Rapid climate smartness assessment of GIZ soil protection and rehabilitation technologies in Benin, Burkina Faso, Ethiopia, Kenya, and India

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Rapid climate smartness assessment of GIZ soil protection and rehabilitation technologies in Benin, Burkina Faso, Ethiopia, Kenya, and India

Rapid Assessment - Final Report

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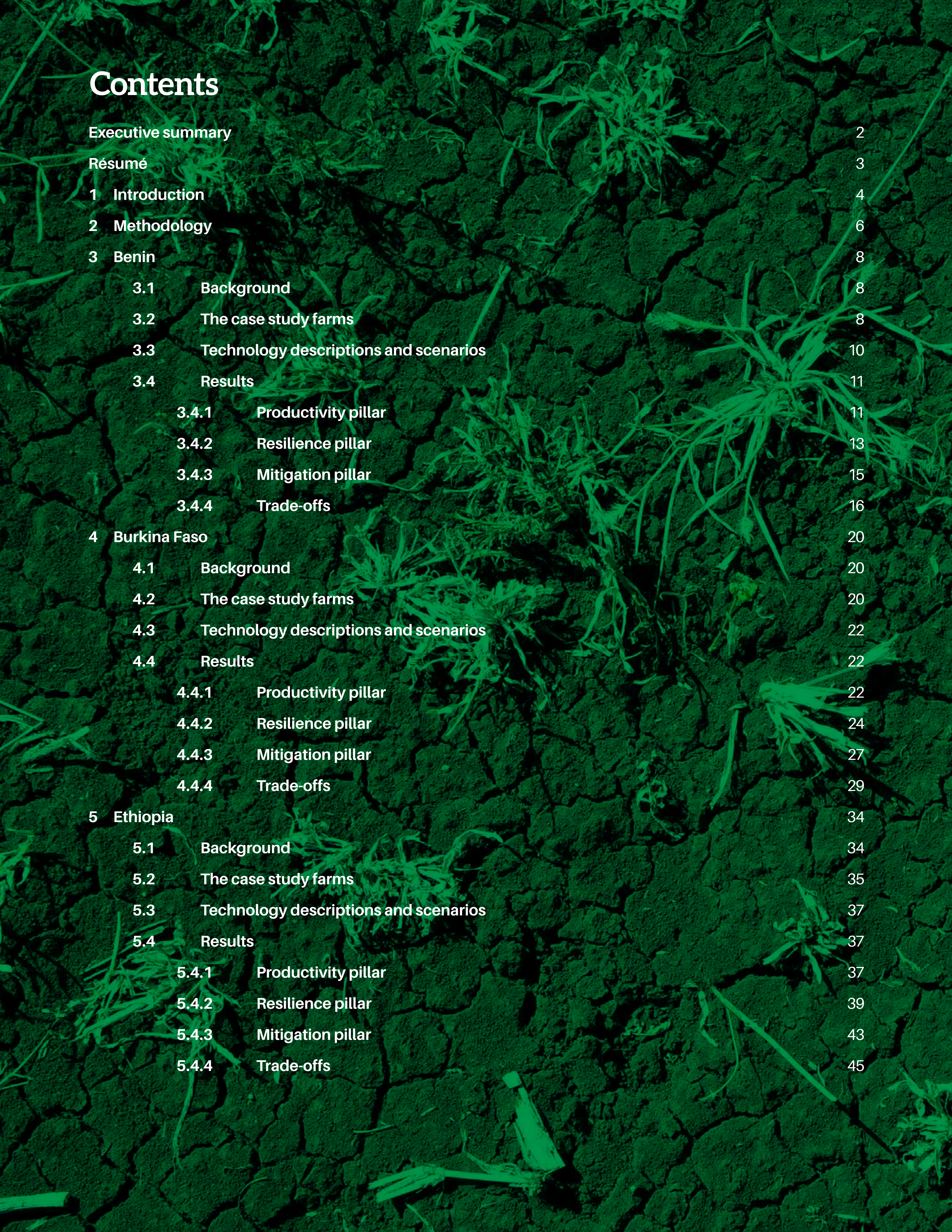

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Executive summary

The results from the rapid assessment activity of the project ‘Climate-smart soil protection and rehabilitation in Benin, Burkina Faso, Ethiopia, India and Kenya’ are presented in this report. The objective of the rapid assessment of climate smartness of GIZ endorsed soil rehabilitation and protection technologies in Benin, Burkina Faso, Ethiopia, Kenya and India is to evaluate these technologies in terms of their potential impact on productivity, nitrogen (N) balances, erosion, and greenhouse gas (GHG) emissions. These are suitable (rapid) indicators representing the three Climate-Smart Agriculture (CSA) pillars – food security, resilience and mitigation. The case study approach allowed for a rapid analysis, but also increased the context-specificity of results which warrants cautions to draw too general conclusions. Farming system diversity across and within the target countries and sites was large both in terms of socio-economic and agro-ecological heterogeneity.

This hugely impacts farms’ productivity and environmental performance. This underlines the importance of careful targeting of technologies to farming systems to ensure sustainable intensification. Livestock is an important asset of the majority of farms, distinguished by major farm types in the five countries. It often defines the livelihoods of these farms, adds to food production and is key to nutrient cycling, but is also a major source of GHG emissions. Livestock keeping, paddy rice and residue burning are largest contributors to GHG emissions, depending on the country and farm type. The level to which the supported technologies/interventions address the core idea of soil protection and rehabilitation varies significantly between the GIZ soil programs in the five countries. Intercropping is part of the portfolio of identified technologies in all five countries. It certainly has a potential to contribute to improving soil fertility, but stand-alone, without additional measures, it is unlikely to do so.

True triple-win climate-smart solutions, i.e. interventions that increase productivity, improve resilience and reduce GHG emissions, are rare. Instead, implementing soil conservation and rehabilitation measures often has a positive impact on just one or two of the CSA pillars but a negative effect on the remainder(s); i.e. trade-offs have to be made. None of the proposed technologies addresses climate change mitigation (reducing GHG emissions from agriculture) directly. Whether this should indeed be the focus of the GIZ Soil Program, especially in sub-Saharan Africa, should be further debated.

Résumé

Les résultats de l'activité d'évaluation rapide du projet « La climato intelligence des mesures de protection et de la réhabilitation des sols au Bénin, au Burkina Faso, en Ethiopie, en Inde et au Kenya» sont présentés dans ce rapport. L'objectif de l'évaluation des mesures de protection et de réhabilitation des sols dans le cadre du ProSOL dans ces cinq pays est d'évaluer ces technologies en termes de leurs impacts potentiels sur la productivité, le bilan d'azote (N), l'érosion, et les émissions de gaz à effet de serre (GES). Ce sont des indicateurs appropriés (rapides) représentant les trois piliers de l'agriculture climato-intelligente (ACI) - la sécurité alimentaire, la résilience et la mitigation. L'approche de l'étude de cas a permis une analyse rapide, mais a également mis l'emphase sur la spécificité du contexte des résultats ce qui justifie de mettre en garde de tirer des conclusions trop générales.

La diversité des systèmes agricoles au travers des pays cibles et des zones d'interventions du projet, était grande en termes d'hétérogénéité socio-économique et agro-écologique. Cela impacte énormément la productivité des exploitations agricoles et la performance environnementale. Cela souligne l'importance d'un ciblage minutieux des technologies selon les systèmes agricoles afin d'assurer une intensification durable. L'élevage est un atout important pour la majorité des exploitations, qui se manifeste par des types distinct d'exploitations agricoles dans les cinq pays. Il définit souvent les moyens de subsistance de ces exploitations, ajoute à la production alimentaire et est la clé du recyclage des nutriments, mais est également une source importante d'émissions de GES. L'élevage, la culture du riz et le brûlage des résidus sont les plus grands contributeurs aux émissions de GES, selon le pays et le type d'exploitation.

Les approches que prennent les technologies / interventions pour la protection et la réhabilitation des sols varient considérablement entre les programmes du sol GIZ dans les cinq pays. La culture en association fait partie de la gamme de technologies identifiées dans les cinq pays. Cette pratique agricole a certainement le potentiel de contribuer à l'amélioration de la fertilité du sol, mais seulement si celle-ci est accompagnée de mesures supplémentaires qui viennent appuyer son impact positif. Des solutions climato-intelligentes triple-gagnantes, à savoir les interventions qui augmentent la productivité, améliorent la résilience et mitigent les émissions de GES, sont rares. A la place, la mise en œuvre de mesures de protection et de réhabilitation des sols a souvent un impact positif sur seulement un ou deux des piliers de l'agriculture climato-intelligente, mais un effet négatif sur le reste (s); à savoir des compromis doivent être faits. Aucunes technologies proposées n'abordent directement l'atténuation du changement climatique (réduction des émissions de GES de l'agriculture). Il reste à débattre si cela doit faire l'objet d'une attention particulière dans la mise au point du programme du sol GIZ, en particulier en Afrique subsaharienne.

1. Introduction

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 while also limiting GHG emissions. CSA is complementary 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 adaptation 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 goals such as climate change mitigation (Klapwijk et al., 2014). Although CSA aims at improving food security, adaptation/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 adaptation are main priorities. Low emission growth paths might have more associated costs than the conventional high emission pathways, thus monitoring emissions can open opportunities for climate finance funds (Lipper 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 and to assess the climate smartness of selected GIZ-supported soil protection and rehabilitation measures in the five countries. Soil rehabilitation is often evaluated for productivity and food security benefits, with little or no attention to 'climate smartness'. Likewise, climate-smart agriculture (CSA) initiatives have not given due attention to soil protection and rehabilitation, despite their apparently strong potential to increase climate smartness.
There is a need to align soil protection and climate-smart agriculture, in implementations of agricultural innovation practices that address soil degradation issues and climate change mitigation and adaptation. 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, as well as 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 focuses on the results from the first activity of the project, the rapid assessment of climate smartness of GIZ endorsed soil rehabilitation and protection technologies. The diversity across the five countries in terms of agro-ecology, farming systems and country specific agricultural policies have led to the implementation of diverse soil protection and rehabilitation interventions in the GIZ project sites. During a participatory workshop technologies were discussed and further taken into consideration for this rapid assessment. Many technologies for improving soil fertility are promoted in all countries such as intercropping with legumes, organic and inorganic fertilizers (e.g. NPK, composting, manure, green manure). Physical structures for reducing erosion are also widely promoted, in particular stone bunds in Burkina Faso and vegetative strips in Western Kenya. Management practices such as rotation, small mechanization, using improved seeds are another set of technologies promoted just to name a few.

The objective of the rapid assessment is to evaluate the technologies in terms of their potential impact on productivity, nitrogen (N) balances, erosion, and greenhouse gas (GHG) emissions. These indicators were deemed suitable for rapid representation of the three CSA pillars – food security, resilience and mitigation. The methodology of the rapid assessment is presented in section 2. The rapid assessment for each country follows in alphabetical order, i.e. Benin (section 3), Burkina Faso (section 4), Ethiopia, (section 5) Kenya (section 6) and India (section 7). For each country a brief description of the faming systems or the sampled farms is presented in subsection 1, a description of the technologies modelled in subsection 2, the results per CSA pillar in subsection 3 and finally conclusions and recommendations in subsection 4. The last section, section 8, provides highlights from the whole study. Information concerning details on the surveyed farms and the assumptions made for the implementation of each scenario can be found in the accompanying Appendix document.

2. Methodology

Following participatory workshops that delineated farming system types in each country, potential representative farms were jointly identified by CIAT, GIZ and local partners 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 potential 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 simply represents on-farm food/energy production, not the actual consumption, which should be taking into account additional food purchases and subtract the produce that is sold. Energy contents were based on a standard product list developed by the US Department of Agriculture USDA (source: http://bit.ly/1g33Puq). Total amount of energy produced on the farm was then divided by 2500 kcal 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. Note that such productivity excludes food that is purchased as well as the possibility that produced food is sold and not consumed on-farm. As such, this indicator is not referring to a household's own food security but rather to its contribution to overall food security.

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: http://www.iwr.msu.edu/rusle/factors.htm

GHG emissions: The 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 the graph below. 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).

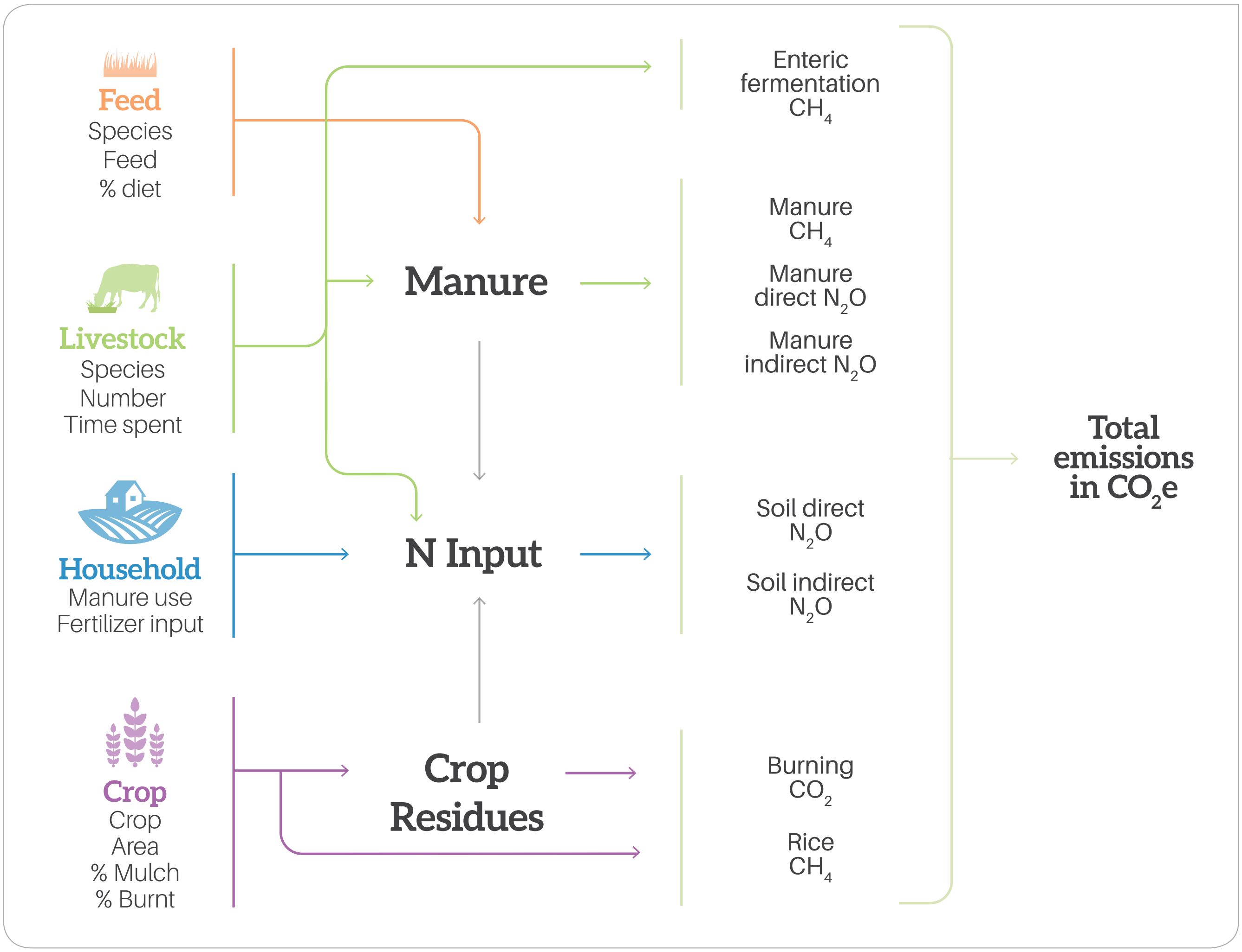

Figure 1: Scheme of the GHG emission calculations.

3. Benin

3.1. Background

The agricultural sector in Benin is the main source of the national economic wealth, contributing 30% of the total Gross Domestic Product (GDP). A major part of active population, i.e. more than 60% of men and 35.9% of women, are engaged in agriculture, the dominant sector of the country. Although the sector generates over 75% of Benin's total exports, its productivity remains too low to cover the food needs of a population that continues to grow (République du Benin).

In Benin, the project "ProSOL" aims to rehabilitate or protect 20,000 ha and has reached during its first year more than 15,000 farmers in the 17 communes of its intervention zone. The approach sets out at the individual farm and offers a variety of measures and technologies to foster agricultural practices favourable for soil protection and biomass production and use on the field for soil protection, use of legume plants, physical measures to prevent soil erosion and to harvest water, use of agroforestry and better integration of animal husbandry and plant production. It furthermore supports policy development with regard to soil rehabilitation, soil information and extension systems in close collaboration with the National Committee of the UN Convention to Combat Desertification. It promotes the evaluation and dissemination of research work and experiences with soil fertility management and promotes networking among stakeholders. Furthermore the project supports local governments to integrate SSM into their community development plans.

3.2. The case study farms

Five farm types were identified during the workshop in Bohicon. Workshop participants included representatives from GIZ, the National Institute for Research in agriculture INRAB, the Research Center for Culture and Development CRCD, NGOs ALDIPE and ODAS, and CIAT (Kalčić and Birnholz, 2016). Workshop participants identified communities and villages for each farm type across the counties of Zou and Collines. In regards to the distribution of different farming systems in the two counties, participants agreed that the percentage of households that fall within each type is the same in each of the 2 counties. With the help of Firmin Amadji (CRCD), Fulgence Dotonhoue (ProSOL/GIZ Bohicon) and Omram Agossadou (ALDIPE) one case study farm was selected for each of the farm types. The farms chosen were typical farms that could be used as a representative of the farmers within each farm type.

Table 1: Percent distribution of households of each farm type across Zou and Collines counties and selected villages for representative sampling

Type	Small-scale farming systems	Lowland farming systems	Integrated farming systems	Medium-scale farming systems	Large-scale farming systems
Share	60%	10%	5%	20%	5%
Villages in Collines	Aglamidjodji (Savalou); Mamatchoke (Bante)	Govi	Kpakpassa	Agbodranfo (Savalou); Agova (Bante)	Medetekpo (Savalou)
Villages in Zou	Edjegbemingon (Bohicon)	Zoungodo (Zogbodomey)	Hla (Za-Kpota)	Agbanghizoun (Azozoundji; Zou)	Houto (Djidja)

One case study farm was selected for each of the farm types. The farms chosen were typical farms that could be used as a representative of the farmers within each farm type. These farms were visited and detailed information was collected for the use as input data to model GHG emissions, nitrogen balance, erosion and farm production.

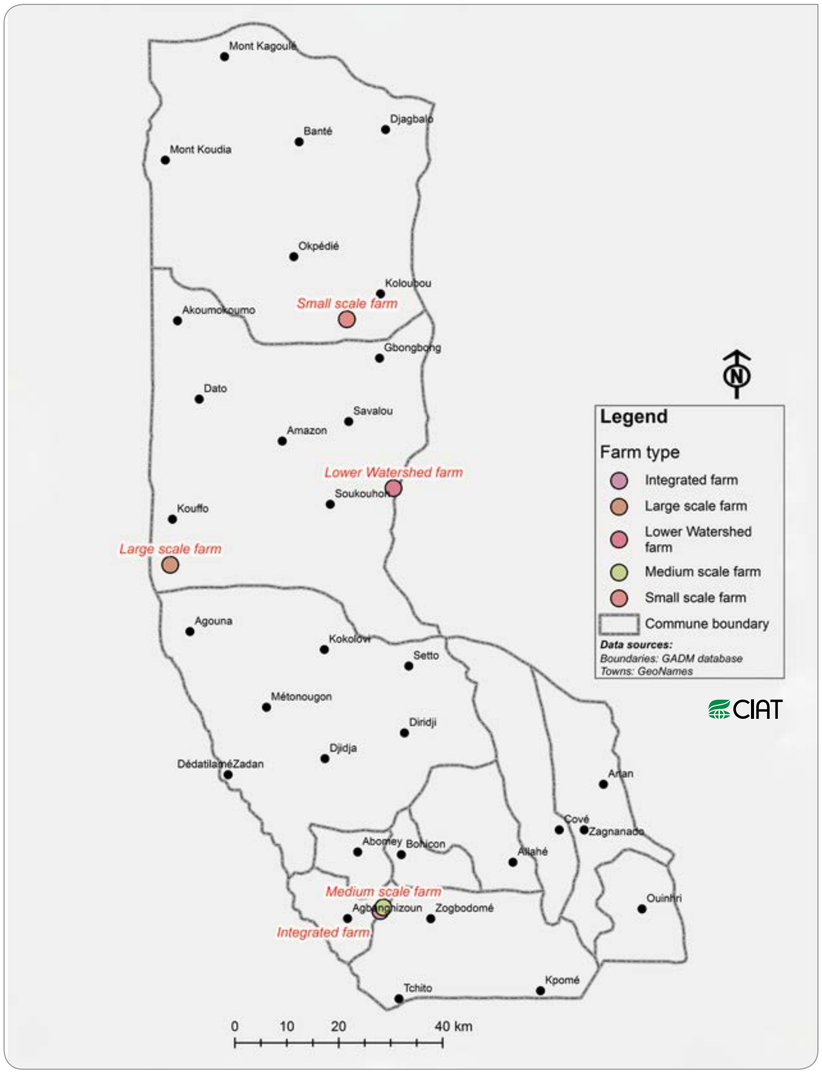

Figure 2: Location of case study farms.

1. Small-scale farm: This farm has a land area of 4 ha which is all cultivated. The crops they grow include maize, rice, cashew nuts, palm oil and cassava. The maize crop is fertilized. They own a small flock of 7 sheep and 5 goats and about 120 chickens but the manure is not used for fertilization.

2. Lowland farm: The farm consist of 12.5 ha, again all cultivated. They grow maize, cowpea, groundnut, soybean, cashew, teak, cassava, yam, tomato, chili peppers and okra. The lowland farm is only applying 17 kg N /ha on the vegetable crops (tomato, okra and chili) nor do they apply any manure. The maize yield is particularly low on this farm. This farm keeps 8 goats and 10 chickens but does not collect any manure from them.

3. Integrated farm: This farm is just a little smaller than the lowland farm, at 11.2 ha. The crop diversity is lower with maize, cowpea, groundnut, orange and teak; all grown without fertilizer application. This farm has a big livestock herd consisting of more than 24 cattle, 14 sheep, 7 goats, 85 pigs and almost 350 chickens. All the manure collected is used for fertilization.

4. Medium-scale farm: Of its land size of 6.8 ha, 4.8 ha are managed and only 2.3 under cultivation the rest is in fallow. The farm grows maize, cowpea, groundnut, soybean and okra. No input use was recorded. Livestock numbers are low, with 1 goat and about 50 chickens. The manure that is collected is used for fertilization.

5. Large-scale farm: The large farm has 31.5 ha to its disposition, of which 20.5 ha are cultivated. The farm is quite diversified with maize, cotton, cowpea, groundnut, cashew, orange, teak, cassava, tomato, chili peppers and okra. None of the manure of the 5 cattle, 6 goats and 50 chickens is collected; the cattle is actually herded off-farm all year round. In this farm some mineral fertilizer is, however, applied to the maize (30–44 kg N/ha) and cotton (44 kg N/ha) crops.

3.3. Technology descriptions and scenarios

The following scenarios represent selected soil rehabilitation interventions that are currently promoted by GIZ in Benin, described in the GIZ booklet “Mesures de Gestion Durable des Terres (GDT) et d’Adaptation aux Changements Climatiques (ACC) – Compendium des Fiches Techniques du Fomatteur” (2016). All assumptions are described according to impact dimensions and summarized in the Appendix III Scenario Assumptions.

The interventions fall in three categories:

1. Soil fertility interventions: Intercropping with pigeon pea, Mucuna relay

2. Managing climate change risk interventions: Improved varieties (drought-tolerant crops)

3. Agro-forestry interventions: Orchard rehabilitation

The first scenario incorporates intercropping with pigeon pea. This crop is planted following maize in the first season and remains during the second season after which it is harvested. Maize yield is assumed to decrease from the competition with pigeon pea. The pigeon pea rows act as barriers reducing soil erosion. Furthermore, pigeon pea residues are not burned (as is commonly practiced) but incorporated to the fields in preparation for the following season.

The second scenario is Mucuna planted in relay in the maize plots. It provides additional N to the soil which benefits maize (10% yield increase) in the following year as crop residues remain on the fields. Improved soil cover is assumed to reduce soil erosion.

The third scenario introduces improved varieties of drought tolerant maize. The yields are assumed to increase by 10% assuming an average over time where there is no complete crop failure in the times of drought.

The final scenario is orchard rehabilitation. This intervention means to improve fruit and nut tree productivity by improving tree spacing. This involves cutting down unproductive trees to remain with the most vigorous. Annual crops such as maize may be planted in between clearings in the first years of rehabilitation. This intervention applies to cashew plantations and orange orchards. It is assumed that 10% of the nut and fruit fields we cleared and maize was cultivated there. A 5% increase in tree productivity is assumed. This scenario was not implemented on the medium scale farm as there was no orchard.

