Testing of tools for calculating GHG emissions from agriculture in the "Adaptation of Agriculture to Climate Change" project in Namibia

UNIQUE forestry and land use

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Client

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

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Authors

Matthias Seebauer (UNIQUE forestry and land use GmbH, Germany)

Gilbert Wathum (UNIQUE forestry and land use GmbH, Uganda)

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LIST OF ABBREVIATIONS

ABMS	Activity Baseline and Monitoring Survey
AFOLU	Agriculture, Forestry and Other Land Use
CA	Conservation Agriculture
CFA	Cool Farm Alliance
CFT	Cool Farm Tool
CSA	Climate Smart Agriculture
Ex-ACT	Ex-Ante Carbon Balance Tool
FAO	Food and Agriculture Organization of the United Nations
FYM	Farm Yard Manure
GHG	Green House Gas
GIS	Geographic information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)
ha	hectare
HWSD	Harmonized World Soil Database
IPPC	Intergovernmental Panel for Climate Change
kg	kilogram
NDC	Nationally Determined Contributions
NPK	Nitrogen Phosphorus Potassium
NUST	Namibia University of Science and Technology
VCS	Verified Carbon Standard
SALM	Sustainable Agricultural Land Management
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Use
SOC	Soil Organic Carbon
tCO_2e	tonnes of Carbon Dioxide equivalent

1 INTRODUCTION

This report presents the results of the testing of three tools for assessing GHG emissions and mitigation in the GIZ-supported project: "Adaptation of Agriculture to Climate Change in Northern Namibia". The project supports the Ministry of Agriculture, Water and Forestry with the implementation of the ministry's "Comprehensive Conservation Agriculture Programme 2015-2019" in three regions: Kavango West, Kavango East, and Zambezi (Figure 1). The goal of the 5-year project (February 2015 – September 2019) is to enable small-scale farmers in northern Namibia to successfully use climate-adapted farming methods.

More than half of Namibia's estimated 2.1 million inhabitants[1] live in the northern part of the country depending mostly on rain-fed agriculture, which is extremely vulnerable to the climate change impacts like increased rainfall variabilities, droughts and heat waves. In the country's Nationally Determined Contributions (NDC)[2], climate change is projected to negatively impact on food security in many ways – such as lower crop yields and increased risks of crop failure, reduced livestock production, decline in fisheries production, reduced water availability, lower water quality, loss of soil fertility and increased soil erosion. Agriculture plays an important role in the country's NDC in adapting to climate change and mitigating it. This project, therefore, contributes to the country's effort – particularly in adapting to climate change but also in mitigation. The project focuses on four areas of action: (1) farmer training in conservation agriculture (CA), (2) advisory services, and the provision of seeds/seedlings and fertilisers; (3) policy support for the government to mainstream climate change and CA in its strategies and policies; (4) knowledge management through documenting an evidence base for CA and its climate adaptation and mitigation benefits. The project has conducted farmer trainings and stakeholder workshops; set up CA research by implementation of demonstration fields both on research stations and on farms; and collected baseline and monitoring data. The project is promoting several practices such as residue retention/mulching; crop rotation/intercropping (grain-legume); inorganic/organic fertiliser use (farmyard manure/compost, green manure cover crops); reduced tillage in form of low-soil-disturbance ripping, direct seeding, and basin/dibble stick planting.

[1] Namibia Statistic Agency, 2011.

[2] Namibia's INDC proposes to apply conservation agriculture on about 80,000 ha till 2030 (Government of the Republic of Namibia, 2015).

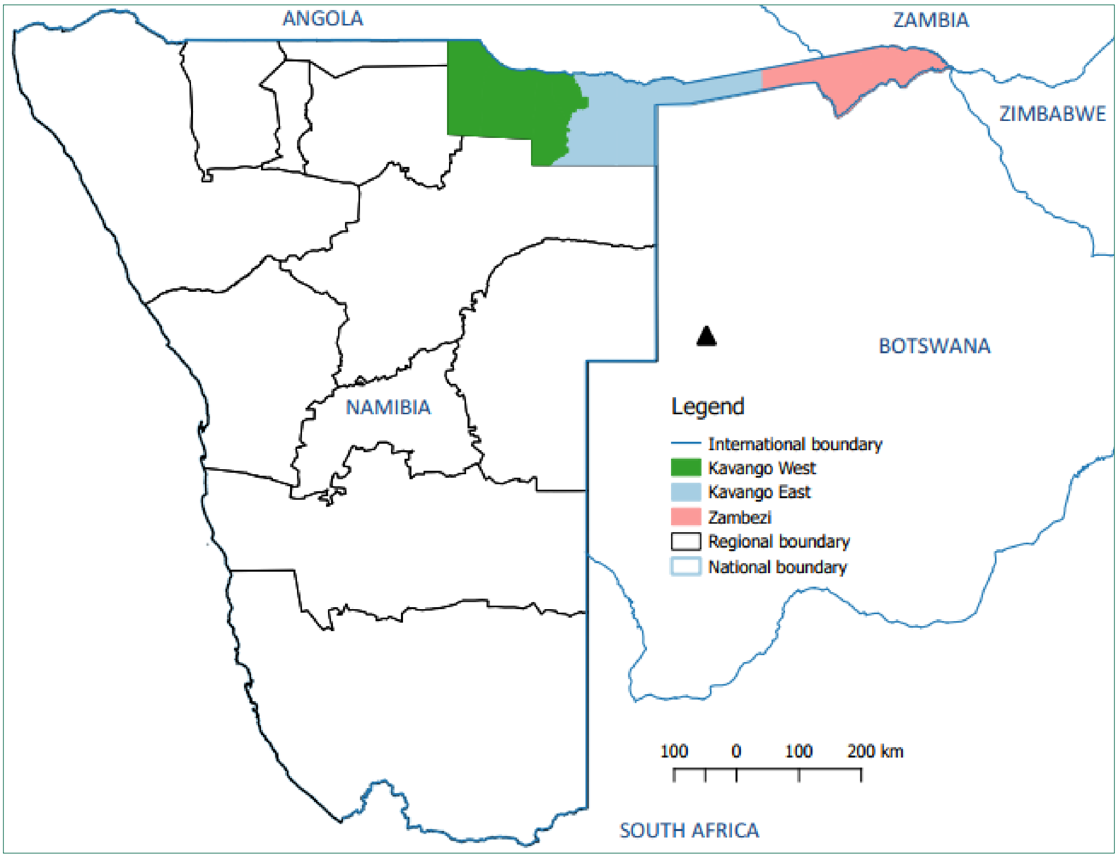


Figure 1: The project location

Source: UNIQUE (GIS data from DIVA-GIS)

As agriculture plays a key role in adaptation to and mitigation of climate change in Namibia, GIZ contracted UNIQUE to test and evaluate tools for assessing GHG emissions and mitigation potentials of the project's set of interventions (CA practices). This is relevant for the project's monitoring, reporting and decision-making regarding its climate protection impacts and for the country's NDC implementation. Three GHG quantification tools were selected for testing: two calculators, i.e. the **Ex-Ante Carbon Balance Tool** (**Ex-ACT**) and the **Cool Farm Tool** (**CFT**) and one carbon standard quantification protocol, which requires the use of a process-based soil carbon model, i.e. the **Sustainable Agricultural Land Management (SALM) methodology.**

Section 2 of this report gives an overview of agricultural emission quantification in general; section 3 describes the methods applied in this study – including the tools and data used. The results are presented in section 4.

2 BACKGROUND - STATE OF THE ART IN AGRICULTURAL EMISSIONS QUANTIFICATION

The Intergovernmental Panel for Climate Change (IPCC) has compiled the best available scientific methods into published guidelines for estimating emissions and emission removals from the land use sector. This guidance is designed for GHG accounting at the national level, not the product level (IPCC, 2006).

However, most of the project-level offset schemes such as the Clean Development Mechanism and the Verified Carbon Standard (VCS) have also designed their eligible Agriculture, Forestry and Other Land Use (AFOLU) project-based accounting methodologies along the IPCC guidelines. The IPCC protocols follow a sector and component-based quantification approach ('silo' approach). Within the AFOLU sector, the GHG emissions sources and sinks are disaggregated into the following components:

- Non-CO_2 emissions: Enteric fermentation (CH_4), manure management (CH_4 and N_2O), rice cultivation (CH_4 and N_2O), agricultural soils (N_2O), burning of biomass (N_2O);
- CO_2 emissions or emission removals: Carbon stock changes in biomass (above- and belowground biomass, litter, deadwood, harvested wood products) and carbon stock changes in soil organic carbon (SOC).

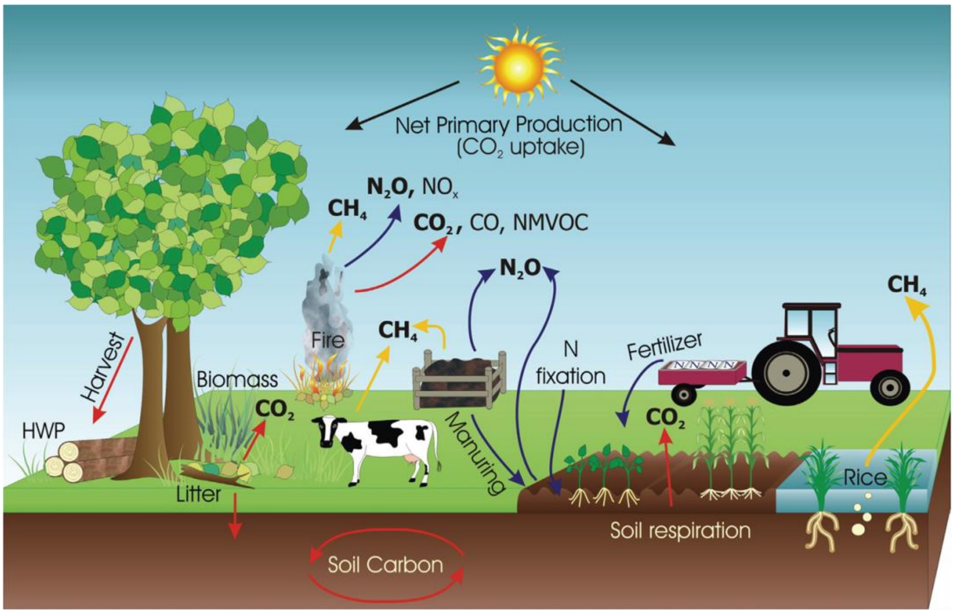


Figure 2 Sources and sinks of farm emissions (IPCC 2006b)

Fundamental to the IPCC guidelines is the concept of hierarchical tiers (Tiers 1, 2, 3) for estimating GHG emissions and removals. The three tiers are a function of methodological complexity, regional specificity of the emission factors, and the extent and spatial resolution of the activity data. The three tiers progress from least to greatest level of certainty (IPCC 2006). Moving from lower to higher tiers will usually require increasing investments in terms of baseline establishment and monitoring costs as well as institutional and technical capacities.

2.1 Emissions quantification and climate-smart practices in small-holder farms

Emission quantifications of whole farms can be used to assess the GHG emissions in an integrated farming system and are well suited to determine which mitigation activities and in which combination of activities is most efficient in terms of GHG emission reductions. The concept of climate-smart agriculture (CSA) seeks to increase sustainable productivity increases; strengthen farmers' and agro-ecosystems' resilience in the face of climate change and reduce greenhouse gas emissions as a co-benefit. It consists of agricultural practices that increase yields, create climate risk-adjusted returns, improve soil fertility, nutrient availability and reduce emissions through carbon sequestration or increased product efficiency. CSA is a concept to tackle the challenge of stagnating yields while incorporating the climate change dimension. Table 1 below shows some examples of climate-smart practices and highlights the combined effects on food security/ crop productivity, adaptation and mitigation benefits.

Table 1: Examples of climate smart agriculture practices and the impacts on food security, adaptation and mitigation

Based on Smith et al 2007 & FAO 2009

Activity	Examples	Productivity/ Food Security impact	Adaptation impact	Potential mitigation co-benefit
Cropland management				
Agronomy	Crop rotation with legumes to produce biomass, fix nitrogen, reduce soil erosion and weeds, minimize pests and diseases and increase carbon stock. Combinations are available worldwide according to agro-ecological zones and prevailing farming systems and farm size.	+++ High productivity, input cost reduction. Herbicide inputs may increase if combined with reduced/zero tillage. High potential to increase productivity of small-holder farms.	+++ Strong adaptation benefits due to reduced erosion, increased water infiltration and water holding capacity. Less soil water evaporation losses.	+++ Enhanced biomass and residue production. Depending on food, feed, fibre and fuel utilization biomass will be composted or used as manure which will decompose and increase soil organic carbon stocks.
Water management	Drip and other low energy irrigation systems, water conservation technologies such as check dams are appropriate technologies to improve crop production in rain-fed agricultural systems that lack sufficient water. Drainage of peatlands increases emissions.	+++ High potential to increase productivity and secure food supply for rural communities.	+++ Water management is an excellent tool to adapt to extreme weather conditions like drought. Makes farmers more independent from changing rainfall patterns.	+- Depending on land use situation water management practices can even have negative effects on carbon stock balance, since extensive areas can be converted into agriculture land and loose carbon stock. On existing

Activity	Examples	Productivity/ Food Security impact	Adaptation impact	Potential mitigation co-benefit
				farmland, mitigation effect is positive. N_2O emissions from higher moisture and fertilizer inputs.
Agroforestry	Intercropping or rotational cropping of crops and trees, introduction of perennial fodder or fertilizing shrubs/trees such as Sesbania, Gliricidia sepium, Faidherbia albida, Tephrosia	+ Yield of the agricultural crop does not necessarily increase and might decrease, depending on competition with trees. Yields can increase due to more drought and pest resilience. Systems can diversify income.	++ Canopy cover is reducing sun stress and water evaporation losses, fruit tree planting can diversify nutrition	+++ High in particular if tree biomass is increased
Grazing land management				
Grazing intensity	Participatory land-use planning to define access rights and reduce overstocking.	++ Controlled grazing considering livestock carrying capacity generally improves herder resilience.	++ Strong adaptation benefits due to reduced erosion, increased water infiltration and water holding capacity and less soil water evaporation losses	+ Depending on baseline carbon stocks and carbon equilibrium substantial additional soil carbon sequestration potential
Increased productivity	Fodder planting, efficient fertilizer application, building water points, winter sheds and improved animal health to reduce body weight losses and reduce production cycle	++ Healthy pasture and animals will increase food security	+ Healthy pasture and animals will increase climate resilience	+ Reducing emissions per product unit
Nutrient management	Nutrient management can be improved by synthetic or organic fertilizer, animal manure or a combination; precise fertilizer application and use of N inhibitors	++ Healthy pasture and animals will increase food security	+ Healthy pasture and animals will increase climate resilience	+ Positive if grazing intensity is sustainable

To date, most of the studies that have evaluated mitigation options in the agricultural context have explored them using a single method to mitigate a specific pollutant, including specific GHGs (A. del Prado et al. 2010). Given the complex nature of the interactions in farming systems and between adaptation, food security and mitigation activities, using appropriate indicators and methods of analysis is essential to establish a baseline that captures all relevant information, as well as for meaningful monitoring and evaluation (FAO 2012).

