Climate smartness of GIZ soil protection and rehabilitation technologies in Western Kenya

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Rapid Assessment Report

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An Notenbaert, and Birthe Paul

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Acknowledgements

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1. Introduction

The agricultural sector in Kenya is a fundamental part of the economy, contributing 25% directly to the total Gross Domestic Product (GDP), and another 27% indirectly (Government of Kenya, 2010). It accounts for 65% of Kenya's total exports and provides more than 70% of informal employment in the rural areas. Therefore, agriculture is not only the driver of Kenya's economy but also the means of livelihood for the majority of Kenyan people (Government of Kenya, 2010). Soils are fundamental to agricultural production. And their good management is vital for sustainable agricultural production (Sigunga, 2011). Yet, in sub-Saharan Africa soils are eroded and their fertility depleted at an alarming rate, and Kenya is no exception (Batjes, 2014). In addition, agriculture is highly exposed to climate change, as rainfed farming activities directly depend on climatic conditions (Grant, 2005). At the same time, agriculture also directly contributes to climate change through greenhouse gas (GHG) emissions and a reduction of (soil) carbon stocks in agricultural land.

Globally, agriculture is a principal source of climate change, directly contributing 14% of anthropogenic GHG emissions, and another 17% through land use change; the latter mostly in developing countries. The majority of future increase in agricultural emissions is expected to take place in low- to middle-income countries (Smith et al., 2007). While industrialized countries must dramatically reduce current levels of GHG emissions, developing countries face the challenge of finding alternative, low carbon or green growth development pathways. In this sense, climate-smart agriculture (CSA) aims at transforming agricultural systems to sustain food security under climate change. Although CSA aims at improving food security, resilience and mitigation, it does not imply that every recommended practice should necessarily be a 'triple win'. Mitigation in developing countries should be a co-benefit, while food security and resilience are main priority. Low emission growth paths might have more associated costs than the conventional high emission pathways, thus monitoring can open opportunities for climate finance funds (Lipper et al. 2014). CSA is complemental to sustainable intensification (SI), aiming at increasing agricultural productivity from existing agricultural land while lowering the environmental impact. SI's focus on resource use efficiency and CSA's pillar on mitigation both focus on achieving lower emissions per unit output. Increased resource use efficiency contributes to resilience and mitigation through increased productivity and reduced GHG per unit output (Campbell et al., 2014). Both, CSA and SI underline the importance of potential trade-offs between agricultural production and environmental degradation. In fact smallholder farmers are confronted with trade-offs almost on a daily basis. They have to weigh short-term production objectives against ensuring long-term sustainability and global goods such as climate change mitigation (Klapwijk et al., 2014).

The project 'Climate-smart soil protection and rehabilitation in Benin, Burkina Faso, Ethiopia, India and Kenya', was designed to build on CIAT's expertise in both soil science and CSA to assess the climate smartness of selected GIZ-endorsed soil protection and rehabilitation measures in the five countries. Soil rehabilitation is often evaluated for productivity and food security benefits, with little attention to climate smartness. Likewise, CSA initiatives have not given due attention to soil protection and rehabilitation, despite their apparently strong and potential to increase climate-smartness. Thus the goal of the project is to produce detailed information on the climate smartness of ongoing soil protection and rehabilitation measures in these countries, identify suitable indicators for future monitoring and evaluation, potentials to increase the climate smartness of these measures. This project contributes directly to the objectives of the BMZ-GIZ Soil program on 'Soil Protection and Rehabilitation for Food Security' as part of Germany's Special Initiative "One World – No Hunger" (SEWOH), which invests in sustainable approaches to promoting soil protection and rehabilitation of degraded soil in Kenya, Ethiopia, Benin, Burkina Faso and India. It furthermore supports policy development with regard to soil rehabilitation, soil information and extension systems. The climate-smart soil protection and rehabilitation research project allows GIZ to widen the scope of soil protection and rehabilitation for food security by aligning with the goals of climate smart agriculture.

This report presents results from the rapid assessment of climate-smartness, the first activity of the project. It evaluates the potential impact of GIZ Kenya endorsed soil rehabilitation and protection technologies on productivity, nitrogen (N) balances, soil erosion, and greenhouse gas (GHG) emissions. These are suitable (rapid) indicators representing the three CSA pillars – productivity, resilience and mitigation.

This activity follows up on a previous scoping study that modelled potential impact and trade-offs of soil technologies on two farms in Kenya and Ethiopia, but recommended to base further household modelling on farm typologies (Paul et al., 2015). Data for the assessment was obtained from various sources. During a participatory workshop in Kisumu, five distinct farming systems were identified in Western Kenya (Koge et al., 2016a). Subsequently, interviews were conducted in farm households that were representative of the identified farm types (Koge et al., 2016b). Data collected from these farms form the basis of the baseline calculations of the indicators mentioned above. The soil technology scenarios were derived from workshop discussions, as well as technical documents by GIZ and implementing partner GOPA to reflect practices promoted in Western Kenya as closely as possible.

2. Methodology

Following the participatory workshop that described four to six farming system types per country, potential representative farms were jointly identified by CIAT, GIZ, GOPA, and ministry staff for a rapid assessment. The rapid assessment is based on a case study approach thus only one farm per type was selected and sampled. The head of the household was interviewed and household data collected using a questionnaire similar to IMPACTlite (http://bit.ly/2h3KAZf). Information about crops and livestock was collected including data about plot sizes, yields, use of crop products and crop residues, labour activities and inputs. Similar information was gathered for the livestock activities if any. In some cases, soil samples were taken from different plots.

The data collected served as input for the model used for the rapid assessment. The rapid assessment model, named *Kalkulator*, calculates the following indicators:

Productivity: Farm productivity was calculated based on the energy (calories) produced on farm – crop and livestock products – and compared to the energy requirement of an adult male equivalent to 2500 kcal per day (AME). Energy from direct consumption of on farm produce was calculated by multiplying the energy content of ever crop and livestock product with the produced amount. It is thus important to note that the indicator only represents food/energy production from the own farm, and does not include food that the household might purchase with additional income. Energy contents were based on a standard product list developed by the US Department of Agriculture USDA (source:http://bit.ly/1g33Puq). The total amount of energy produced on the farm was then divided by 2500 k cal to obtain the number of days for which 1 AME is secured. For the sake of cross-farm comparability, these data were then also expressed on a per-hectare basis.

Soil nitrogen balance: This balance was calculated at the plot level following the empirical approach of NUTMON as described in Van den Bosch et al. (1998). The following soil N-inputs were considered i) mineral fertilizers, ii) manure, iii) symbiotic fixation by legumes crops, iv) non-symbiotic fixation, and v) atmospheric deposition. The N-outputs are i) crops and residues exported off the field, ii) leaching of nitrate, iii) gaseous loss of nitrogen (NH_3 and N_2O) and iv) soil erosion. For calculating N inputs from manure and fertilizer, and N outputs from crop and residues, farmer reported data on quantities from the household survey was used. For N inputs from N fixation and deposition as well as N outputs from leaching, gaseous losses and soil erosion, transfer functions were used that are based on the rainfall and soil clay content of the specific site. The N balance is calculated for each plot (kg N/plot) and then summed to obtain the field balance expressed in kg N per farm. These results are then, again, converted into kg N per ha.

Soil erosion: Soil erosion is calculated at plot individual field level following the Revised Universal Soil Loss Equation (RUSLE; Renard et al., 1991; Amdihun et al., 2014).

Soil loss (t/ha/year) = R*K*LS*C*P

where,

R = Erosivity factor (a function of rainfall in mm/month)

K = Erodibility factor

LS = Slope length factor (function of the length and gradient of the slope)

C = Crop cover factor (function of the crop type)

P = Management factor (function of agricultural management practices).

Further information on each factor can be found at: www.iwr.msu.edu/rusle/factors.htm

GHG emissions: GHG emissions are calculated at farm level following the guidelines of the International Panel on Climate Change (IPCC, 2006). Emissions from livestock (methane from enteric fermentation), manure (methane and nitrous oxide), and field emissions (nitrous oxide) are taken into account as illustrated in Figure 1. Household survey data on livestock feed, livestock numbers and whereabouts, manure and fertilizer use, crop areas, and residue allocation was used as input data for the calculations. Most of the calculations follow IPCC Tier 1 methods, while Tier 2 calculations were performed for enteric fermentation and manure production.

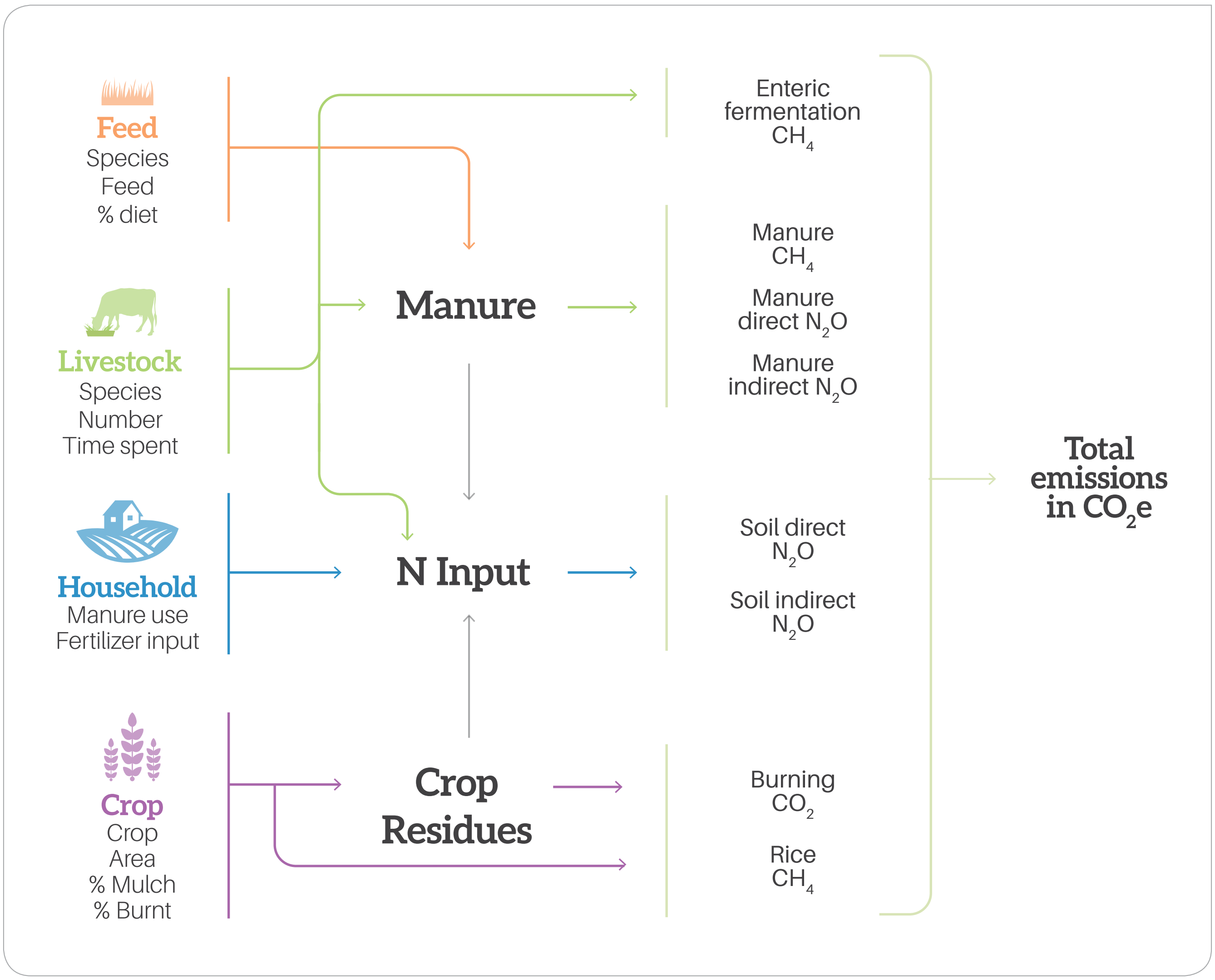

Figure 1: Scheme of the GHG emission calculations.