3.4. Results

3.4.1. Productivity pillar

3.4.1.1. Baseline productivity

Farm productivity was calculated by summing up all the calories from crop and livestock products (except meat)[1] produced on farm and dividing this by the calorie requirements of an average adult (AME = Adult Male Equivalent) which are 2500 kcal/day. Productivity is thus expressed in number of AME days (Figure 3). Note that such productivity excludes food that is purchased as well as the possibility that produced food is sold and not consumed on-farm. Production on the farms is diverse including cereals, legumes, tubers, nuts/fruits and vegetables, timber (no calories) and some livestock, although livestock keeping is mostly extensive. The lowland farm is most diversified but the least productive per ha (409 AME days/ha) compared to the most productive, the medium scale farm (2581 AME days/ha). The large scale farm is the second last in terms of productivity per area. This is due to the large proportion of area under fruits/nuts and teak. These latter are low in calories but high in cash value. The integrated farm has the second highest productivity per ha (1934 AME days/ha) with oranges (6 ha), groundnuts and milk contributing to the bulk of the calories.

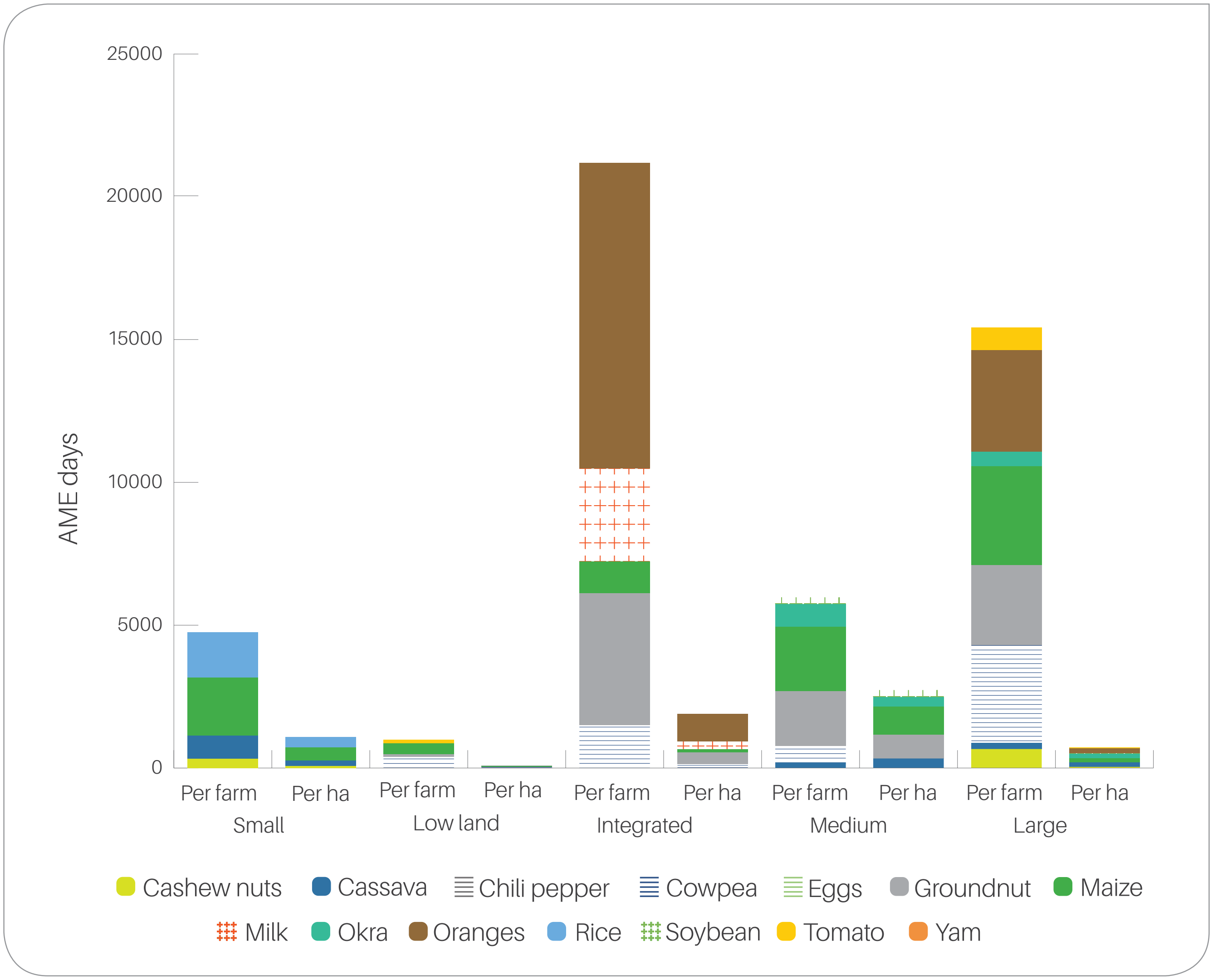

Figure 3: Baseline productivity and contribution from the different products across farm types. *Productivity is expressed as number of days that 1 adult male equivalent (AME) can be fed from livestock and crop products produced on the farm.*

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[1] To be able to calculate production of meat from livestock, data on herd dynamics (offtake of animals per year) and impact of animal feed on livestock productivity are required, which were not available for this report.

3.4.1.2. Changes in productivity

The productivity impacts of the technologies are mostly positive, although quite small (Figure 4).

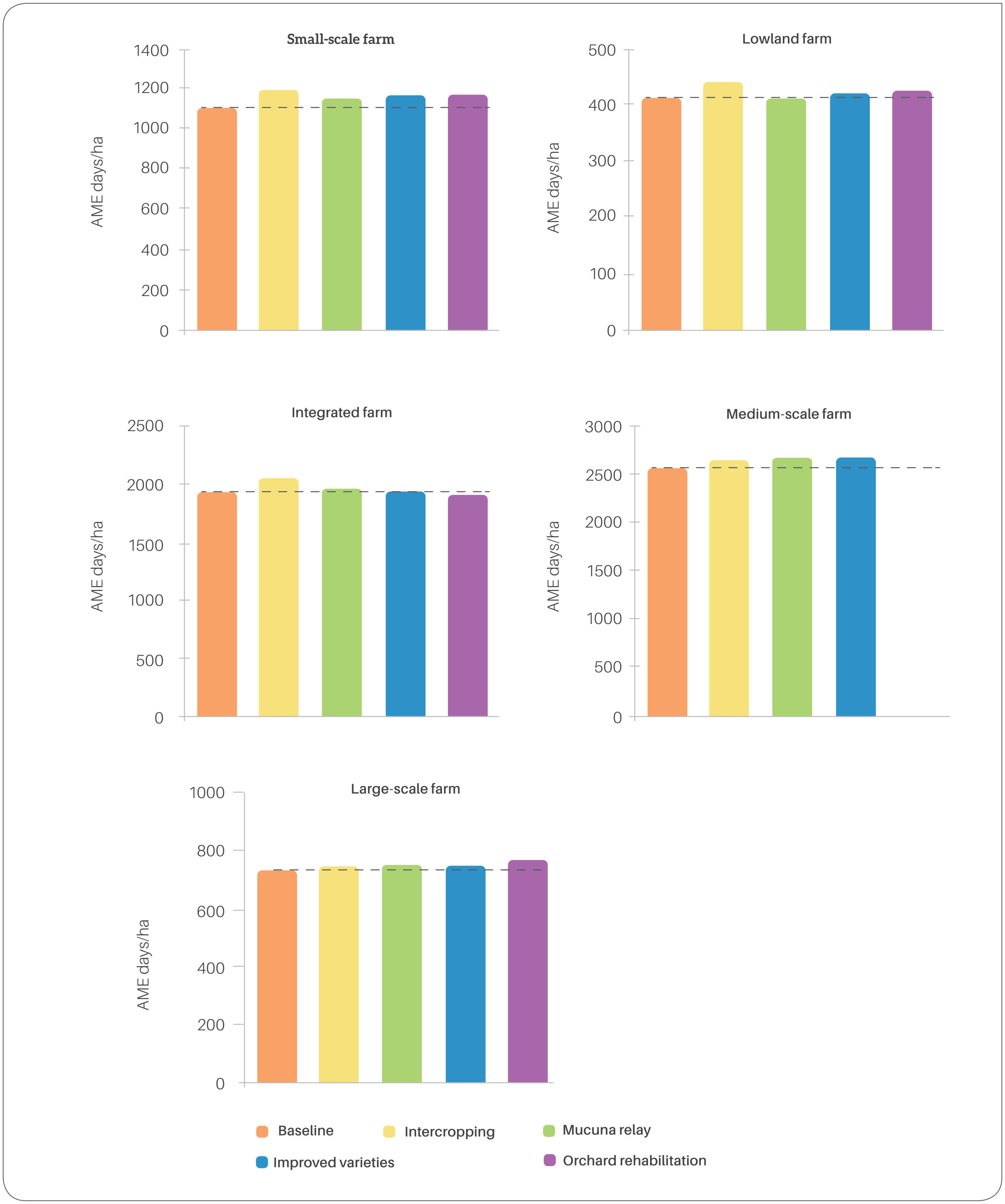

Figure 4: Baseline and scenario productivity per farm type. *Results are expressed in days of Adult Male Equivalent calories (AME = 2500 kcal/day) on a per hectare basis*

Intercropping with pigeon pea is projected to be most beneficial in terms of productivity, especially so on the small-scale, lowland and integrated farms. Also, Mucuna relay has an overall positive impact. The impact of improved varieties and orchard rehabilitation varies across farm types. Due to the limited importance of crop agriculture, no impact is expected on the integrated farm in response to these interventions.

3.4.2 Resilience pillar

3.4.2.1 Baseline N balance

The nitrogen balance is calculated for each of the fields found on the farm. The "per farm" N balance is the sum of N balance of the individual plots.

The N balance ranges from as low as -36 kg N to as high as +481 kg N per ha across the five farms (Figure 4). As the use of inorganic fertilizers is limited, manure[2] is the most important source of soil nutrients. Retention of residues in the fields is limited, as most residues are either grazed by livestock – often not belonging to the farmer – or burned.

Thus, minimum N is returned in this form. Not surprisingly, the highest N balance is found on the integrated farm which provides a lot of N through collected manure. This is the farm with the highest livestock density. The only other farm with a positive N balance is the large farm; also a farm with a relatively high livestock density.

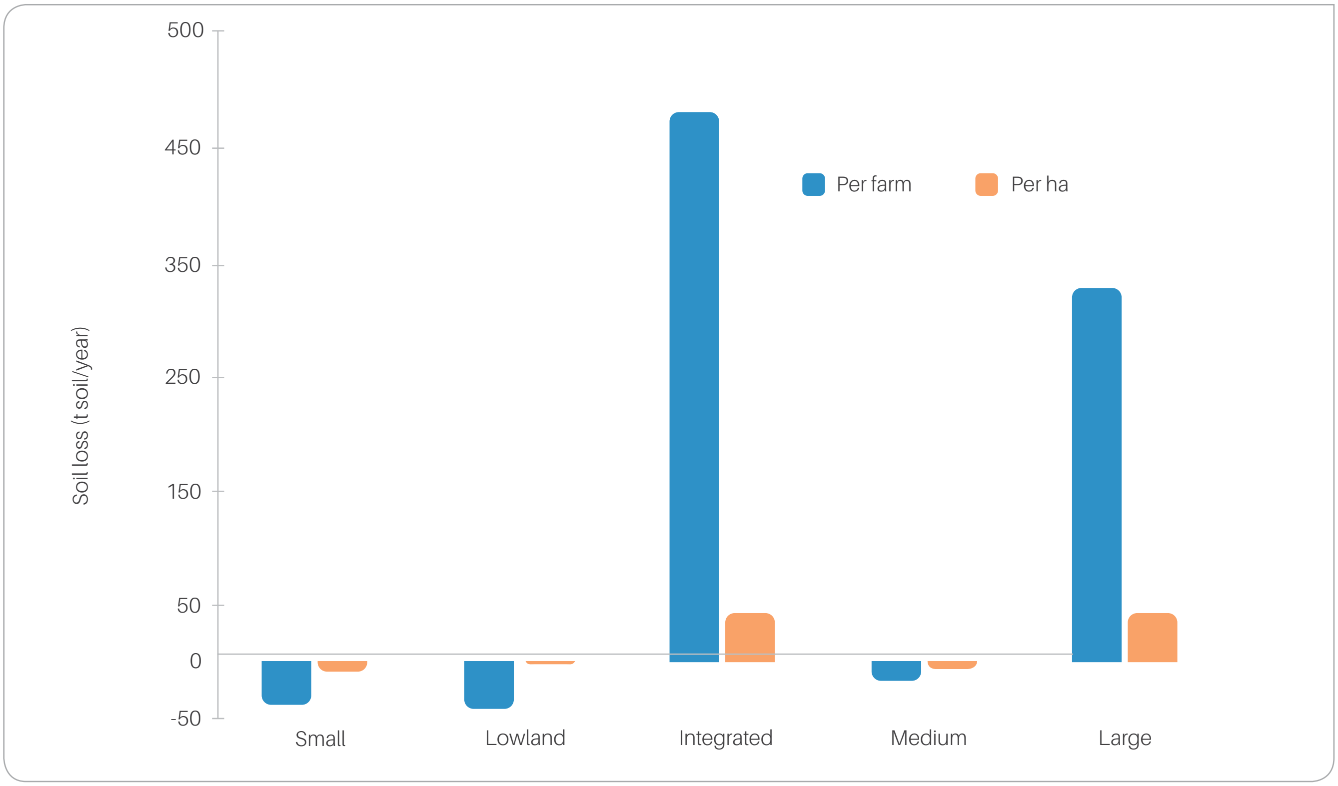

Figure 5: Baseline N balance at field level per farm and hectare across farm types

3.4.2.2 Changes in N balance

While orchard rehabilitation and improved varieties are expected to increase productivity, more N is expected to be removed from the field through product and residue removal. The changes in N balance are thus in the opposite direction of the productivity changes. In the case of intercropping with pigeon pea, there is the compensating effect of N fixation which somewhat diminishes the negative effect of N mining through increased crop and residue removal. On the farms where there is livestock and consistent use of manure, the effect is further diminished.

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[2] Dung deposited by transhumant livestock passing through the farm was not considered.

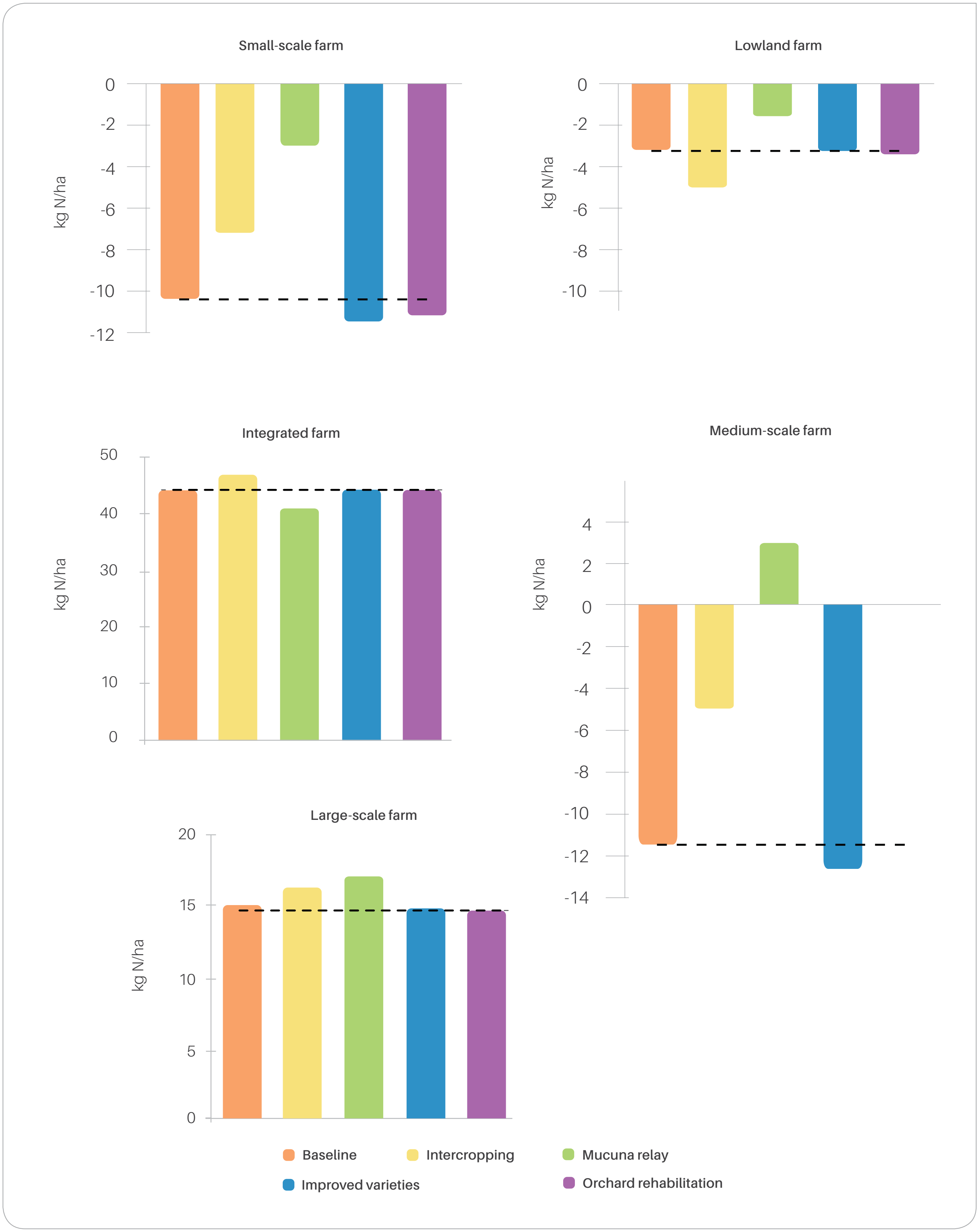


Figure 6: Baseline and scenario soil N balance per farm type (kg N/ha)

The N balance increases in four out of the five farm types in response to the adoption of Mucuna. This is due to the additional N inputs from fixation. In addition, Mucuna residues are entirely left in the field as green manure. The exception is the integrated farm where Mucuna is grazed, and therewith more N removed from the field than added through biological N fixation.

3.4.3 Mitigation pillar

3.4.3.1. Baseline greenhouse gas emissions

GHG emissions comprise emissions through enteric fermentation (methane), manure management (methane and nitrous oxide), off-farm livestock emissions (when cattle graze outside the farm but spend time on the farm all year round), emissions from rice production (methane), and emissions from burning residues (carbon dioxide, methane and nitrous oxide). For easy comparison, these emissions are converted into equivalents of carbon dioxide (CO_2e).

Generally, the GHG emission intensity is low across all farms (less than 3 t CO_2e/ha; Figure 7). The integrated farm has the highest GHG emission intensity due to the large contribution of livestock emissions, while the lowland farm has the lowest GHG emission intensity. On all farms but the integrated farm, residue burning is the main sources of GHG emissions, contributing more than half of on-farm emission in all four cases. Soil emissions are the second largest source of GHG on those farms.

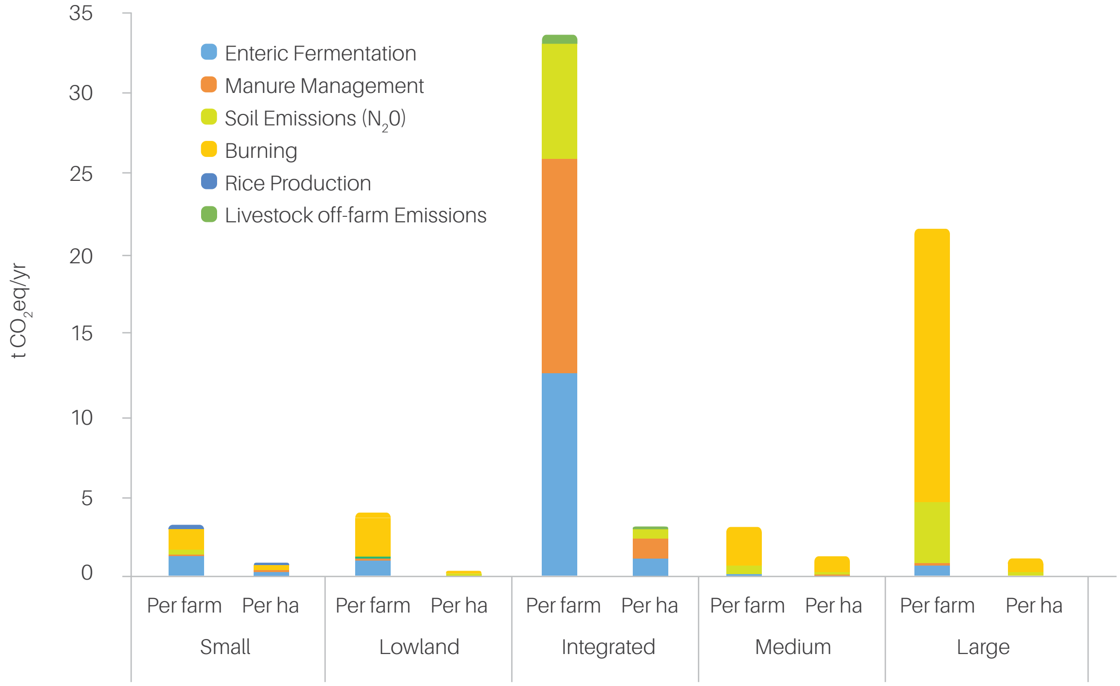


Figure 7: Baseline GHG emissions across farm types per hectare (left) and farm (right). *Emission sources include enteric fermentation, manure management, burning of residues, rice production and soil emissions*

3.4.3.2. Changes in greenhouse gas emissions

Intercropping pigeon pea with maize is the only intervention that specifically addresses one of the largest sources of GHG emissions, those from burning residues. In the scenario, the practice of intercropping with pigeon pea is systematically done with incorporating pigeon pea and maize residues into the ground and not burning them. As a result, GHG emissions from burning will decrease; however, the increase in residues incorporated to the soils will increase nitrous oxide emissions. This scenario does not impact the integrated farm by much because residues are used for feeding livestock and burning was not practiced on that farm. Similarly, on the large farm, only cotton residues are burned, thus this intervention does not decrease emissions from burning. So apart from this scenario, the changes in GHG emission intensities are small across the different farms (Figure 8). The majority of (little) increases in emissions is due to an increase of nitrous oxide emissions at the soil level in response to increased inputs of N (e.g. through Mucuna).

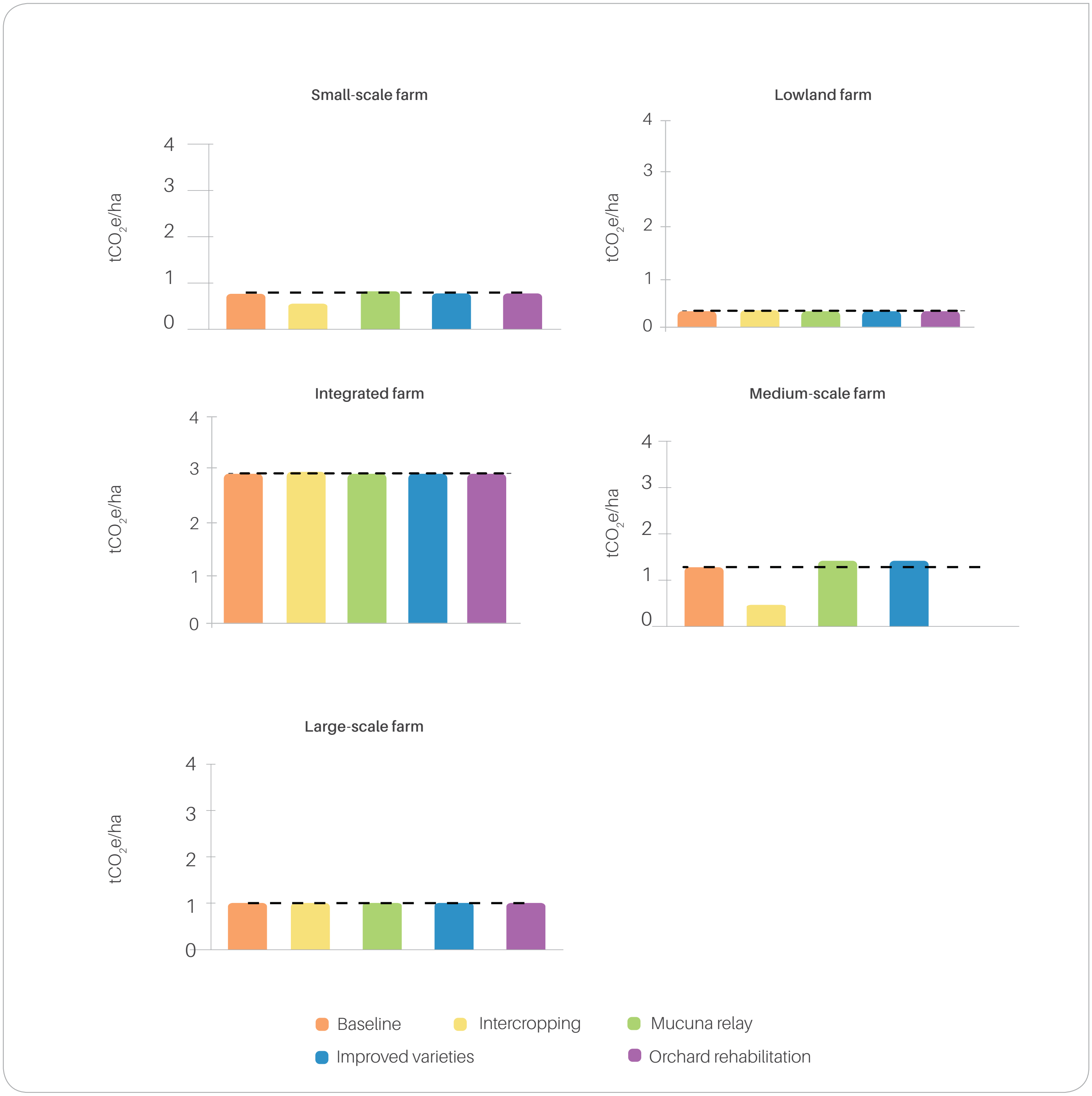


Figure 8: Baseline and scenarios GHG emission intensity per farm type (t CO_2e/ha)

3.4.4. Trade-offs

True triple-win climate-smart solutions, i.e. interventions that increase productivity, improve resilience and reduce GHG emissions, are rare. Instead, implementing soil conservation and rehabilitation measures often has a positive impact on just one or two of the CSA pillars but a negative effect on the remainder(s); i.e. trade-offs have to be made.