2.2 Existing land use GHG quantification tools

As the IPCC Methodology forms the mandatory basis for the national GHG emission accounting under UNFCCC, most of the project based accounting standards and specific methodologies (e.g. CDM, VERRA, Gold Standard, etc.) in the land use sector have widely adopted this methodological guidance including the use of default emission factors. Along with this, numerous tools have been developed to support the quantification of GHG emissions from agricultural and forestry activities.

According to Denef et al. (2012), these tools can be divided in three main categories: (1) calculators, (2) protocols and guidelines, and (3) process-based models. This study used the definition of these three categories. "Calculators" include automated web-, Excel-, or other software-based calculation tools, developed for quantifying GHG emissions or emission reductions from whole farms, specific agricultural and forest activities, or offset projects. "Protocols and guidelines" include guidelines, protocols and other reports that describe quantification procedures for GHG accounting from agricultural and forestry practices. "Process-based models" comprise process-based, empirical and mechanistic research models that can directly or indirectly assess GHG emissions from agricultural or forest activities (Denef et al. 2012).

A detailed description of the available calculators, protocols and guidelines, and process-based models for the land use sector is available in Denef et al. 2012, Milne et al. 2012 and FAO 2012. The scope of application of these tools differs: calculators are decision support tools for farmers, policy makers or projects, protocols describe quantification guidelines for GHG accounting from agricultural projects, normally undergoing the general carbon-project registration cycle. Process based models including Life Cycle Assessments are more oriented towards research.

Table 2: Global coverage of tools developed for land based GHG emission quantification

Calculators and protocols reviewed from Denef et al. 2012 and FAO 2012; Whole farm system models from Crosson et al. 2011

Country of use	Total numbers of calculators	Total number of protocols	Total number of whole farm system models
Europe	7	1	>10
North America	>10	>10	8
New Zealand and Australia	>10	-	5
World	5	>10	1
Developing countries	1	5	1

It is evident that most of the tools have been developed either in Europe, North America or in New Zealand and Australia, both the easy-to-use calculators and the more scientific whole farm models. An exception are the protocols and guidelines with a number of them being applicable on a global scale. This seems logic, since accounting standards such as the VCS or the CDM claim to be generically applicable to projects in most parts of the world. Very few of the tools are explicitly applied in developing countries.

In this study, the aim was to use three quantification tools with the available data and information from the project region in Namibia representing two calculators and one protocol:

- Ex-Act Tool → calculator
- Cool Farm Tool → calculator
- VCS SALM Methodology → protocol

3 METHODOLOGY

3.1 Overall approach

The study comprised three main parts: 1) selection of GHG quantification tools to be tested, 2) gathering of relevant data, and 3) testing/applying the tools under field conditions in the project.

The approach taken in testing of the tools was to compare GHG emissions under conventional farming system with that under conservation agriculture (CA). Conventional farming in this context means the farming practices traditionally being used before the adoption of CA practices introduced by the project[3].

The tool testing covered GHG mitigation in crop production only[4], and the three major crops where data were adequately available: millet, maize, and cowpeas[5].

3.2 The GHG quantification tools

The three tools are: the **Ex-Ante Carbon Balance** (**Ex-ACT**); the **Sustainable Agricultural Land Management (SALM) methodology**; and the **Cool Farm Tool** (**CFT**).

3.2.1 The structure and functioning of the tools

1. The **Ex-ACT** is an Excel-based GHG accounting calculator developed by the FAO. It is used to estimate GHG mitigation potential of agriculture, forestry and fishery project activities on activity, farm or landscape level. It calculates net carbon balance (tCO_2e per unit of land) from greenhouse gas (GHG) emissions and carbon sequestration resulting from

[3] Conventional farming in the region is characterized by slash and burn, burning of crop residues, repeated tilling of the soils, and limited application of organic and in-organic fertilizers. CA practices include no/reduce tillage, crop rotation and green manure cover cropping.

[4] Livestock improvement interventions were not prominent in the project.

[5] Note that in the Ex-ACT tool, millet was named as grains and cowpeas as beans and pulses.

adoption of improved land management options, as compared to a "business as usual" scenario.

The tool consists of a set of linked Excel sheets where the user inputs basic data on land use and management practices. The tool automatically performs the calculations. The user can chose which land management options/practices to consider from a range of activities in agriculture, forestry and fishery. Each of the land management options is associated with an impact on GHG emissions or carbon sequestration i.e. an "emission factor". To calculate net carbon balance, the tool uses default "emission factors" derived from scientific studies, which are already populated in the tool. Alternatively, the user can add own project specific data to derive specific "emission factors". The tool and user guides can be accessed **here**.

2. The **SALM methodology** is a set of tools for the calculation of GHG emissions and carbon sequestration specifically in smallholder agriculture contexts. The tool was developed in a GHG mitigation project in Kenya. It has been approved by the Verified Carbon Standard (VCS) as robust carbon accounting methodology in smallholder farming systems. The SALM methodology contains a set of procedures and formulae for calculating GHG emissions and carbon sequestration from a range of practices, namely: use of synthetic fertilizers, burning of agricultural residues, use of woody perennials and nitrogen fixing trees (agroforestry), use of fossil fuels for agricultural management, and crop residue management.

   The GHG emissions and carbon sequestration of these practices are calculated (SALM methodology accessible here), whereby the carbon sequestration, i.e., Soil Organic Carbon (SOC) change in the topsoil, is modelled using a soil carbon model. Thus, one of the advantages of this tool is that it uses a model instead of recurrent soil measurements to estimate soil carbon change. In this study, the "RothC soil carbon model" has been used. The net GHG mitigation impact is calculated as the difference between baseline scenario and project scenario. Most of the input data for applying the SALM methodology has to come from project-specific surveys or comparative surveys in the project region – in addition to a few default values.

3. The **Cool Farm Tool** is an online GHG emission calculator developed and owned by the Cool Farm Alliance. Users must sign up to access and use it. It calculates GHG emissions for particular livestock and crop products - hence a tool for estimating the carbon footprint of a product. It covers numerous agricultural practices that generate GHG emissions or cause carbon sequestration during production, namely: inorganic or organic fertilizer use, different tillage options, cover crops, use of woody perennials (agroforestry), residue management, land use change, pesticide use, paddy rice cultivation[6], livestock feed production, manure management, field energy use, primary processing, and waste water treatment. In this study, only the first six practices were considered for testing of the tool. The GHG emissions and carbon sequestration in the CFT are automatically calculated by using "emission factors" derived from scientific studies. The output of the CFT is the net GHG emission per unit of the product. Therefore, to estimate the GHG impact of a project, two runs of the tool have to be performed for each product – one for the baseline scenario and

[6] Paddy rice cultivation is considered a separate activity in the CFT as the practice generates methane emissions.

the other for the project scenario. Detailed descriptions of the CFT and its application can be obtained **here**.

All three tools account for soil organic carbon changes in the topsoil (30 cm) in line with the IPCC Good Practice Guidance.

3.2.2 Data

The tools require two categories of data to calculate GHG emissions: (i) data for calibrating the tool according to the specific project region, and (ii) data for running the calculations. The first category comprises basic data like project location, soil characteristics, and weather data, which can be obtained from secondary sources. The second category came from the project's baseline and/or monitoring surveys. The list of both categories of data used in this study is presented in Annex 2.

Project data included soil analyses from the project's Mobile Soil Lab[7], and data from the CA adoption baseline and monitoring surveys conducted in the framework of the project's collaboration with the Namibia University of Science and Technology (NUST). Only the topsoil 30 cm results from the Mobile Soil Lab were considered in this study in line with the IPCC GPG. Weather data (2012-2016) of five weather stations located in the regions were obtained from WeatherNet (SASSCAL WeatherNet, 2017)[8]. In addition, the consultants collected data on amount and types of household energy, number of trees planted on-farm (agroforestry), extent of land converted from forest to agriculture, and amount and type of fertilizers and pesticides used in conventional farming. These additional data were obtained by interviewing six lead farmers/groups who had originally participated in the surveys of NUST[9].

Survey data were processed in a simple database to provide inputs for final entry and use in the tools. Where organic matter is applied to the field e.g. in residue retention, and manure application, an indirect method was applied to estimate the organic matter inputs. The calculation of residue inputs from crops (and green manure) was based on crop yield data from the surveys. The harvest fresh yields of the major crops (Table 1) was converted to tons of dry matter per ha on the basis of the equations reported in Table 11.2 in Volume 4 of the 2006 IPCC Guidelines[10]. The calculation of manure inputs was based on information on the amount and types of livestock animals in each farm. The factors from Tables 10A-4 to 10A-9 in Volume 4 of the 2006 IPCC Guidelines were used to calculate the amount of manure produced by animal type[11]. The average yields and respective residues for the three main crops and the organic inputs from manure are presented in Table 2 and Table 3. These were the input data used for modelling GHG mitigation (section 3.2.3).

[7] Please refer to the extensive proejct documentation for a detailed decription on the soil sampling
[8] Accessed here
[9] A questionnaire was used in the interview – it was adapted by including additional questions in the questionnaire that had already been used in the NUST survey. Five of the surveys were conducted in Kavango West, and one in Kavango East.
[10] http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf
[11] http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf

Table 3: Yields of major crops used in the tools

Crops	Yield under conventional farming (kg/ha)	Yield under CA (kg/ha) 2017	Target Yield under CA (kg/ha)
Millet	188	395	1,000
Maize	1,802	1.590	2,500
Cowpeas	588	422	750

Source: Project surveys.

Note: Yields under conventional farming and yield after one year of CA (2017) came from project surveys, Target yields under CA from project results matrix, i.e., the target to be achieved by project. For cowpeas, % yield increase of 128% under CA (maize case) from project result matrix was assumed.

Table 4: Estimated residues of major crops in tonnes carbon per ha

Crops/Yields	Residues under conventional farming (t C/ha)	Residues under CA (t C/ha) 2017	Residues under CA target yield (t C/ha)
Millet	0.15 (13%)	0.26 (12%)	0.57
Maize	1.04 (16%)	0.96 (13%)	1.31
Cowpeas	0.58 (16%)	0.51 (7%)	0.65
Cover crops	0	3.27[12] (only for soil model)	3.27 (only for soil model)

Source: Authors' analysis.

Note: The uncertainty (standard error of the mean at 95% confidence interval) is shown in brackets for each of the averages derived from the project survey data.

Table 5: Livestock numbers and organic matter (manure) available in t C per farm and ha

Livestock type	Total number	Av. per farm
Calve	164	4
Cow	684	17
Goat	387	10
Donkey	33	1
Poultry	1,074	27
Sheep	11	0

Mean tC/ farm	Mean tC/ha	SE %
2.27	0.29	16%

Source: Authors

3.2.3 Calibration and modelling of GHG emissions and carbon sequestration

Each tool was calibrated, i.e., set up for modelling purpose by inputting in it the data for parameterisation/calibration listed in Annex 2: project location, soil characteristics, and weather data. Then the tool was run and the results scaled up as described in section 3.1.

1. Ex-ACT

The latest Ex-ACT Excel version (Version 7) downloaded from the FAO website was used and calibrated as shown in Figure 3.

[12] An input value of 3.27 t C/ ha/ year is used for the modelling in all strata based on Kaizzi et al (2006) and Anthofer (2005)

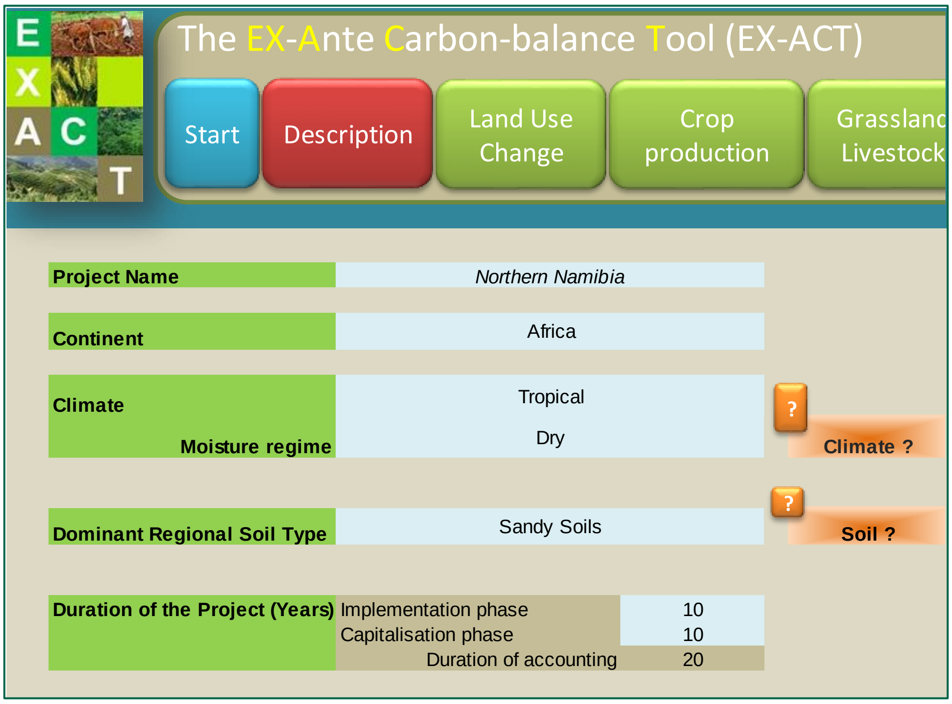


Figure 3: Ex-ACT calibration

Then for modelling GHG mitigation, data for the conventional agriculture for the three main crops as well as for the CA application were entered into the tool (table 4) under the tab 'Crop production'. The corresponding yields of the crops in the project (table 2) were entered as well as the aerial shares of each crop related to one ha.

