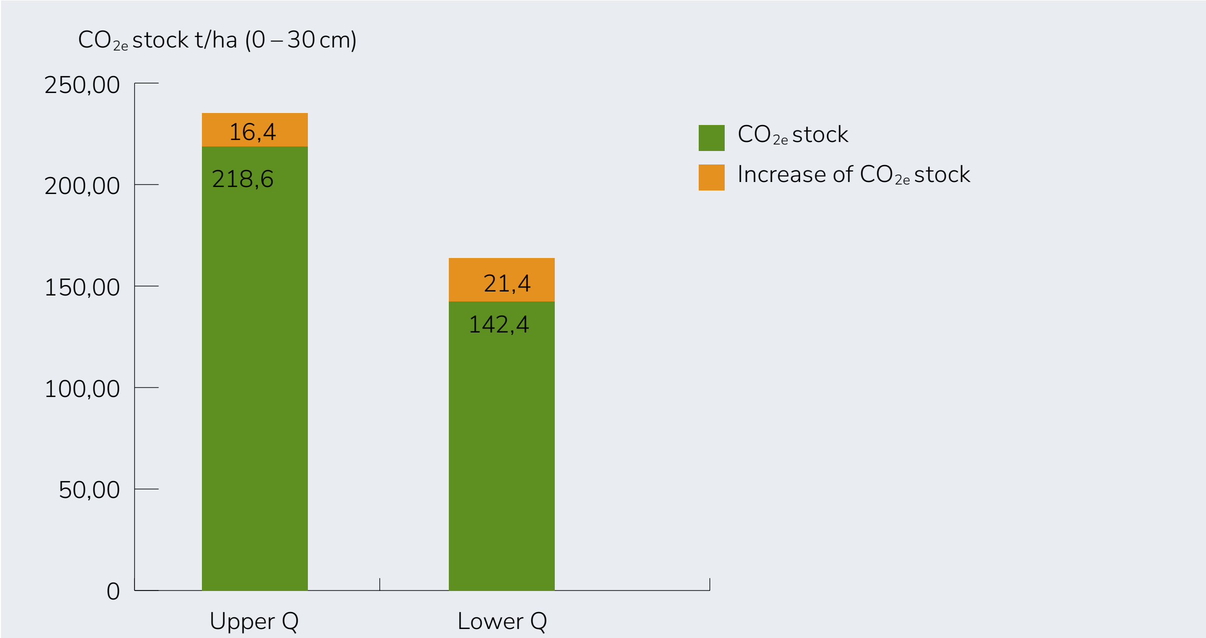
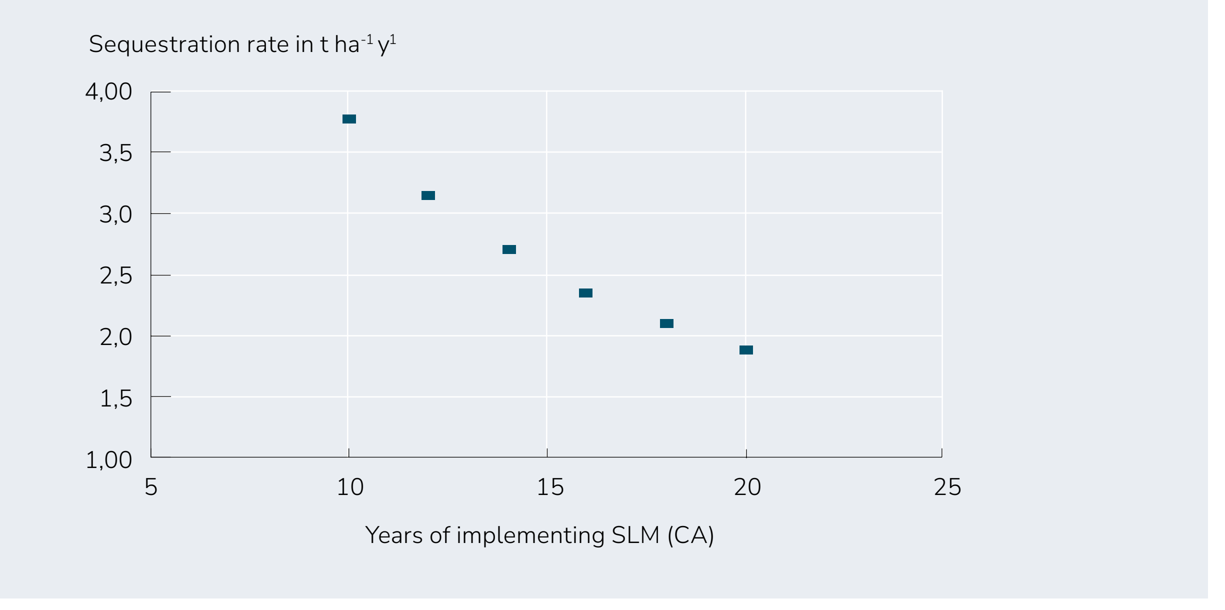