Plotting changes in productivity (AME days/ha) against changes in N balance (Figure 9) shows that most interventions increase productivity (except agroforestry on the integrated farm) yet with little to no improvement to the N balance which would mean N mining of the soil over time. Mucuna relay on all farms except the integrated farms and intercropping on the medium and to a certain extent the integrated.

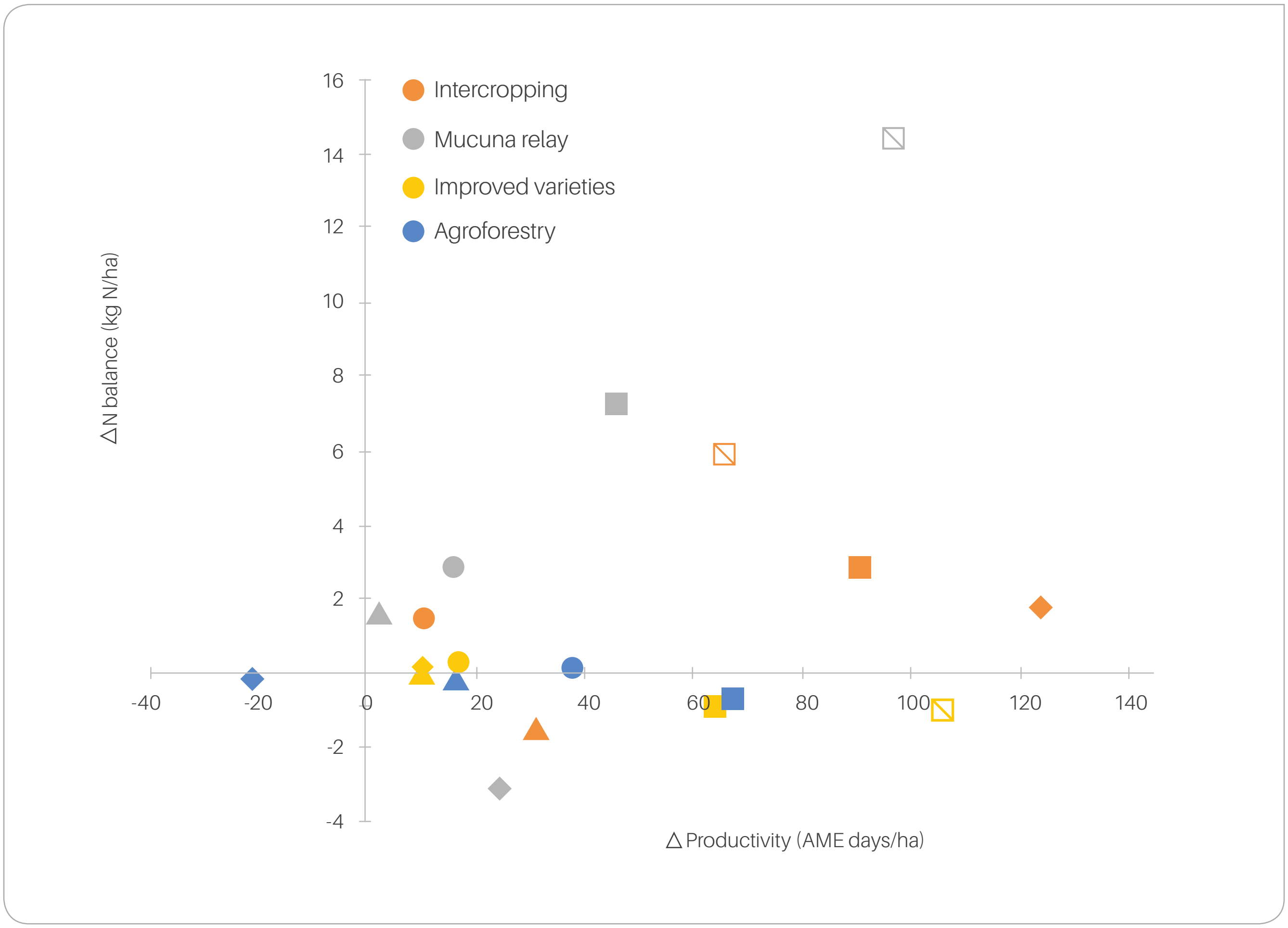


Figure 9: Trade-offs between productivity (AME days/ha) and field N balance (kg N/ha) change from baseline. Colours represent the scenarios, and shape the farm types (□ =Small scale farm, △ =Lowland farm, ◇ =Integrated farm, ⧄ with patterns=Medium scale farm and ○ =Large scale farm)

As for synergies and trade-offs between productivity (AME days/ha) and GHG emissions (Figure 10), it can be seen that most productivity increasing interventions are projected to come with very small GHG emission intensity increases. Intercropping on the small and medium farms are the only win-win interventions, increasing productivity while at the same time reducing GHG emission intensities.

Looking at all three pillars, it is only intercropping on the small and medium farms that is truly climate smart, i.e. having a positive impact on all three pillars.

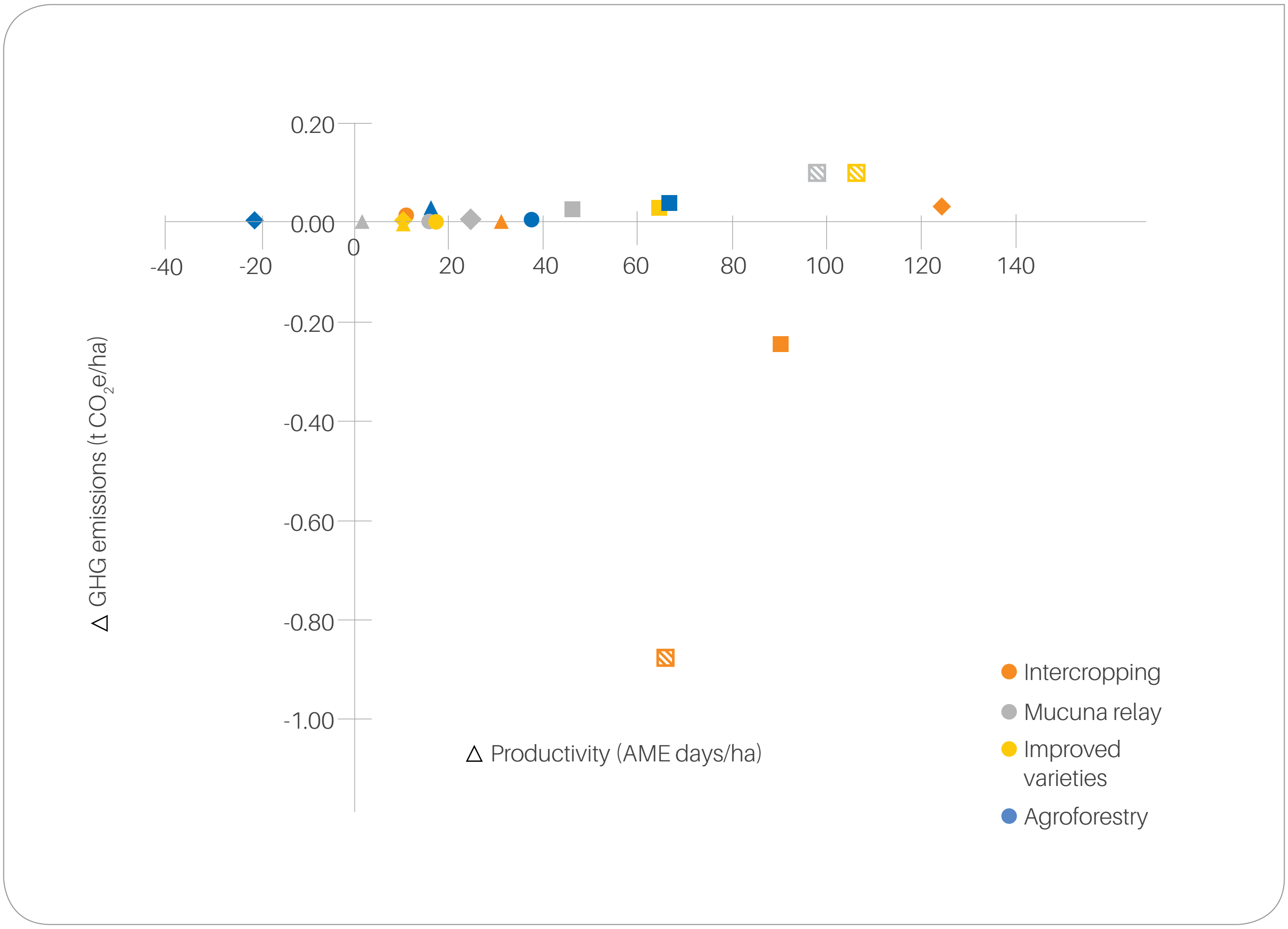


Figure 10: Trade-offs between productivity (AME days/ha) and GHG emissions (t CO_2e/ha) change from baseline. Colours represent the scenarios, and shape the farm types (☐ =Small scale farm, △ =Lowland farm, ◇=Integrated farm,▧with patterns=Medium scale farm and ○=Large scale farm)

Photo: Peter Casier

4. Burkina Faso

4.1 Background

Burkina Faso is a landlocked Sahelian country challenged by low and variable rainfall and low agricultural potential. Historically, agriculture has been dominated by cotton production, the key cash crop. The non-cotton agricultural sector remains characterized by low yields, almost exclusive dependence on rainfall, and generalized underuse of modern production technologies (AGRA, 2014). So far, Burkina Faso's economic development is largely dependent on agriculture, with cotton being the main export product. The agricultural sector is a fundamental part of the economy, contributing about 30% to the total Gross Domestic Product (GDP) and occupying approximately 86% of active population (Burkina Faso, 2013). The sector provides 61.5% of agricultural households' cash revenues. About 67% of these revenues come from crop production, 31% from livestock and 2% from environmental products (Burkina Faso 2011).

4.2 The case study farms

A participatory workshop was organized in Bobo-Dioulasso to describe and classify the farms of the ProSOL intervention sites (Kalčić and Birnholz, 2016). Workshop participants, invited for their expertise of the farming systems and working with farmers in the sites, included representatives from GIZ, GOPA/AFC ProSOL consulting group, Ministry of Agriculture, Water Resources, Sanitation and Food Security (MARHASA), National Institute for Environment and Research in Agriculture (INERA), Multipurpose Agricultural Center (CAP-Matourkou), Textile Fibre Company SOFITEX and CIAT. Four farm types were identified during the workshop: (1) large-scale/modern farms, (2) medium-scale/semi-modern farms, (3) small-scale/traditional/manual farms and (4) small-scale/traditional/manual farms managed by a woman or a young man. Kalčić and Birnholz (2016) provide a detailed description of these four farm types. Reference maps produced for the workshop mapping soil and climate characteristics of the study sites can be found in Appendix III. It should be noted that the debate on percentage of households that fall within each type was not concluded. In regards to distribution of different farming systems in the two provinces, participants agreed that the percentage of households that fall within each type is the same. There was a consensus that large farms are less numerous. However, participants did not reach a common understanding on the percentage of small- and medium-scale farms, but agreed that the medium-sized farms are the most numerous among farm households.

After the workshop – and with the help of GOPA/AFC ProSOL consulting group and extension officers from the MARHASA Provincial Extension Services – one representative case study farm was selected for each of the farm types. The case study farmer for the small scale was selected in the commune of Lena (Houet), the medium-scale farmer was selected in Karankasso-

Vigué (Houet) while a large-scale farm and a small-scale female-headed farm representative were selected in the commune of Koumbia (Tuy; Figure 11). These farms were visited, and detailed information was collected for the use as input data to model GHG emissions, nitrogen balance, erosion and farm production.

1. Large-scale / Modern farm: This farm has 24 ha, of which 20.5 is cultivated. The farmer has good financial assets and therefore access to draught power. He has about 17 local cattle, some sheep, pigs and poultry. Crop production is market-oriented, with maize and cotton as main crops. Other crops grown are rice, cowpea and groundnut. Cotton production dominates, and is rotated with the other crops. Input use is relatively high on this farm.
2. Medium-scale / Semi-modern farm: The total land area of the farm, 7 ha, is cultivated. Crops grown include maize, sorghum, cotton, cowpea and groundnut. Household production in this farm has a dual purpose, i.e. for home consumption and for sale. The input use is slightly lower than on the large-scale farm. Also yields for maize and groundnut are lower than yields at large-scale farms; yields of cotton and cowpea, on the other hand, are higher. The farmer has a quite big herd of cattle and sheep, and also keeps some poultry.
3. Small-scale / Traditional / Manual farm: This type of farm has the smallest cultivation area; the sampled farm cultivates 3.25 ha. The production is mainly for subsistence (maize, sesame, cowpea, and groundnut); surplus produce is sold at the local market. The input use and yields are low. Small-scale farms usually do not keep cattle or sheep, but only around 40 heads of poultry.
4. Small-scale / Traditional / Manual farm managed by a woman or a young man: This small-scale farm is managed by a woman. She cultivates an even smaller farm of only 1.5 ha. She grows groundnuts and soybeans without input use and has therefore very low yields. This farmer does not own any livestock.

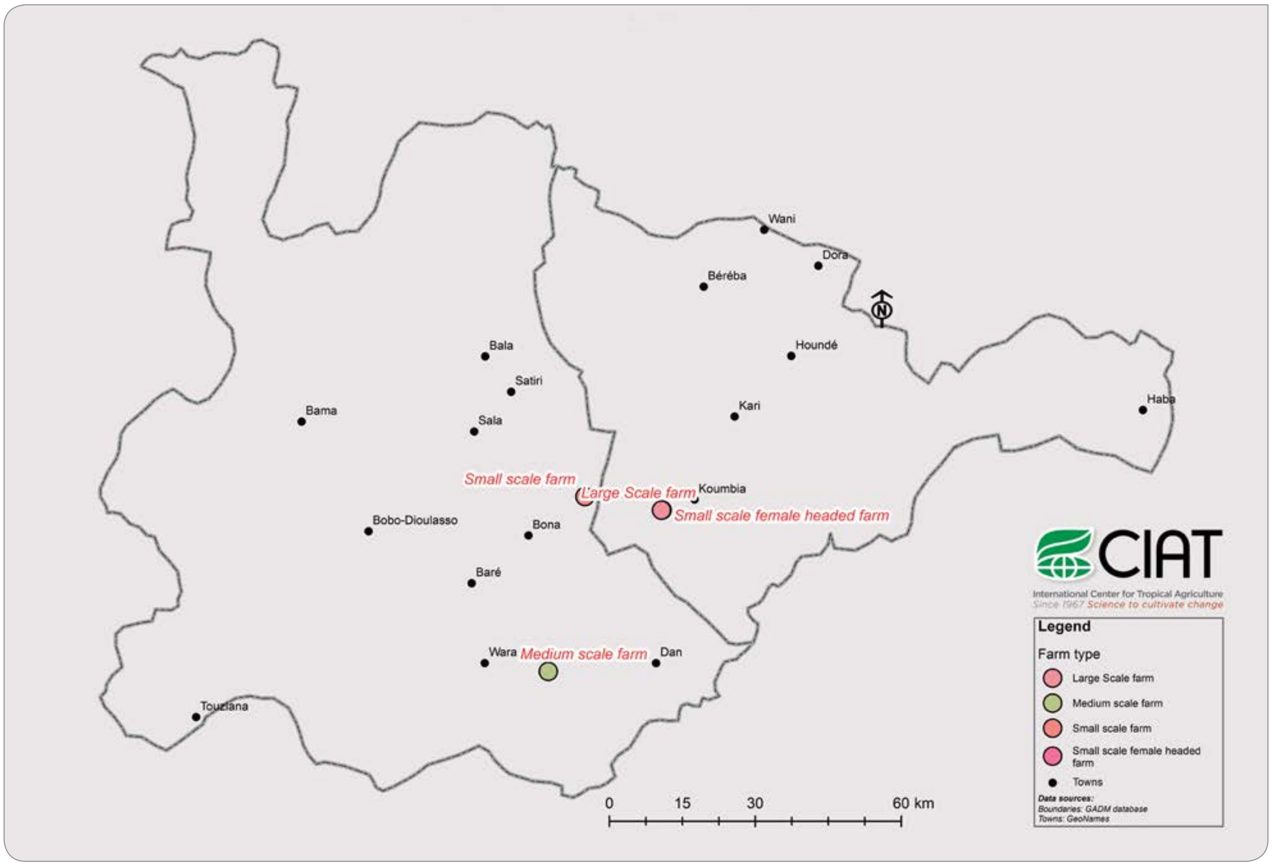


Figure 11: Location of case study farms in the Hauts-Bassins region

4.3. Technology descriptions and scenarios

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

Stone bunds: This intervention is promoted to reduce soil erosion resulting from poor soil structure (insufficient rainwater infiltration) and intensive rains during the cropping season. This technology has been put in place in selected watersheds at landscape level. The bunds require space, namely approximately 10% of the land where they are implemented. This loss in crop area is, however, fully compensated by an increase in yield in response to better water capturing and reduced soil erosion/loss of topsoil fertility.

Composting with manure: Producing compost from crop residues and amending with manure is promoted to improve soil fertility. It is assumed that compost should be applied at a recommended rate of 5 t DM/ha. As compost is usually a limited good, only maize plots are fertilized with compost.

Intercropping of sorghum or maize with cowpea: Intercropping a cereal with cowpea is assumed to increase the overall productivity on the plot although yields of both crops are slightly lower in comparison to a mono-cropped stand, due to competition. Intercropping also reduces soil erosion because of improved soil cover.

Relay cropping with mucuna: On all farms but the female-headed one, mucuna is planted in relay in the maize plots providing N inputs to the soil for cotton that is cropped in the following season. At the same time the mucuna crop provides good soil cover to reduce erosion while also providing an extra source of feed for livestock, improving both the quantity and the quality of feed during the dry season resulting in higher milk yields.

4.4. Results

4.4.1. Productivity pillar

4.4.1.1. Baseline productivity

Productivity is highest on the medium- and the large-scale farms with maize being the largest contributor to calories (Figure 12). Expressed on per ha basis, these farms have similar productivity providing enough kcal for about 2000 AME days. For these farms it is important to note that the production of cotton, which occupies a large area on the farms, does not produce directly consumable calories. Cotton production is, however, an important income earner. Legumes are the largest contributors to productivity on the two small-scale farms. The female-headed small-scale farm has a slightly higher productivity on a per hectare basis. Production of milk from livestock, as well as eggs do not contribute significantly to farm productivity, because livestock is raised extensively. However livestock is known to be an important means of resilience for farming households in sub-Saharan Africa and thus must not be underappreciated towards contributing to household livelihoods. On the larger farms, cattle also contributes draught power, thus allowing farmers to cultivate larger tracts of land.

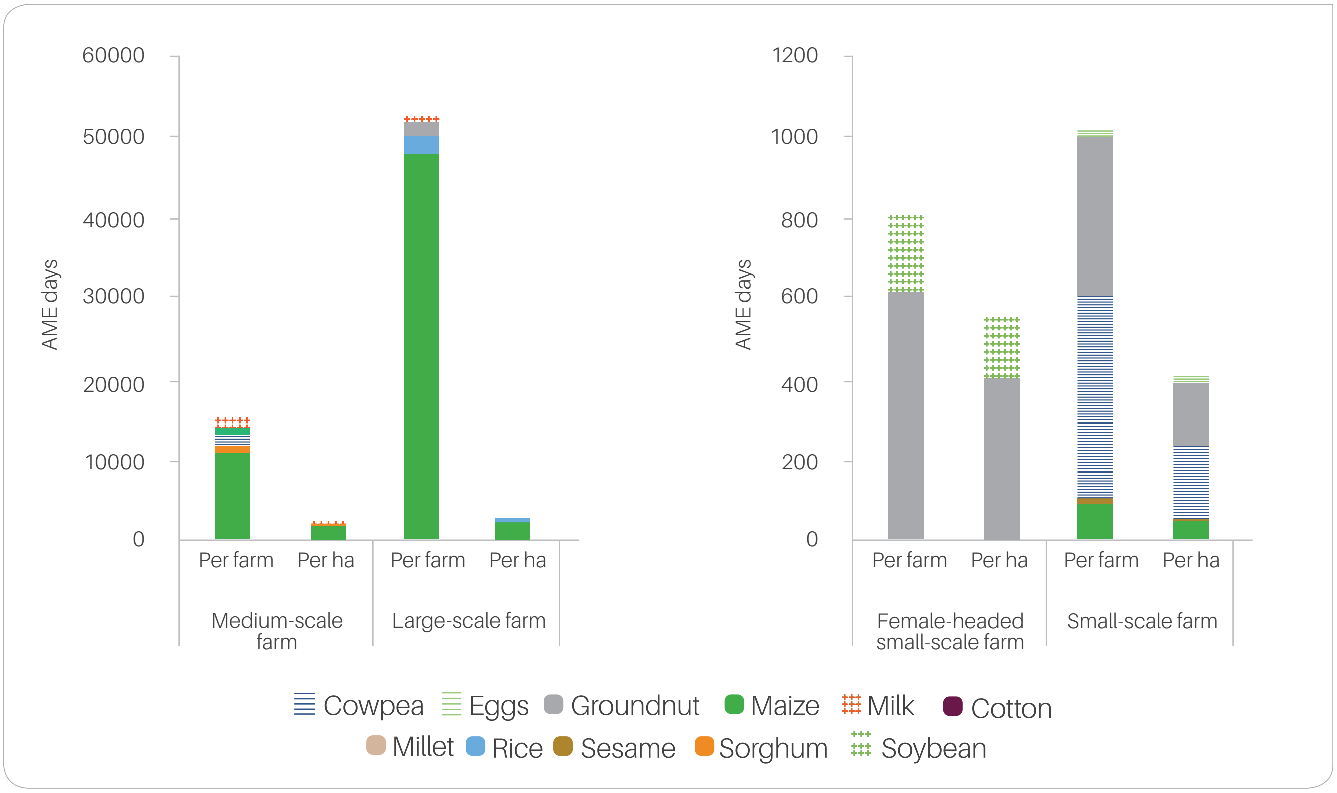


Figure 12: Baseline productivity and contribution from the different products across farm types. *Productivity is expressed equivalents of number of days that 1 adult male (AME) can be fed from livestock and crop products produced on the farm*

4.4.1.2. Changes in productivity

In most cases, introducing the various technologies described earlier is projected to increase productivity across all farm types (Figure 13). This is mainly due to the increases in yields and in animal productivity that result from additional inputs of N, intercropping or from increasing the area of legumes (which have a high calorie content).

Stone bunds remove space available for cultivation but retain soil fertility thus we expect neither an increase nor decrease in productivity from this intervention. Composting with manure at the recommended rate of 5 t DM/ha is expected the have most impact on productivity across all farm types. Maize productivity increases because of the additional N-inputs from the compost. It is important to note that no limitation to compost availability was assumed as far as the area under maize is concerned. However, in reality, the availability of compost from the own farm will be limited and therefore the required additional compost must be purchased/imported. Intercropping cereals (sorghum and maize) with cowpea is expected to increase productivity even though crop yields of the two individual crops are reduced in comparison to mono-cropped conditions. This is the case in the female-headed small scale farm. As the farm was already cropping cowpea, the intercropping scenario meant introducing sorghum to that field. The decrease in cowpea yields are compensated by the introduction of the new crop. On the other three farms, the introduction of cowpea to either the sorghum or maize plots increased productivity only little. Here, the anticipated reduction in the cereal yields (-20%) is barely compensated by the introduction of the legume crop. Yet, intercropping is beneficial, as far as crop and diet diversification is concerned. Planting mucuna as a green manure cover crop in relay with maize is done to improve soil fertility, as well as to provide soil cover. This results in an increase in cotton production, as cotton is planted after maize-mucuna. However, cotton production adds no calories. Yet, on the medium and large scale farms, mucuna crop residues are assumed to be grazed by livestock thus increasing livestock productivity. However, since milk production contributes so little to the total farm calories, the increase in livestock productivity seems negligible at farm level.