Table 6: Calibration of the crop production tab in Ex-ACT

Practice	Main season crop	Improved agronomic practices	Nutrient manage-ment	No till & residue retention	Water manage-ment	Manure application	Residue manage-ment	Yield	Area (ha)		
								(t/ha/yr)	**Start**	**Without project**	**With project**
Conventional agri-culture	**Millet**	No	No	No	No	No	Burned	0.2	0.4	0.4	0
Conventional agri-culture	**Maize**	No	No	No	No	No	Burned	1.8	0.16	0.16	0
Conventional agri-culture	**Cowpea**	No	No	No	No	No	Burned	0.6	0.45	0.45	0
Conservation agri-culture	**Millet**	Yes	Yes	Yes	No	Yes	Retained	0.4	0	0	0.4
Conservation agri-culture	**Maize**	Yes	Yes	Yes	No	Yes	Retained	1.6	0	0	0.15
Conservation agri-culture	**Cowpea**	Yes	Yes	Yes	No	Yes	Retained	0.4	0	0	0.45

2. SALM methodology

Since most mitigation benefits of the Namibia project are related to enhanced soil fertility, the soil organic carbon (SOC) pool represents the most significant carbon pool. Hence, this pool was the one considered for testing the SALM methodology. The RothC soil model, which is recommended by the SALM methodology, was used. It was first calibrated by inputting the project location, soil organic matter (SOM), soil clay content and weather data. The data are detailed in Annex 2, and summarised in Figure 4 and Figure 5 below.

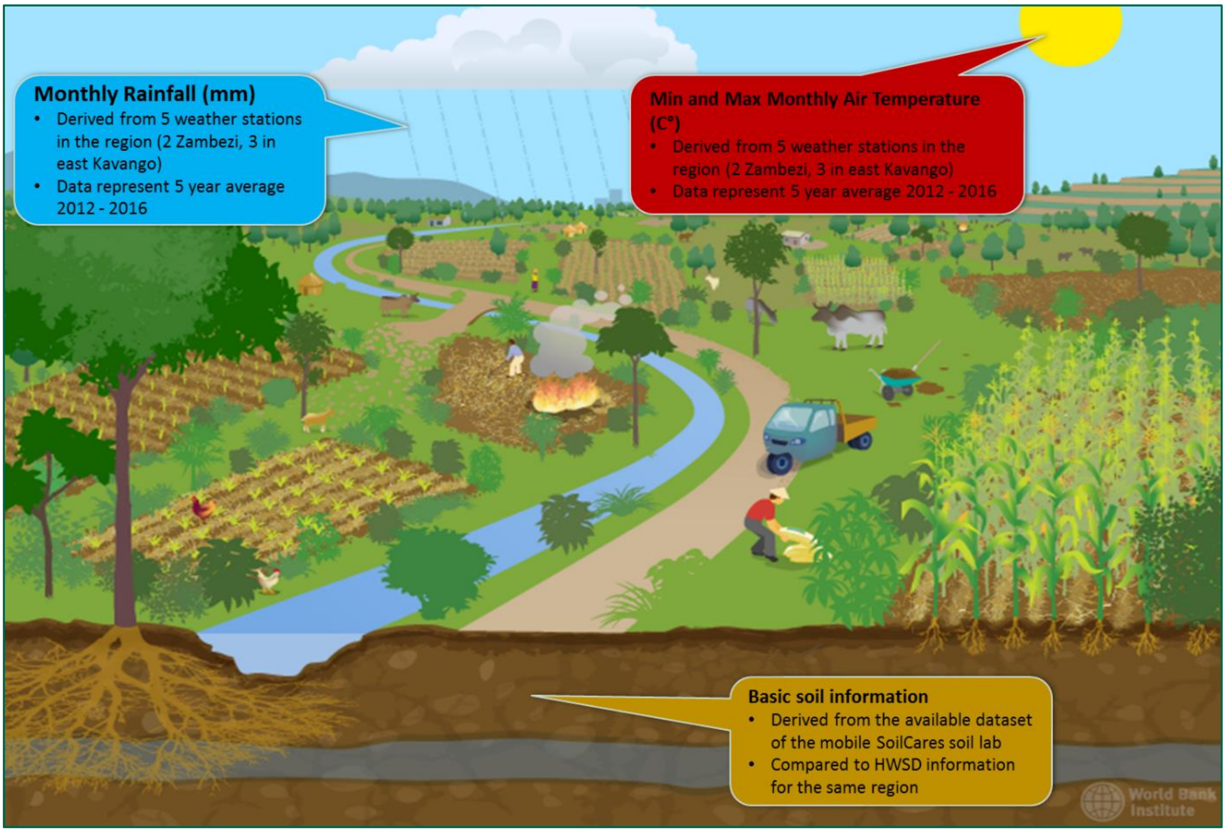


Figure 4: Data required for calibrating the RothC model of the SALM method. HWSD refers to Harmonized World Soil Database

Source: UNIQUE, image from the World Bank Institute

The results from the project soil samples analysis (using the Mobile Soil Lab) showed that the majority of soils are sandy soils. The average organic matter content in the topsoil is extremely low at 0.4%. The Harmonized World Soil Database (HWSD) value coincided exactly with the test sample values, which therefore can be assumed as highly reliable (IIASA, FAO 2008)[13].

[13] Accessible here: https://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/

Based on this SOC value the calculation of the average soil carbon stocks in the topsoil[14] (first 30 cm) results in 19.7 t C per ha (Figure 6).

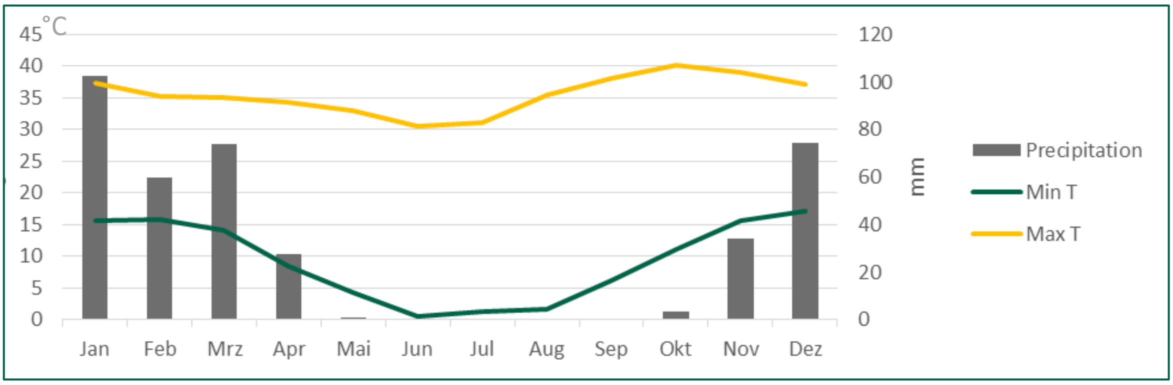


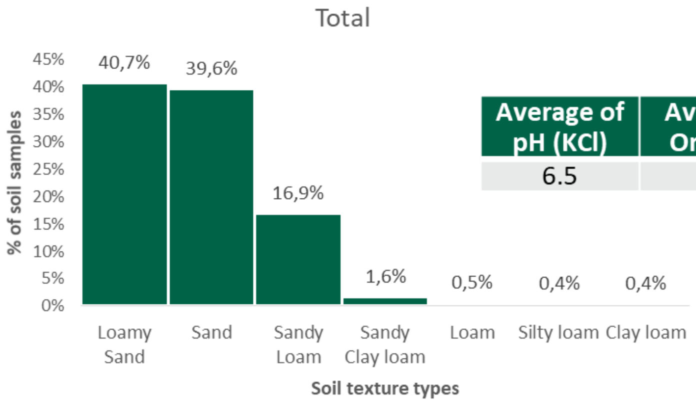
Figure 5: Weather data average (2012 – 2016) for the program region

Source: SASSCAL WeatherNet, 2017

Table 7: Soil information representative for the program region

Source: Project data & data from Harmonised World Soil Database (HWSD)

- Soil information from mobile soil lab –568 samples, only considering the topsoil (30 cm)



Average of pH (KCl)	Average of Organic %	Average of Total Nitrogen %
6.5	0.4%	0.04%

- Results from the Harmonized World Soil Database (HWSD) – topsoil 30 cm

Region	% Sand fraction	% Silt fraction	% Clay fraction	% Organic carbon	pH	Av. Bulk Density
Kavango	84.8	7.8	7.4	0.4	7.5	1.7
Zambezi	82.4	9.7	7.9	0.4	7.0	1.7
Total Average	84.0	8.4	7.6	0.4	7.3	1.7

- Average topsoil SOC stocks: OC% x BD x 30 cm (soil depth) = 19.7 tC/ ha

[14] The default IPCC soil depth is 30 cm representing the topsoil. The VCS SALM Methodology therefore only allows accounting for this soil depth

Then two model runs were performed using carbon inputs from crop residues and livestock manure (see Table 4 and 5). In addition, the rates of adoption of different farming practices presented in Table 8 were used. The first run was for conventional conditions in 2017, and the second assuming an increase of yields as per the project's results matrix (Table 3). One advantage of this tool is that multiple crops and input values (residues, manure, cover crops, etc.) can be modelled at once and directly compared between the baseline (conventional agriculture) and the project scenario.

Table 8: SOC sequestration factors using RothC

Change of agricultural land management	SOC sequestration potential (tCO_2e/ha/year)	
	2017 project data	Target crop yield
Shift from conventional to CA agriculture including residue retention, cover crops, and FY manure	-1.33	-1.61

Note: Negative sign is used here to denote net emission reductions or carbon sequestration

3. Cool Farm Tool (CFT)

An offline (Excel) version of the CFT downloaded from the CFT website was used. This was because the number of runs required exceeded that allowed by the free online version. The online and offline version were first tested and confirmed to give the same results – before continuing with the use of the Excel version[15]. The CFT was calibrated by inputting the basic calibration data: project location, soil characteristics, and weather data (see Annex 2 for details). Figure 7 shows a screenshot for calibrated millet CFT under the project scenario.

[15] It may not be recommendable to use the offline version for a complex and highly rigorous analysis or long-term use because its development is no longer supported by the CFA. However, for testing the tool, the consultants considered it adequate – especially after testing both the offline and online versions and ending up with the same results.

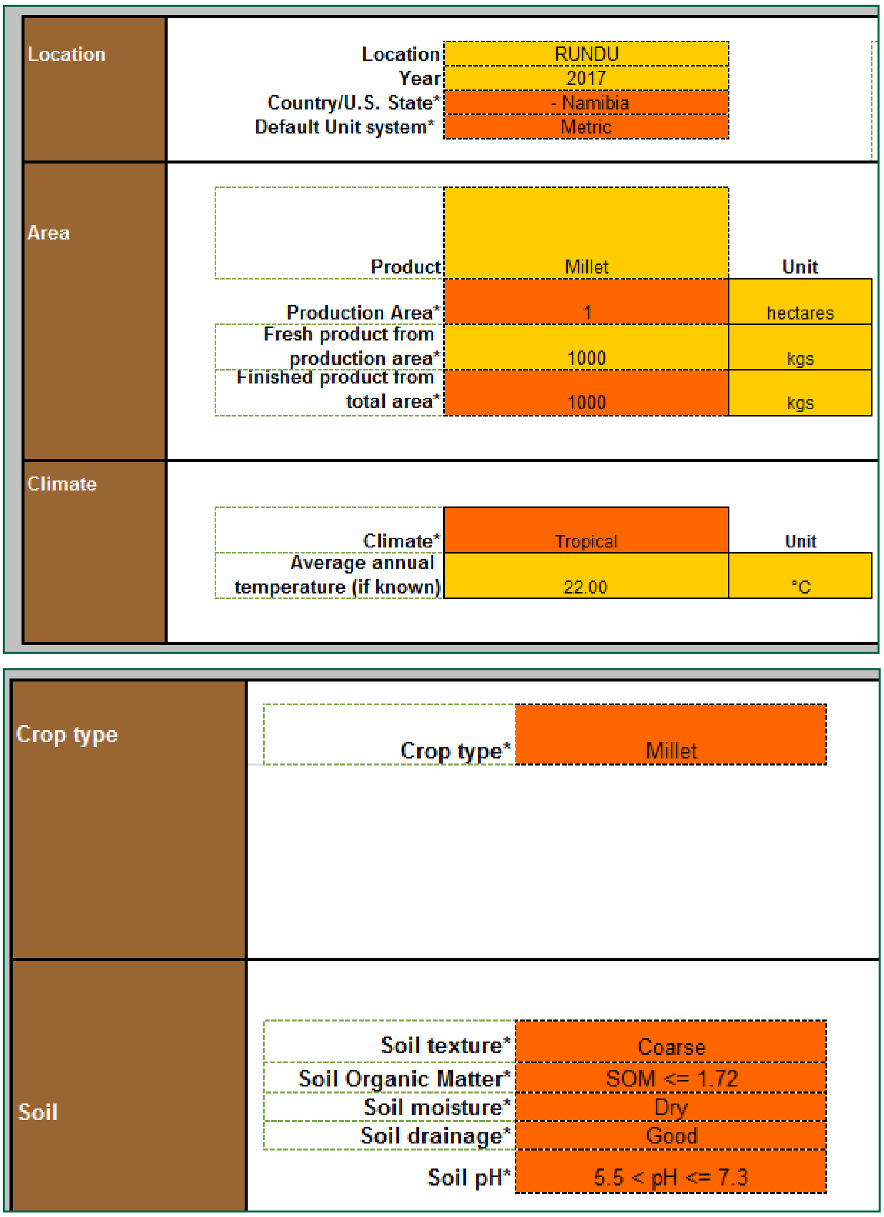


Figure 6: Calibration of CFT

Source: Authors

Once calibrated, the tool was ready for modelling GHG emissions and/or carbon sequestration. Several runs were performed because each product, e.g. millet, had to be analysed twice – one run for the conventional scenario and the other for project scenario. Hence, six runs were performed using the yield data shown in Table 3, section 3.2.2 and adoption rates of farming practices shown in Table 8 below. The adoption rate in the conventional system was set to zero because – although some farmers were reportedly using some of the practices before the project interventions but to a negligible degree. The adoption rate assumed in the project scenario (under CA) was derived from a study of CA adoption in southern Africa, which estimated about 20% of farmers adopting CA in the region[16].

Table 9: Rates of adoption of different farming practices/techniques

Practice	Adoption under conventional farming (% of total crop area)	Adoption under CA (% of total crop area)
Residue retention/mulching	0%	20%
Organic fertiliser use (Farm yard manure)	0%	20%
Inorganic fertiliser	0%	20% (rate: 160 kg/ha NPK; 40 kg/ha urea)[17]
No-tillage/Reduced tillage	0%	20%
Green manure cover crops	0%	20%
Agroforestry (long-term trees)	0%	0% (no long-term trees)

Source: Project surveys

3.3 Assessing suitability of the tools

3.3.1 Practices covered by the tools

Table 9 below summarises all practices/techniques in the project whose GHG emissions and/or carbon sequestration impacts the tools could theoretically assess. Each of the practices affects GHG emissions/carbon sequestration as follows:

1. Residue retention: leaving crop residues and other biomass on the fields and/or incorporating them into the soil result in increased soil organic carbon.
2. Crop rotation: the project promotes rotating cereals and legumes on the same crop field at different times.
3. Inorganic fertilizers: application results in GHG emissions because of processes such as volatilisation and hydrolysis. While all the three tools calculate fertilizer emissions, the CFT also includes GHG emissions generated in the production of the fertilizers ("embedded GHG emissions").
4. Intercropping – the practice of growing two or more crops on the same field at the same time by inter-planting them. The carbon impact of intercropping can be quantified only by the Ex-ACT, when the practice is considered as improved agronomic practice.
5. Organic fertilizer use – this takes the form of either farmyard manure (FYM), compost or raw manure (e.g. freshly collected cow dung). The practice generates carbon sequestration

[16] Mango *et al*., 2017.