3. Farming systems

Four farm types were identified during the initial workshop in Kisumu Western Kenya. Workshop participants included representatives from GIZ, Ministry of Agriculture, Livestock and Fisheries, local NGOs, Government agricultural and environmental organizations, farmers, GOPA, University of Leeds, Stockholm Environment Institute (SEI) and CIAT (Koge et al. 2016a). We did, however, sample a resource-poor female-headed household. As there are some important lessons to learn from this farm, it was treated as a distinct type and is here reported alongside the other four farm types.

Resource-poor female-headed household: This farm type is characterized by a female household head. The farm covers around 1-2 acres of land and has no livestock, low productive assets, low income, low technology adoption, reliance on scarce family labour only, and low level of education. This farming system is characterized by low yields and low soil fertility due to low input use, but a minimum level of manure needs to be purchased.

Small mixed subsistence: Most of the farm, 1-2 acres in size, is under cultivation. Livestock herds are rather small with an average of not more than 5 local cattle, with no option for grazing on (communal) land outside the farm. Main crops grown are maize and beans though farmers have diversified and grown other crops to minimize risks of crop loss from attacks by pests, diseases, weeds and unfavourable weather conditions. Farmers in this category also have little resources, low yields and low soil inputs.

Medium dairy commercial farms: have 3-8 acres of land with both livestock and crop production, specializing in dairy production mainly for sale. Their dairy cows are mostly improved (mixture of local and exotic) breeds. This farming system is characterized by high-quality feeds, zero-grazing, artificial insemination services and potential for value addition as the milk can also be processed into by-products and sold at a higher price. The combination of improved cow breeds and improved feeds often results in a higher milk production of on average 10 litters per cow per day. Farmers in this category have also embraced modern technologies such as hay-making, silage production, biogas production and coolers for their milk. Key output markets for this type of farm include milk brands such as Brookside, schools and cooperatives, among others.

Medium horticulture commercial: This farm type comprises 3-8 acres of land with dairy and crop production but specializing in horticulture production. They grow a variety of vegetables, tomatoes, cabbages, onions and capsicums, all mainly for sale. The farms in this category are labour intensive. Youths are mostly drawn to commercial horticulture farming. Farmers require knowledge and management skills in running this farming enterprise. It includes high risk investments because of potential pests and diseases and vagaries of the weather, but on the other hand returns are also high. Farmers in this category have embraced innovative technologies such as irrigation and greenhouses. They also keep records on crop productivity and attract micro-finance institutions for credits and savings.

Large commercial farms usually have more than 10 acres of land, are highly commercialized and are growing mostly sugarcane, maize or coffee in Bungoma and Kakamega, and rice in Siaya. This type of farm is sensitive to market fluctuations. Households are generally small in size and well educated, and crop production is mostly mechanized. Farmers in this category have more productive assets than all the other identified farm types and therefore exhibit a high adoption of innovative technologies as they have enough capital and land to do so. They rely more on hired labour than household labour. Mineral fertilizers and organic manure are used and contributing to the high crop productivity found in these farms.

With the help of GIZ county program managers and county agricultural employees from the Ministry of Agriculture and County Departments of Agriculture, Livestock and Fisheries, one case study farm was selected for each of the farm types. The chosen farms were deemed representative of the farmers within each farm type. The percentage of households that fall within each type in each of the 3 counties was discussed during and directly after the workshop, and used as a guide to determine in which county the case study farm would be selected for each of the types.

Table 1: Percent distribution of households of each farm type across Siaya, Bungoma and Kakamega. Percentage distribution of resource-poor female-headed households could not be reported as this type was only added after the distribution discussions.

Counties	Resource-poor-female-headed	Small mixed subsistence	Medium dairy commercial	Medium horticulture commercial	Large commercial
Siaya	NA	70%	5%	20%	5%
Kakamega	NA	60%	10%	10%	20%
Bungoma	NA	50%	5%	10%	35%

Most of the large commercial farms are found in Bungoma and most of the medium dairy commercial farms in Kakamega. Therefore, the representative farms for these two types were selected from these two counties. One small subsistence mixed farmer and one resource-poor female headed household was selected from Siaya, while a medium horticulture commercial farmer was selected from Bungoma (Figure 2).

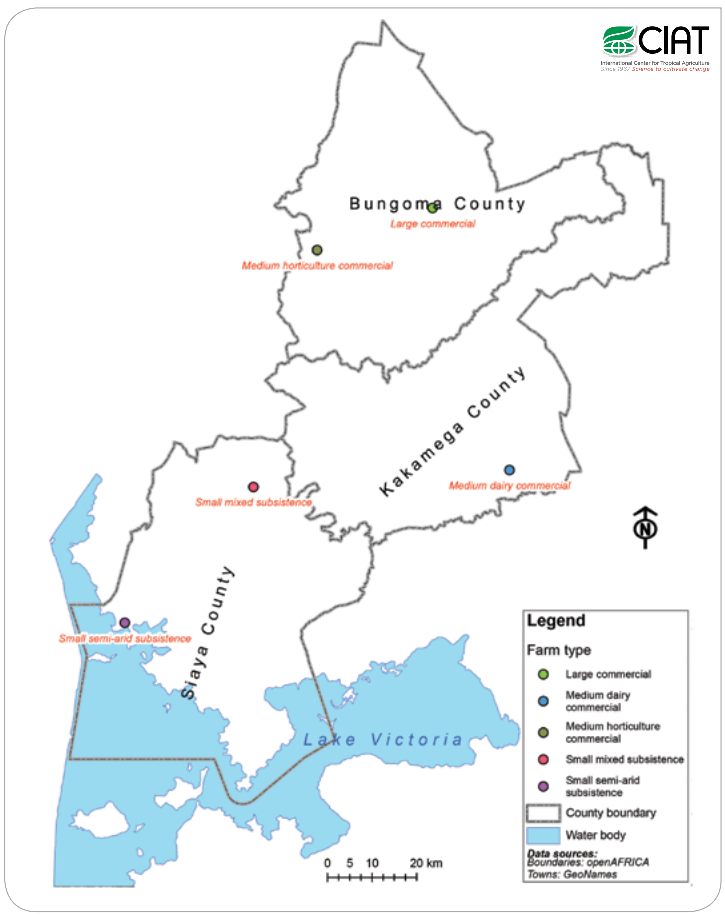

Figure 2: Location of case study farms in Western Kenya.

4. Technology descriptions and scenarios

The following scenarios represent soil rehabilitation interventions that are currently promoted by GIZ and partners in Western Kenya or that are under discussion for future promotion. All assumptions are described according to impact dimensions and summarized in the Appendix Scenario Assumptions.

Three distinct soil fertility improvement scenarios were implemented:

i. The liming + DAP scenario assumes that 15 kg N/ha DAP was applied to all non-legume crops across all farm types that are not already receiving other fertilizers. At 18% N content of DAP, this corresponds to 83 kg fertilizer/ha. In response to the addition of lime and N-fertilizer, all yields were assumed to increase by 30%.

ii. In the compost-only scenario, all crop residues are assumed to be removed from the field for composting. 30% of the N in these residues is lost to the environment during composting. The yields were assumed to increase by 20%.

iii. The lime + compost scenario combines the previous two scenarios. The yields were assumed to increase by 30%. This scenario was not applied to the large commercial farm.

In addition, a Conservation Agriculture (CA) scenario was assessed by introducing zero-tillage and soybeans in rotation or intercropping, depending on the farming system at hand. Both cropping systems are covering the soil well, thereby reducing erosion and suppressing weeds, while at the same time adding N to the farm by biological nitrogen fixation (BNF).

Vegetative strips of vetiver ("Veg. strip vetiver") and Napier ("Veg. strip Napier") are the two scenarios in which soil protection measures are implemented. As these strips require space, for all farm types, 10% of the area under maize and other cereals are replaced with either vetiver or Napier. Milk production is assumed to increase due to improved feeding (10% increase with vetiver and 20% with Napier). More manure is produced as consequence of increased milk production.

5. Results

5.1 Productivity pillar

5.1.1 Baseline productivity

The small mixed subsistence and the medium commercial horticulture farms have the highest productivity per hectare compared to all three other farms (Figure 3). This is due to the high proportion of maize produced on both farms, beans on the small mixed and vegetables on the medium commercial horticulture farms. On the mixed commercial dairy and on the large commercial farm, there is a higher percentage of calories from livestock products compared to the other farms. Both these farm have the highest productivity at the farm level but not per hectare. On the mixed commercial dairy farm, 60% of calories come from livestock products, and 40% from crop products. On the large commercial farm nearly 50% of calories come from livestock and 50% from crop products (all of which is maize, as no calories are counted from coffee). The poor female-headed household has the lowest productivity – per hectare and for the entire farm, which is due to the absence of livestock and low crop production. The medium commercial horticulture farm has the most diversified production, counting 15 different sources of calorie production. The resource-poor female headed household and the large commercial farmer have the least diversified calorie production base with four and two sources only.

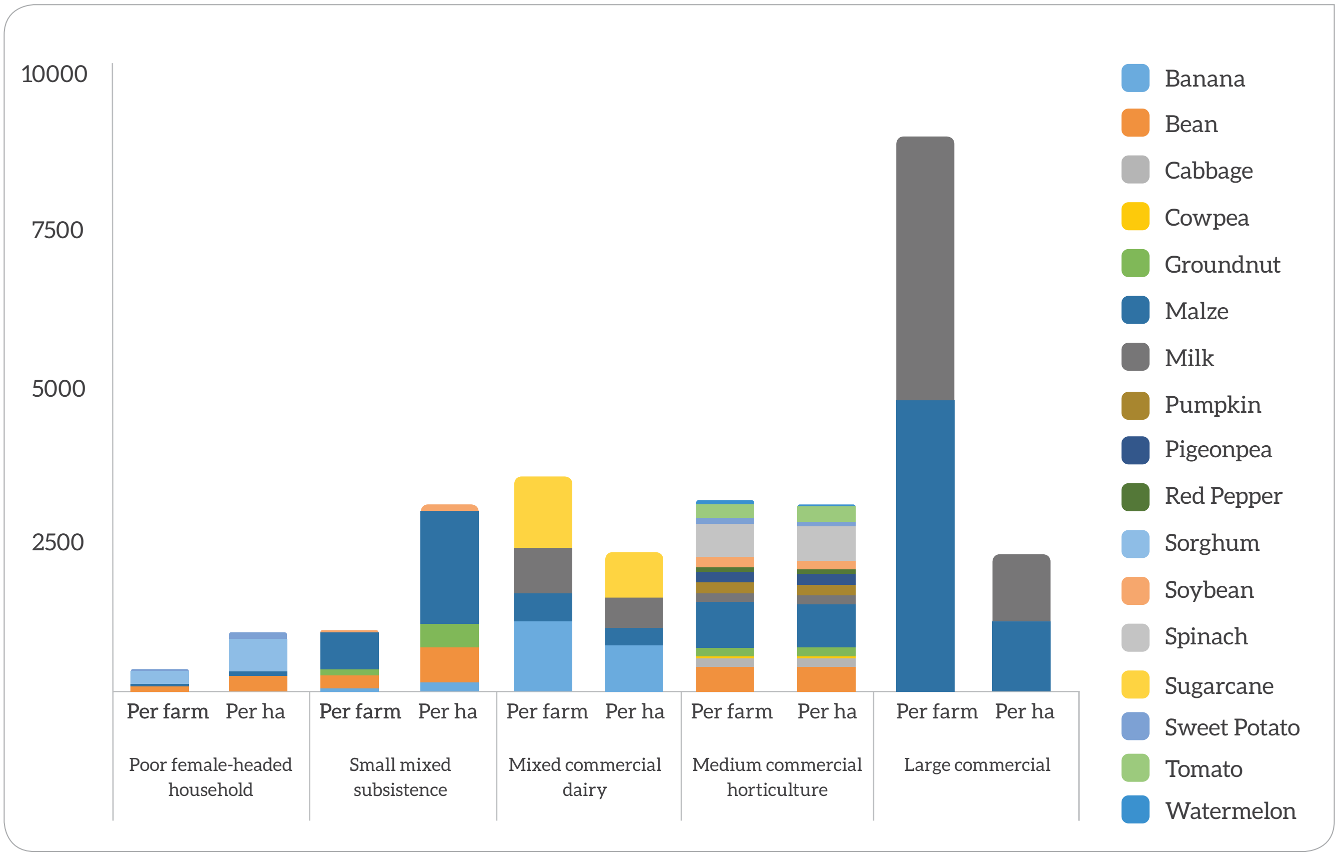

Figure 3: Baseline productivity and contribution from the different products across farm types. Productivity is expressed as number of days that 1 adult male equivalent (AME) can be fed from livestock and crop products produced on the farm .