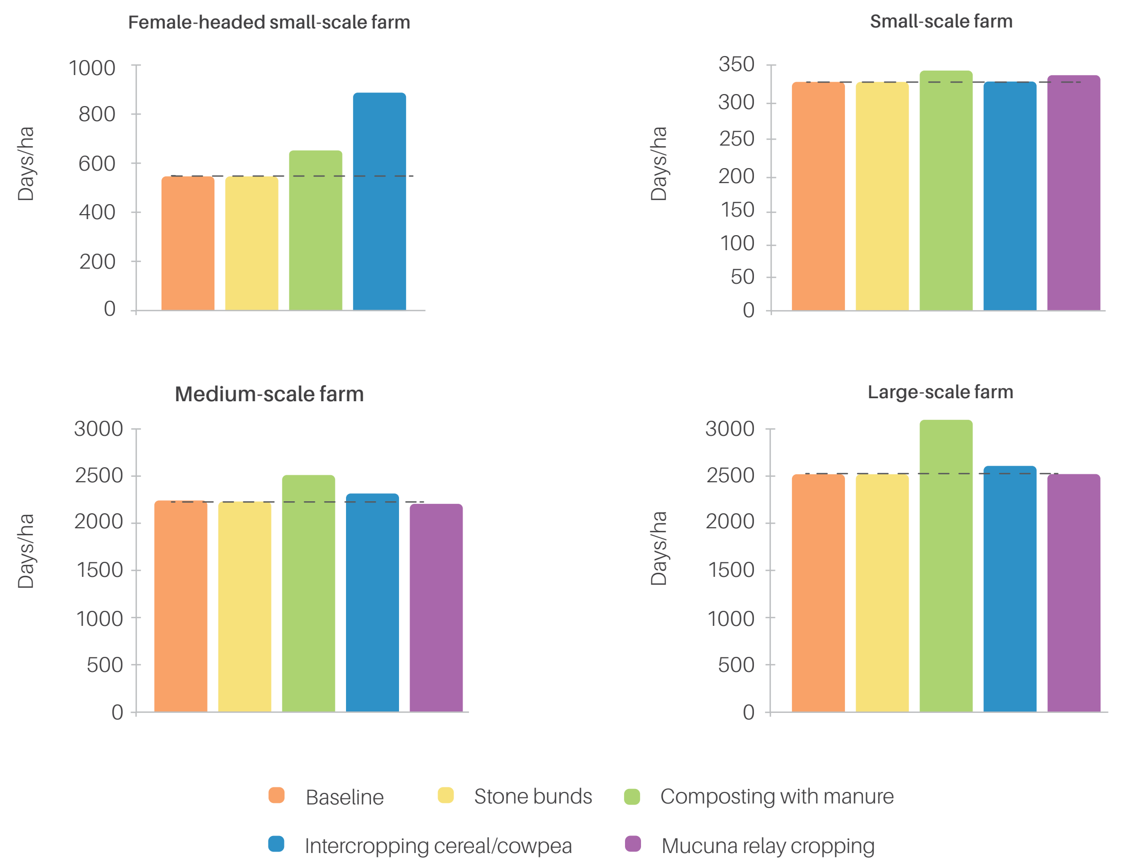


Figure 13: Baseline and scenario productivity per farm type. *Results are expressed in days of Adult Male Equivalent calories (AME = 2500 kcal/day) on a per hectare basis*

4.4.2. Resilience pillar

4.4.2.1. Baseline N Balances

A negative N balance was calculated for all farms except the medium-scale farm (Figure 14). On the medium-scale farm, the positive N balance is due to inputs of N fertilizer to the maize fields. On all other farms N being exported from the fields in harvested crop products represent the biggest loss of N, as N inputs in the form of inorganic fertilizer, manure or compost are absent or too little to compensate for these withdrawals.

Apart from maize and cotton production, all other crops are grown in an extensive manner (low input, low output). Therefore, the overall N-fluxes are comparably small, and the N balance per ha is close to 0 (ranging from -10 kg to +14 kg/ha). Nevertheless, this does not oppose the need for long term measures to increase the amount of N over time to counteract soil N depletion.

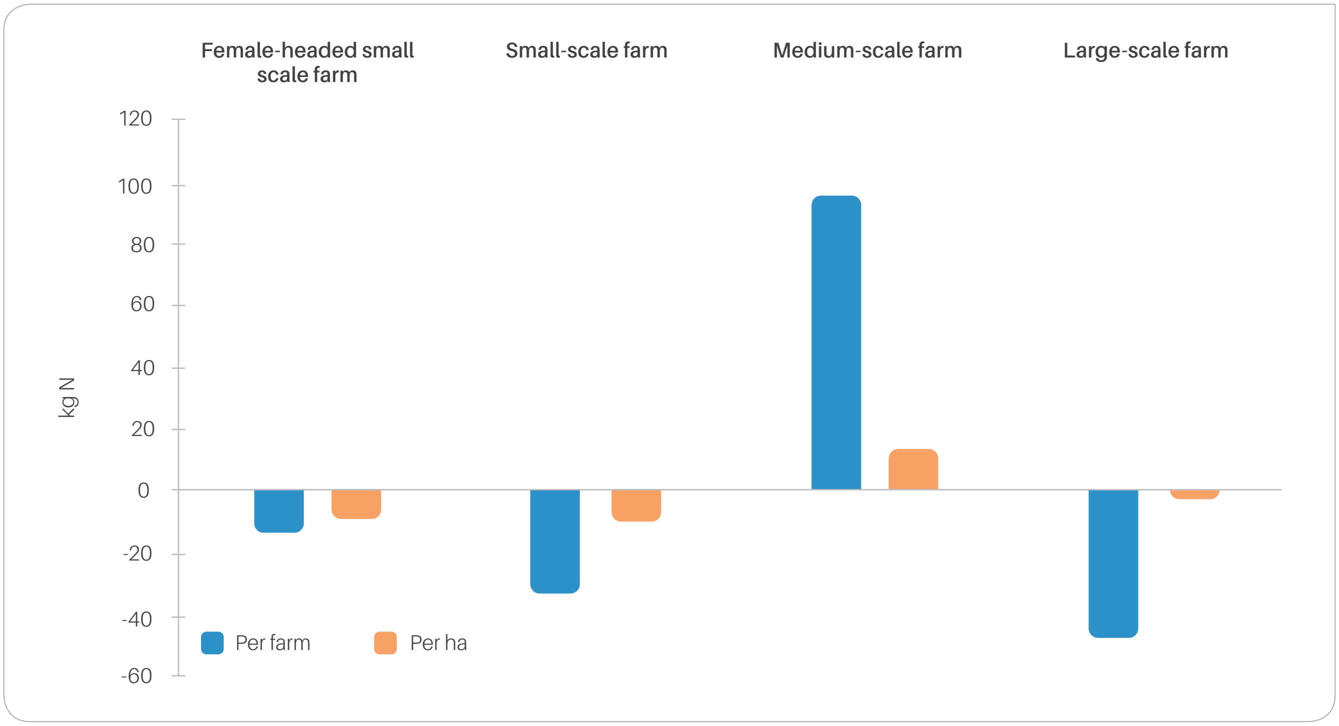


Figure 14: Baseline N balance at field level per farm and hectare across farm types

4.4.2.2. Changes in N balance

Implementing the different technologies affects the N balance differently across farms (Figure 15). The N balance improves the least across interventions in the medium-scale farm because here N inputs through the interventions are not sufficient to replace the assumed decrease in the use of inorganic fertilizer. It is only the introduction of mucuna that overall will improve the N balance on the medium-scale farm. The addition of compost and manure impacts the N balance the most on the other farms, making it positive. This effect is expected to be largest on the female-headed small-scale farm, where yields remain relatively low and thus also the associated removal of N. However, it should be reiterated that this farm type has no livestock other than poultry, and that thus large quantities of manure or compost are not easily available. Intercropping with cowpea has a large negative effect on the N balance on both the medium- and the large-scale farm despite the atmospheric N fixed by this legume. This is because this scenario simultaneously assumed a reduction in N fertilizer application, while most of the fixed N is also exported via the harvested cowpeas. Relay cropping with mucuna improves the N balance across the three farms where it was implemented, mainly through the N fixation and the retention (part of) the crop from the fields.

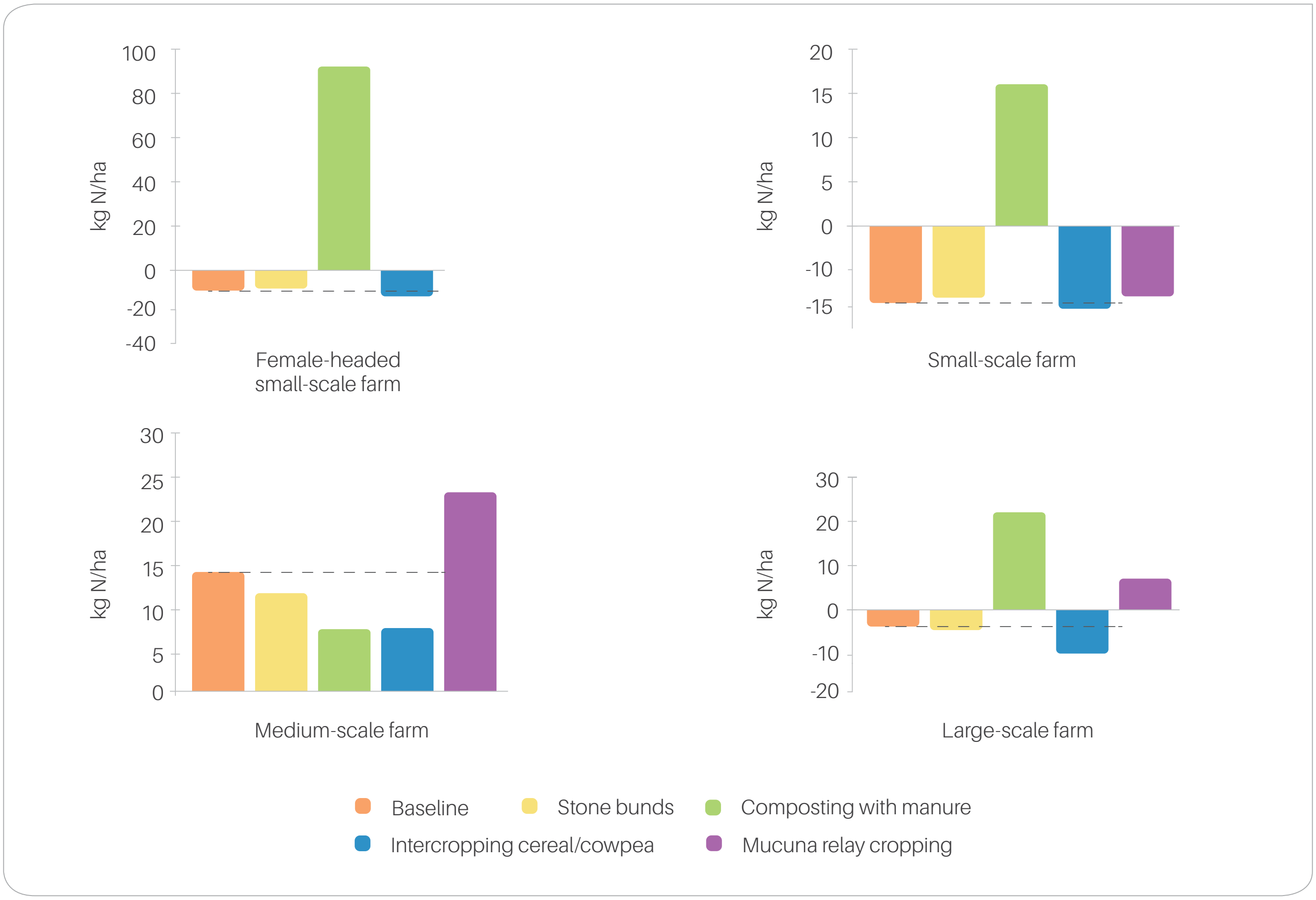


Figure 15: N balance of baselines and scenarios across farms (kg N/ha)

4.4.2.3 Baseline erosion

Soil erosion is negligible with less than 5 t/ha/year across all farms (Figure 16), which is not surprising as all farms sampled were located on rather flat land. The difference in rainfall is what explains most of the difference in erosion rates apart from the different crop rotations on each farm. Indeed, rainfall is 170 mm less in the area where the medium-scale farm is located.

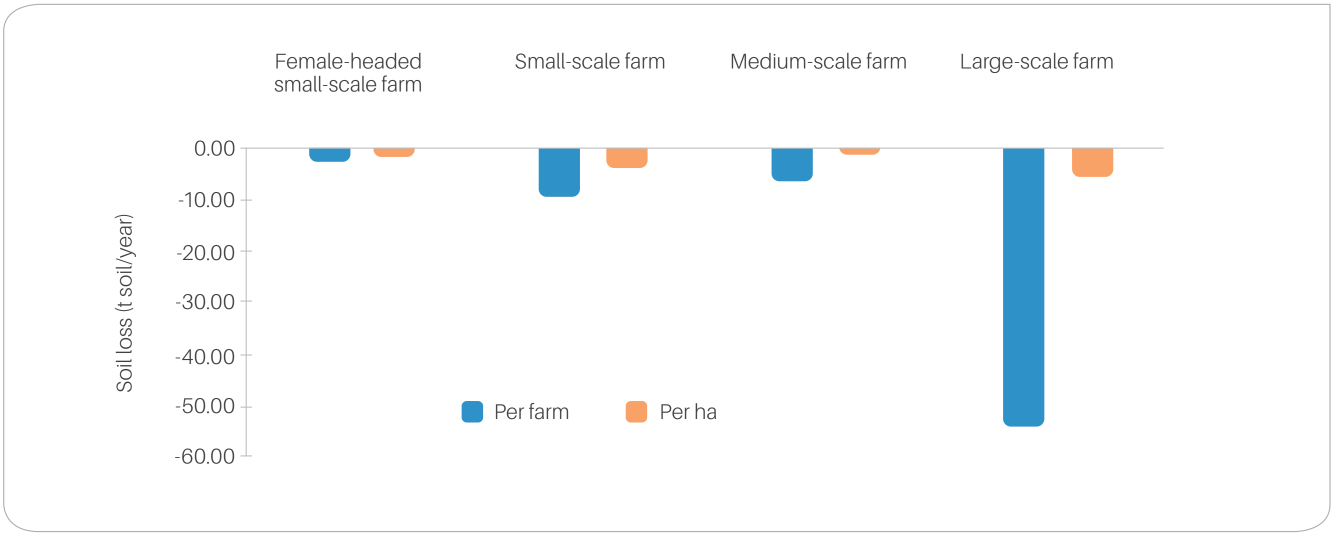


Figure 16: Baseline soil erosion (t soil/year), per farm or per hectare

4.4.2.4. Changes in erosion

All interventions reduce soil erosion except for the compost/manure scenario (Figure 17). As expected, stone bunds impact soil erosion the most, not only because of the characteristics of the intervention, but also because of its scale (applied to all fields). Intercropping and relay cropping, if implemented, reduce erosion as well, but comparably less.

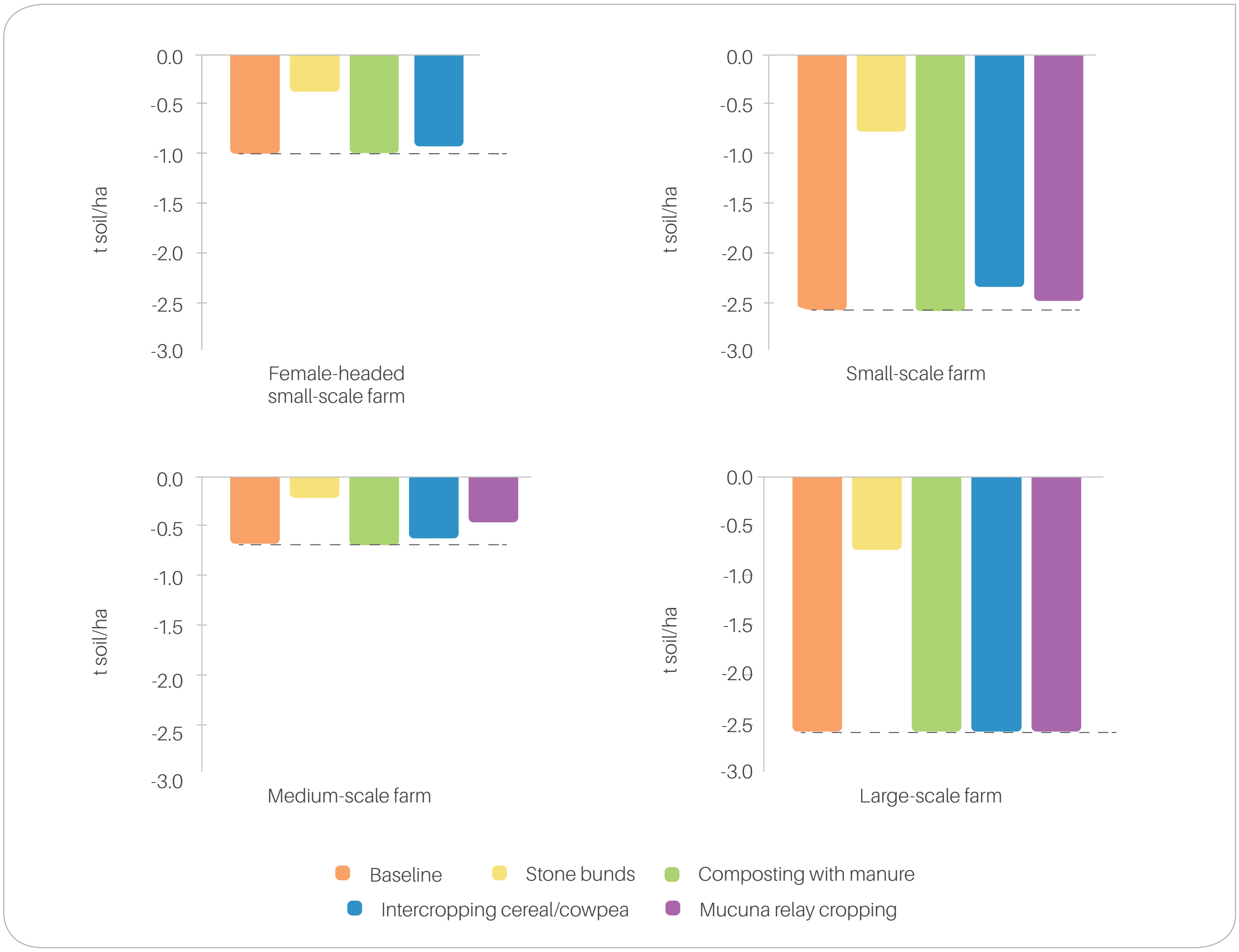


Figure 17: Soil erosion baselines and scenarios across farms (t soil/ha)

4.4.3. Mitigation pillar

The total GHG balance comprises emissions from enteric fermentation (methane), manure management (methane and nitrous oxide), soils (nitrous oxide and methane), and burning residues (carbon dioxide and methane). For easy comparison, these are converted into equivalents of carbon dioxide (CO_2e) and expressed per ha.

4.4.3.1. Baseline greenhouse gas emissions

Both small-scale farms have very low GHG emissions because of low input levels and little to no livestock production (Figure 18). On the medium and large-scale farms, emissions from livestock and from residue burning are the major contributors to the farm GHG emissions. Indeed, on both farm close to 40% of the area is under cotton cultivation, the crop residues of which are all burned. Per ha, the medium-scale farm has the highest GHG intensity, because of the higher livestock density compared to the large-scale farm.

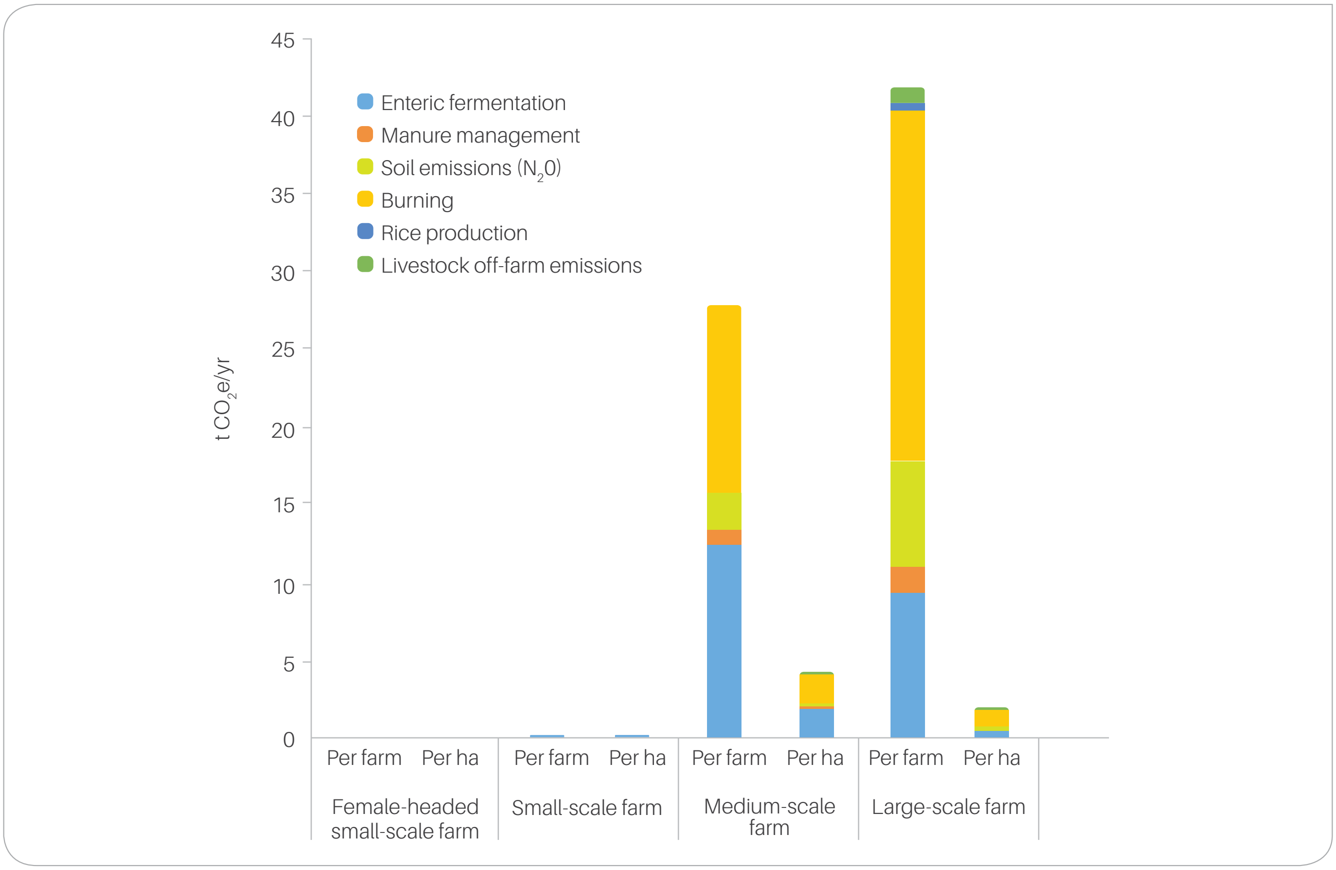


Figure 18: Baseline GHG emissions across farm types. *Emission sources include enteric fermentation, manure management, burning, rice production, off-farm livestock and soil emissions across farm types*

4.4.3.2 Changes in GHG emissions

GHG emissions are affected by the interventions differently across the farm type (Figure 19). On the two small-scale farms, compost and manure application increase GHG emissions the most because of the extra nitrous oxide emissions from soils. Across the other interventions on the small-scale farms the GHG emissions increase only little because of the low level of inputs. Unlike on the small farms, the compost and manure intervention is associated with a decrease in GHG emissions on the medium- and large-scale farms. Although there is an input in N from additional compost/manure, there is also a reduction in the nitrous oxide emissions from soils due to reduced inorganic fertilizers. However, since most of the compost/manure has to be imported (to provide for the recommended application rates), the emissions from the production of this compost (elsewhere) are not counted for, while this is the case for compost produced on-farm. Thus, if the idea is to eventually produce all compost on-farm, it must be expected that emissions would increase above baseline levels, because of the amount of manure, and thus animals, required, as well as the GHG emissions during the composting process. Stone bunds reduce GHG emission the most on the large-scale farm. This is rather an artefact of the reduction of the maize plots (10 ha to 9 ha), which entails a reduction in mineral fertilizer required. There is a slight increase in GHG emissions in the mucuna relay scenarios. This is due to the increase in N coming from the crop residues on the fields. And the increased livestock productivity (more manure production) from better feeding.