[17] According to project staff, the advice farmers receive from the project is to apply 4 bags (200kg) of NPK and 1 bag (50kg) of urea on CA plots. From survey, however, average fertiliser application rate on CA plots was 167kg/ha and 47kg/ha for NPK and urea respectively. It is considered, therefore, that those adopting fertiliser application under CA will thus apply 160 kg/ha NPK; 40 kg/ha urea.

through increased soil organic carbon but can also cause GHG emissions due to decomposition.

6. No-tillage and reduced tillage: under no-tillage planting is done at defined spots (planting holes) without disturbing the surrounding soil by e.g. ploughing. In reduced tillage, minimal ripping of the soil is done to open up seeding rills. Other practices include direct dibble stick/basin planting. The carbon impact of no/reduced tillage comes from reduction in soil disturbance, hence, reduced decomposition and loss of soil carbon.
7. Green manure cover crops – involves planting crops or non-crop plants that provide soil cover, and are later incorporated into the soil – resulting into increased soil carbon.
8. Pesticide application generates GHG emissions when applied mechanically using energy for the tractor.
9. Agroforestry – trees planted on crop fields store biomass carbon above and below ground.

Not all the practices described above were considered in the calculations. Due to the scope of the tools (Table 9), and data availability, the following practices were tested with the tools (Table 10).

- For CFT: residue retention, organic fertilizer use, no/reduced tillage, and green manure cover crops.
- For Ex-ACT: nutrient management, no till & residue retention and manure application.
- For the RothC carbon model under the SALM methodology: residue retention (mulching) from both crop residues and cover crops, application of manure.

Table 10: Practices with quantifiable GHG emissions and carbon sequestration impacts

Practice		Reported use on farmer CA demo fields[18]	Possible to quantify GHG emissions with tool			Remarks
			Ex-ACT	SALM	CFT	
1.	Residue retention	High (72%)	Yes	Yes	Yes	Considered as mulching
2.	Crop rotation (grain-legume)	Low (31%)	Yes	No	No	Can be considered under improved agronomic practice in Ex-ACT
3.	Inorganic fertiliser use	High (100%)	Yes	No	Yes	Use causes GHG emissions. The project provides fertilisers
4.	Intercropping	High (67%)	Yes	No	No	Can be considered under improved agronomic practice in Ex-ACT
5.	Organic fertiliser use (FYM/compost)	Negligible (0%)	Yes	Yes	Yes	Can increase soil carbon or cause GHG emissions
6.	Organic fertiliser use (raw manure)	Very low (11%) - cow dung used	Yes	Yes	Yes	Can increase soil carbon or cause GHG emissions
7.	No-tillage	Very low (8%)	Yes	No	Yes	
8.	Reduced tillage (ripping; direct seeding & basin/dibble stick planting)	High (89% for ripping only; Others: very low < 11%)	Yes	No	Yes	Ripping equipment provided by project
9.	Green manure cover crops	None (0%)	Yes	Yes	Yes	If considered as organic fertiliser
10.	Use of herbicide/pesticide	Very low (6%)	Yes	No	Yes	Use causes GHG emissions
11.	Agroforestry	None (0%)	Yes	Yes	Yes	Has high carbon storage potential

Source: Project surveys and authors' survey. The percentage figures are percentages of farmers in the surveys reporting use of the practice.

3.3.2 Tools suitability

The tools' suitability was assessed based on the criteria described below:

Access: is the tool easy to get, i.e., publicly and freely available?

Both the Ex-ACT and SALM are publicly and completely freely available. For use of its full functionalities, the CFT is not completely free: users must pay some fees in order to export their results or to perform and store more than five calculations ("runs") on their account. An account for storing five "runs" with the ability to view but not export the results is free.

Comprehensiveness: the number of agricultural practices/techniques.

All the three tools are quite comprehensive – with ability to evaluate most of the practices being promoted in the project (see Table 9).

[18] Research plots were not considered. Instead, demo plots of farmers were considered since they represent actual adoption of the practices on the ground.

Data needs: can the data required by the tool be easily obtained by the project and/or from secondary sources?

All the tools could be applied using the data gathered through various sources in this study (see section 3.2.2). However, both the Ex-ACT and CFT employ a number of “emission factors” which lower their data needs. Therefore, the data need of the tools, ranked from lowest to highest is Ex-ACT, CFT, and then SALM methodology.

Ease of operating: extent of automation, availability of guidelines, and technical knowledge required to operate the tool.

Both the Ex-ACT and the CFT are fully automated – the user only has to enter basic data in order to perform the calculations. The SALM methodology requires more technical knowledge and is not automated. All tools have guidelines. It is tedious to use the CFT since each product requires a separate run of the tool, and two runs are required – one for the business as usual scenario and another for the project scenario. Both the Ex-ACT and the SALM methodology do this in a single analysis.

Reliability: is the tool’s scientific rigor proven/known so that the results are reliable?

Because the Ex-ACT and CFT apply many regional “emissions factors” and parameters, the variability of the results can be quite high. The SALM methodology offers more reliable results and can therefore serve as a carbon accounting methodology.

Transparency: does the tool provide background information – including calculation procedures and/or formulae to understand its functioning?

Both the Ex-ACT and the SALM methodology provide more details in their technical guidelines, which are available freely on the web. The property rights of the CFT are tightly controlled by the CFA.

The first five criteria are perhaps the most important for any project; transparency is important particularly in carbon accounting methodology development.

Table 11: Tools’ suitability assessment

Tool	Ex-ACT	SALM methodology	CFT
Access	+++	+++	+
Comprehensiveness	+++	++	+++
Data needs/availability	++	+	++
Ease of operating	++	+	++
Reliability	+	++	+
Transparency	+++	+++	++

4 RESULTS

4.1 Estimates of GHG emissions and mitigation benefits

For the estimate of GHG emissions and mitigation over total project area, two scenarios are presented: (i) assuming CA adoption on the project's target area of 1,500 ha and (ii) assuming 20% adoption of improved practices on the total crop area in the project regions i.e. 47,800 ha (derived from 19.8% x 241,400 = 47,800 ha with CA)[19]. The calculation has been carried out over a period of 20 years.

4.1.1 Ex-ACT

Figure 7 below shows the results of the GHG mitigation analysis from the Ex-ACT:

Components of the project	Gross fluxes Without	 With	 Balance
	All GHG in tCO2eq Positive = source / negative = sink		
Land use changes			
Deforestation	0	0	0
Afforestation	0	0	0
Other LUC	0	0	0
Agriculture			
Annual	2	-23	-25
Perennial	0	0	0
Rice	0	0	0
Grassland & Livestocks			
Grassland	0	0	0
Livestocks	0	0	0
Degradation & Management	0	0	0
Coastal wetlands	0	0	0
Inputs & Investments	0	0	0
Fishery & Aquaculture	0	0	0
Total	2	-23	-25
Per hectare	2	-22	-24
Per hectare per year	0.1	-1.1	-1.2

Figure 7: Results from Ex-ACT results table

The negative results[20] indicate that the practices adopted (improved agronomic practices; nutrient management, no till & residue retention, and manure application) generate a carbon sequestration of 24 tCO_2 per ha over the analysis period of 20 years as compared to the con-

[19] Total crop areas in the regions are estimated at about 241,400 ha.
[20] Positive numbers would mean GHG emissions.

ventional farming practices. This is equivalent to a GHG mitigation rate of 1.2 tCO_2 per ha per year. When up-scaled to the 1,500 ha (project target) and 47,800 ha (20% of total crop area in the regions), the estimated GHG mitigation is 1,800 and 57,360 tCO_2e per year, respectively.

4.1.2 SALM methodology

The modelled SOC sequestration potential ranged from 1.3 tCO_2e to 1.6 tCO_2e per ha per year. Scaling this up to the project's target CA area of 1,500 ha results in 1,994 tCO_2e and 2,420 tCO_2e per year respectively. Assuming CA adoption on 20% over the total crop area in the regions (47,800 ha under CA adoption), the estimated GHG mitigation potential ranged from 63,556 tCO_2e to 77,119 tCO_2e per year.

4.1.3 CFT

Average GHG mitigation was estimated at 2.1 tCO_2e per ha and year (Table 11). Scaling this to project target of 1,500 ha of CA, and 20% of total crop area in the region (47,800 ha) resulted in 3,158 tCO_2e per year and 100,633 tCO_2e per year respectively.

Table 12: GHG emissions and mitigation from the use of CFT

Crop/Mitigation	GHG emissions under conventional farming (tCO_2e/ha)	GHG emissions under CA (tCO_2e/ha)	Potential GHG emission reductions due to CA (tCO_2e/ha)	Conventional GHG emissions (tCO_2e/ton of product)	CA GHG emissions (tCO_2e/ton of product)	Potential GHG emission reductions due to CA (tCO_2e/ton of product)
Millet	3.41	1.40	-2.01	18.17	1.40	-16.77
Maize	3.41	1.13	-2.28	1.89	0.45	-1.44
Cowpeas	3.40	1.37	-2.03	5.78	1.83	-3.95
All crops - average	3.41	1.30	-2.11	8.61	1.23	-7.39

Source: Authors' analysis. Cowpea represented all legumes. Millet and maize were assessed separately as their yields were different. Negative sign is used here to denote net emission reductions or carbon sequestration.

4.1.4 Summary of estimated GHG mitigation

Table 13 below summarises the overall GHG mitigation potentials estimated by each tool. The overall GHG mitigation estimates also differed among tools due to the different scopes of the tools in terms of practices (see Table 13).

Table 13: Overall GHG mitigation potentials estimated by the tools

Tool	Potential GHG mitigation per ha of land (tCO_2e/ha/year)	Potential GHG mitigation over project target area - 1,500 ha (tCO_2e/ha/year)	Potential GHG mitigation over 20% of total crop area in the regions (tCO_2e/ha/year)
Ex-ACT	1.2	1,800	57,360
SALM methodology	1.6	2,420	77,119
CFT	2.1	3,158	100,633

Source: Authors' analysis.

Table 14 shows the average annual GHG mitigation estimates per practice.

Table 14: GHG mitigation potentials by different practices

Crop/Mitigation	Potential GHG mitigation by the practice (tCO_2e/ha/year)			
	No/Reduced tillage	**Cover cropping**	**Organic fertilizer**	**Residue retention**
SALM methodology	-0.2	-0.6	-0.3	-0.7
CFT	-0.9	-0.7	0.1	-0.3
	No till & residue retention	**Improved agronomic practices**	**Manure application**	**Nutrient management**
Ex-ACT	-0.3	-0.3	-1.2	-0.3

Source: Authors' analysis. (minus = sequestration)

From the practices assessed using the CFT, no tillage/reduced tillage had the greatest GHG mitigation potential[21], followed by cover cropping, and then residue retention/mulching. Use of FYM resulted in net GHG emissions of about 0.1 tCO_2e/ha/year. This can be attributed to the predominant practice of manure management in the project, which is characterised by open storage and broadcasting of FYM (cow dung). This practice generates more GHG emissions as compared, for example, to using the cow dung for fully aerated compost production.

The SOC sequestration potential estimated by the SALM methodology was lower than that of the CFT, mainly since the RothC soil model does not allow to considering reduced tillage. If the result is multiplied with the IPCC default reduced tillage factor for tropical dry conditions[22], 1.09, the overall mitigation potential increases to 1.8 tCO_2e/ha/year and the impact from reduced tillage would be 0.2 tCO_2e/ha/year.

Using the Ex-Act tool, the practice of manure application had the greatest GHG mitigation potential (1.16 tCO_2e/ha/ year) whereas the other categories resulted in mitigation potentials of around 0.3 tCO_2e/ha/ year.

[21] The CFT considers tillage to impact significantly on soil carbon storage. The tillage factor it uses ranges from 0.8 to 0.9 when transitioning from no tillage to reduce or conventional tillage in tropical climates.

[22] Source: IPCC 2006: Guidelines for National Greenhouse Gas Inventories, Volume 4 Agriculture, Forestry and Other Land Use, Chapter 5 Cropland, table 5.5. on page 5.17. (www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_05_Ch5_Cropland.pdf)

Compared to the total potential emissions identified within a farm according to the IPCC (see Figure 2), only a small part of the emissions and removals of such typical mixed crop and live-stock smallholder farming systems were included in the analysis. This is mainly because Con-servation Agriculture is specifically targeting agronomic and nutrient management practices. Figure 9 illustrates this integrated farming system and emphasizes the many interactions be-tween the different production systems. With regard to the emission quantification of such systems and introducing climate smart actions such as agronomy, however, implies consider-ing these interactions including direct as well as indirect impacts on GHG emissions within the whole system.

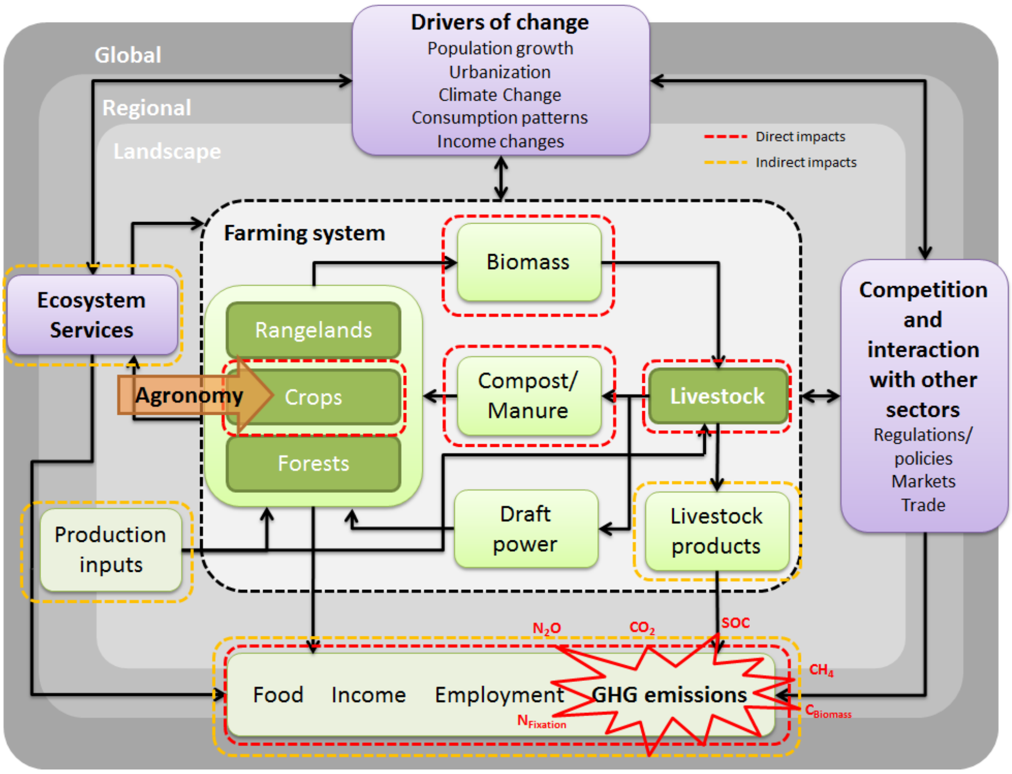


Figure 8 Main interactions in typical mixed crop-livestock systems in developing countries

Source: adapted from Herrero et al. 2010

A study conducted by Seebauer (2014) in the frame of the Kenya Agricultural Carbon Project[23] assessed the potential mitigation benefits within smallholder farms as a result of adopting various sustainable agricultural land management practices. Similar to this study, the SALM methodology was compared with the Cool Farm Tool. Figure9 shows the mitigation potentials after 2 years of project implementation for different carbon pools and emission sources repre-senting the integrated crop and livestock smallholder farming systems.