5.1.2 Changes in productivity

Introducing the technologies described earlier is projected to generally increase productivity across all farm types (Figure 4). This is mainly due to the increases in yields and in animal productivity (i.e. milk) that result from additional inputs of N or from increasing the area of legumes (high calorie content). The vegetative strips have the least impact on productivity across all farm types. Although improving soil fertility to the areas where they are placed and thus potentially increasing crop yields to those fields, a) these strips cannot be consumed directly, and b) vegetative strips reduce the cultivatable area. Conservation agriculture impacts productivity the most on the poor female-headed household and on the mixed commercial dairy farms. In the first case, this is because of the increase in area under cultivation in the short rainy season (in the baseline, only 0.04 out of 0.32 ha were cultivated) and from the addition of soybean (source of high calories). Keeping the soil covered throughout the year through adding cover crops (mainly legumes) as intercrop or rotation is one of the three principals of CA. The farms where livestock products (especially milk) are important sources of calories, can improve productivity from the grass strips because of improved feeding. This is the case for the mixed commercial dairy and the large commercial farms.

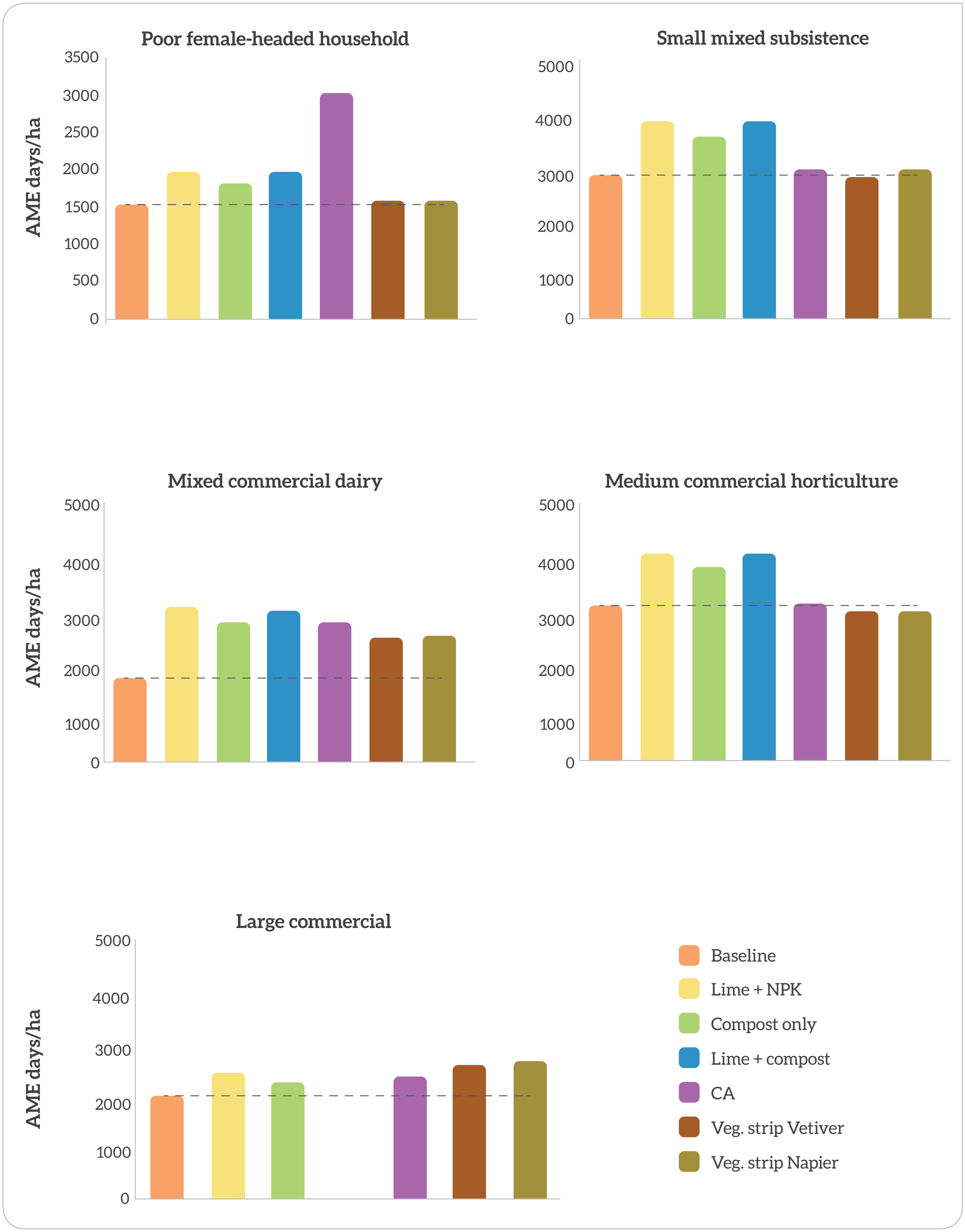

Figure 4: Baseline and scenario productivity per farm type. Results are expressed in days of Adult Male Equivalent calories (AME = 2500 kcal/day) on a per hectare basis. The dashed line represents the baseline N balance.

5.2 Resilience pillar

5.2.1 Baseline N balances

A negative N balance was calculated for all farms except the small mixed subsistence and large commercial farms (Figure 5). On the small mixed subsistence farms, the positive N balance is mainly due to the high livestock density. Five cattle are kept on the farm and fed on 70% off-farm grazing. All of the manure produced on-farm is used to fertilize the half a hectare cropland. This combination from nutrient import through off-farm grazing and nutrient return on a small piece of arable fields leads to nutrient abundance. On the large commercial farm, the N balance is positive mainly because of the use of inorganic fertilizers for the coffee crop. On all the other farms the major loss of N is due to N being exported from the fields in the form of harvested crop products. This is specifically the case on the mixed commercial horticulture farm where a lot of N is exported out of the fields through nutrient-rich crop harvest and sale without sufficient compensation through application of on-farm manure, compost or other fertilizers.

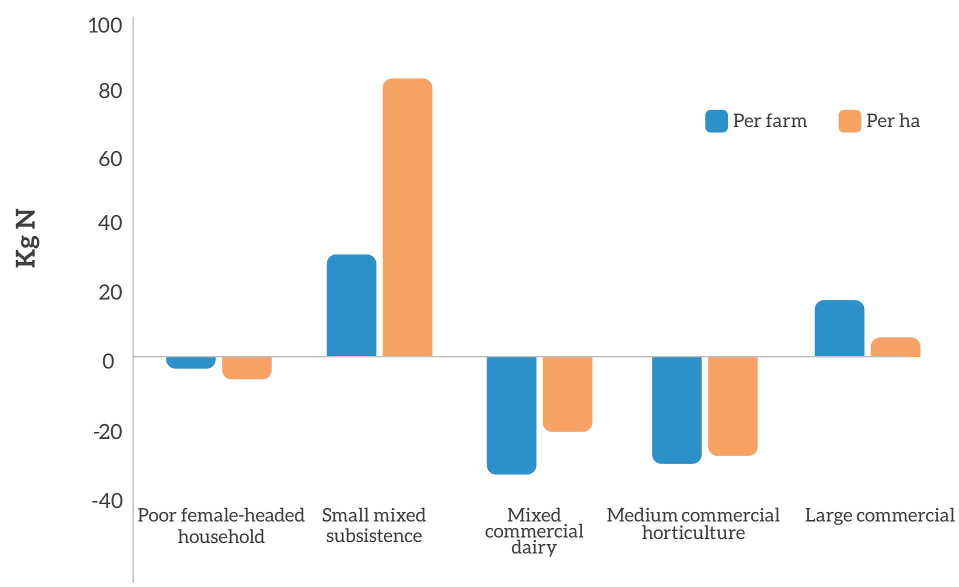

Figure 5: Baseline N balance at field level per farm and hectare across farm types.

5.2.2 Changes in N balance

Implementing the different soil technology scenarios affects the N balance differently across farms (Figure 6). The N balance improves the least across interventions in the mixed commercial dairy, the medium commercial horticulture and the large commercial farms.

In the mixed commercial dairy farm the N balance ranges from -30 to -15 kg N/ha, in the medium commercial farm from -47 kg to -16 N/ha and in the large commercial farm from 5.6 to -38 kg N/ha. There is more impact seen on the small farms especially for the soil fertility improvement interventions. The balance ranges from -8.7 to 68 kg N/ha on the poor female-headed household farm and from 71 to as high as 168 kg N/ha on the small mixed subsistence farm. The vegetative strips and CA have the lowest impact compared to the three soil fertility improvement interventions.