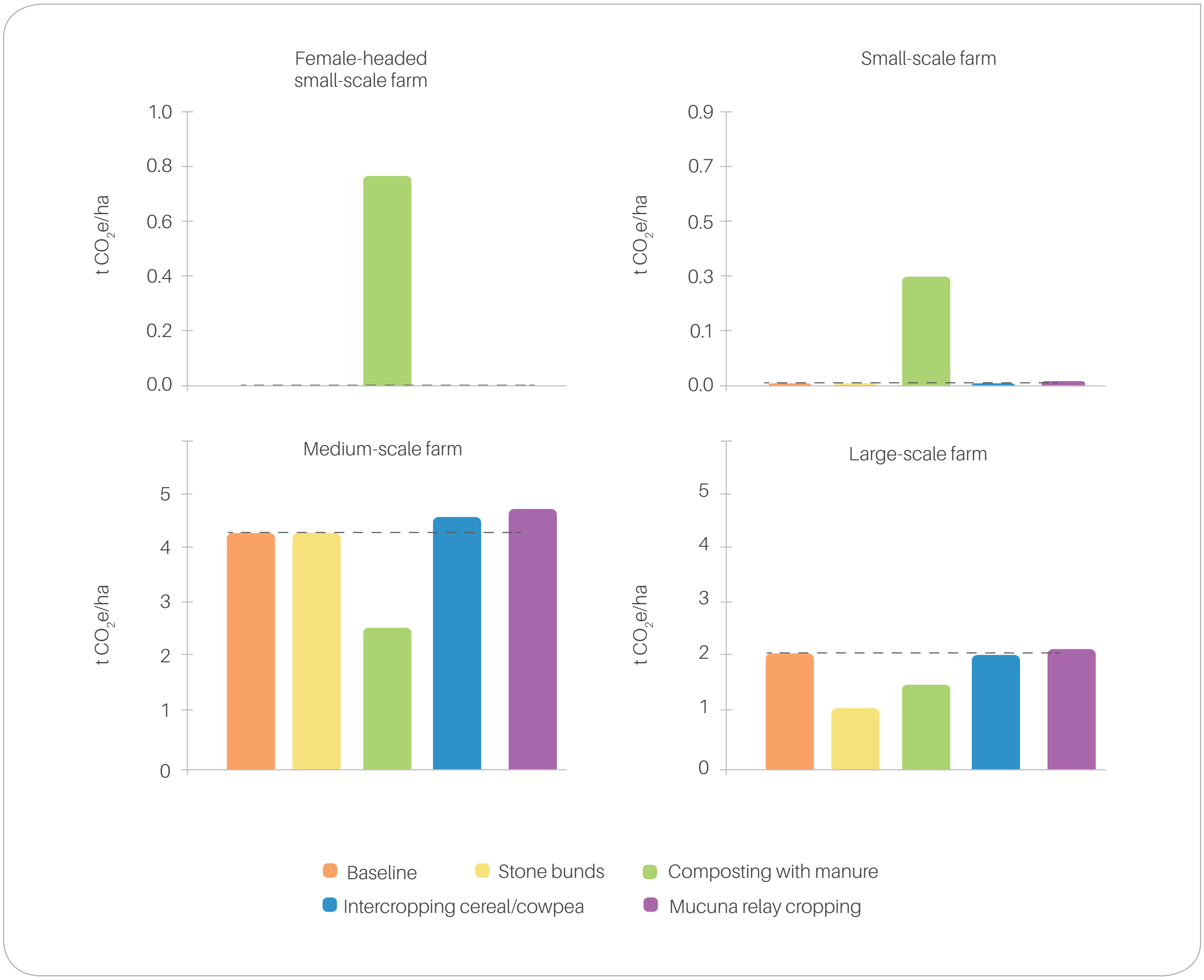


Figure 19: GHG emission intensity baselines and scenarios across farms (t CO_2e/ha)

4.4.4 Trade-offs

Truly triple-win climate-smart solutions, i.e. interventions that increase productivity, improve resilience and reduce GHG emissions, are rare. Instead, implementing soil conservation and rehabilitation measures often has a positive impact on just one or two of the CSA pillars but a negative effect on the remainder(s); i.e. trade-offs have to be made. Plotting changes in productivity against changes in N balance allows for a few insights (Figure 20). Firstly, composting with manure is the only clear win-win intervention, increasing productivity and N balance on most farms. The only exception is the medium-scale farm, where the notable productivity increase associated with compost application goes hand in hand with a small decrease in N balance. The N balance, however, remains positive on this farm too. Secondly, intercropping shows the biggest increases in productivity (except on the small-scale farm). This positive impact, however, needs to be traded off with decreases in N balance. Thirdly, relay cropping on the medium- and large-scale farms has a positive impact on the N balance with barely any trade-off observed in terms of productivity.

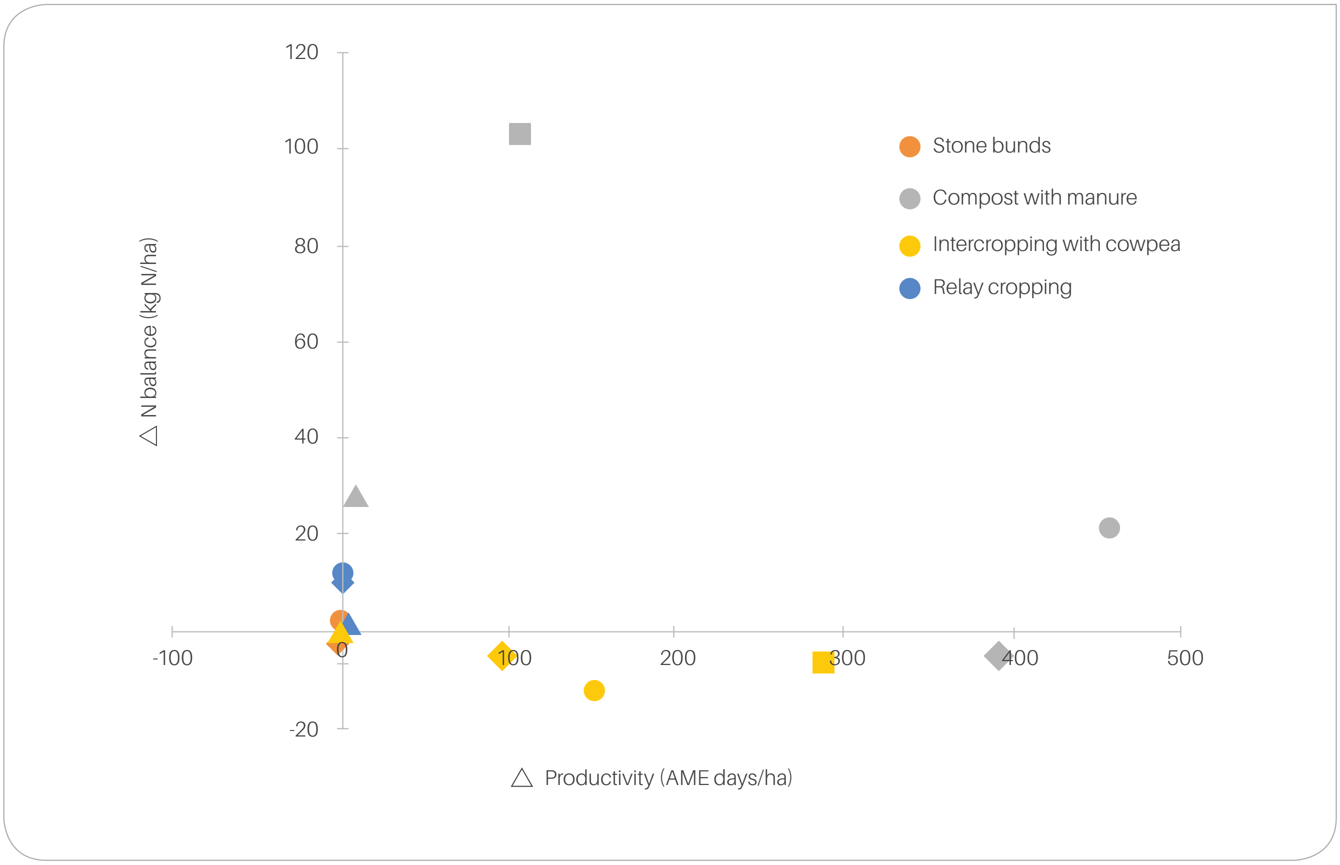


Figure 20: Trade-offs between changes in productivity (AME days/ha) and field N balance (kg N/ha) when moving from baseline to soil conserving technologies. Colours represent the scenario and shape the farm types (□ =female-headed small-scale, △ =small-scale, ◇ =medium-scale and ○ = large-scale)

Also within only one pillar, trade-offs can be observed (Figure 21). Comparing the impact of the interventions on soil erosion and N balance, shows that firstly, intercropping has a positive effect on soil erosion but shows a clear trade-off in terms of reducing the N balance on all farm types. Secondly, relay cropping represents a win-win solution, be it with small positive impacts in general and hardly any on the small farm. Thirdly, stone bunds show a positive impact on soil erosion with small but positive interaction with the N balance on the small female-headed and medium farm. On the small and large farms, on the other hand, the gains in terms of soil erosion come with a small trade-off in terms of N balance. Lastly, the loss in N balance caused by intercropping is compensated by small reductions in erosion. As for synergies and trade-offs between productivity and GHG emissions (Figure 22), the impact of the compost with manure intervention varies considerably between farm types. On medium- to large-scale farms, it represents a win-win solution. On the small farms, the increase in productivity comes with an increase in GHG emission intensity too.

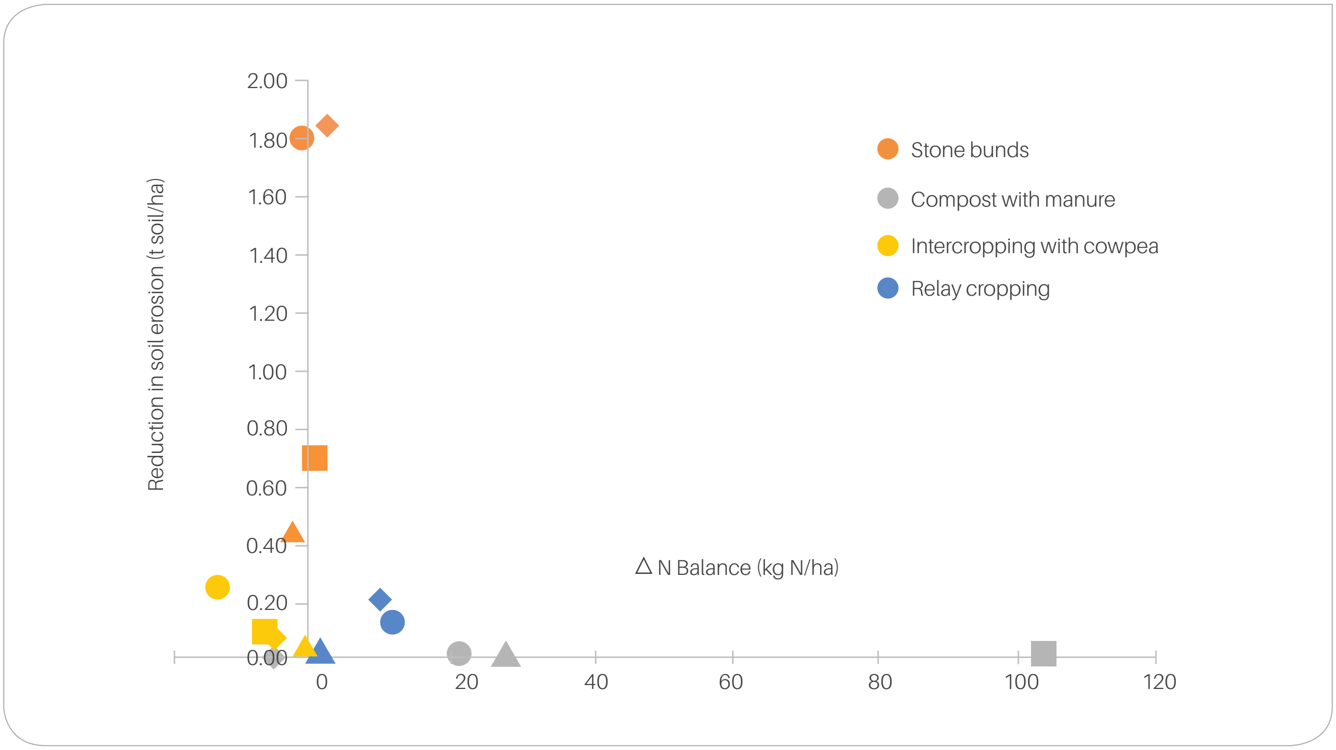


Figure 21: Trade-offs between changes in field N balance (kg N/ha) and Reduction in soil erosion (t/ha) comparing baseline and soil conservation scenarios. Colours represent the scenario and shape the farm types (□=female-headed small-scale, △=small-scale, ◇=medium-scale and ○= large-scale)

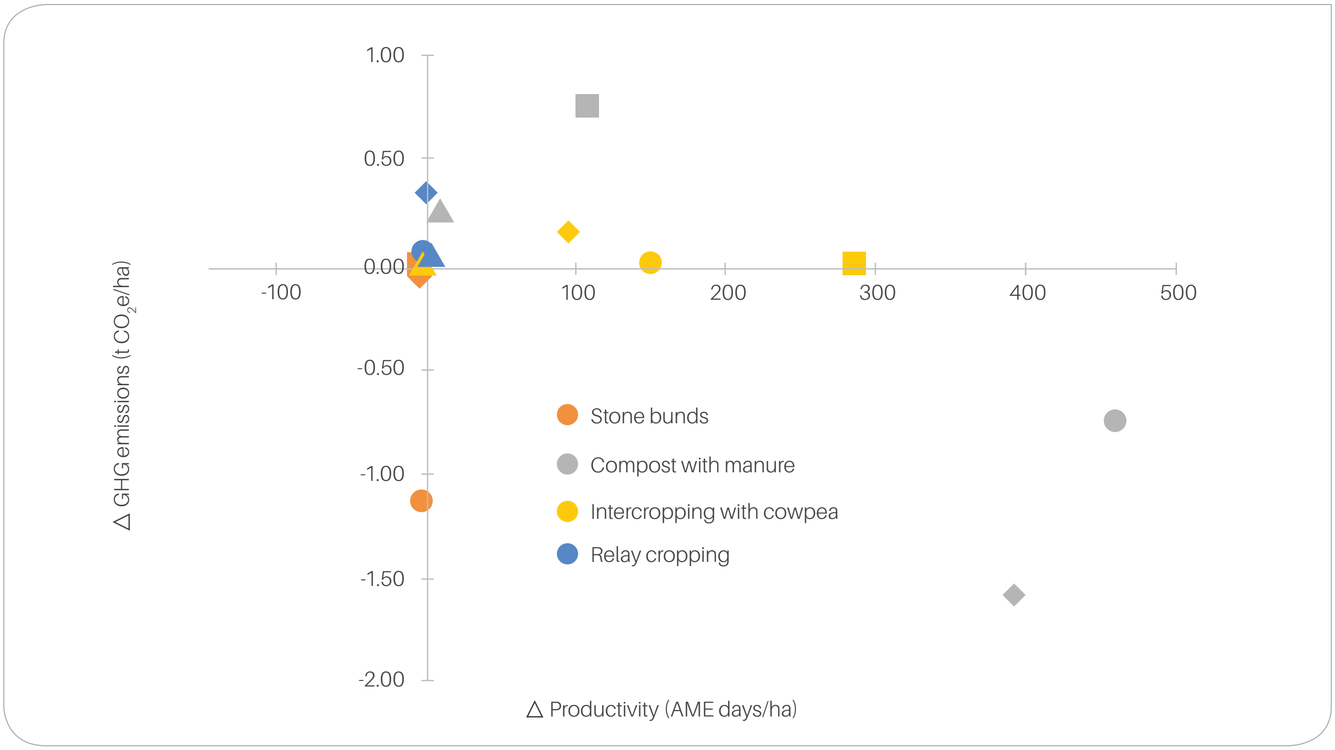


Figure 22: Trade-offs between changes in productivity (AME days/ha) and GHG emissions (t CO_2e/ha) comparing baseline and soil conservation scenarios. Colours represent the scenario and shape the farm types (□=female-headed small-scale, △=small-scale, ◇=medium-scale and ○ = large-scale)

Finally, comparing soil erosion reduction with GHG emission intensity impacts (Figure 23), shows that a reduction in soil erosion is possible without big trade-offs in terms of GHG emission intensities, through e.g. stone bunds. Relay cropping also reduces soil erosion on the medium- and large-scale farms, but puts a trade-off, namely a higher GHG emission intensity.

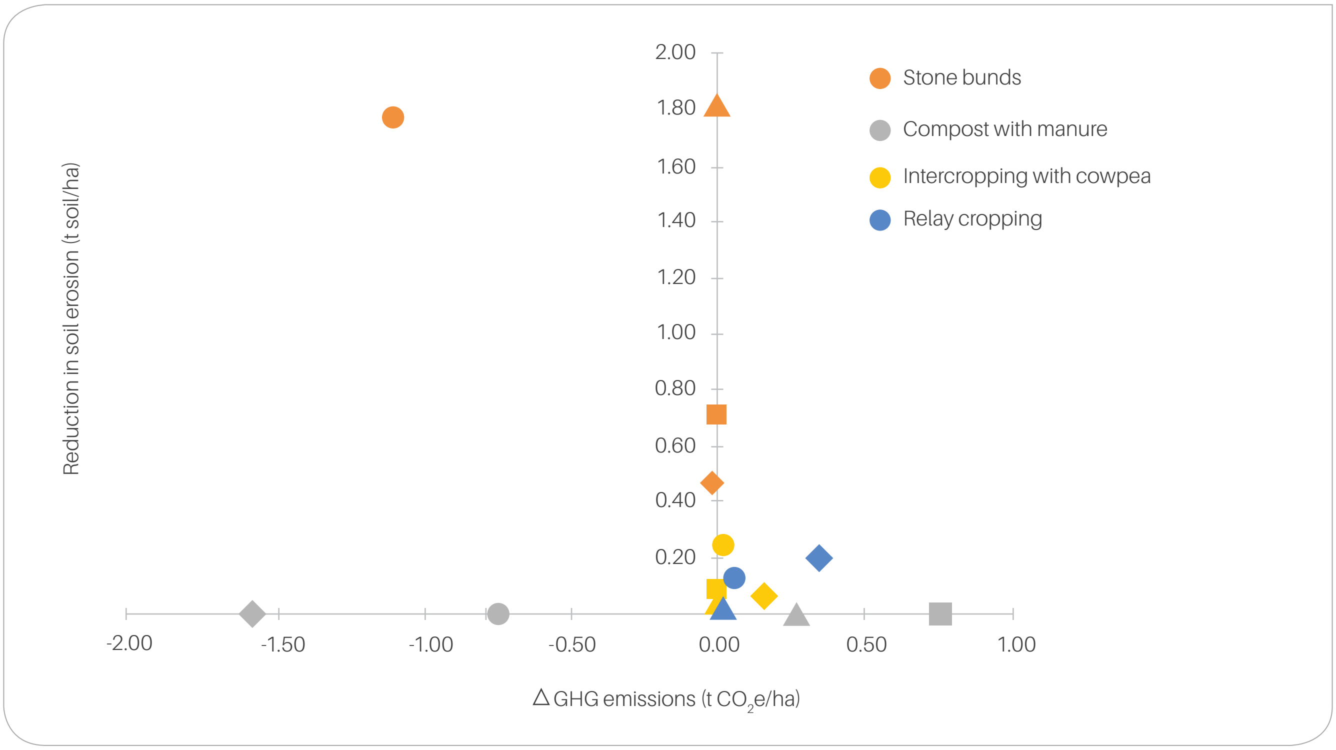


Figure 23: Trade-offs between changes GHG emissions (t CO_2e/ha) and Reduction in soil erosion (t/ha) comparing baseline and soil conservation scenarios. Colours represent the scenario and shape the farm types (□=female-headed small-scale, △=small-scale, ◇ =medium-scale and ○ = large-scale)

5 Ethiopia

5.1 Background

Ethiopia has prioritized agriculture as the sector to lead national development and to support greater industrialization in the country. Agriculture contributes 53% of GDP, generates 85% of foreign exchange earnings and employs 80% of the population (Deressa et al., 2009). National policies such as the Agriculture Development Led Industrialization Policy together with the Growth and Transformation Plan focus extensively on agriculture and how productivity can be increased across the country to meet specific targets. However, farmers across the country face many obstacles to increasing their production. Even with elevated government support to the agricultural sector, extension services are still spread thin, access to markets and inputs vary widely across the country, and soil fertility and erosion remain significant in the highlands in particular. High population densities and small farm sizes characterize much of the highlands where intensive agriculture takes place.

Ethiopia has the highest population of livestock of any country in Africa and they are highly valued and utilized in agricultural production for tilling, threshing and providing manure for both fertilizer and fuel. The crop production in the country is highly diverse and includes numerous grains and legumes and horticultural production for markets. The Government of Ethiopia is committed to supporting agriculture and in promoting more sustainable approaches that do not undermine the natural resources base on which livelihoods depend. This commitment offers considerable opportunity for innovation in achieving the production goals set by national policies.

In Ethiopia, the GIZ Soil Protection and Rehabilitation for Food Security Program builds on ongoing activities within the Ethiopian national program on Sustainable Land Management (SLM), which receives significant support from GIZ. As part of the SLM program, GIZ has been demonstrating Integrated Soil Fertility Management (ISFM+) technologies in different regions of Ethiopia. It is a 3-year program that started in 2015 and will end in 2017. The program is implemented in three regions of Ethiopia, namely Tigray, Amhara and Oromia on approximately 25,000 ha. In the appendix can be found agro-ecological reference maps of the target areas. At this initial stage, the program aims at boosting biomass (grain & residue) yields through optimum application of organic and inorganic fertilizer and the use of improved germplasm and agronomic practices to increase availability of high quality organic soil amendments.

The program envisions to see increased yields of main crops (wheat, maize and teff) by 20%, and improved livelihoods of smallholder farmers, effective and sustainable supply of inputs by private sectors, and ISFM+ science incorporated in curricula of agricultural technical and vocational schools. The '+' in ISFM+ refers to the project's inclusive implementation approach, aiming at combining behavioural change communication strategies with farmer-acceptable and locally-adapted soil fertility improvement technologies, including supply chain aspects for the sustainable supply of ISFM inputs.

5.2 The case study farms

Five farm types across target sites in Oromia and Amhara were identified during the initial workshop in Addis Ababa. Workshop participants included representatives from GIZ, Regional State Bureaus of Agriculture, Ethiopian Institute of Agriculture, universities, and CIAT(Gurmessa et al., 2016).

One case study farm was selected for each of the farm types. The farms chosen were typical farms that could be used as a representative of the farmers within each farm type. These farms were visited and detailed information was collected for the use as input data to model GHG emissions, nitrogen balance, erosion and farm production. The location of these farms can be found on Figure 24.

1. Poorest farmer: This farm is 0.08 ha in size and is all under cultivation and there are 3 household members. This is an example of a resource-poor household with no off-farm income, small livestock herd and crops are mainly for household consumption. Maize and potatoes are the only crops grown. Labour is provided by household members only because they cannot afford to hire casual workers and the land is small. No fertilizers are used on the farm and most of the manure collected is used as fuel. Maize yields are the lowest compared to other farm typologies i.e. 1250 kg/ha. Maize residues are fed to livestock. There are 3 heifers and no non-ruminants on the farm. Most of the feed is purchased such as teff straw and wheat straw and the livestock spend their time in between the yard and stable.
2. Small mixed cereal farmer: This farm is 0.5 ha in size and is all under cultivation, though an extra 1 ha has been rented for cultivation. The household has 6 members. Maize, wheat, faba bean and teff are grown on the farm. Maize yields (i.e. 2800 kg/ha) are higher than all other typologies except the coffee based commercial farm. Crop residues are mostly fed to livestock. DAP fertilizer and urea are applied on crop fields as well as all the manure collected. There are 3 local cattle (1 dairy and 2 male cattle), 4 local sheep, 1 donkey and 4 chicken on the farm, all of the local breed. Wheat straw makes up the largest portion of the cattle and donkey's feed basket and grazed grasses the least. The goats mostly graze off-farm during the wet season and are mostly fed on 'atela' during the dry season.
3. Medium mixed cereal farmer: This farm is 1.69 ha in size, of which 0.185 ha is grazing land and an additional 0.25 ha has been rented for cultivation. The household has 5 members. Main crops grown are maize, coffee and teff though there are a few scattered bananas on the farm. Maize yields (i.e. 968 kg/ha) are lower than all other typologies except the double cropping farm and teff yields are the lowest compared to all other typologies. Maize stover is mostly fed to livestock. There are 5 local cattle (1 dairy and 3 male cattle), 2 local sheep and 1 donkey. Teff makes up the largest portion of the cattle feed basket in the dry season and livestock mostly graze on pasture during the wet season. The sheep only feed on grazed natural grasses throughout the year. The livestock spend their time in the stable, yard, crop fields grazing on crop residue, on-farm pasture and off-farm grazing areas as well. DAP fertilizer and urea are applied on crop fields as well as all the manure collected.
4. Double cropping farmer: This farm is 2.63 ha in size which is all under cultivation and an additional 0.25 ha has been rented for cultivation. The household is relatively large with 11 members. Crops grown are maize, wheat, sorghum, teff, niger seed and potatoes, with sorghum and niger seed occupying the largest areas i.e. 1.13 ha and 0.75 ha respectively. Maize yields (i.e. 700 kg/ha) are lower than all other typologies and the highest teff yields i.e. 1467 kg/ha. There are 3 local cattle on the farm (1 dairy and 2 male cattle) and 1 donkey. All residues are fed to livestock. Teff makes up the largest portion of the cattle feed basket in the wet season and livestock mostly feed on residue in the dry season. The livestock spend their time in the stable, yard, crop fields grazing on crop residue and off-farm grazing areas. Most of the manure collected in the stable and yard is applied to crop fields together with urea and DAP fertilizers.
5. Coffee-based commercial farmer: This farm is 9.3 ha in size, of which 2 ha is grazing land and an additional 1 ha has been rented for cultivation. The household has 5 members. Maize and coffee are the main crops of which the latter is solely for sale though fruit trees and teff are also grown. Maize produces the highest yield among all typologies i.e. 3864 kg/ha. This farm produces the highest maize yields out of all the typologies i.e. 3864 kg/ha. Crop residues are mostly fed to livestock. There are 12 local cattle (3 dairy, 4 heifers, 4 male cattle and 1 calf), 9 local sheep, 1 donkey and 7 chicken. On-farm and off-farm grazed grasses form the largest portion of the feed basket. The livestock spend their time in the stable, yard, crop fields grazing on crop residue, on-farm pasture and off-farm grazing areas as well. DAP fertilizer and urea are applied on crop fields as well as all the manure collected.