[23] More information is available online: http://www.vcsprojectdatabase.org/#/project_details/1225

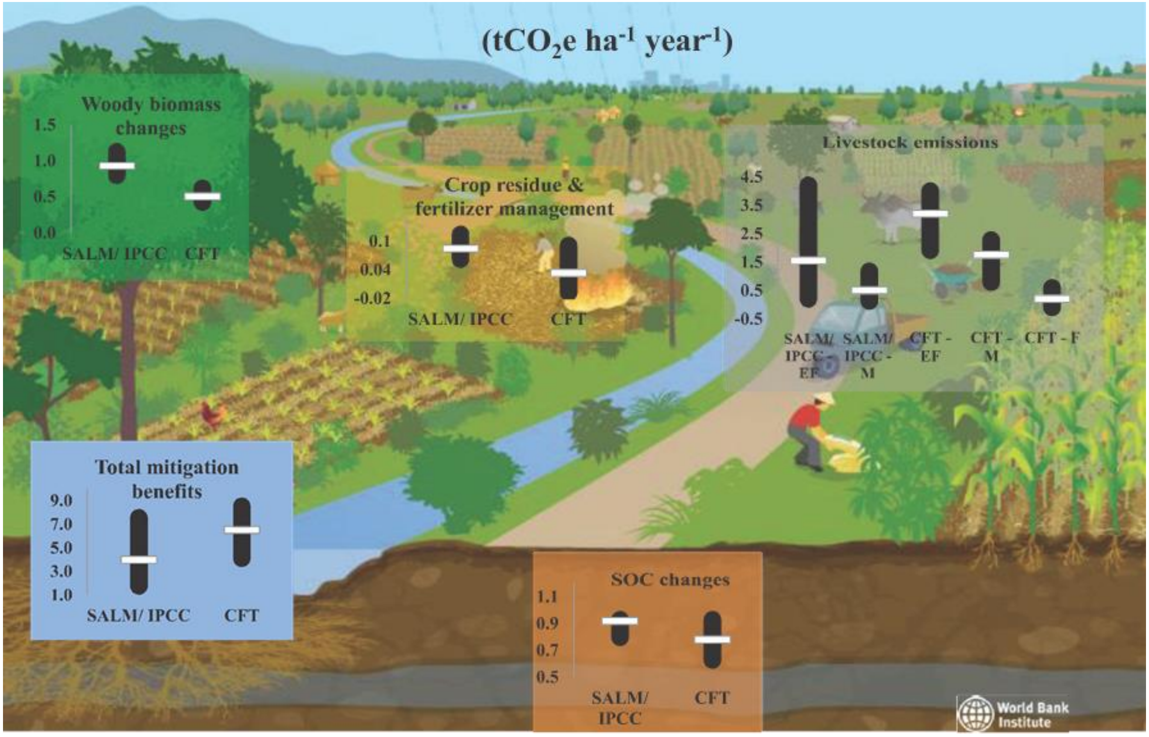


Figure 9: Annual carbon benefits in integrated crop and livestock smallholder farming systems (tCO2 e ha^{-1} yr^{-1})

SALM/IPCC = SALM methodology and IPCC emission factors; CFT = cool farm tool; EF = enteric fermentation; M = manure management; F = emissions from feed characteristics. Positive values indicate benefits (emission reductions or emission removals)

Source: Seebauer 2014

The annual benefits from woody biomass of trees planted in the project range from 0.8 and 1.1 tCO_2 ha^{-1} using the SALM methodology and 0.4–0.6 tCO_2 ha^{-1} with the CFT. The sequestration rate is low due to the fact that the average diameter (DBH) is around 5 cm after 2 years of project implementation. The emission reduction benefits from improved crop residue and fertilizer management are very low. The annual benefits from soil carbon sequestration due to adoption of management practices such as mulching, composted manure and introduction of soil fertility trees are on average 0.9 tCO_2 ha^{-1} using the RothC modelling approach and 0.8 tCO_2 ha^{-1} applying the empirical model approach of the CFT. GHG emission reductions in livestock management account for the largest share of all mitigation benefits. The results based on the CFT in particular reflect also the changes in management and feeding practices in the project. On average, the highest annual benefits calculated with the CFT are emission changes from enteric fermentation (3.2 tCO_2 ha^{-1} yr^{-1}), followed by manure management and emission changes from improved feeding practices.

The overall average mitigation benefits of the two quantification methods results in 4–6.5 tCO_2 ha^{-1} yr^{-1} for the SALM Methodology and the CFT respectively. This rate is comparable to, for instance, improving carbon stocks in forest through improved forest management methods.

5 CONCLUSIONS

The application of the three tools indicated the mitigation benefits from the conservation agriculture being piloted in the project range from 1.2 tCO_2/ha/year using Ex-ACT to 1.6 tCO_2/ha/year using the SALM methodology (RothC soil model) to 2.1 tCO_2/ha/year applying the CFT. These benefits cover mainly sequestration of soil organic carbon (SOC) as a result of residue retention, use of cover crops, manure application and reduced tillage practices. This certainly represents only a snapshot of possible mitigation practices in agriculture. Paustian et al. (2016) presents a comprehensive overview decision tree on the potential mitigation options in cropland in relation to the different baseline conditions.

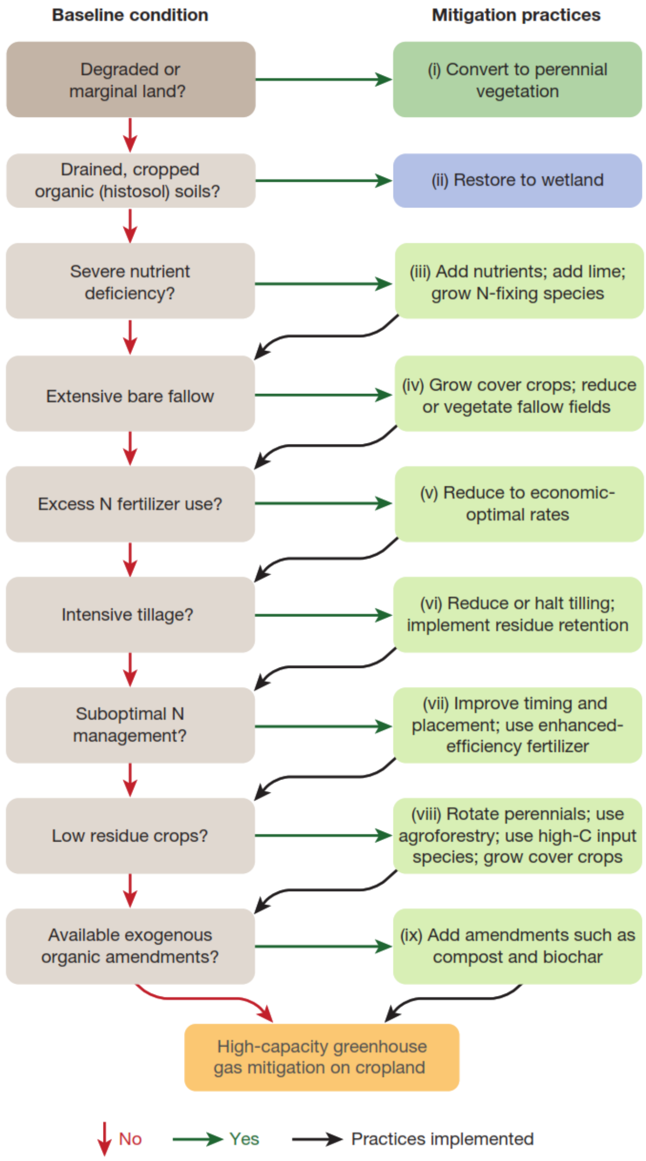


Figure 10 Decision tree for cropland GHG mitigating practices

Source: Paustian et al. 2016

In general, on global scale, soil C sequestration rates on land maintained in agricultural use are lower than for land restoration to grassland or forest, and vary on the order of 0.4–3.7 tCO_2 $ha^{-1}year^{-1}$, as a function of land use history, soil or climate conditions, and the combination of management practices applied (Paustian et al. 2016).

The introduced quantification tools all have their limitations. So far no tool exists that can be used by a large number of smallholders in developing countries. Although there is strong consensus on quantification frameworks, GHG estimates are hampered by inherent variability, a lack of available data, and limited capacities for measurement. Almost all countries have a wide range of uncertainty in their agriculture and land use GHG inventories. Even developed countries that have chosen to account for cropland and grazing land emissions in the Kyoto Protocol have uncertainties ranging between 13 and 100 percent (Lokupitiya & Paustian 2006).

Since the scope of practices covered by the tools differed, and the majority of the practices being promoted in the project have impacts on soil carbon sequestration, a tool with particular focus on soil carbon would be most appropriate. Hence, SALM methodology is recommended over the Ex-ACT and CFT – especially if a robust soil carbon accounting is also desired by the project. Both the Ex-ACT and the CFT do also estimate GHG mitigation due to soil carbon sequestration; however, their estimates would be less reliable. If the objective is to obtain a quick overview estimate and broad overview of the project's GHG mitigation impacts or potentials, the Ex-ACT is recommended.

The **Cool Farm Tool** offers by far the most options of different farming activities and practices that can be accounted for in terms of emission reductions and removals. At the same time it is user-friendly, however, the online version (which is the only version constantly updated) needs a stable internet connection. The CFT can be seen as a farm foot-printing tool, which allows tracking emissions of a specific crop or livestock product considering the farm specific production processes and practices including direct and indirect inputs (e.g. energy, fertilizer, feed, etc.) However, each product of a farm (crops, dairy, etc.) needs to be accounted for in a separate run. Baseline conditions, such as conventional agriculture, and project scenarios like conservation agriculture can be compared in the way that the farm GHG footprint at baseline condition is estimated and then repeatedly compared with project footprints during project implementation (or just one footprint at the end of implementation). The CFT assessed in the frame of other studies (e.g. Seebauer 2014) demonstrates that the adoption of various management practices affects the whole farm emission intensity and that more comprehensive whole farm quantification potentially could estimate more mitigation benefits from such practices. However, the inherent uncertainty related to the emission factors applied by calculators such as the CFT has substantial implications for reported agricultural emissions. Further, since the user is responsible for the input of precise and accurate activity data, the goal and scope need to be defined for its intended use. Nevertheless, the CFT is a user-friendly and comprehensive 'tier 2' calculator to inform users on the sources and mitigation options on a farm level.

The **Ex-Ante Carbon-balance Tool** (Ex-ACT) is an appraisal system developed to providing ex-ante estimates of the impact of agriculture and forestry development projects, programs and policies on the carbon-balance. The tool helps project designers to estimate and prioritize project activities with high benefits in economic and climate change mitigation terms. Ex-ACT can be applied on a wide range of development projects from all AFOLU sub-sectors, including other projects on climate change mitigation, watershed development, production intensification, food security, livestock, forest management or land use change (FAO 2016). Being very cost effective, the tool provides less accurate results compared to the other two tools in specific farm-based project activities.

The **SALM Methodology** is most appropriate if the objective is to have a more robust calculation, which for example, is capable of meeting carbon market standards. In this study, only the RothC soil carbon model has been used since the program activities mostly enhance soil fertility and soil organic carbon. The same methodology also allows estimating other farm based emission reductions and removals such as increases in tree or shrub biomass, or the reduction of emissions from burning biomass or from inorganic fertilizers. With regards to these fertilizer emissions, the CFT uses the same IPCC default approach as proposed in the SALM methodology, and average application rates of 160 kg NPK fertilizer per ha and 40 kg urea per ha proposed in the project result in emissions of approximately 512 kg CO_2 per ha.

In contrast to the other tools, SALM represents a set of protocols on how to estimate different farm based mitigation benefits including the use of a scientific soil carbon model with high level of confidence. This means, however, that projects have to set up their own accounting system using Excel or more advanced database and calculations systems. In Annex 3, the ABMS of the Kenya Agricultural Carbon Project is presented in more detail.

With regard to the project assessed in Namibia, a substantial amount of data for the testing of the tools was provided. However, such data were generally available in a decentralized way. There was no system of unified data management. Hence, it is recommended to develop a proper data/information management system for the project. Once developed, all data collected can be fed into this system. Developing such a system requires knowledge of the data and reporting needs of various interested stakeholders (government, GIZ, etc.) involved in the project as well as the data requirements for the quantification tools selected.

Upscaling and expanding agricultural GHG mitigation practices and programs will require an integrated research support and implementation approach. Paustian et al (2016) concludes that targeted basic research on soil processes, expanding measurement and management practices through web-based computer and mobile apps, and help drive advanced model-based GHG metrics. This will facilitate the implementation of climate-smart soil management policies, via cap-and- monitoring networks, and further developing global geospatial soils data can improve predictive models and reduce uncertainties. Ongoing advances in information technology and complex system and ‘Big Data’ integration offer the potential to engage a broad-range of stakeholders, including land managers, to ‘crowd-source’ local knowledge of agricultural trade systems, product supply-chain initiatives for ‘low-carbon’ consumer products, and national and international GHG mitigation policies; it will also promote more sustainable and climate-resilient agricultural systems, globally.