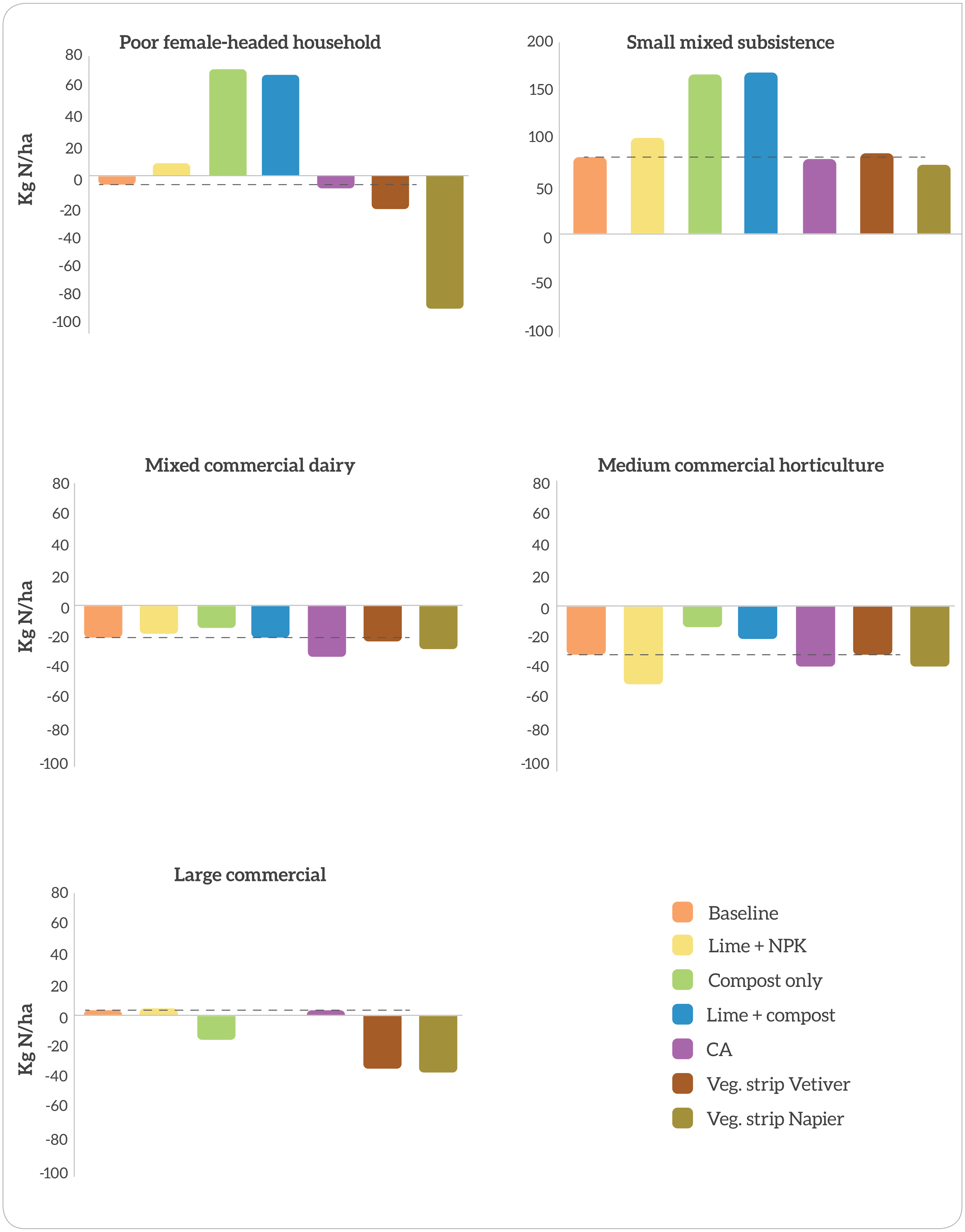

Figure 6: N balance of baselines and scenarios across farms (kg N/ha). The dashed line represents the baseline N balance.

5.2.3 Baseline erosion

In this study, most farms sampled were found on relatively flat land. Erosion was greatest on the medium commercial horticultural farm at close to 1 ton of soil/ha. There was the least erosion on the mixed commercial dairy farm less than 200kg soil/ha (Figure 7).

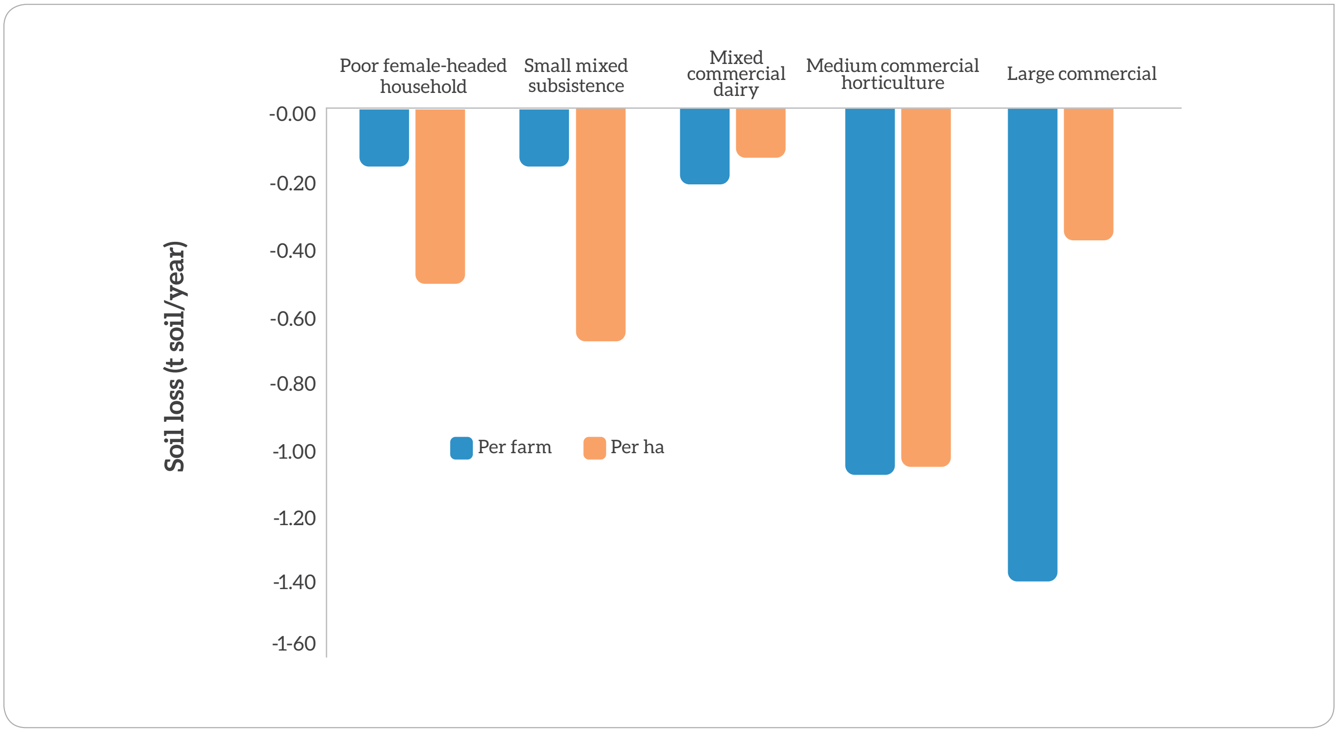

Figure 7: Baseline soil erosion (t soil/year), per farm or per hectare.

5.2.4 Changes in erosion

In the scenarios only the vegetative strips were considered to have a direct impact on soil erosion acting as a physical barrier (Figure 8). The technology of conservation agriculture had different impact on erosion. This is mainly due to the change in crop cover from the baseline, as new crops were introduced in the crop rotation. In some cases, soil erosion decreased such as in the small mixed farm, slightly decreased in the medium horticultural farm and increased in all other three farms.

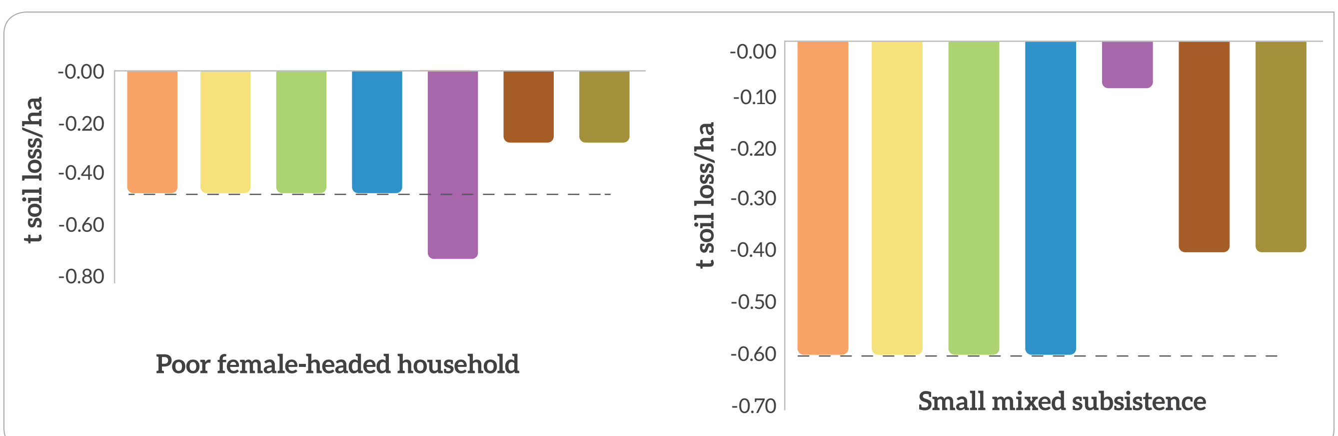

Figure 8: Soil erosion baselines and scenarios across farms (t soil/ha).

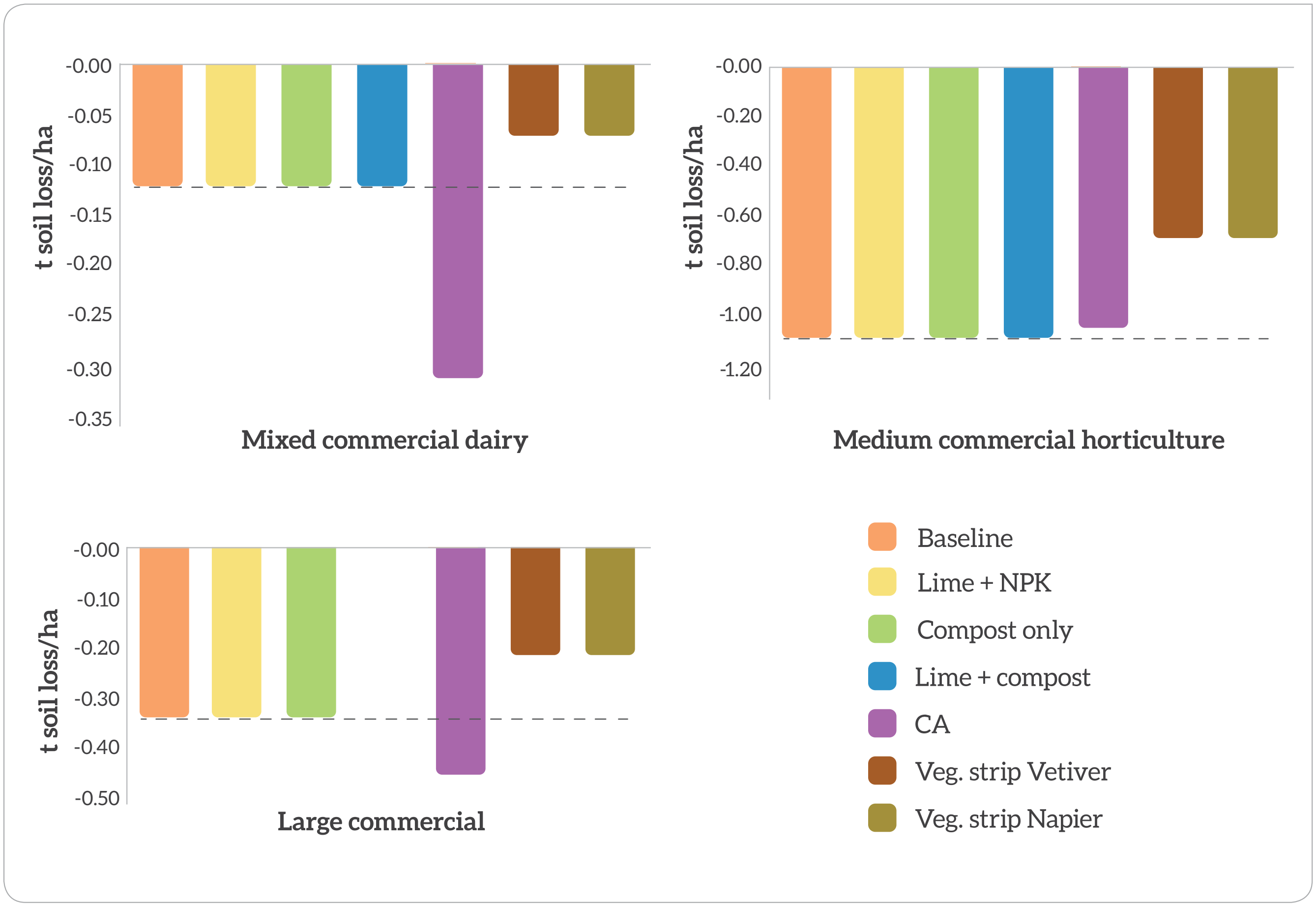

Figure 8: Soil erosion baselines and scenarios across farms (t soil/ha).