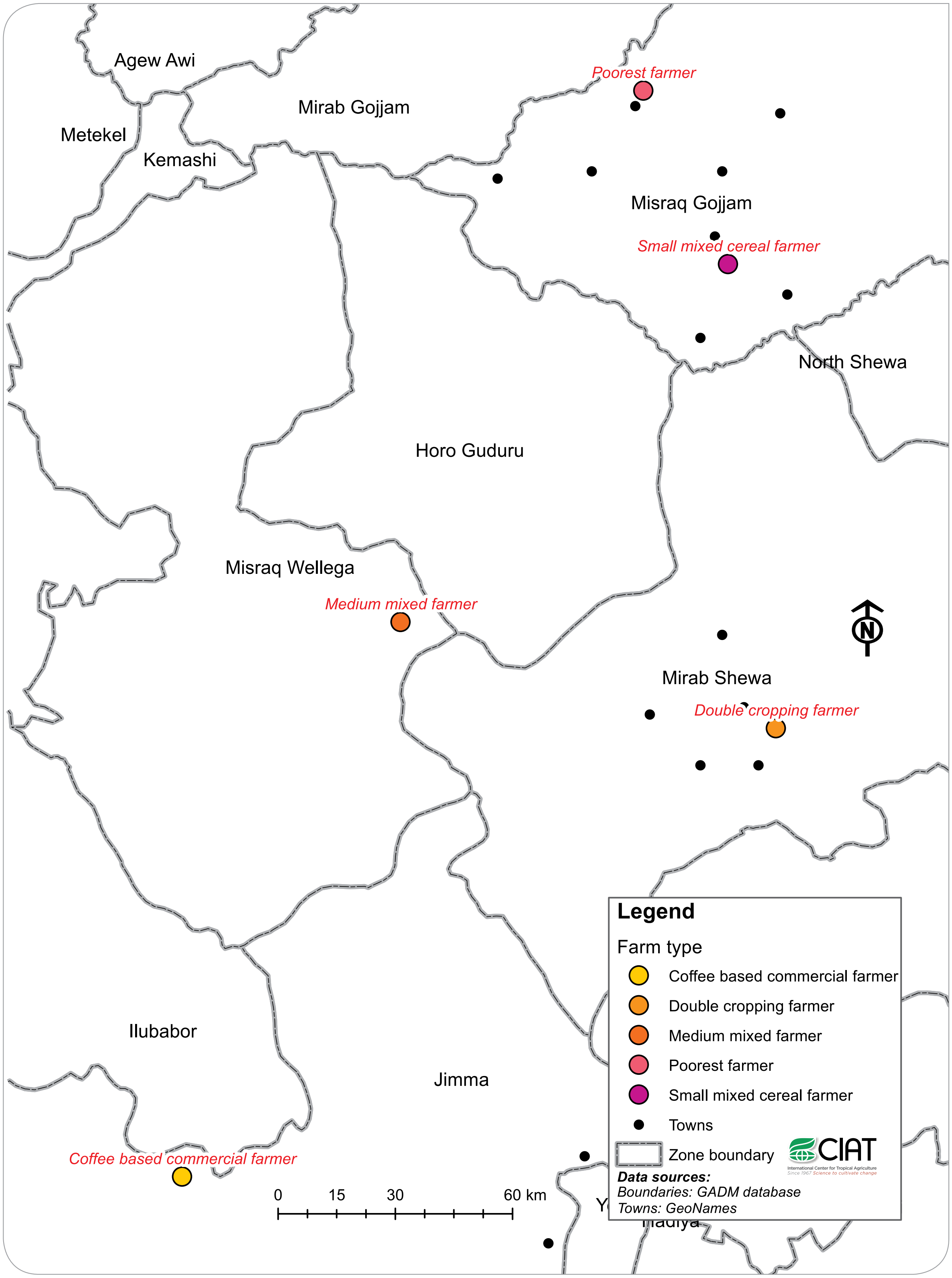


Figure 24: Location of the case study farms in Ethiopia

5.3 Technology descriptions and scenarios

Four different intervention scenarios were chosen during the workshop to represent soil rehabilitation interventions that are currently supported by GIZ and partners in Ethiopia, or that are under discussion for future promotion: i) Reduced tillage and surface residue retention/mulching; ii) Intercropping/double cropping in combination with rhizobia inoculation, iii) Small-scale mechanization; iv) Improved seeds in combination with improved agronomy (including fertilizer + liming). All assumptions are described in detail according to impact dimensions in the Appendix II Scenario Assumptions.

Reduced tillage and mulch: This scenario is characterized by 5% reduction in manure application, 5% increase in crop yield, 5% increase in milk production, retention of 2/3 of the crop residue in the field as mulch, and reduced soil erosion.

Intercropping, double cropping and rhizobia: In this scenario chickpea is grown on residual moisture after wheat and teff (double cropping), and it is assumed that 0.5 t/ha chickpeas can be harvested. Further, the assumption is that maize and sorghum are now (always) intercropped with beans, which allows for reducing N fertilizer application by 25–35% due to the additional N fixed by the bean crop and an increased manure application of 10–30%. Intercropping assumes a 20% reduction in maize and sorghum yields (due to the competition with the bean crop), but an additional bean yield of about 250 kg/ha. Inoculating legumes with rhizobia increases assumed legume yields by 30%. It is expected that these technologies increase milk production by 25–40% due to an increased production of crop residues.

Small-scale mechanization: Introducing mechanized threshing (reducing post-harvest losses), small-scale irrigation, soil rippers (for breaking up the plough pan) and contour ploughing in this scenario is assumed to increase crop yield in the poorest farms by 5% (assuming that these may not be in the position to purchase irrigation equipment). The other farms are anticipated to increase yields by as much as 50% due to their ability to purchase equipment. This technology also reduces soil erosion.

Quality seeds + improved agronomy (including fertilizer + liming): This scenario is characterized by application of 87 kg N/ha of mineral fertilizers (100 kg/ha di-ammonium phosphate [DAP] and 150 kg/ha urea), which is the recommended fertilizer application rate, 10% increase in manure application, a resulting 20–75% increase in crop yield, and 5–20% increase in milk production due to an increased availability of crop residues for feeding livestock.

5.4 Results

5.4.1 Productivity pillar

5.4.1.1 Baseline productivity

The poorest farm has the highest productivity per hectare followed by the small mixed cereal farm (Figure 25). This is mostly attributed to higher potato and wheat production per hectare when compared to the other farms. The coffee commercial mixed farm has the lowest productivity per hectare due to the minimal contribution of coffee to the productivity indicator (kcal). However, the coffee commercial farm's baseline overall farm productivity is higher than all the other farm types because of the high farm level production of maize, teff, and milk. Additionally, the medium and small mixed cereal and commercial coffee farms have the highest productivity per hectare for livestock products. This is a result of higher milk production compared to the other farms; whereas the poorest farm and the double cropping farm have the lowest livestock productivity per hectare due to absence of dairy cattle, hence no milk production. Despite the small farm size of the small mixed cereal type, it has much higher wheat yields due to fertilizer application. This helps explain the high productivity per hectare. Generally, the smaller farmers have higher production per hectare, as they have to be more intensive to produce the needed output for farm households.

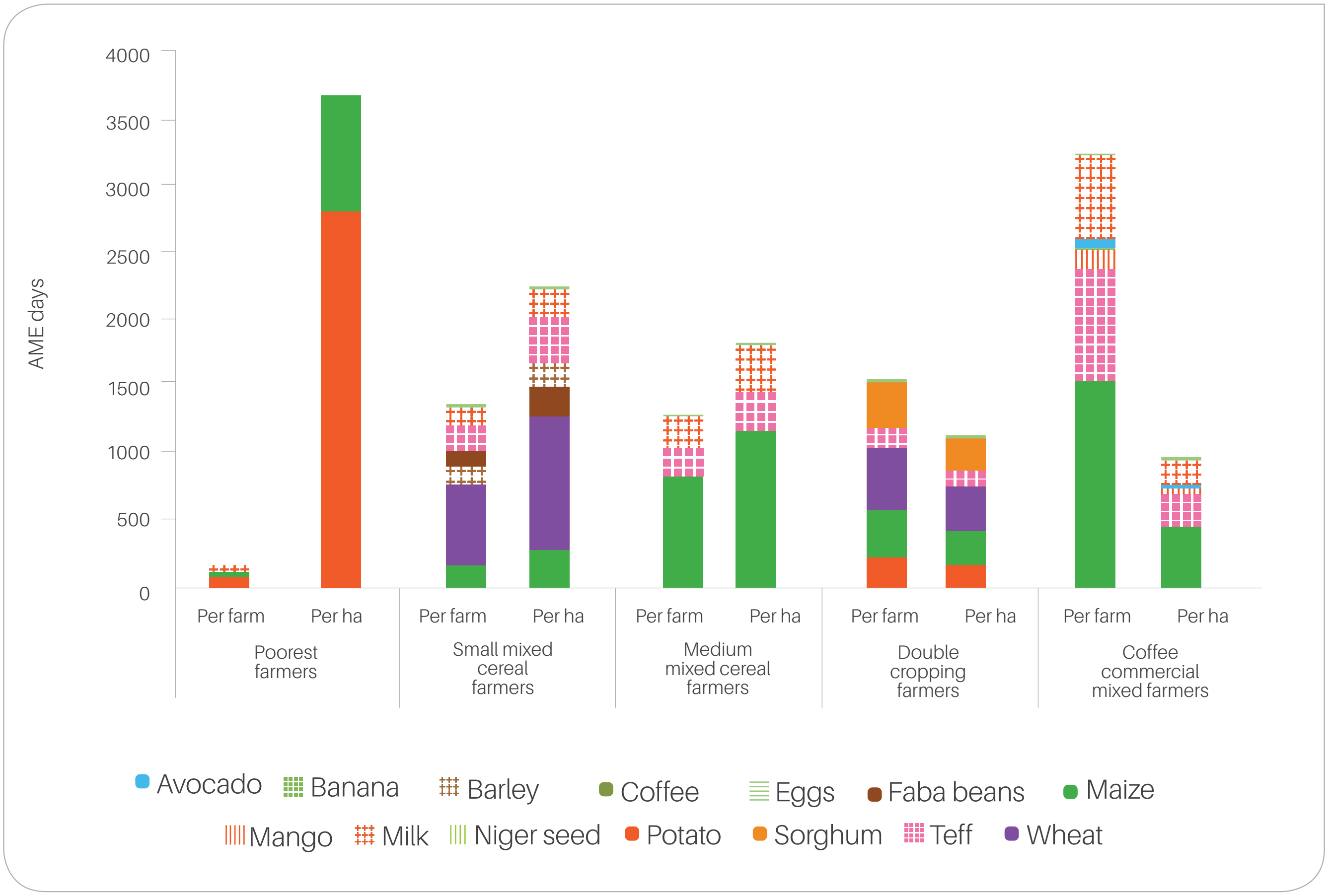


Figure 25: Baseline productivity and contribution from the different products across farm types. *Productivity is expressed as number of days that 1 adult male equivalent (AME) can be fed from livestock and crop products produced on the farm*

5.4.1.2 Changes in productivity

Implementation of technologies mentioned in chapter 3 are expected to maintain or increase to varying degrees productivity in nearly all cases across all farm types (Figure 26), i.e. both crop and milk production. Increase in yield has mostly been attributed to increase in soil fertility through recommended fertilizer application (see Appendix II on fertilizer application rates) and/or increased manure application, legume inoculation with rhizobia, and intensive cropping systems (intercropping and double cropping) with N-fixing legumes. Reduced post-harvest losses, reduced tillage ploughing (rippers) and irrigation have also shown to increase crop production across all farms. Small-scale mechanization and quality seeds in combination with improved agronomy are the only technologies that show positive impacts on productivity across all farm types. Quality seeds in combination with improved agronomy (including fertilizer and liming) has the largest impact on productivity in the small and medium mixed cereal farms. Small-scale mechanization, which is characterized by reduced post-harvest losses, reduced tillage ploughing technologies and irrigation, has quite high productivity impacts in all farms except the poorest farm. Reduced tillage has the lowest positive impact on productivity across all farms except the poorest farm, whereby intercropping and double cropping result in the least crop production, and even a reduction from baseline levels.

Increased crop productivity is assumed to increase crop residue fed to livestock and consequently increase milk production. Introduction of small-scale mechanization leads to the highest milk production, double the baseline value.

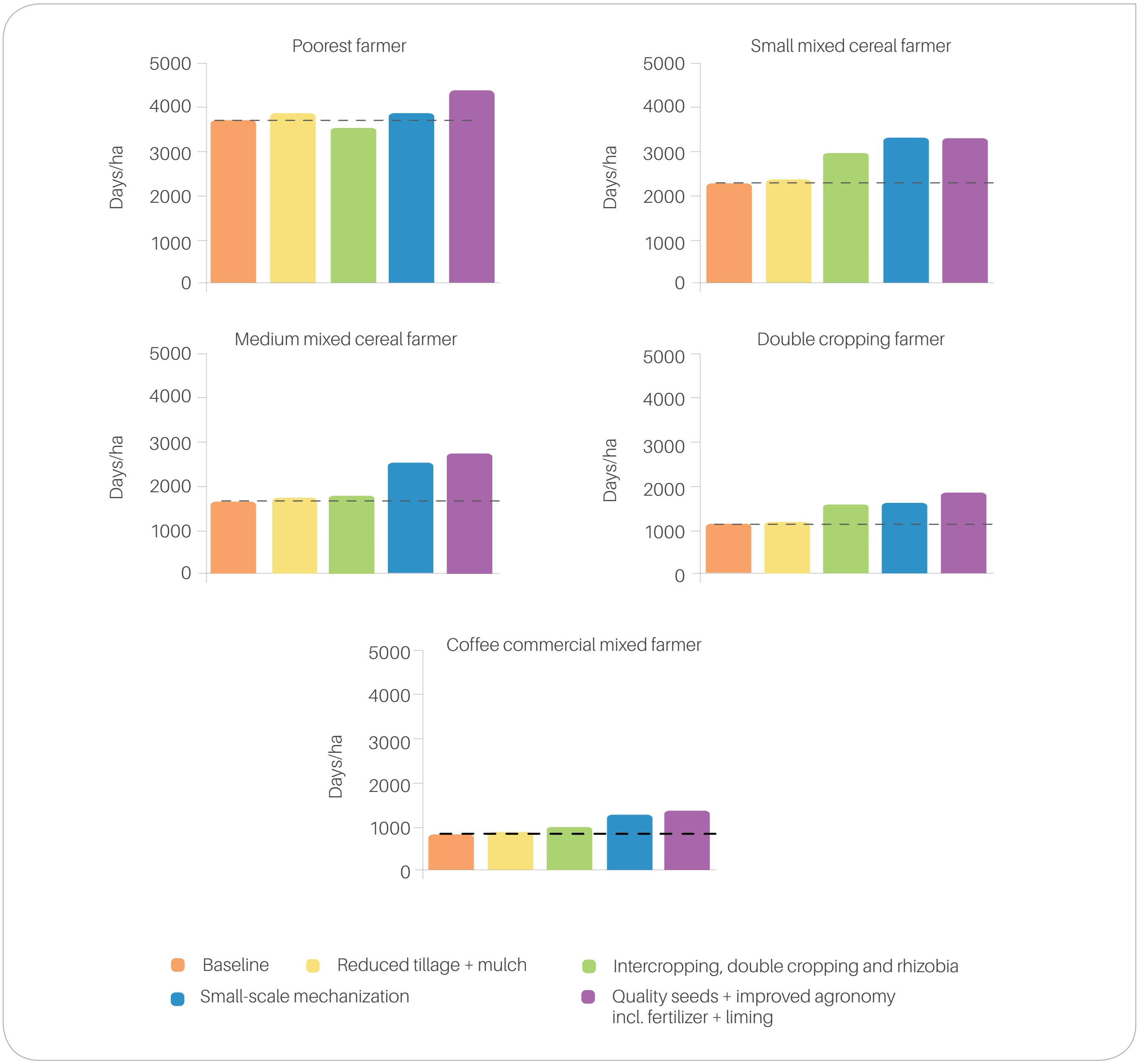


Figure 26: Baseline and scenario productivity per farm type. *Productivity is expressed as number of days that 1 adult male equivalent (AME) can be fed from livestock and crop products produced on the farm*

5.4.2 Resilience pillar

5.4.2.1 Baseline nitrogen balance

There is a moderately positive N balance on the poorest and both mixed cereal farms and the balance is negative on the double cropping and the coffee farms (Figure 27). On the small mixed cereal farm, this is due to the high livestock density (5 cattle) on less than half a hectare. The poorest farm has the highest N balance per hectare due to the high organic manure inputs on a farm that is only 0.03 hectares. The positive N balance on both cereal farms is due to the high input of inorganic fertilizers to the cereal crops. In the case of the small mixed cereal farmer sampled for this study, he was applying more fertilizer to the wheat crops than the recommended rate. This is not a common practice. On the contrary experts from the study area claim that in general farmers from this type are more likely to apply less than the recommended rate mainly due to financial reasons. The double cropping farm has the lowest N balance per hectare, which is mainly due to lower inorganic inputs than the other farms, i.e. 30 kg N/ha and less. The coffee commercial mixed farm also has lower N balance per hectare than most farms because inorganic fertilizers are not applied on its coffee plots, which occupy a large percentage of this farm.

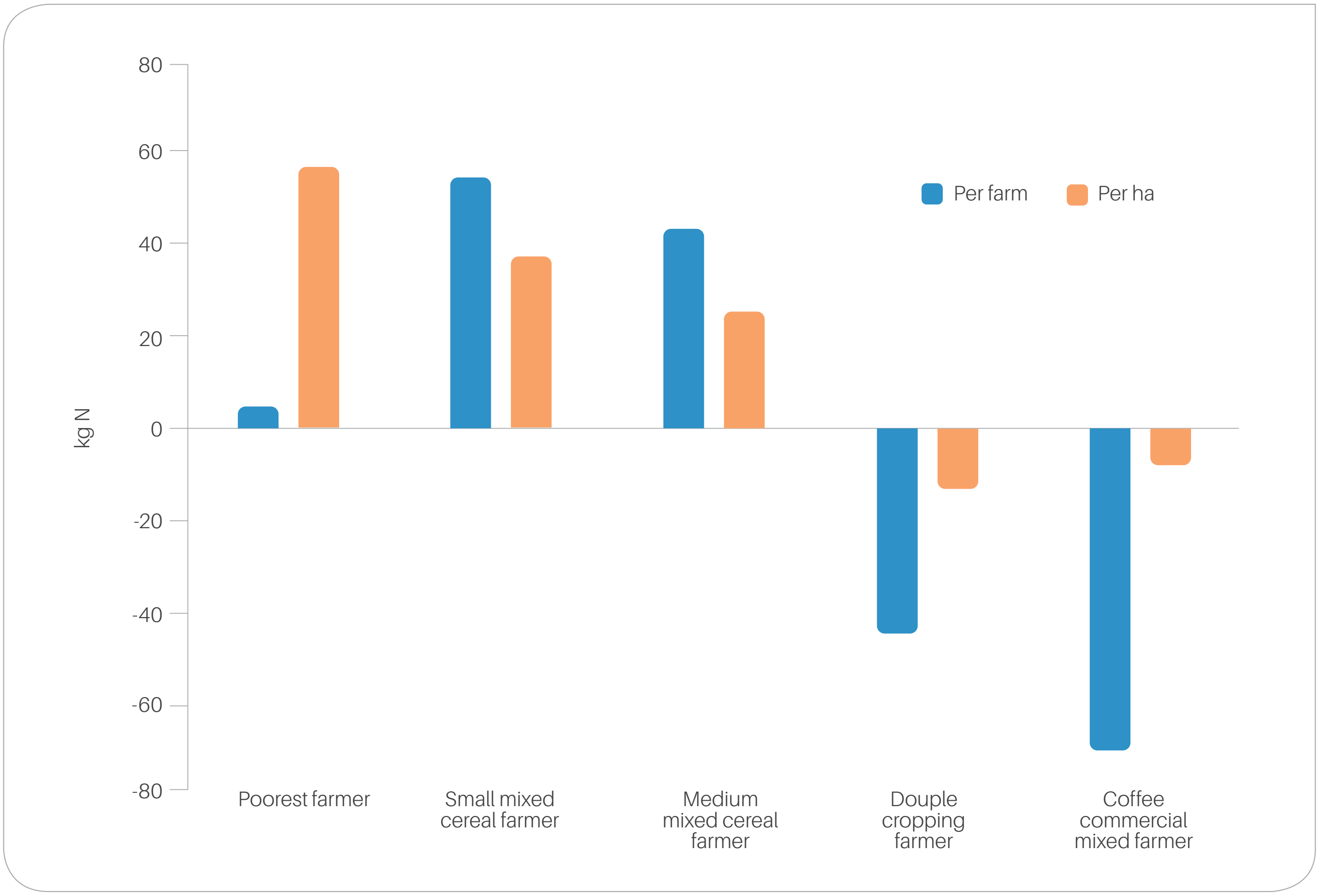


Figure 27: Baseline nitrogen balance at field level per farm and hectare across farm types

5.4.2.2 Changes in nitrogen balance

Implementing the different technologies would affect the N balance differently across the farms (Figure 28; note the different scales for each farm type). Quality seeds combined with improved agronomy (including fertilizer and liming) increase the N balance the most in the poorest farm, double cropping farm and the coffee commercial mixed farm, which is largely due to the increased N input from additional fertilizer application. The N balance increases markedly (by almost 100 kg N/ha) with the quality seeds and agronomy intervention in the poorest farm.

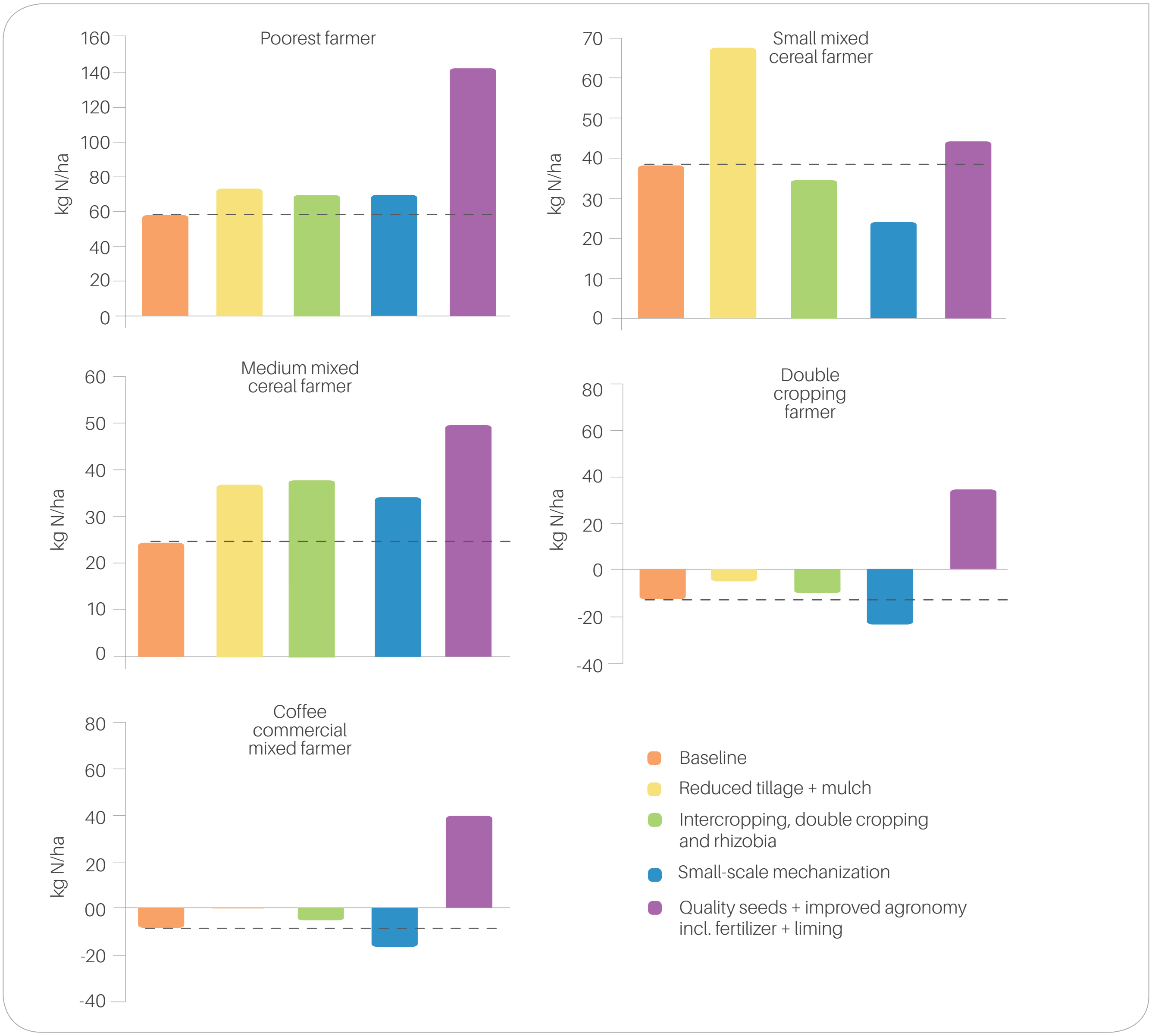


Figure 28: Nitrogen balance baselines and scenarios across farms (kg N/ha)

Small-scale mechanization results in the least increase in N balance in all the farms except the double cropping farm and it is also the only technology that causes a decrease from the baseline N balance in the small and double cropping farms and the coffee commercial mixed farm.