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7 ANNEX

Annex 1: Fieldwork schedule

Date	Activity	Remark
10/15/2017	Arrival in Windhoek	
10/16/2017	Travel to Rundu	Travel by road
10/17/2017	Field trip to CA demonstration plots	Mashare Conservation Agriculture trials
10/18/2017	Classroom session	Introduction of tools and examples of actual use
10/19/2017	Field trip to farmer CA plots & cluster farmer interview	
10/20/2017	Classroom session & Return flight to Windhoek- Matthias	Question & answer sessions on use of tool
10/21/2017	Assess data gaps and prepare for collection	Interview guide for farmer interviews
10/22/2017	Assess data gaps and prepare for collection	Interview guide for farmer interviews
10/23/2017	Field data collection –Farmers	2 Lead farmers
10/24/2017	Field data collection –Farmers	3 Lead farmers
10/25/2017	Return flight Gilbert to Windhoek	Friday flight to Windhoek overbooked
10/26/2017	GIZ Windhoek office - meet and greet/debrief & data follow up	Some key GIZ personnel not available at the time in Windhoek office.
10/27/2017	Data synthesis (database)	
10/28/2017	Return flight - Gilbert to UGANDA	

Annex 2: List of data used

Main category	Data/parameter	Unit	Source	Tool data applies to		
				Ex-ACT	SALM	CFT
Data for parameterisation/calibration						
Project location	Area location in Latitude /Longitude	Degrees	Google Earth		√	√
Crop calendar	Start and end months	-	Project/local knowledge		√	
	No. of crop seasons/ year	-	Project/local knowledge		√	
Soil	Dominant soil type	Category	Project Mobile Soil Lab	√		
	Soil texture	Category	Project Mobile Soil Lab			√
	Soil organic matter	Category	Project Mobile Soil Lab			√
	Soil moisture	Category	Köppen–Geiger Climate Classification[24]	√		√
	Soil drainage	Category	Project Mobile Soil Lab			√
	Soil pH	Category	Project Mobile Soil Lab			√
	Average clay content (30 cm depth)	%	Project Mobile Soil Lab		√	
Climate	Climate type	Category	Köppen–Geiger Climate Classification[25]	√		√
	Average temperature of project area	°C	SASSCAL WeatherNet, 2017[26]		√	√
	Average monthly min & max temperature	°C	SASSCAL WeatherNet, 2017		√	
	Average precipitation per month	mm	SASSCAL WeatherNet, 2017		√	
Data for running the calculations						
Area	Total project area	ha	Project Results Matrix & local crop area stats	√	√	√
	Agricultural land area	ha	Baseline survey & local crop area stats	√	√	√
Project planted trees	Planted short term trees	m/ha	Baseline/monitoring survey		√	
	Short term trees density	trees/m	Baseline/monitoring survey		√	√
	Long-term trees density	trees/ha	Baseline/monitoring survey	√	√	√
	Long term trees sizes	DBH clas-	Baseline/monitoring		√	√

[24] Accessed here
[25] Accessed here
[26] Accessed here

		ses	survey			
Household energy sources	Fire wood	hours/day	Baseline/monitoring survey		√	
	Charcoal	hours/day	Baseline/monitoring survey		√	
	Manure	hours/day	Baseline/monitoring survey		√	
	Crop residues	hours/day	Baseline/monitoring survey		√	
	Fossil fuels	hours/day	Baseline/monitoring survey		√	
Area and yields of major crops	Yield of millet	kg/ha	Baseline/monitoring survey	√	√	√
	Yield of maize	kg/ha	Baseline/monitoring survey	√	√	√
	Yield of cowpeas	kg/ha	Baseline/monitoring survey	√	√	√
	Area under millet	ha	Baseline/monitoring survey	√	√	√
	Area under maize	ha	Baseline/monitoring survey	√	√	√
	Area under cowpeas	ha	Baseline/monitoring survey	√	√	√
	Residues yields from respective crops	kg/ha	Default – automatic tool calculation	√	√	√
Field treatments/practices	Inorganic fertiliser application by type	kg/ha	Baseline/monitoring survey	√	√	√
	Crop area inorganic fertilisers are applied	ha	Baseline/monitoring survey	√	√	√
	Organic fertiliser (compost) application	kg/ha	Baseline/monitoring survey	√	√	√
	Crop area under compost application	ha	Baseline/monitoring survey	√	√	√
	Pesticides application	l/ha or no. of times	Baseline/monitoring survey	√	√	√
	Crop area pesticides are applied	ha	Baseline/monitoring survey	√	√	√
	Crop area under mulching	ha	Baseline/monitoring survey	√	√	√
	Crop area where crop residues are burnt	ha	Baseline/monitoring survey	√	√	√
	Crop area with residues used for feeding livestock	ha	Baseline/monitoring survey	√	√	√

	Crop area with residues removed for cooking/ heating	ha	Baseline/monitoring survey	√	√	√
	Crop area with residues removed for composting	ha	Baseline/monitoring survey	√	√	√
	Crop area under no-tillage	ha	Baseline/monitoring survey	√	√	√
	Crop area under reduced tillage	ha	Baseline/monitoring survey		√	
	Crop area under cover crops	ha	Baseline/monitoring survey	√	√	√
Livestock	No. of different livestock in juvenile phase	No./farm or total	Baseline/monitoring survey	√	√	√
	No. of different livestock in adult productive phase	No./farm or total	Baseline/monitoring survey	√	√	√
	No. of different livestock in adult unproductive phase	No./farm or total	Baseline/monitoring survey	√	√	√
	% of livestock feed from open grazing per livestock type	%	Baseline/monitoring survey	√	√	√
	Quality of grazing pasture	Category	Baseline/monitoring survey			√
	% of livestock feed from crop residues per livestock type	%	Baseline/monitoring survey	√	√	√
	% of livestock feed from grasses per livestock type	%	Baseline/monitoring survey	√	√	√
	% of livestock feed obtained from fodder legumes per livestock type	%	Baseline/monitoring survey	√	√	√
	Dry matter intake per livestock type and life phase	kg	Default – automatic tool calculation		√	√
	Manure management system per livestock type	Category	Baseline/monitoring survey		√	√

Annex 3: Activity Baseline and Monitoring System of the Kenya Agricultural Carbon Project

Source of information: VCS Project Design Document and VCS Project Monitoring reports, available [here]

Project overview

The Kenya Agricultural Carbon Project (KACP) is a pilot Agricultural Land Management project being implemented in Kenya since 2009. Its development was supported by the World Bank BioCarbon Fund (BCF), and it is funded by the Foundation Vi Planterar träd ("We plant trees") and the Swedish International Development Agency (SIDA). The project promotes Sustainable Agricultural Land Management (SALM) practices for implementation on smallholder farms for livelihood improvement and generation of GHG removal through soil and tree carbon sequestration. It uses a holistic agricultural extension and farm enterprise development approach. Typical practices adopted by farmers include use of crop residues for mulching and composting for soil organic input, use of cover crops, water harvesting, terracing and agroforestry – aimed at increasing soil fertility and productivity, developing resilience, and sequestering carbon dioxide. The resulting carbon credit is considered as a co-benefit and paid to farmer groups as rewards. The project is implemented in Vi Agroforestry programme regions of Kisumu and Kitale, in six (6) divisions of Bungoma, Siaya and Kisumu counties in Western Kenya. The project so far has reached 1,730 farmer groups consisting of 29,497 farmers implementing SALM on 21,452 ha of agricultural lands in 2017; of this, 20,049 ha are currently under SALM adoption. The extension system is set up in such a way that field advisors train the registered farmer groups on SALM practices, do assessments, and monitor and evaluate the project activities. The farmer groups are formally contracted by Vi Agroforestry. The eligible land for adoption is either cropland or grazing land.

Monitoring system

Agricultural activities in the baseline are assessed and adoption of SALM practices are monitored as a proxy of the carbon stock changes using activity-based model estimates. The graphic below summarizes the ABMS project monitoring system in the KACP.

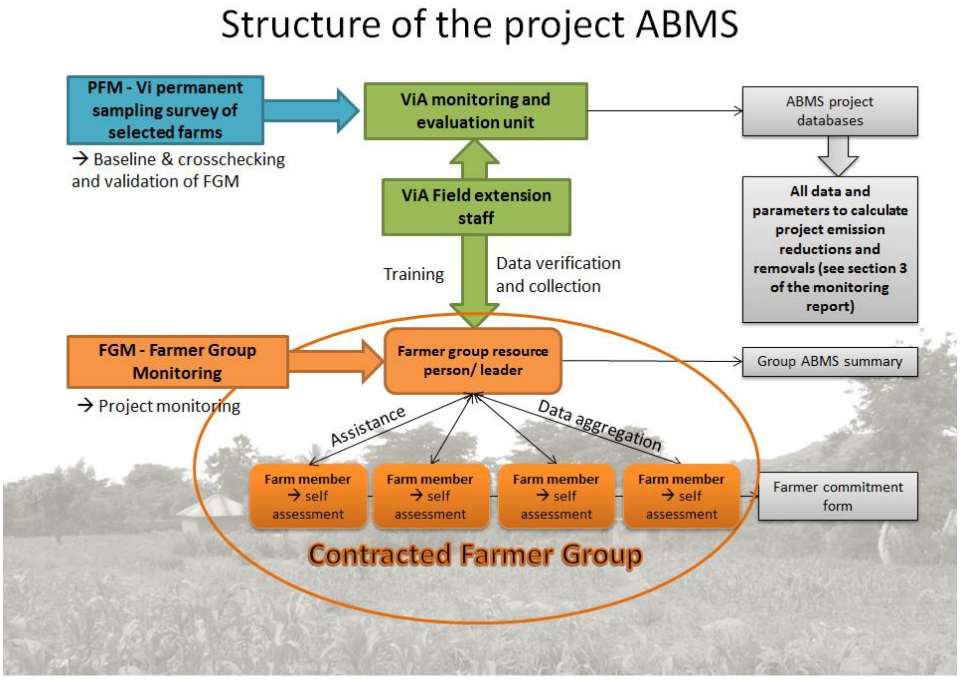


Figure 11 ABMS Monitoring systems in the KACP project

The ABMS monitoring is structured in two different surveys, the Vi Permanent Farm Monitoring and the Farmer Group Monitoring. The data gathered from the field in both surveys are the input values to run the RothC carbon model to derive local SOC emission factors, and secondly to determine the area under SALM adoption (adoption rate). In addition to the locally monitored field data, available datasets are used to parameterize the RothC models separately for Kisumu and Kitale, e.g. climate data and soil data. The basic distinction between the two monitoring systems is that the Vi Agroforestry Permanent Farm Monitoring (PFM) is entirely implemented by the field officers of Vi Agroforestry on permanent sample farms, so-called ABMS farmers and is representative for the whole KACP project area. It is used to establish the total KACP baseline and to estimate the baseline GHG emissions and removals for the project area (45,000 ha). Further it monitors the overall project performance in terms of project implementation (SALM adoption, crop responses) and is used to verify the results of the Farmer Group Monitoring.

The Farmer Group Monitoring (FGM) on the other hand is a farmer-self assessment system within each of the contracted farmer groups. Farmers annually record all relevant data themselves which are needed to monitor the KACP and report the data to the Vi Agroforestry field officers via a strong system of verification and data aggregation. These data, representing a full inventory of all farms in the project instance(s), are used to model the actual (ex-post) GHG emissions and removals (from SOC and tree biomass) of a particular group of project instances during a verification event.

Organizationally, the field data from these two surveys are collected, cleaned and aggregated first for each project location Kisumu and Kitale and then centrally processed, analysed and archived at the central project monitoring and evaluation unit at the Vi Agroforestry program office in Nairobi. A web-based data entry system (the Project MIS system) was adopted to accelerate the data entry on a more standardized basis. The web-based system includes a data entry module which can work offline and data can be synced to the project server when internet is available. The module has several mathematical and logical validations to avoid data entry mistakes as well as control mechanisms to ensure the quality of data. The data sent to the server is immediately available for further processing using different web-based interfaces (MIS). All the calculations to monitor the project performance as a whole and to provide the parameters needed for the RothC soil modelling and other calculations related to the SAM methodology previously done in Excel are now integrated into the MIS system.