5.3 Mitigation pillar

5.3.1 Baseline GHG emissions

The large commercial farm has the highest emissions per farm, first of all because of the significant size of the farm, and because of the high number of livestock and high fertilizer input to the soils triggering nitrous oxide emissions. The small mixed subsistence farm, however, has the highest emission intensity (CO_2e/ha) because of the high number of livestock per area. Here enteric fermentation is the major source of GHG emissions. Soil nitrous oxide emissions contribute comparably little because of the lower use of inorganic inputs and the low "make use" of the cow manure as organic fertilizer. In comparison to the small mixed subsistence farm, the mixed commercial dairy farm has slightly lower per farm emissions and especially a much lower GHG emission intensity. The lower livestock number (only two dairy cows) explain the big difference in emissions from enteric fermentation. In addition, the livestock production on this farm is more intensive, i.e. less animals and less area are needed to produce a similar amount of animal products. As this farm's land size is bigger, the emission intensity is lower. The poor female-headed household has lowest emission intensity because there is no livestock and no fertilizer use, closely followed by the medium commercial horticultural farm with its small animal herd and limited fertilizer application.

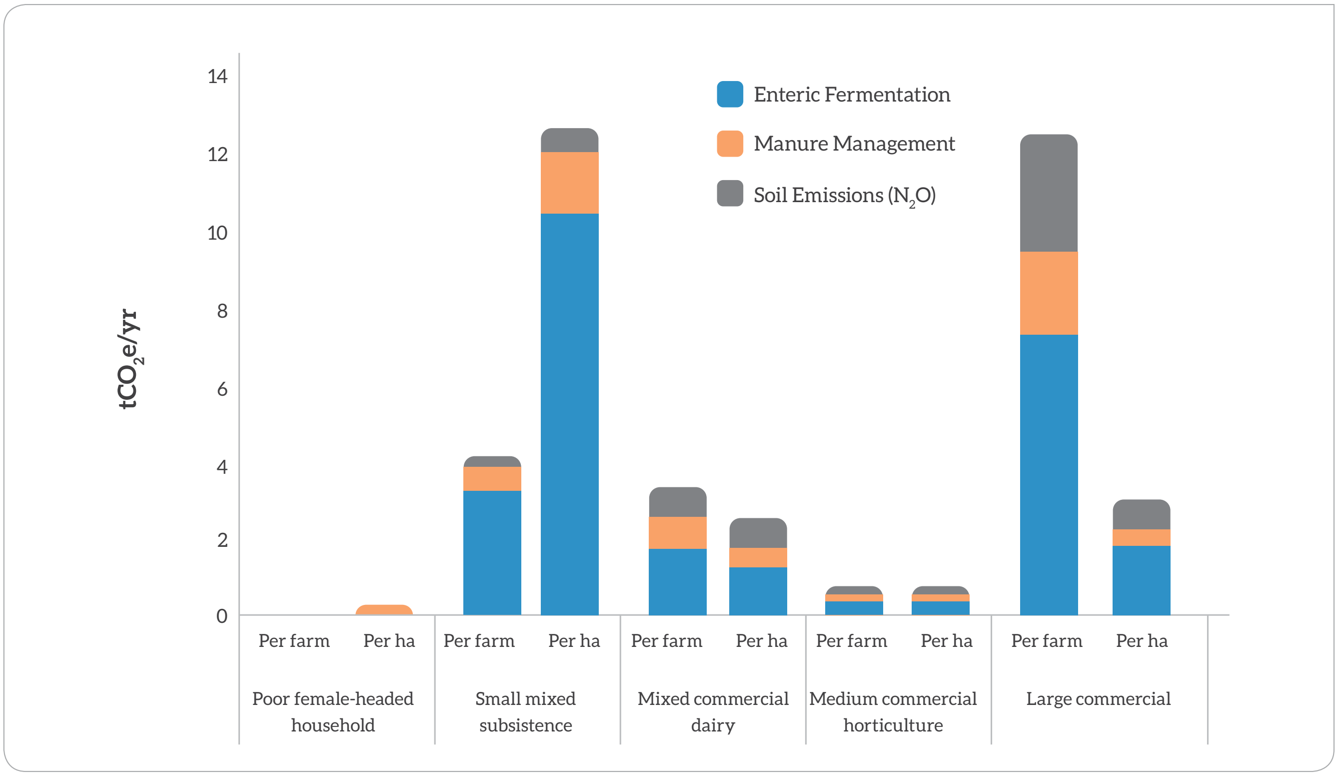

Figure 9: Baseline GHG emissions from enteric fermentation, manure management and soil emissions across farm types.

5.3.2 Changes in GHG emissions

In the three first interventions, additional N is added to the soil. This by consequence, applying IPCC tier 2 method, increases soil nitrous oxide emissions and thus overall farm GHG emissions (Figure 10).

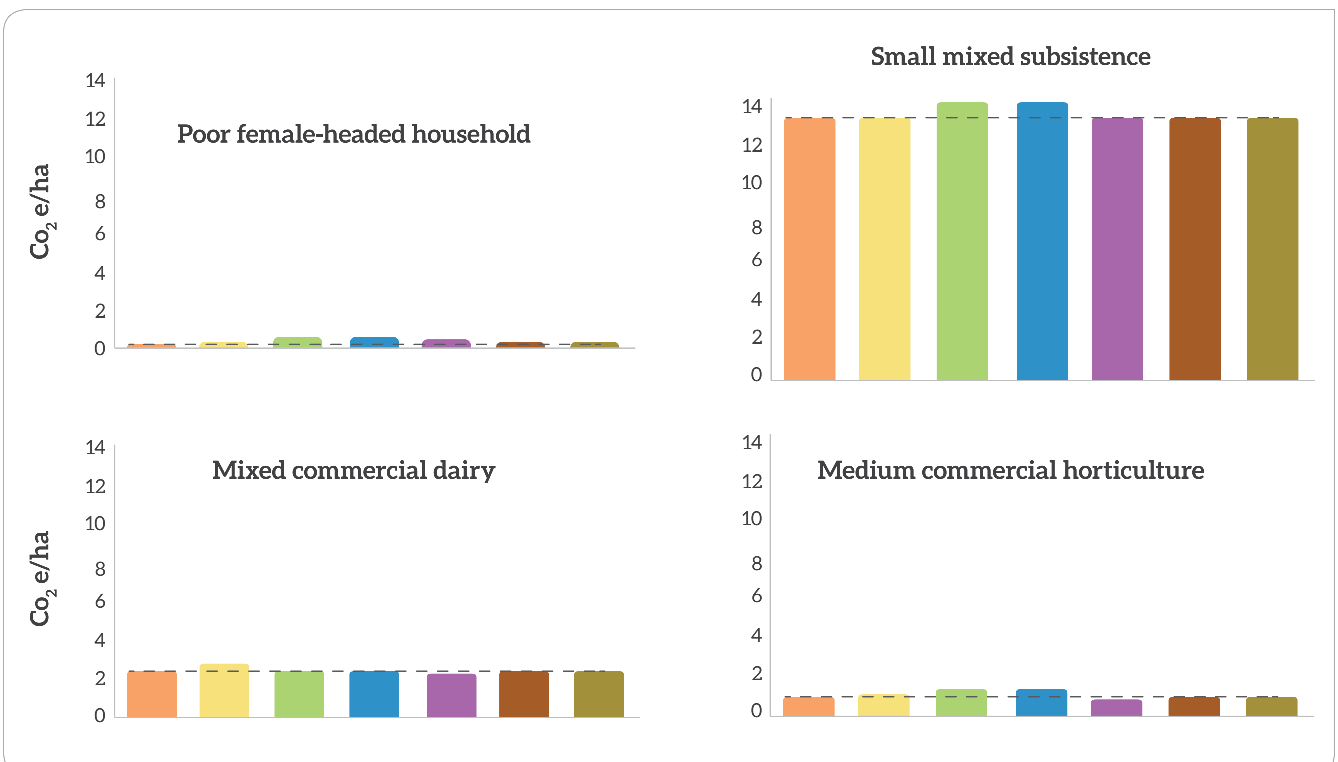

Figure 10: GHG emission intensity baselines and scenarios across farms.

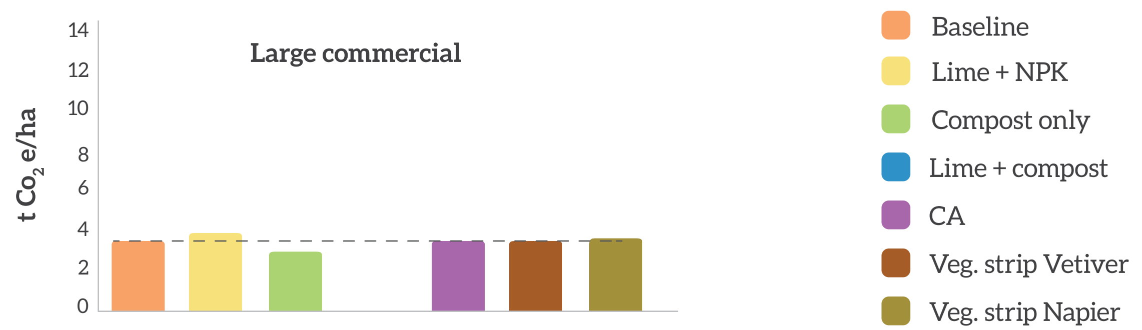

Figure 10: GHG emission intensity baselines and scenarios across farms. The dashed line represents the baseline.

There is greater relative change from the baseline in the poor female-headed household farm because it is the most extensive. Thus, any input will increase emissions. Although the percentage change is large (compared to the other farms), this farm still has the lowest GHG emissions overall. Similarly, there is a relatively big change in the medium commercial horticulture because of the low baseline GHG emissions. The only soil fertility improvement intervention with a positive effect, i.e. reducing the GHG emissions per area of land, is composting at the large commercial farm. On all other farms, GHG emissions increase after the implementation of the three outlined soil fertility improvement measures lime+NPK, lime+compost, and compost only. The CA intervention has mixed impacts depending on the farm type.

On the two small and on the large commercial farm, there is virtually no change in GHG emission intensity. On the medium commercial dairy farm the emission intensity is projected to go up slightly, whereas in the medium commercial horticultural farm, CA is projected to cause a small decrease in emission intensity. Under baseline conditions, GHG emission intensity is lowest for the female-headed farm and highest for the small mix subsistence farm.

The emission intensity changes, on the other hand, are highest for the first of these and lowest for the second, across the scenarios. The high emission intensity at the dairy farm is due to the high stocking rate, with most emissions coming from livestock. The small changes in emission intensities in the dairy farm are caused by little changes in livestock management. In other words, as long as the livestock numbers do not change, emission intensity will not change significantly.