TABLE 22 Estimated increase of SOC in g/kg for the forecast

	Unit	Stock	Increase	Target
Farmers (upper quartile)	**g/kg**	15.30	2.30	17.60
Farmers (lower quartile)	**g/kg**	9.97	2.99	12.96

FIGURE 25 Annual sequestration rate depending on the time when the new level is achieved

Source: own calculations



These figures are slightly higher than the estimated project removals of the WKCP due to SOC changes amounting to 1.2 t CO_{2e}/ha/year. This is because the project developers operate with rather conservative estimations for the SOC sequestration rate. The total sequestration rate of the WKCP, including agroforestry, sums up to 3.6 t CO_{2e}/ha/year, leaving room for amending these figures once the monitoring results indicate the real figures.

The forecast of the sequestration rate corresponds to the results of the soil analysis and the calculated carbon sequestration of CA and ISFM farmers versus the CTRL group. The sequestration rate is predicted to range between 0.44 t CO_{2e}/ha/year for the ISFM farmers and 3.38 t CO_{2e}/ha/year for CA farmers.

4.3.4 Soil biodiversity

Microbial communities in soils are intricately linked to ecosystem functioning due to their vital roles in the biogeochemical cycling of nutrients, soil structure maintenance, as well as feed-back to plant communities as both, mutualists, and pathogens. Soil microorganisms carry out the dichotomous roles of mineralizing soil organic C and stabilizing C inputs into organic forms. Beneficial plant growth-promoting bacteria and fungi that inhabit the rhizosphere may help to counteract the negative consequences of drought by optimizing plant growth in increasingly stressful conditions. Soil microbial communities' abundance and diversity are positively influenced by farm practices that include the use of organic inputs, crop diversification and rotation, agroforestry systems, special tillage (e.g., no-till and conservation tillage), and agronomic practices such as mulching and cover crop management. Additionally, also soil properties (soil C, soil moisture) positively influence soil microbial communities' abundance and diversity.

The results of the living soil lab on the abundance of bacteria and fungus are based on a limited number of successful cultivation of bacteria and fungus colonies. Therefore, the absolute figures are not representative, yet the results indicate a tendency.

The results show that CA and ISFM farmers had more soil microbial communities compared to the CTRL farmers. The CA and the ISFM practices lead to improved soil structure, resulting in increased soil fertility. This in turn improves crops' growth performance and hence the rate of photosynthesis. Bacteria and fungi get their energy sources from photosynthetic products, root exudates and plant litter. The use of the CA and ISFM farming practices may have contributed to increased bacteria and fungi abundance.

4.4 Economics of land degradation

The key to the economics of land degradation is the relation between investments for implementing SLM practices and the resulting environmental and economic benefits for the participating farmers. The total Net Present Value (NPV) is calculated using the cumulated surplus of income of CA and ISFM farmers compared to the CTRL farmers.

The average increase of income of ISFM and CA farmers amounts to USD 1,033 per ha and year and is composed of the average increase of income per ha for agricultural production. This sums up to a NPV of USD 314 Mio on 32,000 ha over a period of 20 years with a discount rate of 10 % (example of WKCP). To assess in how far investments into SLM as part of a carbon project are also economically attractive, the NPV of the project can used to compare it with the total project costs occurring during the whole project duration.