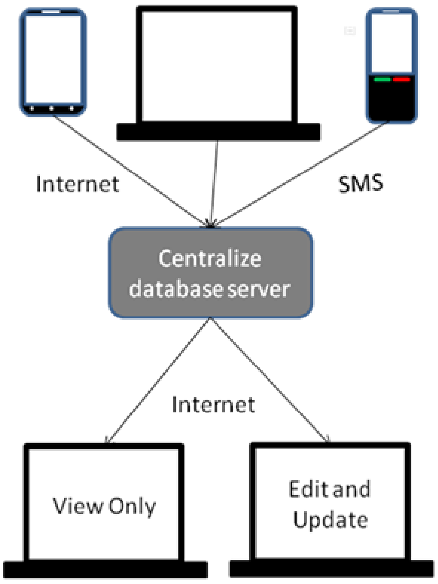
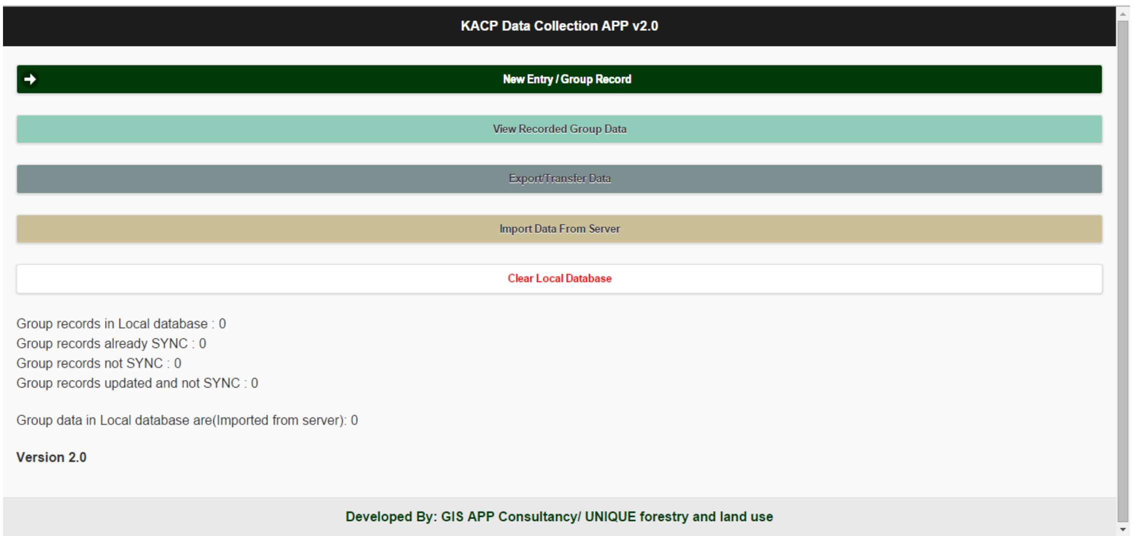
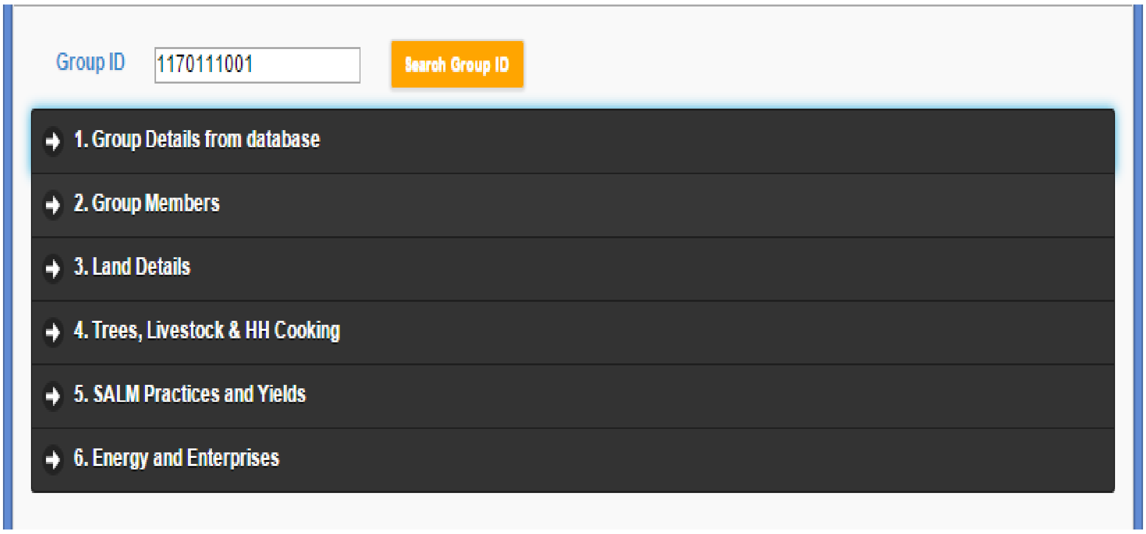
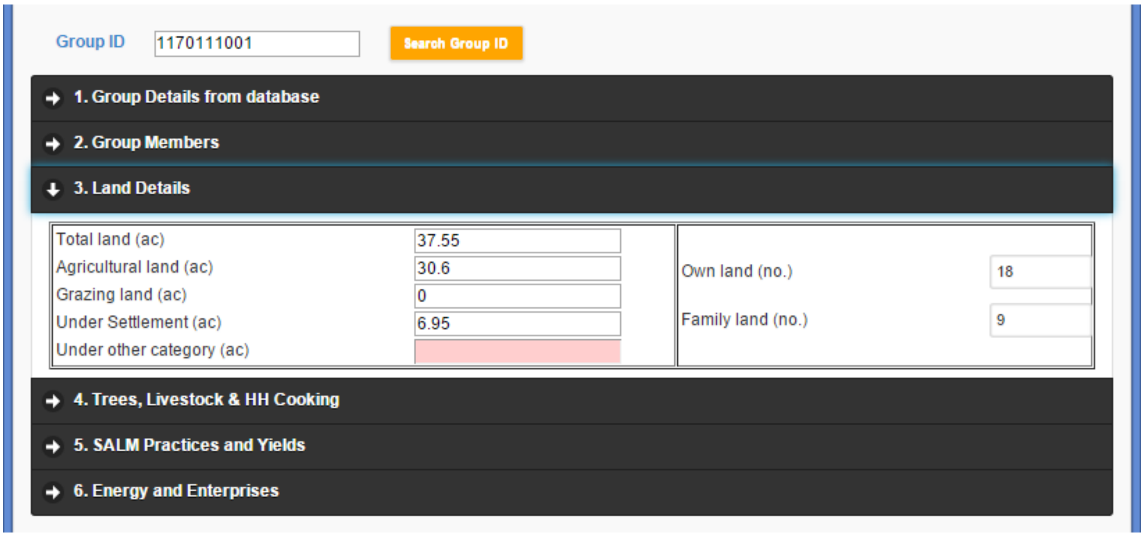


Figure 12 Project MIS data flow concept

In the following some screenshots of the web-based data entry system are shown:







Since 2016 all farm based data are collected by a SMS-phone based system at farmer group level. Kenya with its M-PESA System of Money transfer can be considered the World's leading country in mobile money transfer. Over 17m Kenyans, equivalent to more than two-thirds of the adult population are using this system on a regular basis. This incident means that most farmers in the project region are all equipped with a simple mobile phone and are well-acquainted with its use and handling of SMS-messages. Against this background, the annual farm group summary record sheet containing all relevant summary data of a particular farmer group is sent by SMS using a standard protocol.

The project MIS is divided into three broad components for data collection, data processing and database management i.e.

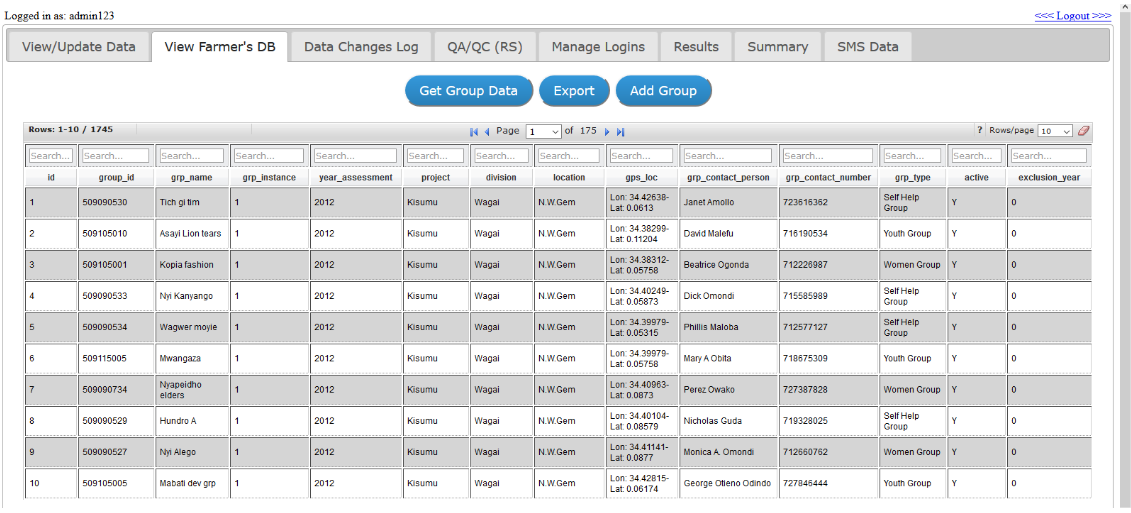
- Android Smartphone – APP to register and verify farmers, farm GPS tracking, training attendance
- Analogue phones – interactive SMS based data collection of SALM and Dairy activity data at the farmer/group level
- Web based software – Open source web based application to manage the master and survey database, reporting and monitoring dashboard

With this system, the project has flexible options to collect and enter data into the web-based MIS; either through data entry interface or directly through SMS based system. In summary, some of the key features of the system are listed below,

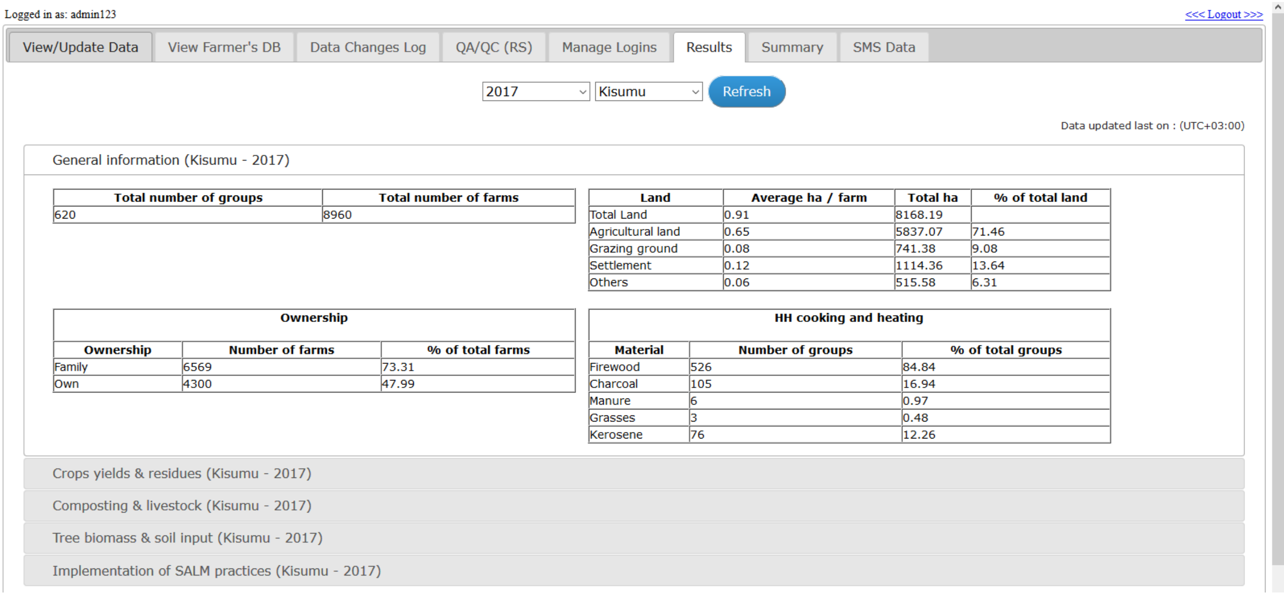
- Centralized online database
- Dashboard to monitor the progress
- Login options specific use rights for data view and editing
- Log of edited records - old value, new value, edited by, time and reason
- Restrict data editing by setting deadlines
- Summary analysis of data on single click (no need of Excel based tools)
- Random selection of a farmer group sample for QA/QC is done by system
- Provision to send comments to lower admin unit
- Export data to excel
- Login management for changing password and setting deadlines for editing
- Create new farmer groups where MIS system designs ID (no scope of duplicate ID)
- Data validation (mathematical and logical)

The project implementing NGO has established standard operating procedures (SOPs) to verify and assure the quality of the farm data which also includes the verification and triangulation of the data collected by the farmers through the separate PFM survey system.

In the following, screenshots are presented of the project MIS system



id	group_id	grp_name	grp_instance	year_assessment	project	division	location	gps_loc	grp_contact_person	grp_contact_number	grp_type	active	exclusion_year
1	509090530	Tich gi tim	1	2012	Kisumu	Wagai	N.W.Gem	Lon: 34.42638-Lat: 0.0613	Janet Amollo	723616362	Self Help Group	Y	0
2	509105010	Asayi Lion tears	1	2012	Kisumu	Wagai	N.W.Gem	Lon: 34.38299-Lat: 0.11204	David Malefu	716190534	Youth Group	Y	0
3	509105001	Kopia fashion	1	2012	Kisumu	Wagai	N.W.Gem	Lon: 34.38312-Lat: 0.05758	Beatrice Ogonda	712226987	Women Group	Y	0
4	509090533	Nyi Kanyango	1	2012	Kisumu	Wagai	N.W.Gem	Lon: 34.40249-Lat: 0.05873	Dick Omondi	715585989	Self Help Group	Y	0
5	509090534	Wagwer moyie	1	2012	Kisumu	Wagai	N.W.Gem	Lon: 34.39979-Lat: 0.05315	Phillis Maloba	712577127	Self Help Group	Y	0
6	509115005	Mwangaza	1	2012	Kisumu	Wagai	N.W.Gem	Lon: 34.39979-Lat: 0.05758	Mary A Obita	718675309	Youth Group	Y	0
7	509090734	Nyapeidho elders	1	2012	Kisumu	Wagai	N.W.Gem	Lon: 34.40963-Lat: 0.0873	Perez Owako	727387828	Women Group	Y	0
8	509090529	Hundro A	1	2012	Kisumu	Wagai	N.W.Gem	Lon: 34.40104-Lat: 0.08579	Nicholas Guda	719328025	Self Help Group	Y	0
9	509090527	Nyi Alego	1	2012	Kisumu	Wagai	N.W.Gem	Lon: 34.41141-Lat: 0.0877	Monica A. Omondi	712660762	Women Group	Y	0
10	509105005	Mabati dev grp	1	2012	Kisumu	Wagai	N.W.Gem	Lon: 34.42815-Lat: 0.06174	George Otieno Odindo	727846444	Youth Group	Y	0



Logged in as: admin123

<<< Logout >>>

View/Update Data | View Farmer's DB | Data Changes Log | QA/QC (RS) | Manage Logins | Results | Summary | SMS Data

2017 | Kisumu | Refresh

Data updated last on : (UTC+03:00)

General information (Kisumu - 2017)

Total number of groups	Total number of farms
620	8960

Land	Average ha / farm	Total ha	% of total land
Total Land	0.91	8168.19	
Agricultural land	0.65	5837.07	71.46
Grazing ground	0.08	741.38	9.08
Settlement	0.12	1114.36	13.64
Others	0.06	515.58	6.31

Ownership

Ownership	Number of farms	% of total farms
Family	6569	73.31
Own	4300	47.99

HH cooking and heating

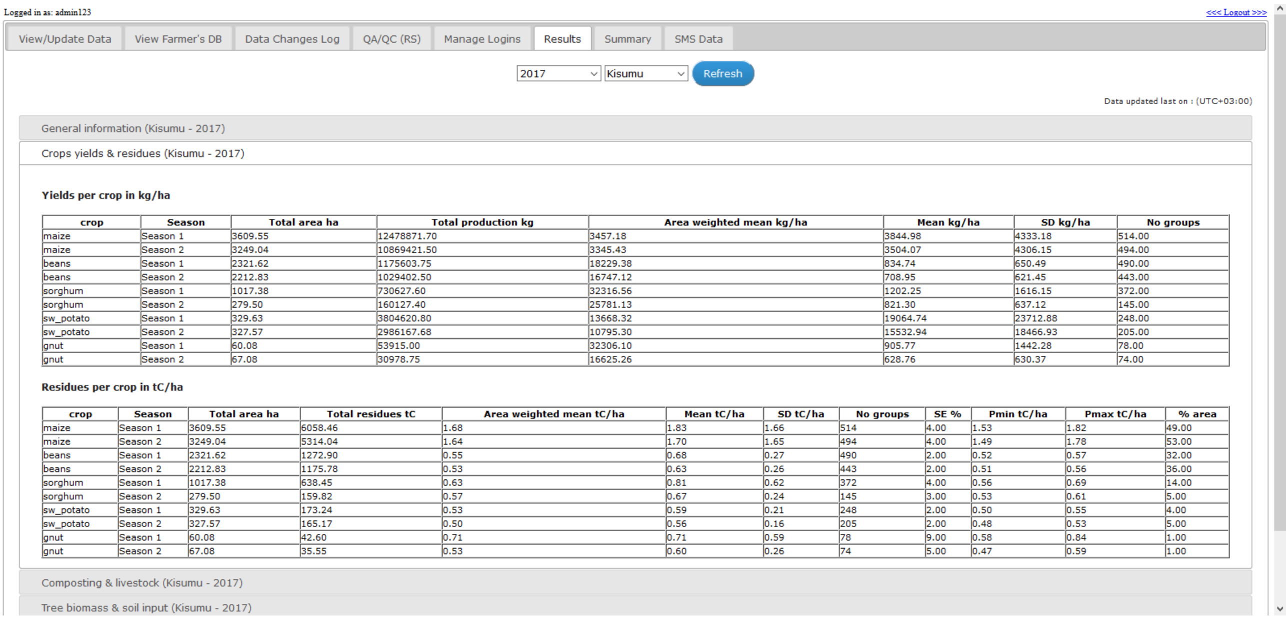
Material	Number of groups	% of total groups
Firewood	526	84.84
Charcoal	105	16.94
Manure	6	0.97
Grasses	3	0.48
Kerosene	76	12.26