5.4 Trade-offs

Trade-offs occur when improvement in one dimension of farm performance cause deterioration in another dimension. We plotted changes in productivity – as food security indicator – against the changes in resilience (N balance, Figure 11) and mitigation (GHG emission intensity, Figure 12). These figures show trade-off and synergy patterns across farm types and soil technology scenarios.

In Figure 11, the majority of dots are in the upper right quadrant of the graph, indicating that improving the N-balance also improves productivity (or vice-versa), representing a synergetic situation. Yet, it should be noted that even a positive changes in N-balance could still mean a resulting overall negative N-balance. Also, a further increase in N-balance in farms that already have a positive balance to start with, is not necessarily desirable, as this could lead to N-losses to the environment and associated eutrophication of water bodies and streams.

Vegetative strip dots are mostly in in the lower right quadrant, meaning that these improve productivity at the expense of the N-balance (trade-off), which seems inevitable as long as these are not adequately fertilized or (N-fixing) legumes included. On the medium commercial horticulture farm, vegetative strips also lead to a reduction in productivity.

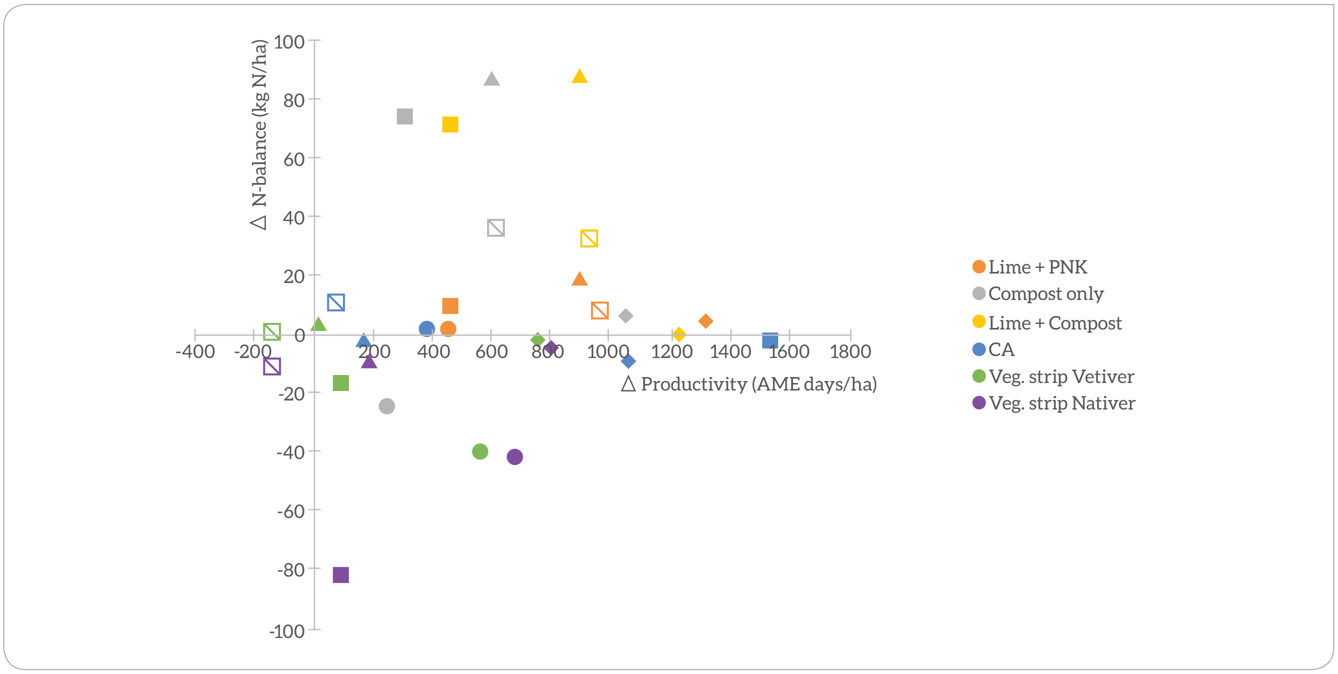

Figure 11: Trade-offs between changes in productivity (AME days/ha) and field N balance (kg N/ha) when moving from baseline to soil conserving technologies. Colours represent the scenario and shape the farm types (□=Poor female-headed household, △=Small mixed subsistence, ◇=Mixed commercial dairy, ⧅with patterns=Medium commercial horticulture and ○=Large commercial).

When looking at synergies and trade-offs between changes in productivity and GHG emissions (Figure 12), the following conclusions can be drawn: even more strongly than in Figure 8, most of the dots are in the upper right quadrant. However, in this case it indicates a trade-off as increasing productivity comes at the expense of increased GHG emission intensities. However, some technologies – such conservation agriculture – have the potential to perform well in terms of increasing productivity without increasing GHG emissions. On the large commercial farm, introducing compost presents a potential win-win solution as well. The poor female-headed household, however, produces much less kcal than the other farms and is thus scoring badly on the amount of greenhouse gases emitted relative to its contribution to food security.

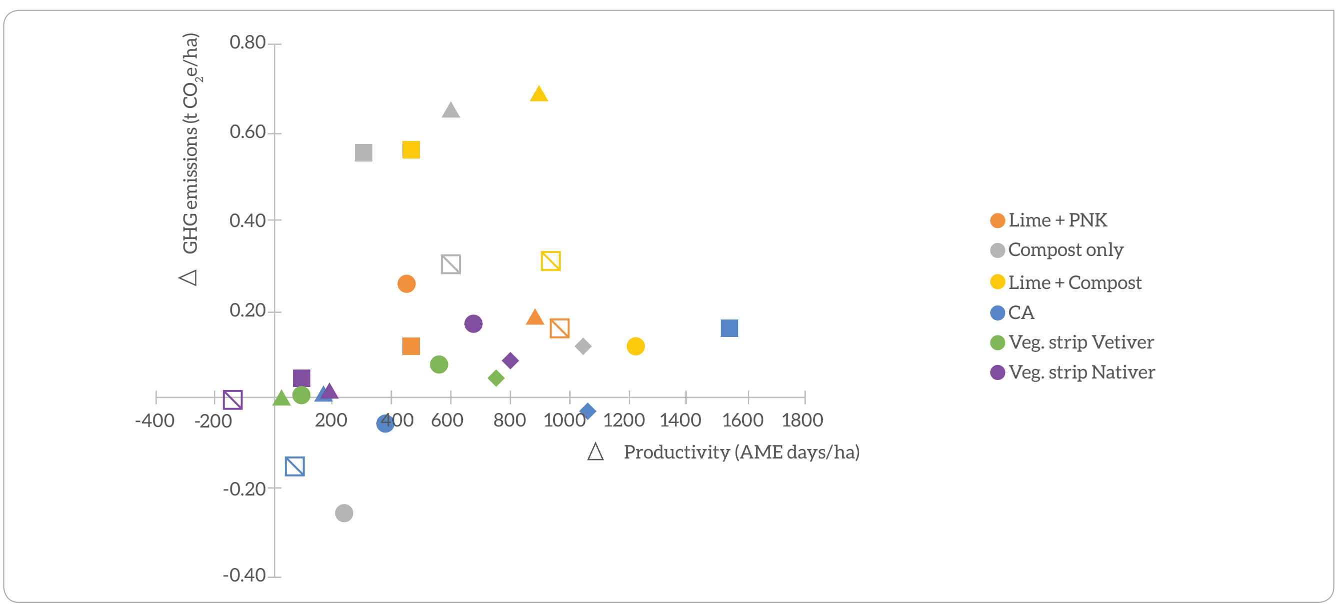

Figure 12: Trade-offs between changes in productivity (AME days/ha) and GHG emissions (t CO_2e/ha) comparing baseline and soil conservation scenarios; Colours represent the scenarios, and shape the farm types (□=Poor female-headed household, △=Small mixed subsistence, ◇=Mixed commercial dairy, ⧅with patterns=Medium commercial horticulture and ○=Large commercial). The dashed line represents the baseline production.

6. Conclusions and recommendations

In this report a fairly simple set of three indicators was used for assessing the climate-smartness of farm types and soil protection and rehabilitation measures in Western Kenya. This allowed for a truly rapid assessment across implementation countries that can feed into decision-making processes in the on-going GIZ Soil Program.

Needless to say, the choice of indicators has its limitations. The use of calorie-based production of crops, milk and eggs as a productivity indicator disadvantages farms with higher importance of livestock production as compared to staple crops. The livestock farms are first of all disadvantaged by the exclusion of meat, secondly by the low calorie content of milk and eggs. The high protein content of livestock products renders them however very important for nutrition security, especially so for young children and pregnant women. This should be kept in mind when evaluating production. Adding up calories produced from the various crops and livestock products and comparing business-as-usual with best-bets, is however a simple and easy-to-grasp way of indicating changes.

Focusing on soil fertility (approximated by the field-level N-balance) as the resilience indicator excludes a large number of important issues that contribute to farmers' resilience to climate change, such as income stability, access to skills, finances and information, crop/livestock diversity, etc. Indeed soil organic carbon could not be modelled in the rapid assessment. SOC has the potential to offset GHG emissions through carbon sequestration.

Despite the short-comings of the indicators used, the rapid assessment clearly shows that there is a large variation in the baseline climate smartness across large different farm types. One of the most important factors influencing this is the number of livestock and the efficiency of the livestock production. Livestock production depends on relatively large land sizes (for feed production) and therefore scores quite low in terms of production and productivity. The livestock manure, however, has the potential to contribute considerably to a farm's soil fertility. In some cases it is doing so already, in other farms the manure is underutilized and just left to contribute to GHG instead.

Appendix I: Surveyed farm details

Table 2: Household size, land sizes and management per farm type. Area managed refers to cultivated land, pasture, tree plots, fallow and unutilized land that is managed by the household. Area under cultivation refers only refers to land being cultivated by the household.

Farm type	Household members (number)	Farm size (h a)	Area managed (ha)	Area cultivated (ha)
Poor female-headed	3	0.56	0.56	0.38
Small mixed subsistence	5	0.33	0.33	0.33
Mixed commercial dairy	5	2.8	1.72	1.54
Mixed commercial horticulture	7	0.97	1.26	1.02
Large commercial	10	5.6	5.2	4.05

Table 3: Crops yields per farm type. Not applicable (NA) indicates that the respective crop is not grown on the farm. All yields are reported in fresh weight (FW).

Farm type	Grain yields of main crops (kg FW/ha/year)		Yields of cash crops (kg FW/ha/year)		Yields of horticultural crops (kg FW/ha/year)			
	Maize	Beans	Coffee	Sugarcane	Kales	Green pepper	Butternut	Cabbage
Poor female-headed	1724	299	NA	NA	NA	NA	NA	NA
Small mixed subsistence	2168	626	NA	NA	NA	NA	NA	NA
Medium dairy commercial	5560	729	NA	NA	62253	17557	6721	11861
Medium horticulture commercial	5337	NA	NA	80062	NA	NA	NA	NA
Large commercial	2250	NA	982	NA	NA	NA	NA	NA

Table 4: Fertilizer application rates (kg/ha).

Farm type	NPK	CAN	DAP
Poor female-headed household	NA	NA	NA
Small mixed subsistence	NA	NA	61
Medium dairy commercial	NA	NA	158
Medium horticulture commercial	NA	NA	124
Large commercial	544	247	247

Table 5: Livestock herd composition (no.) and total TLU (tropical livestock unit).