TABLE 23 Calculation of the NPV of the increased income of CA and ISFM farmers

Source: own calculations

Farming system	Total	Difference to
	On farm income	CTRL group
	USD per ha and year	USD per ha and year
Conservation Agriculture (CA)	1.732	1.177
Integrated Soil Fertility (ISFM)	1.443	888
Control group of conventional/ traditional agriculture (CTRL)	555	
Economic benefit from the implementation of SLM practices		
Average increase of income of ISFM and CA farmers	1.033	USD per ha and year
Estimated area of the participating farmers (based on WKCP forecast)	32.000	ha
Total annual increase of income of ISFM and CA farmers	33.047.360	USD per year
Net Present Value of 20 years at 10% discount rate	314.251.656	USD
short	**314**	**Mio USD**

Interpretation of the result

The annual increase of income per ha may be lower for other areas, since the farming system may be not as productive or may not provide all opportunities to diversify or adopt SLM practices, due to different natural conditions that affect the performance of agricultural production. A comprehensive analysis that includes most farming systems from all agro-ecological zones in Siaya, Bungoma and Kakamega, should be considered to provide a more detailed socio-economic analysis. However, even if the annual income increase should be less than found for the farms, participating in the study, e.g. as low as 50 % of the average, the result will still be USD 160 Mio.

The annual sequestration rate of carbon in agricultural soil may differ depending on the natural conditions, on the basic soil parameters and on the opportunities to implement SLM in a specific farming system. Since the SOC content of crop land in Western Kenya is rather low according to various researchers, which suggests a high level of soil health degradation, the potential to increase the SOC content should be rather high. The annual sequestration rate of 1 to 2.5 t C/ha/year is considered realistic, if the SLM practices are implemented on most of agricultural land of a farm household.

Clear evidence of the impact of SLM practices on the farm income and ecosystem services. This study provides evidence of the benefits that SLM practices provide in the farming systems of Western Kenya. On the other hand, is it difficult or impossible to prove the evidence for the specific impact of a single SLM practice, since the practices for every farming system are highly diversified and interconnected. Nevertheless, it is obvious that SLM practices in combination with diversifying the agricultural production increases the potential for additional income and create additional environmental benefits.

05

Conclusion and recommendations

Conclusion

SLM practices have been extensively promoted due to the challenges climate change causing land degradation and the increased demand for food impose on agricultural production systems. More recently, carbon sequestration on agricultural crop lands has gained interest of the scientific community and project developers, because of its potential to contribute to climate change mitigation and, indirectly to climate adaptation. Carbon sequestration in soils and the reduction of CH_4 and N_2O are the main GHG emissions of the agricultural sector. Implementing SLM practices could contribute substantially to the National Determined Contributions of Kenya (Aynekulu et al., 2022b). Besides mitigation aspects, some SLM practices, such as applying compost and manure, are believed to simultaneously increase farm yields, income, food security and improve the livelihoods of small-scale farmers.

This case study assessed the impact of SLM approaches on carbon sequestration and on the economic performance of farming households in Western Kenya. This was done by interviewing 64 small-scale farmers, and analysing a total of 170 soil samples, comparing ISFM farms, CA farms and conventional farms as control group (CTRL). Both SLM approaches, ISFM and CA, combine various SLM practices such as the cultivation of cover crops, inter-cropping, mulching, crop rotation and diversification (IPCC, 2022), but set different priorities in the use of the individual practices.

Based on the results outlined in ► Chapter 4, the following findings can be summarized:

1. The participation in trainings is critical to increase implementation rates of SLM practices among smallholder farmers: CA and ISFM farmers who participated in trainings perceived them as highly relevant. Control group farmers, who did not participate in trainings on SLM practices, implemented only a limited number of practices or none at all. For example, those farmers did not cultivate cover crops as opposed to CA and ISFM farmers. In contrast, the use of compost and/or manure was an important practice among CA and ISFM farmers, as almost all of them did apply it. Cover crops, as part of soil and water conservation practices, were used by ISFM and CA farmers on 45% and 74% of their land, respectively. Cross slope barriers were implemented on more than 60% of the cultivated land of ISFM and CA farmers. CA farmers generally seemed to be more advanced in the implementation of SLM practices than ISFM farmers.
2. CA and ISFM farmers had more soil microbial communities compared to the farmers practicing BAU. The SLM practices including using organic inputs, crop diversification and rotation, and mulching and cover crop management improve soil structure and soil fertility. The resulting improved growth performance of crops constitute a larger

energy source for bacteria and fungi, which contributes to their increased abundance on SLM farms.