In the small mixed cereal farm, the N balance ranges from 24–66 kg N/ha across the different technologies and generally becomes less positive across the technologies when compared with the baseline except for the reduced tillage and mulch intervention. The high N balance can be attributed to the high fertilizer inputs per hectare ranging from 50–155 kg N/ha being applied on cereals.

The N balance of the various interventions in the medium mixed cereal farm ranges from 35–50 kg N/ha, with the N balance generally increasing across technologies from the baseline except for small-scale mechanization. The high N balance is also as a result of high fertilizer inputs per hectare with the teff receiving above 87 kg N/ha, which is above the recommended application rates, in addition to high organic inputs.

The double cropping farm and the coffee commercialized mixed farm have lower N balances ranging from -24 to 34 kg N/ha and -17 to 37 kg N/ha respectively and the N balance generally increases across the technologies from the baseline in both farms.

5.4.2.3 Baseline erosion

In this study, the highest level of erosion occurs in the small mixed cereal farm whereby 8.6 t soil/ha/year is lost (Figure 29). The poorest farm and the medium mixed cereal farm lose 7.2 t soil/ha/year and 7 t soil/ha/year respectively. The double cropping farm and the coffee commercial mixed farm have the lowest rates of erosion, i.e. 4.8 t soil/ha/yr.

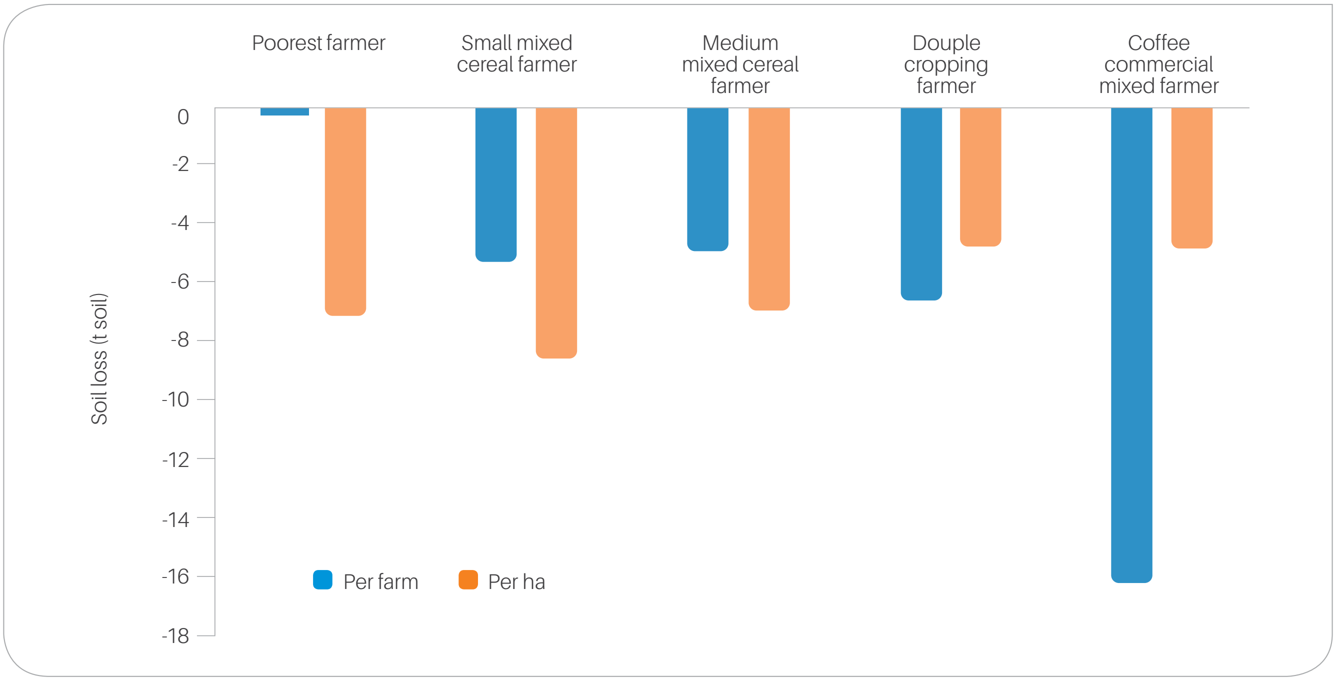


Figure 29: Baseline soil erosion per farm and per hectare across farm types

5.4.2.4 Changes in erosion

Reduced tillage with mulch and small-scale mechanization (which involves using rippers as opposed to conventional ploughing as a form of promoting reduced tillage) are the only technologies that would reduce erosion across all farm types (Figure 30). Out of the two, reduced tillage and mulch results in the highest decrease in erosion across all farms, with erosion decreasing by 3.6–6.4 t soil/ha/year, whereas small-scale mechanization reduces erosion by 1.8–3.2 t soil/ha/year. On the other hand, intercropping/double cropping with rhizobia inoculation increases erosion by 1.3–1.8 t soil/ha/year in the double cropping farm and coffee commercialized farm, whereas in the other farms there’s no change from the baseline. The quality seeds and improved agronomy intervention does not change erosion rates from the baseline across all farm types.

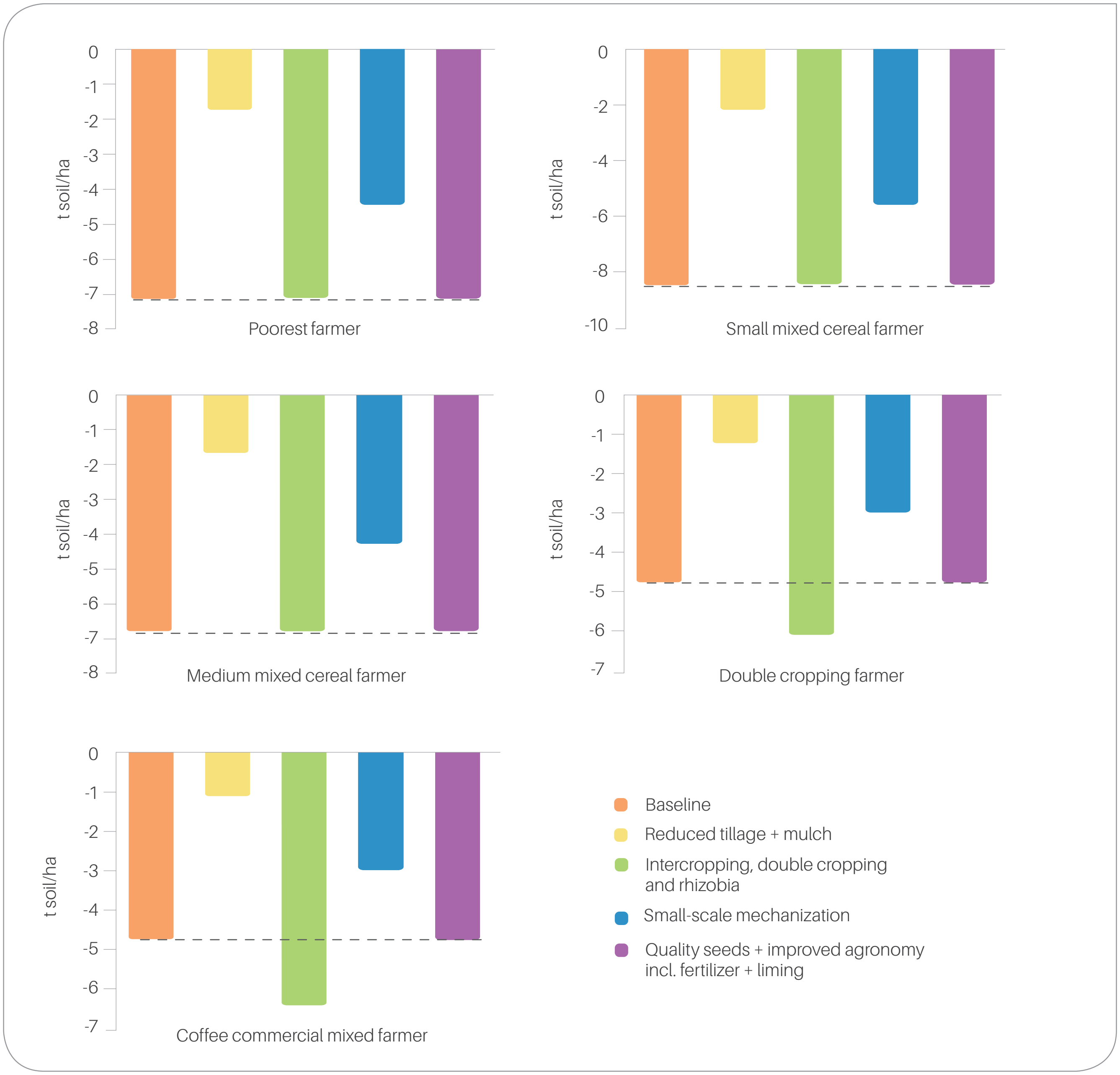


Figure 30: Soil erosion baselines and scenarios across farms (t soil loss/ha)

5.4.3. Mitigation pillar

5.4.3.1 GHG emissions

The highest level of overall GHG emissions across all farms comes from enteric fermentation due to large livestock numbers per area. The highest level of GHG emissions per hectare is from the poorest farm mostly because of the high livestock carrying capacity; only 0.03 hectares of land and 2 cows. All farms (except the poorest farm) have generally similar GHG emissions (less than 10 t CO_2e/year), mostly from enteric fermentation because there is not much difference in livestock carrying capacity among these farm types. The highest level of soil emissions come from the small mixed cereal farm and the medium mixed cereal farmer due to high fertilizer use per hectare, particularly on the cereal crops (maize and wheat; Figure 31).

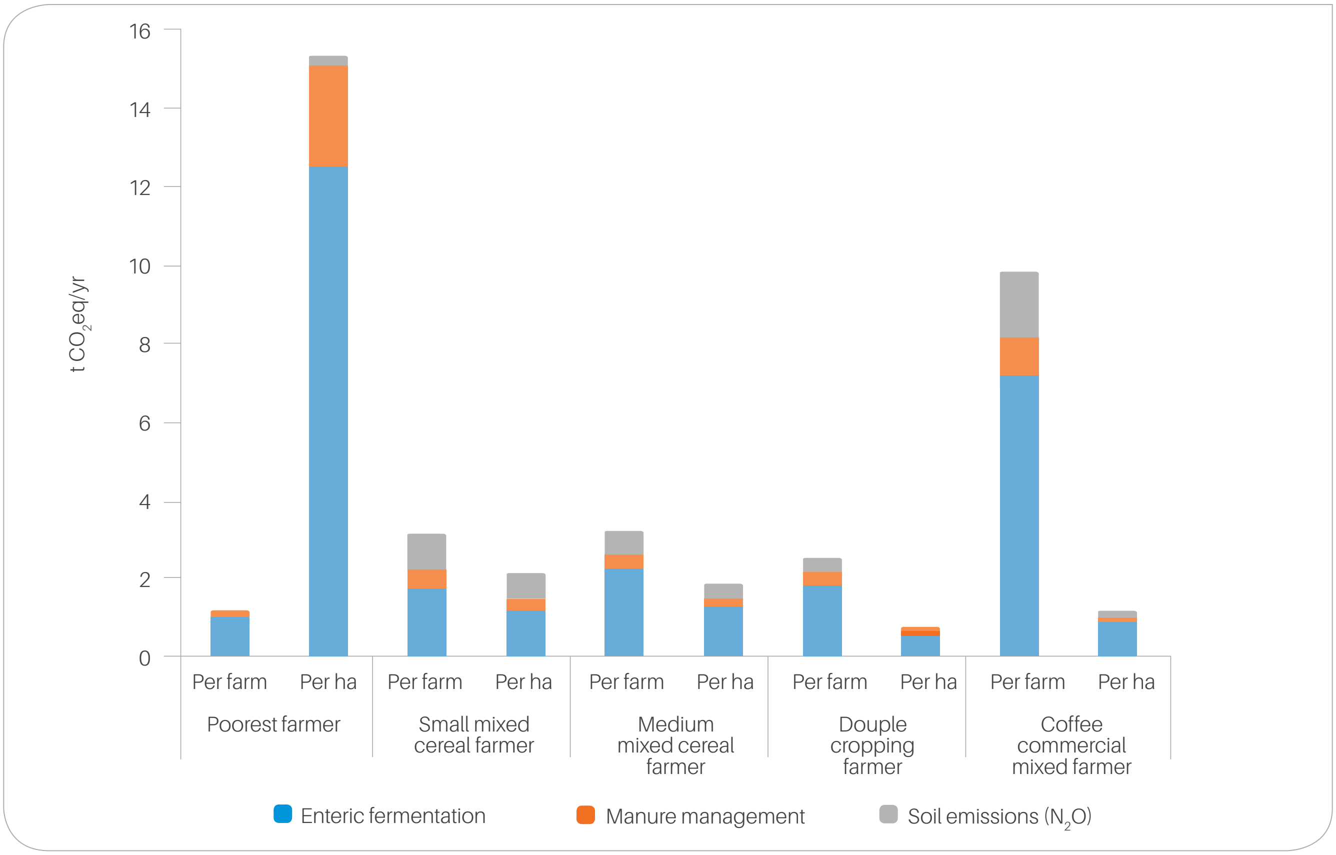
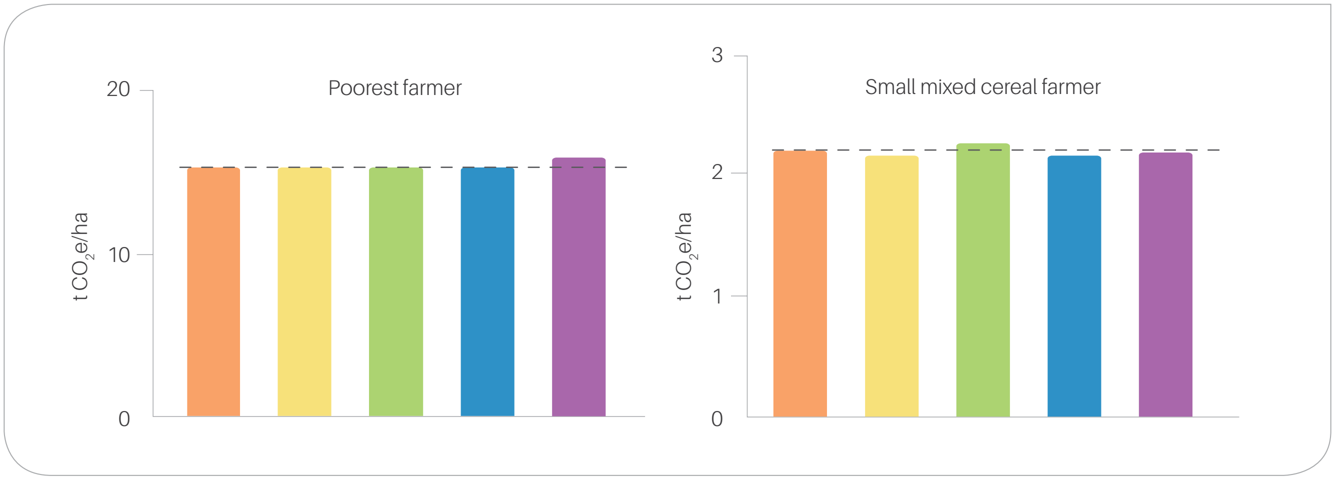


Figure 31: Baseline GHG emissions from enteric fermentation, manure management and soil emissions across farm types

5.4.3.2 Changes in GHG emissions

There is generally little to no change in GHG intensity from the baseline across the technologies in all farms (Figure 32). The 'Quality seeds + improved agronomy (incl. fertilizer + liming)' technology has the highest impact on GHG intensity per hectare across all farms. This is mostly as a result of the increase in fertilizer application (see Appendix II) as one of the impact dimensions of the technology, and therefore the increase in GHG emissions is mostly from soil $N_2 0$ direct emissions. In the poorest farm, there is no change in GHG intensity per hectare from the baseline across all technologies except in the quality seeds + improved agronomy technology where there is an increase of 0.5 t CO$_2$e/ha from the baseline.



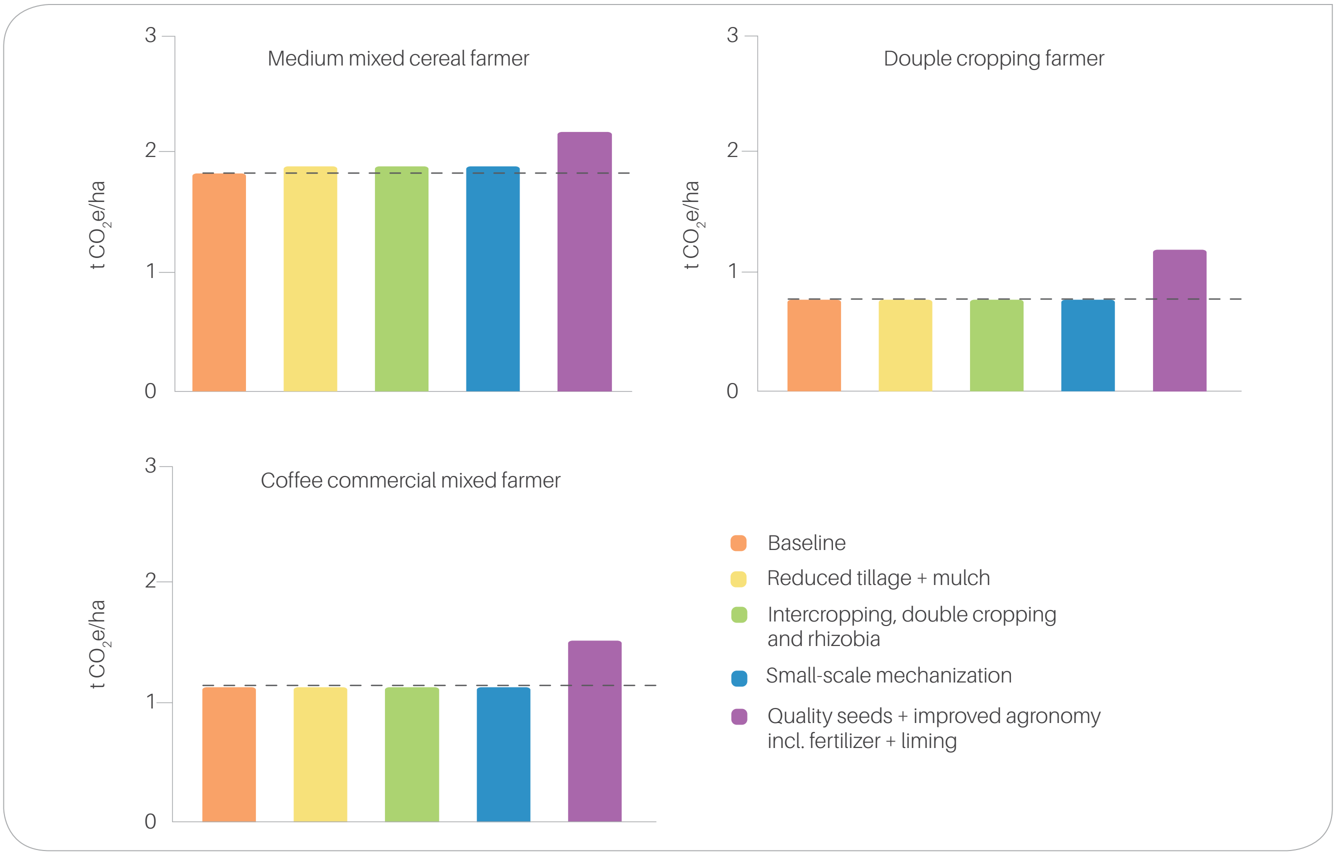


Figure 32: GHG emission intensity baselines and scenarios per farm type. Colours represent different scenarios

In the small mixed cereal farm there is no change in GHG intensity per hectare from the baseline across all technologies except in the quality seeds + improved agronomy and intercropping/double cropping + rhizobia technologies where there is a 0.6 t CO_2e/ha decrease and 0.1 t CO_2e/ha increase from the baseline respectively in GHG intensity. In the medium mixed cereal farm, there is a 0.1 t CO_2e /ha increase in GHG intensity per hectare from the baseline across all technologies except in the quality seeds + improved agronomy technology where there is an increase of 0.2 t CO_2e/ha from the baseline. In the double cropping farm, there is no increase in GHG intensity across all farms except the quality seeds + improved agronomy technology where there is an increase of 0.4 t CO_2e /ha from the baseline. In the coffee commercial mixed farm, there is no increase in GHG intensity across all farms except the quality seeds + improved agronomy technology where there is an increase of 0.3 t CO_2e/ha from the baseline.

5.4.4 Trade-offs

Truly triple-win climate-smart solutions, i.e. interventions that increase productivity, improve resilience and reduce GHG emissions, are rare. Instead, implementing soil conservation and rehabilitation measures often has a positive impact on just one or two of the CSA pillars but a negative effect on the remainder(s); i.e. trade-offs have to be made.

Trade-offs occur when improvement in one dimension of farm performance cause deterioration in another dimension. We plotted changes in productivity – as a food security indicator – against the changes in resilience (N balance, Figure 33) and mitigation (GHG emission intensity, Figure 34). In addition, we plotted changes in mitigation (GHG emission intensity) against the changes in resilience (N balance, Figure 35). These figures show trade-off and synergy patterns across farm types and soil technology scenarios. Plotting changes in productivity against changes in N balance allows for a few insights (Figure 33). Firstly, reduced tillage and mulch, and quality seeds with improved agronomy technologies are win-wins increasing productivity and N balance on all farms. The other technologies increase productivity while maintaining the N balance around baseline levels, except for intercropping, double cropping and rhizobia intervention in the poorest farm type. Different patterns appear when comparing changes in GHG emissions with changes in productivity (Figure 34). We find few synergies of decreased emissions and increased productivity (lower right quadrant). However, the increases in GHG emissions in general are not alarmingly large, which means that adopting any of the tested technologies should not be of concern in terms of negatively affecting the third pillar, mitigation, of climate smartness. When comparing changes in GHG emissions to changes in N balance, we find that some of the technologies do decrease GHG emissions, but at the cost of the nitrogen balance (Figure 35). Again, the increase in GHG emissions in general are not large, especially in all technologies except the quality seeds plus improved agronomy.