Farm type	Local dairy cattle	Improved dairy cattle	Other cattle (male and heifers)	Calves	Sheep	Goats	Pigs	Poultry	Total TLU
Poor female-headed household	0	0	0	0	0	0	0	0	0
Small mixed subsistence	0	0	5	0	0	3	0	23	0.53
Medium dairy commercial	0	2	0	0	0	0	5	41	2.81
Medium horticulture commercial	0	0	0	0	0	3	0	45	0.75
Large commercial	0	6	0	2	3	0	0	4	5.61

Table 6: Livestock (ruminants) feed basket (fraction).

Farm type	Napier	Natural grasses (pasture)	Rhodes grass (green fodder)	Fodder (calliandra and Sesbania)	Dairy meal	Molasses	Crop residues
Poor female-headed household	NA	NA	NA	NA	NA	NA	NA
Small mixed subsistence	0.1	0.9	NA	NA	NA	NA	NA
Medium dairy commercial	0.8	0.1	NA	NA	0.035	0.04	0.03
Medium horticulture commercial	0.55	0.025	0.175	0.13	NA	0	0.12
Large commercial	70	8	NA	NA	NA	NA	20

Table 7: Crop residue management for the main crops (fraction removed from the fields).

Farm type	Napier	Natural grasses (pasture)	Rhodes grass (green fodder)	Fodder (calliandra and Sesbania)	Dairy meal	Molasses
Poor female-headed household	NA	NA	NA	NA	NA	NA
Small mixed subsistence	0.25	NA	NA	NA	NA	NA
Medium dairy commercial	1	NA	NA	NA	0.26	1
Medium horticulture commercial	0.375	1	1	1	1	NA
Large commercial	1	NA	NA	0.43	NA	1

Table 8: Whereabouts of ruminants (fraction of the day 0-1) and manure collection and use (%).

Farm type	Cattle				Sheep				Goats				Manure collection		Manure collected used for fertilization
	Stable	Yard	Pasture	Off-farm	Stable	Yard	Pasture	Off-farm	Stable	Yard	Pasture	Off-farm	Stable	Yard	
Poor female-headed household	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Small mixed subsistence	NA	0.58	NA	0.42	NA	NA	NA	NA	NA	NA	0.58	0.42	NA	40%	100%
Medium dairy commercial	0.9	0.08	0.02	NA	NA	NA	NA	NA	NA	NA	NA	NA	85%	75%	100%
Medium horticulture commercial	NA	NA	NA	NA	NA	NA	NA	NA	0.88	NA	0.125	0	85%	NA	100%
Large commercial	NA	0.67	0.33	NA	0.67	NA	0.33	NA	NA	NA	NA	NA	85%	75%	100%

Table 9: Whereabouts of non-ruminants (fraction of the day 0-1.

Farm type	Poultry				Swine			
	Stable	Yard (free range)	Pasture	Off-farm	Stable	Yard	Pasture	Off-farm
Poor female-headed household	NA	NA	NA	NA	NA	NA	NA	NA
Small mixed subsistence	0.54	0.46	NA	NA	NA	NA	NA	NA
Medium dairy commercial	0	1	NA	NA	NA	NA	NA	NA
Medium horticulture commercial	0	1	NA	NA	1	NA	NA	NA
Large commercial	0.58	0.42	NA	NA	NA	NA	NA	NA

Appendix II: Scenario Assumptions

	Impact dimension	SC1A: Lime + NPK	SC1B: Composting	SC1C: Lime + composting	SC2: Conservation Agriculture	SC3A: Vetiver Strip	SC3B: Napier Strip
Small subsistence semi-arid	Land use change	None	None	None	Short rains: -Replacing sweet potato with soybeans (GIZet al.,2015a) - Soybeangrown on previous sole maize field (0.63 acres) -Added soybeans to fallow fields (0.78 acres)	Reducing maize and sorghum area by 10% for vetiver strips	Decreasing maize and sorghum area by 10% for vetiver strips
Small mixed subsistence	Land use change	None	None	None	Both season: Reducing maize area by 1/4 for soybeans	Reducing maize and banana fields by 10% each for vetiver strips	Reducing maize and banana fields by 10% each for Napier strips
Medium commercial dairy	Land use change	None	None	None	Both seasons: Reducing sole sugarcane field by 1/4; to intercrop with soybean Reducing maize area by 1/4 and allocating that to soybean	Long rains: Reducing maize and banana fields by 10% each for vetiver strips Short rains: Reducing all crop areas by (%) for vetiver strips	Long rains: Reducing maize and banana fields by 10% each for Napier strips Short rains: Reducing all crop areas by (%) for Napier strip
Medium commercial horticulture	Land use change	None	None	None	Reducing maize area by 1/4 for more soybeans (GIZ et al., 2015a))	Reducing maize and sweet potato area (instead of horticulture) by 10% each for vetiver strips (GOPA, 2015),	Reducing maize and sweet potato area (instead of horticulture) by 10% each for vetiver strips (GOPA, 2015),
Large commercial	Land use change	None	None	NA	Long rains: Reducing maize field by 1/4 and allocated this area to soybeans (GIZ et al., 2015a) Short rains: Added maize to make up for the1/4 reduction. Added soybeans to fallow field that was sole maize in the long rains	Long rains: Reducing maize area by 10% to make space for vetiver strips (GOPA, 2015). Short season: Added maize area reduced in previous season. Allocated 10% of this maize area to vetiver strips	Long rains: Reducing maize area by 10% to make space for Napier strips (GOPA, 2015). Short season: Added maize area reduced in previous season. Allocated 10% of this maize area to Napier strips

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(continued)

	Impact dimension	SC1A: Lime + NPK	SC1B: Composting	SC1C: Lime + composting	SC2: Conservation Agriculture	SC3A: Vetiver Strip	SC3B: Napier Strip
Small subsistence semi-arid	Fertilizer application	N (21 kg N/ ha/ crop) application on maize, sorghum and sweet potato	No fertilizer applied	No fertilizer applied	add 100 kg DAP/ ha (= 18 kg N/ha/ crop) on maize, sorghum and sweet potato	No fertilizer applied	No fertilizer applied
Small mixed subsistence	Fertilizer application	N (21 kg N/ ha/ crop) application on maize and banana	Reduced fertilizer application by 50%	Reduced fertilizer application by 50%	No change	No change	No change
Medium commercial dairy	Fertilizer application	N (31 kg N/ ha/ crop) application on sugarcane, Napier, banana and maize	Reduced fertilizer application by 50%	Reduced fertilizer application by 50%	No changes	No changes	No changes
Medium commercial horticulture	Fertilizer application	N (31 kg N/ ha/ crop) application on maize, sweet potato and horticulture crops (cabbage, kale, red pepper, pumpkin, butternut, watermelon and tomato	Reduced fertilizer application by 50%	Reduced fertilizer application by 50%	No changes	No change	No changes
Large commercial	Fertilizer application	N (63 kg N/ ha/ crop) application on maize and Napier	Reduced fertilizer application by 50%	NA	No change	No change	No change
Small subsistence semi-arid	Manure application	No change	70% of 45 kg N/ ha compost + compost from residue left on field (30% lost through decomposing).	0% of 45 kg N/ ha compost + compost from residue left on field (30% lost through decomposing).	No change	No change	No change
Small mixed subsistence	Manure application	No change	70% of 45 kg N/ha from compost + compost from residue left on field (30% lost through decomposing)	70% of 45 kg N/ha from compost + compost from residue left on field (30% lost through decomposing)	No change	No change	No change

(continues)

(continued)

	Impact dimension	SC1A: Lime + NPK	SC1B: Composting	SC1C: Lime + composting	SC2: Conservation Agriculture	SC3A: Vetiver Strip	SC3B: Napier Strip
Medium commercial dairy	Manure application	No change	70% of 60 kg N/ha from compost + compost from residue left on field (30% lost through decomposing)	70% of 60 kg N/ha from compost + compost from residue left on field (30% lost through decomposing).	No change	No change	No change
Medium commercial horticulture	Manure application	No change	70% of 60 kg N/ha from compost + compost from residue left on field (30% lost through decomposing)	70% of 60 kg N/ha from compost + compost from residue left on field (30% lost through decomposing)	No change	No change	No change
Large commercial	Manure application	No change	70% of 60 kg N/ha from compost + compost from residue left on field (30% lost through decomposing).	NA	No change	No change	No change
Small subsistence semi-arid	Crop yield	Increase all yields by 30%	Increase all yields by 20%	Increase all yields by 30%	Increase cereal yields by 10% and legumes by 5% (only for those crops that were intercropped or rotated)	Increase in productivity compensates for reduction in area, i.e. total production remains the same	Increase in productivity compensates for reduction in area, i.e. total production remains the same
Small mixed subsistence	Crop yield	Increase all yields by 30%	Increase all yields by 20%	Increase all yields by 30%	Increase cereal yields by 10% and legumes by 5% (only for those crops that were intercropped or rotated)	Increase in productivity compensates for reduction in area, i.e. total production remains the same	Increase in productivity compensates for reduction in area, i.e. total production remains the same
Medium commercial dairy	Crop yield	Increase all yields by 30%	Increase all yields by 20%	Increase all yields by 30%	Increase maize and sugarcane yields by 10% and legumes by 5% (only for those crops that were intercropped or rotated)	Increase in productivity compensates for reduction in area, i.e. total production remains the same	Increase in productivity compensates for reduction in area, i.e. total production remains the same
Medium commercial horticulture	Crop yield	Increase all yields by 30%	Increase all yields by 20%	Increase all yields by 30%	Increase cereal yields by 10% and legumes by 5% (only for those crops that were intercropped or rotated)	Increase in productivity compensates for reduction in area, i.e. total production remains the same	Increase in productivity compensates for reduction in area, i.e. total production remains the same

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	Impact dimension	SC1A: Lime + NPK	SC1B: Composting	SC1C: Lime + composting	SC2: Conservation Agriculture	SC3A: Vetiver Strip	SC3B: Napier Strip
Large commercial	Crop yield	Increase all yields by 30%	Increase all yields by 20%	NA	Increase cereal yields by 10% and legumes by 5% (only for those crops that were intercropped or rotated)	Increase in productivity compensates for reduction in area, i.e. total production remains the same	Increase in productivity compensates for reduction in area, i.e. total production remains the same
Small subsistence semi-arid	Milk production	No livestock	No livestock	No livestock	No livestock	No livestock	No livestock
Small mixed subsistence	Milk production	No dairy cattle on the farm	No dairy cattle on the farm	No dairy cattle on the farm	No dairy cattle on the farm	No dairy cattle on the farm	No dairy cattle on the farm
Medium commercial dairy	Milk production	10 increase because of 30% higher crop production	10% decrease; not much because Napier is the main diet.	10% decrease; not much because Napier is the main diet.	10% decrease; not much because Napier is the main diet.	10% increase	20% increase
Medium commercial horticulture	Milk production	10 increase because of 30% higher crop production	20% decrease as residues for all crops that were previously fed to livestock are now mostly for compost.	20% decrease as residues for all crops that were previously fed to livestock are now mostly for compost.	20% decrease as residues for all crops that were previously fed to livestock are now mostly for compost.	10% increase	20% increase
Large commercial	Milk production	10 increase because of 30% higher crop production	10% decrease; not much because Napier is the main diet.	NA	10% decrease; not much because Napier is the main diet.	10% increase	20% increase
Small subsistence semi-arid	Residue management	None	2/3 removal of all residue for composting, 1/3 remains on the field	2/3 removal of all residue for composting, 1/3 remains on the field	None (because all residue is left on the field)	None	None
Small mixed subsistence	Residue management	None	2/3 removal of all residue for composting, 1/3 remains on the field	2/3 removal of all residue for composting, 1/3 remains on the field	None (because all residue except maize is left on the field), of which 2/3 maize residue is retained	None	None
Medium commercial dairy	Residue management	None	2/3 removal of all residue for composting, 1/3 remains on the field	2/3 removal of all residue for composting, 1/3 remains on the field	1/3 removal of all residue, 2/3 remains on the field	None	None