3. The study results show significant differences in the economic performance of CA and ISFM farmers compared to CTRL farmers. The income from farming activities of CA and ISFM famers was twice that of the CTRL group farmers: CA farm households gained 1,083 USD per year (1,732 USD per year of cultivated land), and ISFM households gained 1,085 USD/year (1,443 USD/year of cultivated land), whereas CTRL households gained only 324 USD per year(555 USD per year of cultivated land). Thus, regardless of the described differences between the practices of CA and ISFM, the income results show that implementing SLM practices leads to economic benefits compared to BAU. The economic performance of SLM farmers is not only higher, but their income is also more diversified over different farming activities: The revenues from fruits and from other products were for example higher for SLM farmers than for control farmers.

4. The annual carbon sequestration rate in the topsoil was 0.44 t CO_{2e}/ha/year for ISFM farms, while that of the CA farms was 3.38 t CO_{2e}/ha/year. The average sequestration rate depends essentially on the implementation period of the SLM practices. The sequestration rate is expected to reach in average 1.98 t CO_{2e}/ha/year for an implementation period of 20 years and 3.77 t $_{2e}$/ha/year for an implementation period of 10 years.

5. The average increase of income of ISFM and CA farmers amounts to 1,033 USD ha/year and is composed of the average increase of income per ha for agricultural production. This sums up to a NPV of USD 314 Mio over a period of 20 years with a discount rate of 10 %.

Recommendations

Based on the study results, the following recommendations can be given to policymakers to foster the adoption of SLM approaches to increase carbon sequestration in soils in Kenya:

- Access to extension services on SLM significantly influences whether a farmer implements SLM practices. Therefore, access to extension services should be promoted by national policymakers. Supporting farmer groups in the procurement of inputs such as seeds for cover crops and placing an emphasis on farmer-to-farmer approaches can increase adoption rates of SLM practices.
- SLM practices should be promoted, as independent of the exact type of SLM practice,

  implementing SLM practices generally leads to economic benefits for farmers compared to business as usual. Farmers implementing SLM practices had higher and more diversified income than farmers practicing business as usual: While CA and ISFM farmers gained in average 1,587 USD per ha and year, farmers practicing business as usual gained 555 USD per ha and year.
- When designing carbon projects in agriculture, it is recommended to not only include agroforestry practices for carbon sequestration in biomass, but also promote carbon sequestration in soils by implementing SLM practices. They provide crucial co-benefits for the farmers participating in the carbon scheme by increased yields.
- The amount of sequestered carbon to be certified when registering a carbon project at verification bodies is mostly underestimated due to conservative sequestration estimates. It thus can be assumed that within carbon certification schemes there is more carbon sequestered than is remunerated for it.
- High carbon sequestration rates can be reached under the assumption of continuous access to extension services. Selling the carbon sequestered as carbon credits can ensure long-term financing of extension services for small-scale farmers.

06

Literature

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07
Technical Annex

Conversion Factors

Mass	
1 kg (kilogramme)	1000 grams (g)
1 t (metric tonne)	1,000 kilograms (kg)
1 mg (mega gramme)	1 tonne (t) = 1,000 kg =1,000,000 g
1 mg (milligram)	0,001 g
Metric to imperial	
1 t	0,984206 ton (imperial)
1 kg	2.2046 pounds
1 g	0,35 ounces
1 bushel of barley	0.021772 t = 21.772 kg
1 bushels of corn	0.254 t = 25.4 kg
1 bushel of wheat/soybeans	0.0272155 t = 27,2155 kg

Lenght	
1 mm (millimetre)	0.1 cm (centimetre)
1 cm (centimetre)	0.01 m (metre)
1 cm	0.394 inches
1 m (meter)	1.094 yards
1 km (kilometre)	1,000 m = 0.621 miles
1 mi (mile)	1,609.344 m
µm = micrometre	0.000001 m
nm	0.000000001 m

Volume	
1 cbm/m³ (cubic metre)	1,000 l (litre)
1 l	1,000 cm³ (cubic centimetre)
1 l (litre)	1.057 quarts = 0.265 gallons
1 cbm	265 gallons
µL = microlitre	0.000001 litres
1 cbm /m3	35.3 cubic feet

Area	
1 ha (hectare)	1,000 m^2
1 ha (hectare)	2.47 ac (acres)
kg/ha	kilograms per hectare = 0.893 pounds per acre
Mg/ha	megagrams per hectare = 893 pounds per acre = 0.446 U.S. tons per acre
m^3/ha (cubic meters per hectare)	14.3 cubic feet per acre