Crops yields & residues (Kisumu - 2017)

Composting & livestock (Kisumu - 2017)

Tree biomass & soil input (Kisumu - 2017)

Implementation of SALM practices (Kisumu - 2017)



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<<< Logout >>>

View/Update Data | View Farmer's DB | Data Changes Log | QA/QC (RS) | Manage Logins | Results | Summary | SMS Data

2017 | Kisumu | Refresh

Data updated last on : (UTC+03:00)

General information (Kisumu - 2017)

Crops yields & residues (Kisumu - 2017)

Yields per crop in kg/ha

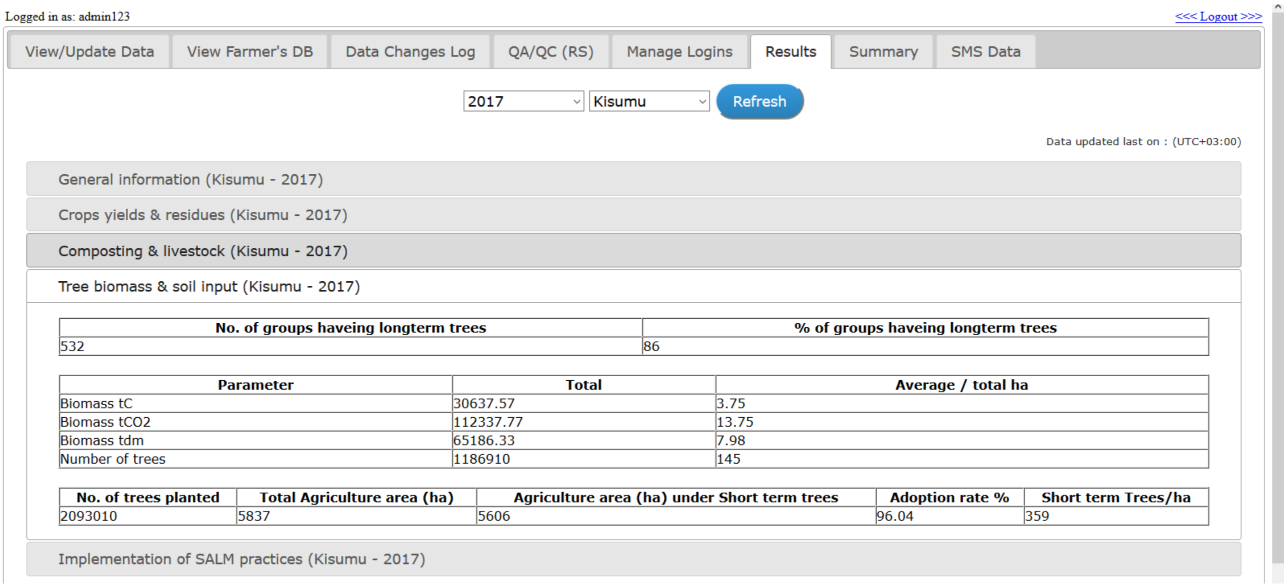
crop	Season	Total area ha	Total production kg	Area weighted mean kg/ha	Mean kg/ha	SD kg/ha	No groups
maize	Season 1	3609.55	12478871.70	3457.18	3844.98	4333.18	514.00
maize	Season 2	3249.04	10869421.50	3345.43	3504.07	4306.15	494.00
beans	Season 1	2321.62	1175603.75	18229.38	834.74	650.49	490.00
beans	Season 2	2212.83	1029402.50	16747.12	708.95	621.45	443.00
sorghum	Season 1	1017.38	730627.60	32316.56	1202.25	1616.15	372.00
sorghum	Season 2	279.50	160127.40	25781.13	821.30	637.12	145.00
sw_potato	Season 1	329.63	3804620.80	13668.32	19064.74	23712.88	248.00
sw_potato	Season 2	327.57	2986167.68	10795.30	15532.94	18466.93	205.00
gnut	Season 1	60.08	53915.00	32306.10	905.77	1442.28	78.00
gnut	Season 2	67.08	30978.75	16625.26	628.76	630.37	74.00

Residues per crop in tC/ha

crop	Season	Total area ha	Total residues tC	Area weighted mean tC/ha	Mean tC/ha	SD tC/ha	No groups	SE %	Pmin tC/ha	Pmax tC/ha	% area
maize	Season 1	3609.55	6058.46	1.68	1.83	1.66	514	4.00	1.53	1.82	49.00
maize	Season 2	3249.04	5314.04	1.64	1.70	1.65	494	4.00	1.49	1.78	53.00
beans	Season 1	2321.62	1272.90	0.55	0.68	0.27	490	2.00	0.52	0.57	32.00
beans	Season 2	2212.83	1175.78	0.53	0.63	0.26	443	2.00	0.51	0.56	36.00
sorghum	Season 1	1017.38	638.45	0.63	0.81	0.62	372	4.00	0.56	0.69	14.00
sorghum	Season 2	279.50	159.82	0.57	0.67	0.24	145	3.00	0.53	0.61	5.00
sw_potato	Season 1	329.63	173.24	0.53	0.59	0.21	248	2.00	0.50	0.55	4.00
sw_potato	Season 2	327.57	165.17	0.50	0.56	0.16	205	2.00	0.48	0.53	5.00
gnut	Season 1	60.08	42.60	0.71	0.71	0.59	78	9.00	0.58	0.84	1.00
gnut	Season 2	67.08	35.55	0.53	0.60	0.26	74	5.00	0.47	0.59	1.00

Composting & livestock (Kisumu - 2017)

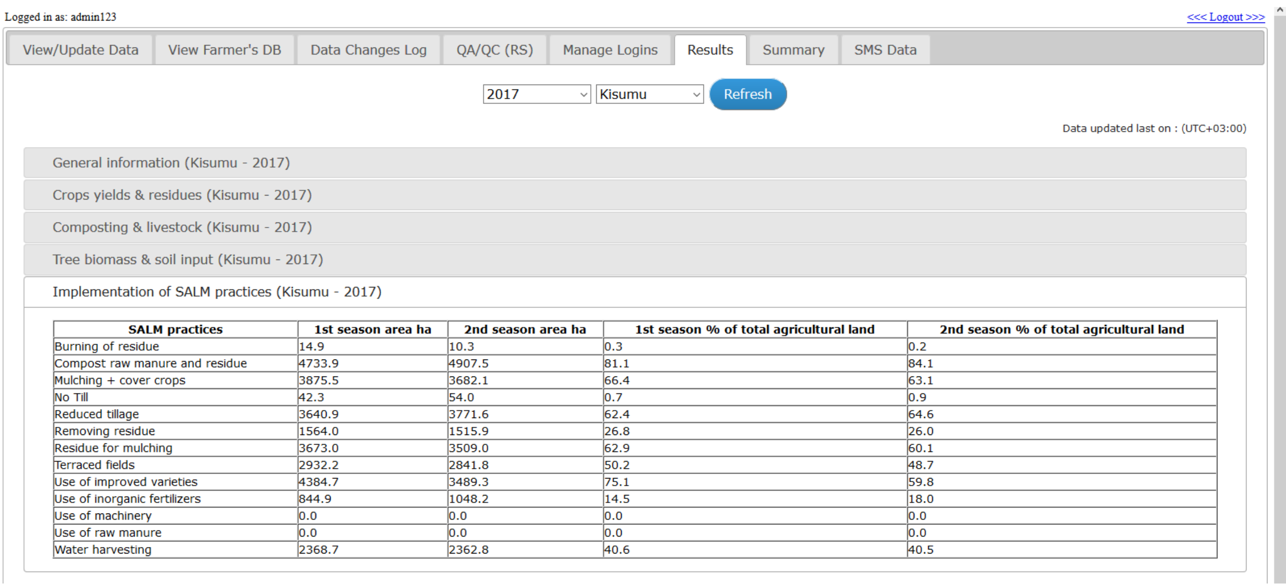
Tree biomass & soil input (Kisumu - 2017)



No. of groups haveing longterm trees	% of groups haveing longterm trees
532	86

Parameter	Total	Average / total ha
Biomass tC	30637.57	3.75
Biomass tCO2	112337.77	13.75
Biomass tdm	65186.33	7.98
Number of trees	1186910	145

No. of trees planted	Total Agriculture area (ha)	Agriculture area (ha) under Short term trees	Adoption rate %	Short term Trees/ha
2093010	5837	5606	96.04	359



SALM practices	1st season area ha	2nd season area ha	1st season % of total agricultural land	2nd season % of total agricultural land
Burning of residue	14.9	10.3	0.3	0.2
Compost raw manure and residue	4733.9	4907.5	81.1	84.1
Mulching + cover crops	3875.5	3682.1	66.4	63.1
No Till	42.3	54.0	0.7	0.9
Reduced tillage	3640.9	3771.6	62.4	64.6
Removing residue	1564.0	1515.9	26.8	26.0
Residue for mulching	3673.0	3509.0	62.9	60.1
Terraced fields	2932.2	2841.8	50.2	48.7
Use of improved varieties	4384.7	3489.3	75.1	59.8
Use of inorganic fertilizers	844.9	1048.2	14.5	18.0
Use of machinery	0.0	0.0	0.0	0.0
Use of raw manure	0.0	0.0	0.0	0.0
Water harvesting	2368.7	2362.8	40.6	40.5

Figure 13 Project MIS screenshots

In summary, the flow of data and information from the smallholder farmers and farmer groups to the MIS was designed and implemented along the following principles:

- Bottom-up approach: Household and farming data are complemented by research data to evaluate multiple benefits and impacts
- Activity-based approach: Proxy indicators indicating ongoing farm activities and resulting outputs are self-reported by farmers and aggregated by farmer groups
- Ownership: Data collection is owned by farmers, information collection informs extension & self-learning structures, increases buy-in for project activities
- Accuracy and quality control: Sampling approaches and project specific formulation and dissemination of SOPs guarantees robust, consistent, verifiable and transparent monitoring over time

- Cost efficient monitoring: Use of SMS based data collection and other innovative information technologies (all open source) and the multiple use of data to measure and monitor multiple impacts such as carbon, water, etc.

Access to the MIS is controlled by logins for different levels of users such as an Administrator login for head office to manage access and logins for other field officers. Based on the role of the field officer, data edit/viewing rights are assigned.

The proxy indicators collected and self-monitored from and by the farmers can then be used to monitor measurable impacts of multiple project benefits as illustrated in the graph below

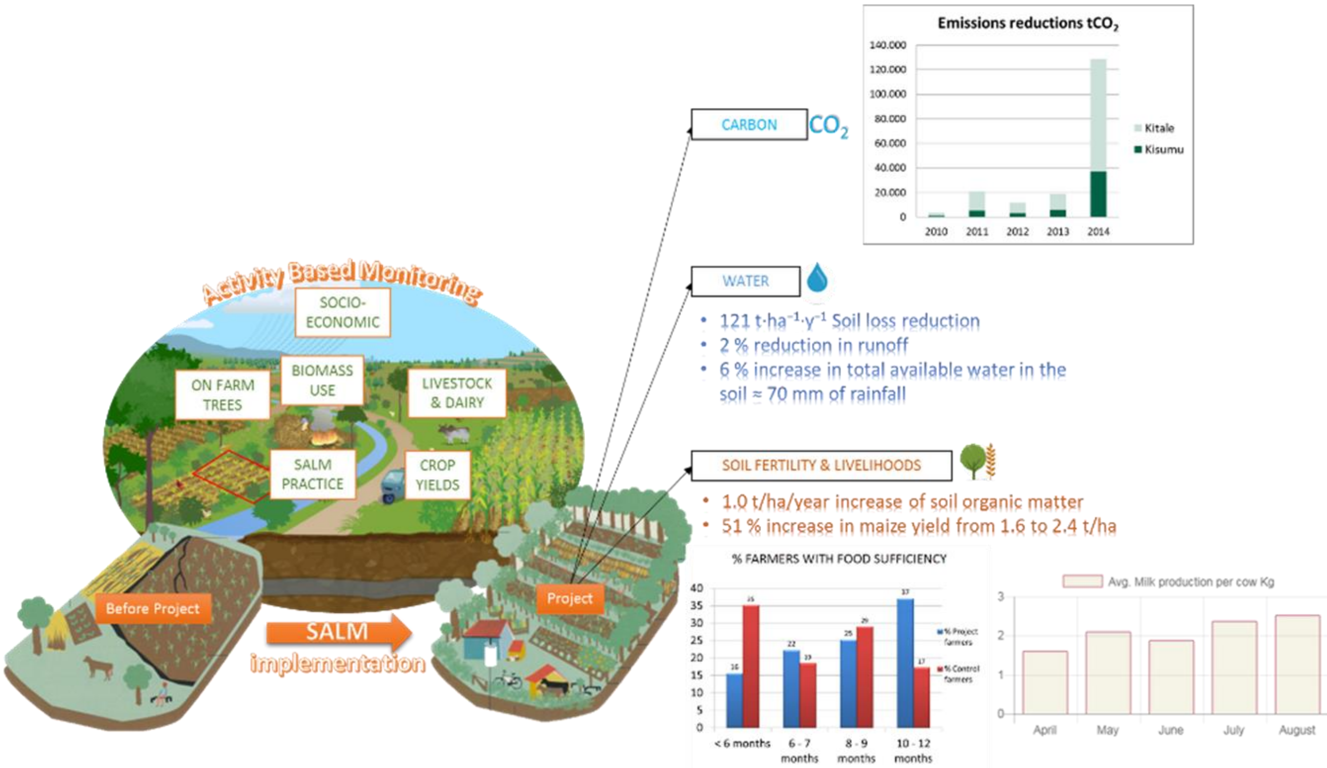


Figure 14: Multiple impact monitoring from the MIS system

Source: UNIQUE, farm sketches adapted from Vi Agroforestry