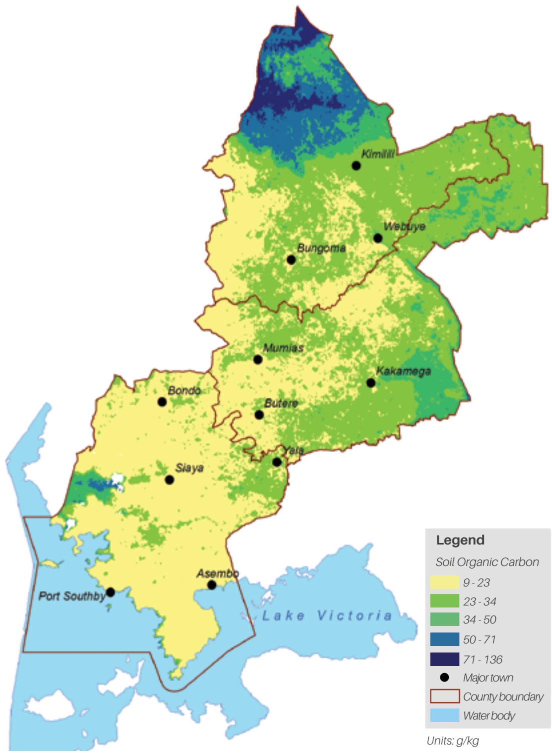
(continues)

(continued)

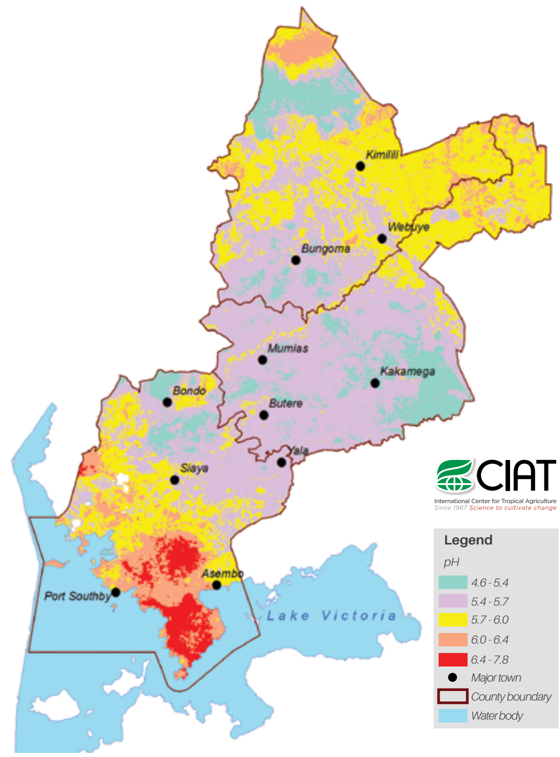
	Impact dimension	SC1A: Lime + NPK	SC1B: Composting	SC1C: Lime + composting	SC2: Conservation Agriculture	SC3A: Vetiver Strip	SC3B: Napier Strip
Medium commercial horticulture	Residue management	None	2/3 removal of all residue for composting, 1/3 remains on the field	2/3 removal of all residue for composting, 1/3 remains on the field	1/3 removal of all residue, 2/3 remains on the field	None	None
Large commercial	Residue management	None	2/3 removal of all residue for composting, 1/3 remains on the field	NA	1/3 removal of all residue, 2/3 remains on the field	None	None
Small subsistence semi-arid	Soil erosion	No change	No change	No change	No change	Reducing soil conservation factor (P) to from 0.8 to 0.5; this should lead to 30% soil loss reduction (GIZ et al., 2015b)	Reducing soil conservation factor (P) to from 0.8 to 0.5; this should lead to 30% soil loss reduction (GIZ et al., 2015b)
Small mixed subsistence	Soil erosion	No change	No change	No change	No change	Reducing soil conservation factor (P) to from 0.8 to 0.5; this should lead to 30% soil loss reduction ((GIZ et al., 2015b)	Reducing soil conservation factor (P) to from 0.8 to 0.5; this should lead to 30% soil loss reduction (GIZ et al., 2015b)
Medium commercial dairy	Soil erosion	No change	No change	No change	No change	Reducing soil conservation factor (P) to from 0.8 to 0.5; this should lead to 30% soil loss reduction (GIZ et al., 2015b)	Reducing soil conservation factor (P) to from 0.8 to 0.5; this should lead to 30% soil loss reduction (GIZ et al., 2015b)
Medium commercial horticulture	Soil erosion	No change	No change	No change	No change	Reducing soil conservation factor (P) to from 0.8 to 0.5; this should lead to 30% soil loss reduction (GIZ et al., 2015b)	Reducing soil conservation factor (P) to from 0.8 to 0.5; this should lead to 30% soil loss reduction (GIZ et al., 2015b)
Large commercial	Soil erosion	No change	No change	NA	No change	Reducing soil conservation factor (P) to from 0.8 to 0.5; this should lead to 30% soil loss reduction (GIZ et al., 2015b)	Reducing soil conservation factor (P) to from 0.8 to 0.5; this should lead to 30% soil loss reduction (GIZ et al., 2015b)

Appendix III: Reference maps of study sites

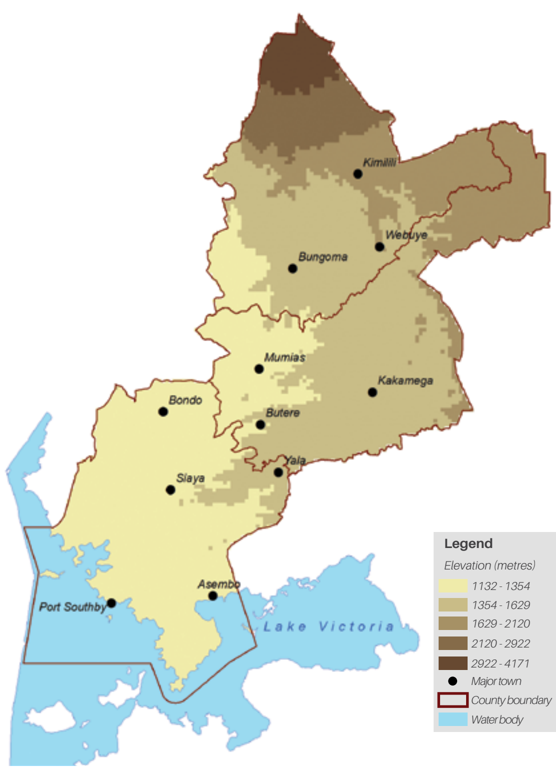
Soil organic carbon



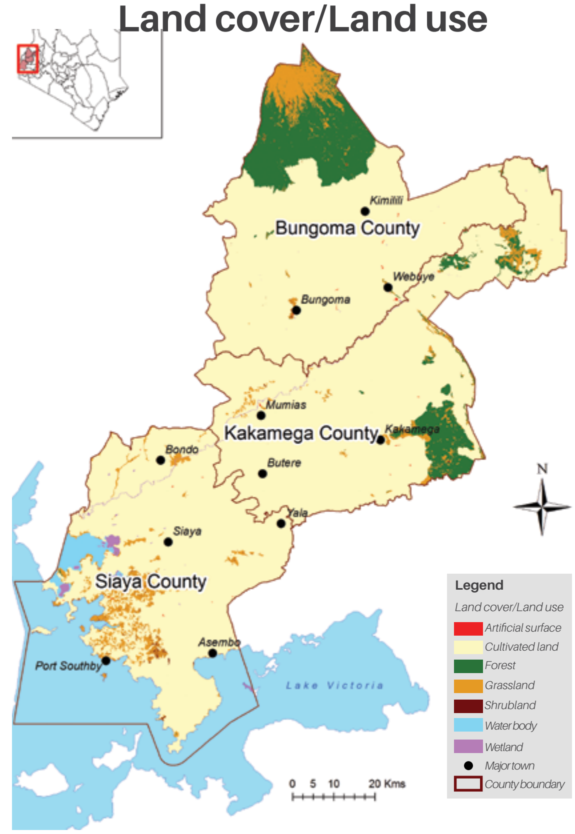
Soil pH



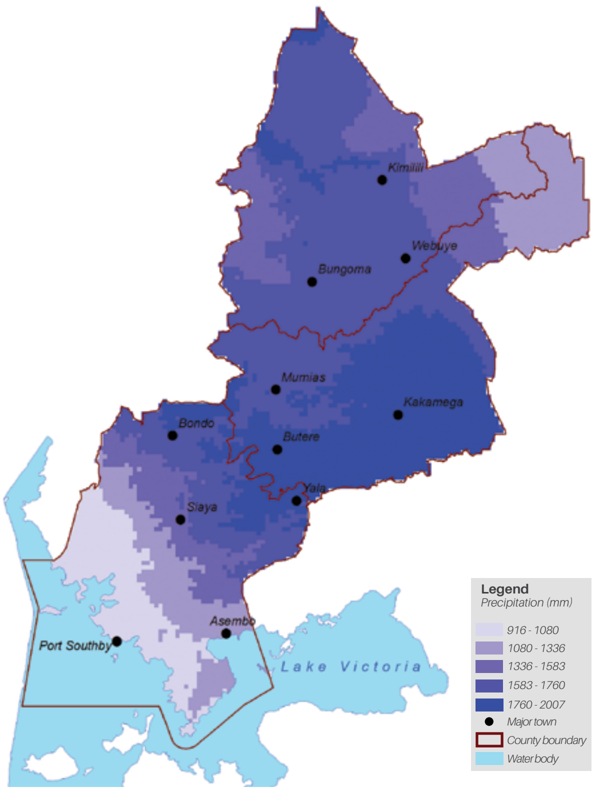
Elevation



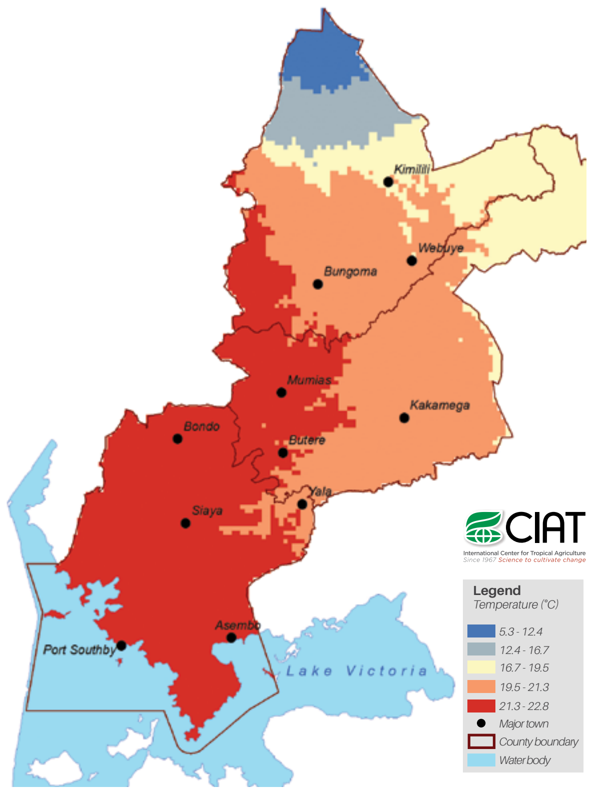
Land cover/Land use



Annual precipitation



Mean temperature



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