Concentration	
g/L	grams per litre = parts per thousand
mg/L	milligrams per litre = parts per million
μL/L	microliters per litre = parts per million
kg/m^3	kilograms per cubic meter = 0.062 pounds per cubic foot
g/kg	grams per kilogram = percent divided by ten
mg/kg	milligrams per kilogram = parts per million

CO_2 – Equations	
1 t of SOM	0,57 t of SOC
1 t of SOC	3.7 t CO_2

Additional tables to figures

TABLE 24 Total revenues from farming activities incl. home consumption

Source: household survey 2022

Crops		Share	KES	Maize	Beans	Sorghum	Potatoes	Cassava	Others
	CA	63.6 %	**96,645**	62,638	9701	14,048	7545	2555	159
	ISFM	48.9 %	**74,311**	44,137	7516	13,968	3357	3786	1548
	CTRL	60.2 %	**37,592**	27,118	5124	1186	476	3212	476

Fruits		Share	KES	Mango	Orange	Pawpaw	Others
	CA	8.0 %	**28,349**	62,638	9701	14,048	7545
	ISFM	16.3 %	**38,531**	44,137	7516	13,968	3357
	CTRL	2.8 %	**22,300**	27,118	5124	1186	476

Animal production		Share	KES	Milk	Chicken
	CA	18.7 %	**28,349**	18,158	10,191
	ISFM	25.4 %	**38,531**	27,977	10,554
	CTRL	35.7 %	**22,300**	13,757	8543

Other products		Share	KES	Seeds	Vermi-juice	FYM	Tree seedlings	Fodder Desmo-dium	Fodder Napier gras
	CA	9.5 %	**14,435**	153	7100	3636	1045	1318	1182
	ISFM	9.3 %	**14,095**	48	1905	2857	8333	952	
	CTRL	1.2 %	**762**					762	

Other revenues		Share	KES	Donations
	CA	0.2 %	**350**	350
	ISFM	0.1 %	**225**	225
	CTRL	0.0 %	**7**	7

Total HH revenues including home consumption						Revenue per ac of cultivated land			
			KES	USD*		KES/ac	USD/ac		acres
	CA		151,940	**1266**		**98,314**	**819**		1.55
	ISFM		151,851	**1265**		**81,766**	**681**		1.86
	CTRL		62,412	**520**		**43,327**	**361**		1.44

TABLE 25 Variable costs of the farm household

Source: household survey 2022

Crops	Seeds	%	KES	Mais seed	Beans seed	Sorghum seed	Potatoes
	CA	26.7%	4560	1589	1861	396	714
	ISFM	26.7%	4324	2288	1413	574	50
	CTRL	13.7%	2537	1422	967	120	29

Seeds		KES	Cowpeas seeds	Nappia seed	Other seeds	Covercrop seeds
CA	3.4%	588	16	395	41	135
ISFM	5.5%	898	57	565	33	243
CTRL	1.4%	252	0	252	0	0

Fertilizer		KES	DAP	NPK	CAN
CA	0.0%	0	0	0	0
ISFM	1.7%	268	220	48	0
CTRL	31.6%	5836	3079	562	2195

Field works		KES	Ploughing	Harrowing I	Harrowing II	Harvest	Transport to market
CA	45.6%	7801	1855	1875	1709	1559	802
ISFM	50.9%	8238	1543	1876	2333	1610	876
CTRL	43.1%	7955	2552	1852	1824	1260	467

Fruits			KES	Mangoe seedling	Orange seedling	Other seedling
	CA	3.6%	612	309	68	234
	ISFM	5.3%	859	633	110	116
	CTRL	0.4%	82	0	31	51

Animal production			KES	Animal replacement	Veterinary 1	Veterinary 2
	CA	14.6%	2496	1642	341	514
	ISFM	8.2%	1324	762	181	381
	CTRL	6.6%	1226	714	331	181

Other inputs			KES	Farm labour
	CA	6.1%	1045	1045
	ISFM	1.8%	286	286
	CTRL	3.1%	571	571

Total variable costs of inputs				Variable costs per ac of cultivated land			
		KES	USD	KES/ac	USD/ac		acres
CA		17,101	143	**11,066**	**92**		1.55
ISFM		16,196	135	**8721**	**73**		1.86
CTRL		18,460	154	**12,815**	**107**		1.44

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