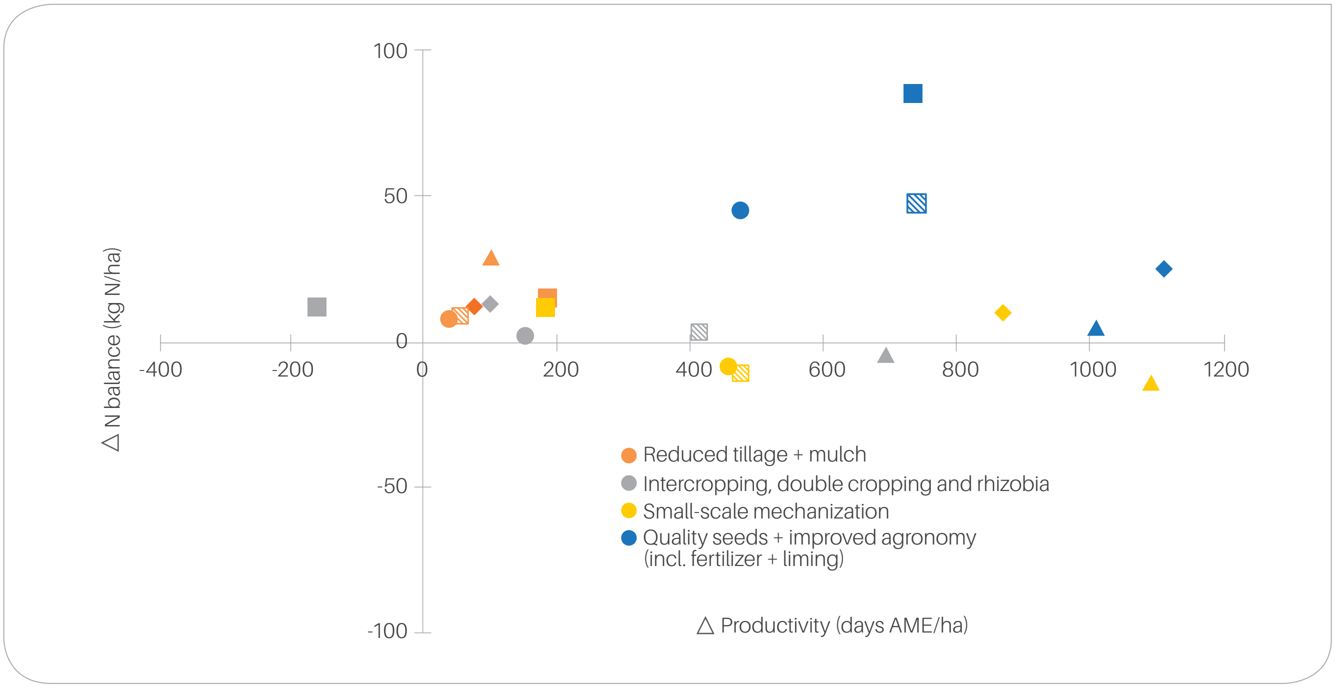


Figure 33: Trade-offs between productivity (days/ha) and field N balance (kg N/ha). Colour represents the scenario and shape the farm types (☐=poorest farm, △=Small mixed cereal farm, ◇ =Medium mixed cereal farm, ▧ with patterns=Double cropping farm and ○ =Coffee commercial mixed farm)

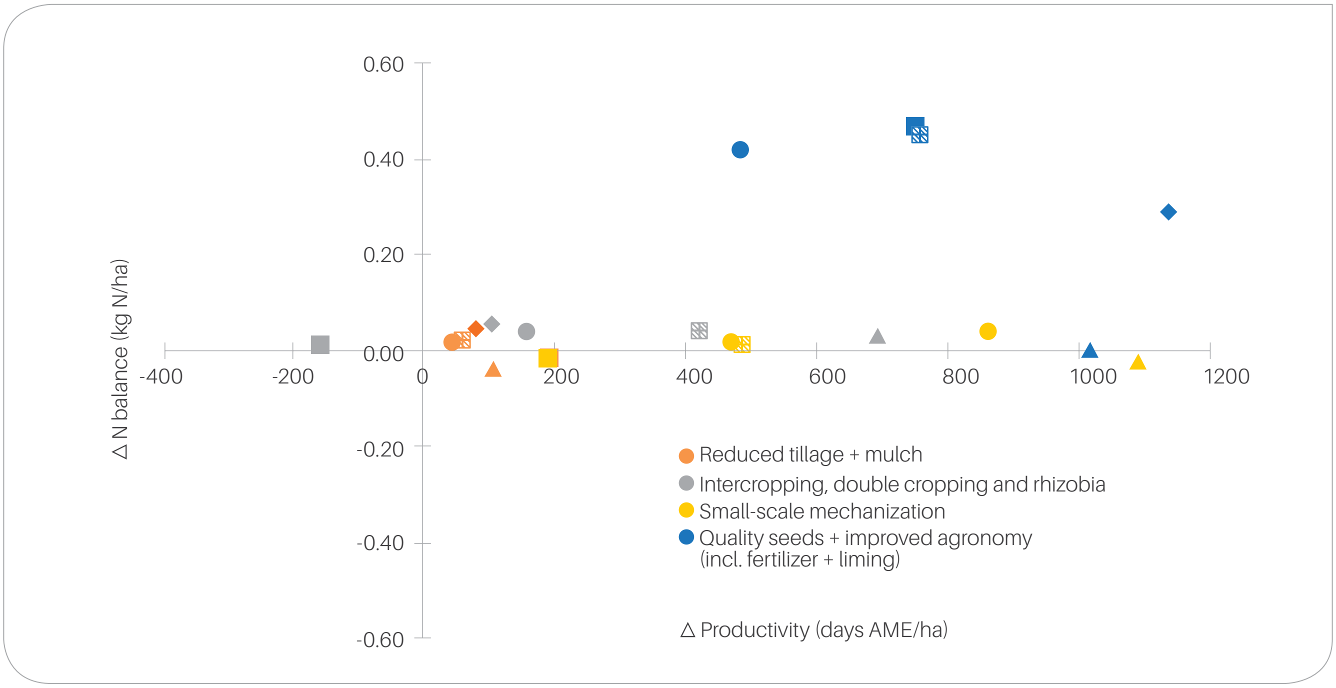


Figure 34: Trade-offs between productivity (days/ha) and GHG emissions (t CO_2e/ha). Colour represents the scenarios, and shape the farm types (□ =poorest farm, △ =Small mixed cereal farm, ◇ =Medium mixed cereal farm, ▧ with patterns=Double cropping farm and ○ =Coffee commercial mixed farm)

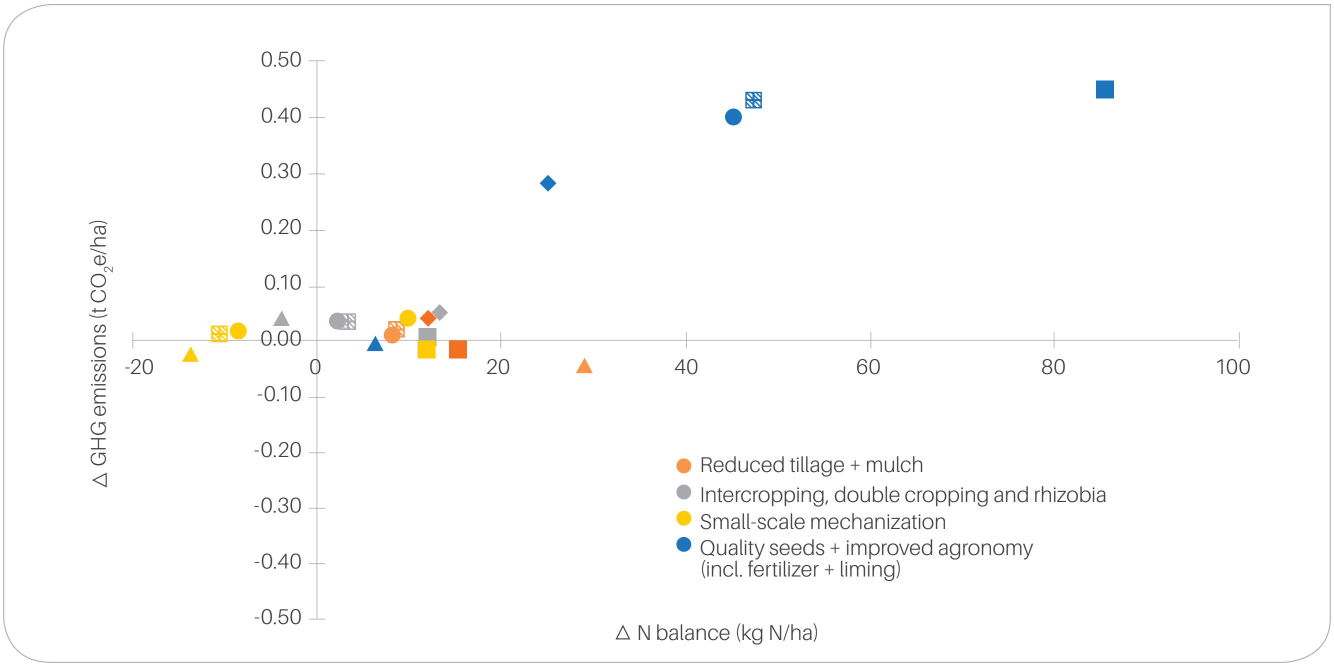


Figure 35: Trade-offs between GHG emissions (t CO_2e/ha) and change in N balance (kg N/ha). Colour represents the scenarios, and shape the farm types (□=poorest farm, △=Small mixed cereal farm, ◇ =Medium mixed cereal farm, ▧ with patterns=Double cropping and ○ =Coffee commercial mixed farm)

6 Kenya

6.1 Background

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, 2008). It accounts for 65% of Kenya's total exports and provides more than 70% of informal employment in the rural areas. Therefore, the 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. Thus, 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 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.

6.2 The case study farms

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). One farming system was added during discussions with GIZ and GOPA after the workshop, i.e. small subsistence semi-arid farms with large livestock herds (10–15 local cattle) under communal grazing management, situated in lower altitudes in Siaya in the vicinity of Lake Victoria. However, during field sampling, this type of farm was not included and no detailed information was collected. In this report no further distinction is made within the small subsistence farms. 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.

Table 2: 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%

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 three 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.

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 36).

1. Poor female-headed: This farm is about 0.56 ha with three household members; a middle-aged lady who is the head of the household and her two children, all uneducated except one of the children. This is an example of a resource-poor household with no off-farm income, no livestock and crops are mainly for household consumption. The main crops are maize and beans though the farmer has diversified and grown a mixture of cereals, legumes and tubers and the only input used for cultivation is farmyard manure which is bought and applied to maize, sorghum and sweet potatoes. The cropping activities are carried out by household members only because they cannot afford to hire casual workers and the land is small. Crop yields are the lowest compared to other farm typologies i.e. 1742 kg/ha maize and 299 kg/ha beans. All crop residue is left on the field during both seasons and firewood from scattered trees is the household's source of fuel.
2. Small mixed subsistence: This farm is 0.33 ha in size and is all under cultivation. The household is relatively small with a male household head, his wife and their three children. Maize and beans are the main crops, though the farmer has diversified and grown groundnuts, soya beans and banana trees. All crops are mainly for household consumption except bananas which are mostly sold. The only input used is DAP fertilizer when planting during the short rainy season which is bought at Ksh. 1000 for 10 kg and is applied to all the crops during the short rains. Maize and bean yields are slightly higher than the poorest farmer typology but lower than all other typologies, i.e. 2168 kg/ha maize and 626 kg/ha beans. Residue management is the same for both seasons and all crop residue is left on the field though some of the maize stover (25%) is also fed to livestock. All crop activities are carried out by household members only and the only input used is DAP fertilizer when planting during the short rainy season. There are currently 23 chicken on the farm, 5 cattle and 3 goats, and all the animals are of the local breed. There are no livestock products yet and all livestock activities are carried out by household members, except tick control which is done by the vet. The feed basket and quantities for all the animals remains the same during both wet and dry seasons. For goats and cattle, off-farm grazed natural grasses makes up the largest portion of the feed basket.
3. Mixed commercial dairy: This farm is 2.8 ha in size, of which 1.72 ha is under cultivation, 0.05 ha is under grassland and 0.1 ha is under trees. This is a small household made up of a household head, the wife and three young grandchildren as the children have already moved out of the house. Crops grown on the farm are sugarcane which covers the largest portion of the land (0.1 ha), maize grown only in the long rainy season and Napier each covering 0.25 ha, a banana plot covering less than 0.05 ha and a home-garden covering 0.05 ha. The Napier is fed to livestock through the cut-and-carry system and the maize is mostly for household consumption. During both the wet and dry seasons, all the sugarcane leaf residue and bottom half of the maize stalks are left on the field as mulch and the sugarcane green tops and maize stover are fed to livestock. Most of the livestock activities are carried out by the farmer himself and costs of inputs can be attributed to deworming and tick control and purchase of feeds. The feed basket for the improved cows varies for the two seasons but for the rest of the livestock it remains the same. For the cows, Napier makes up the largest percentage (80%) of the feed basket for both seasons.
4. Medium horticulture commercial: This farm is 0.97 ha in size and there are nine household members, though the farmer has rented land (0.75 acres) for cultivation and, therefore, the

farmer is managing a total of 1.26 ha of land. The farmer grows 14 different types of crops; legumes, cereals and horticultural crops of which the farmer specializes in the latter for commercial purposes. The horticultural crops grown are kales, pumpkin, butternut, cabbage, amaranth, green-pepper and tomatoes. Legumes on the farm are beans, cowpea and groundnut. Other crops are melon, sweet potato and maize. Mucuna cover-crop is also grown together with maize on one of the plots during the short rains and the farmer's reason for growing mucuna was mainly for conservation of soil moisture as the rainfall is less in the short rainy season and to increase carbon content in the soil from incorporation of the leaves into the soil. Most of the horticultural crops are for sale. The household depends on both hired (casual) and family labour. Manure is applied on all crop fields and DAP fertilizer is applied on maize and horticultural crops only. There are 45 chicken, 8 rabbits and 3 female goats Napier (cut and carry) from a Napier strip on the farm make up the largest percentage of the feed basket for goats. Livestock also feed on boma Rhodes, Sesabania and Calliandra. More crop residue is fed during the dry season than the wet season and maize bran makes up the largest percentage of the feed basket.

5. Large commercial: This farm is 5.6 ha large of which 5.2 ha is under cultivation and the rest is under natural grassland (pasture). This household represents the highly-endowed type of farmer with large productive assets. Household members are many (eight household members excluding two permanent workers) and children are highly educated. Coffee is the main crop which is grown wholly for commercial purposes (sold to coffee mills) and covers 2.8 ha. After harvesting, the coffee berries are then processed on the farm which involves sorting, pulping, drying and fermentation. The coffee is dried on a wire-meshed structure before being stored, awaiting fermentation. Other crops grown are maize and Napier which cover 0.8 ha and 0.4 acre respectively. A narrow banana strip can be found at the edge of the coffee plot. Fertilizers are used on all crops including Napier.

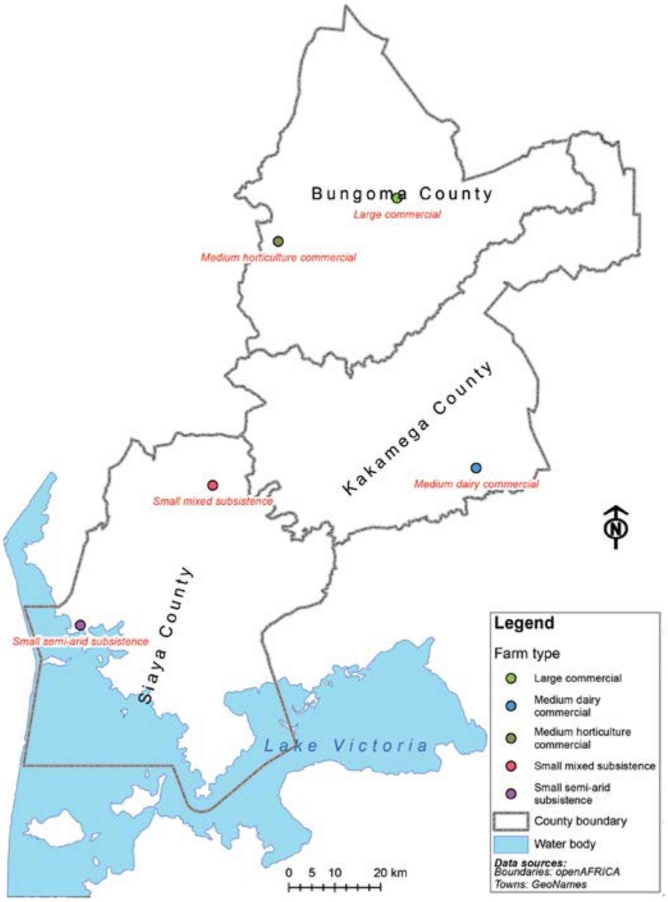


Figure 36: Location of case study farms in Western Kenya

NPK is applied to coffee, CAN and DAP are applied to maize and CAN is applied to Napier. The farmer has 8 improved cows (6 adults and 2 calves), 3 improved sheep and only 4 chicken. Livestock activities are mostly carried out by the permanent workers. Napier makes up the largest percentage and grazed natural grasses make up the largest portions of the feed basket. The cows spend their time in a non-roofed enclosure and on-farm grazing area. The chicken are fed through free range mostly and the sheep spend 16 hours in a roofed enclosure and the remaining hours grazing on the grassland area on the farm.

6.3 Technology descriptions and scenarios

The following scenarios represent soil rehabilitation interventions that are currently promoted by GIZ 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, allyields 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 additions, 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.

6.4 Results

6.4.1 Productivity pillar

6.4.1.1 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 37). 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.

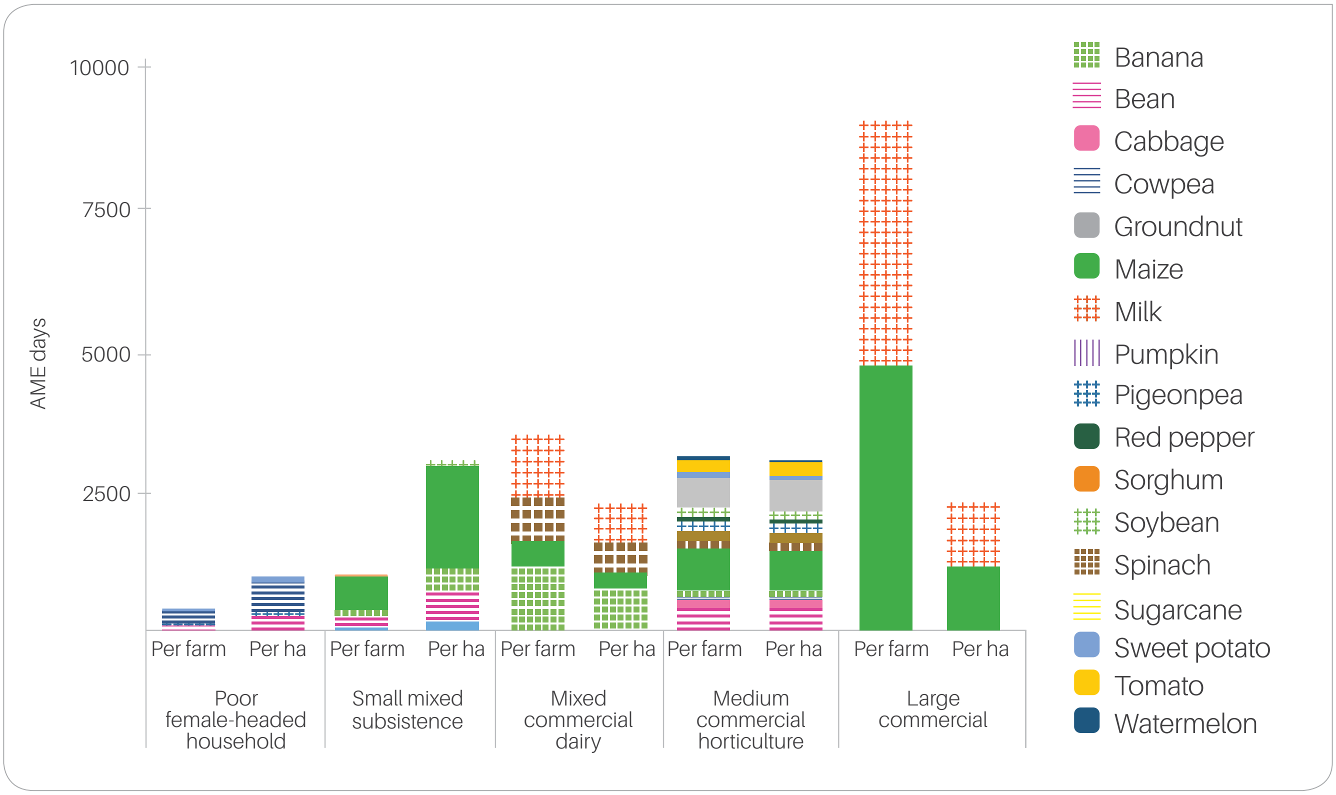


Figure 37: Baseline productivity and contribution from the different products across farm types. *Productivity is expressed as number of days that 1 adult male equivalent (AME) can be fed from livestock and crop products produced on the farm*

6.4.1.2 Changes in productivity

Introducing the technologies described earlier is projected to generally increase productivity across all farm types (Figure 38). 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.

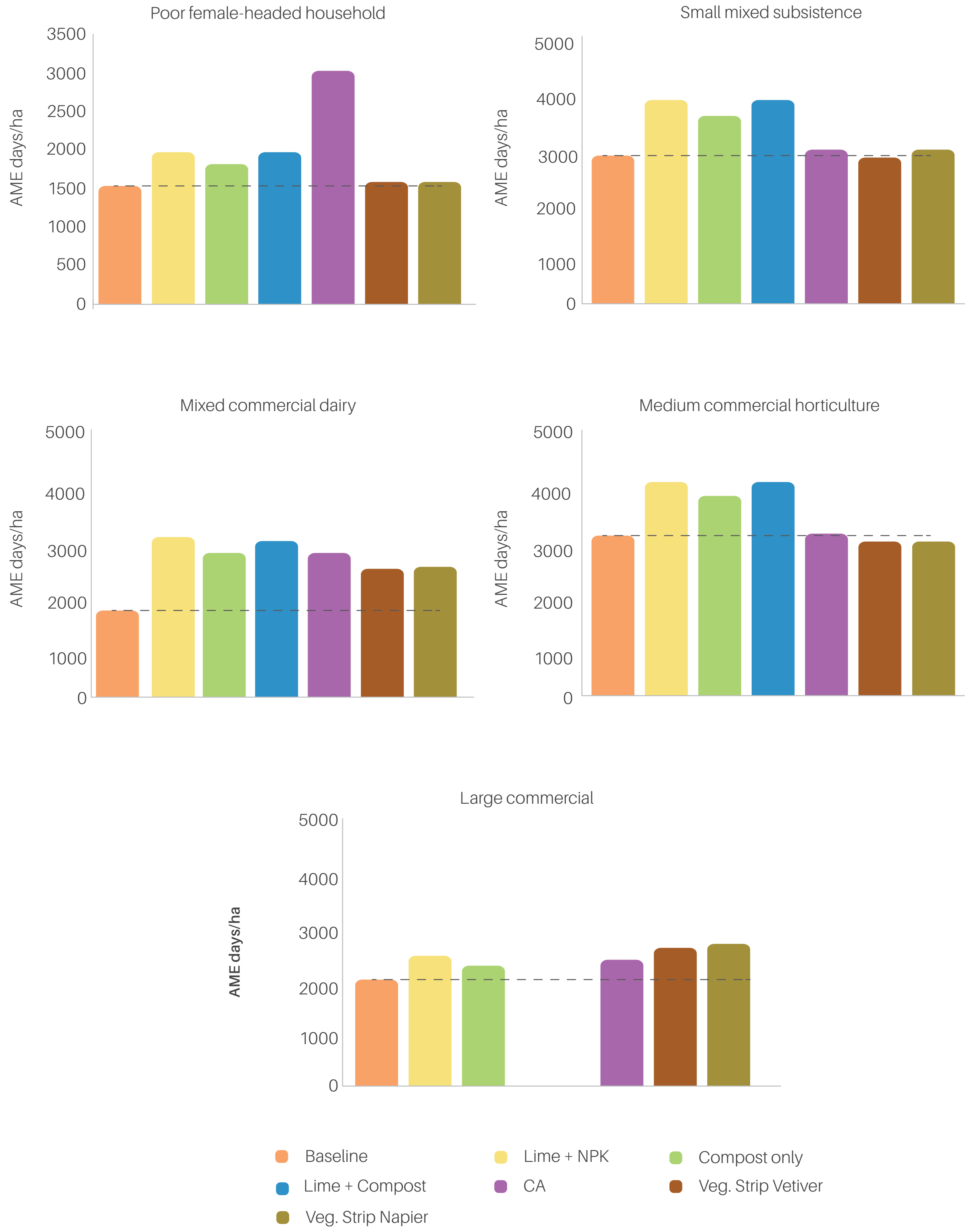


Figure 38: Baseline and scenario productivity per farm type. *Results are expressed in days of Adult Male Equivalent calories (AME = 2500 kcal/day) on a per-hectare basis*

6.4.2 Resilience pillar

6.4.2.1 Baseline N balances

A negative N balance was calculated for all farms except the small mixed subsistence and large commercial farms (Figure 39). 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.

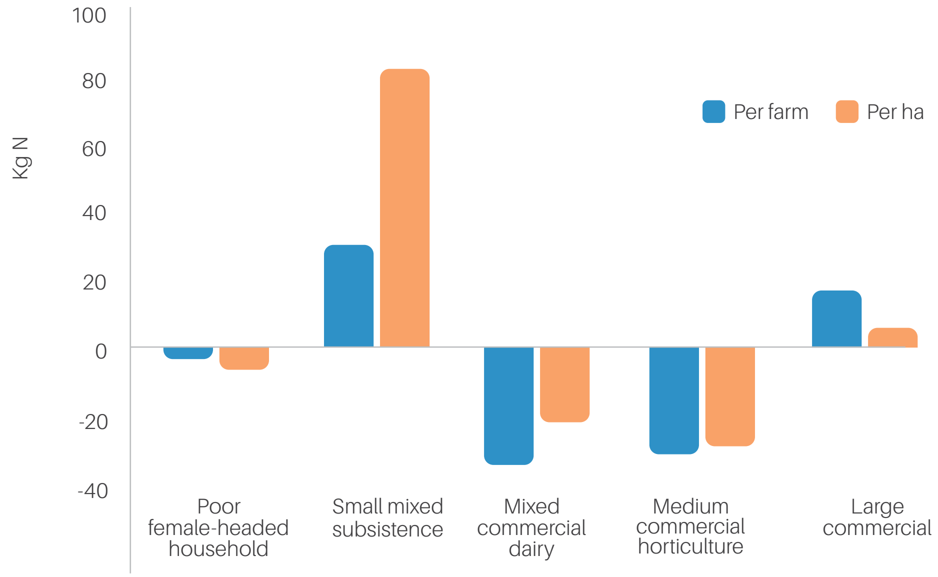


Figure 39: Baseline N balance at field level per farm and hectare across farm types

6.4.2.2 Changes in N balance

Implementing the different soil technology scenarios affects the N balance differently across farms (Figure 40). 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.

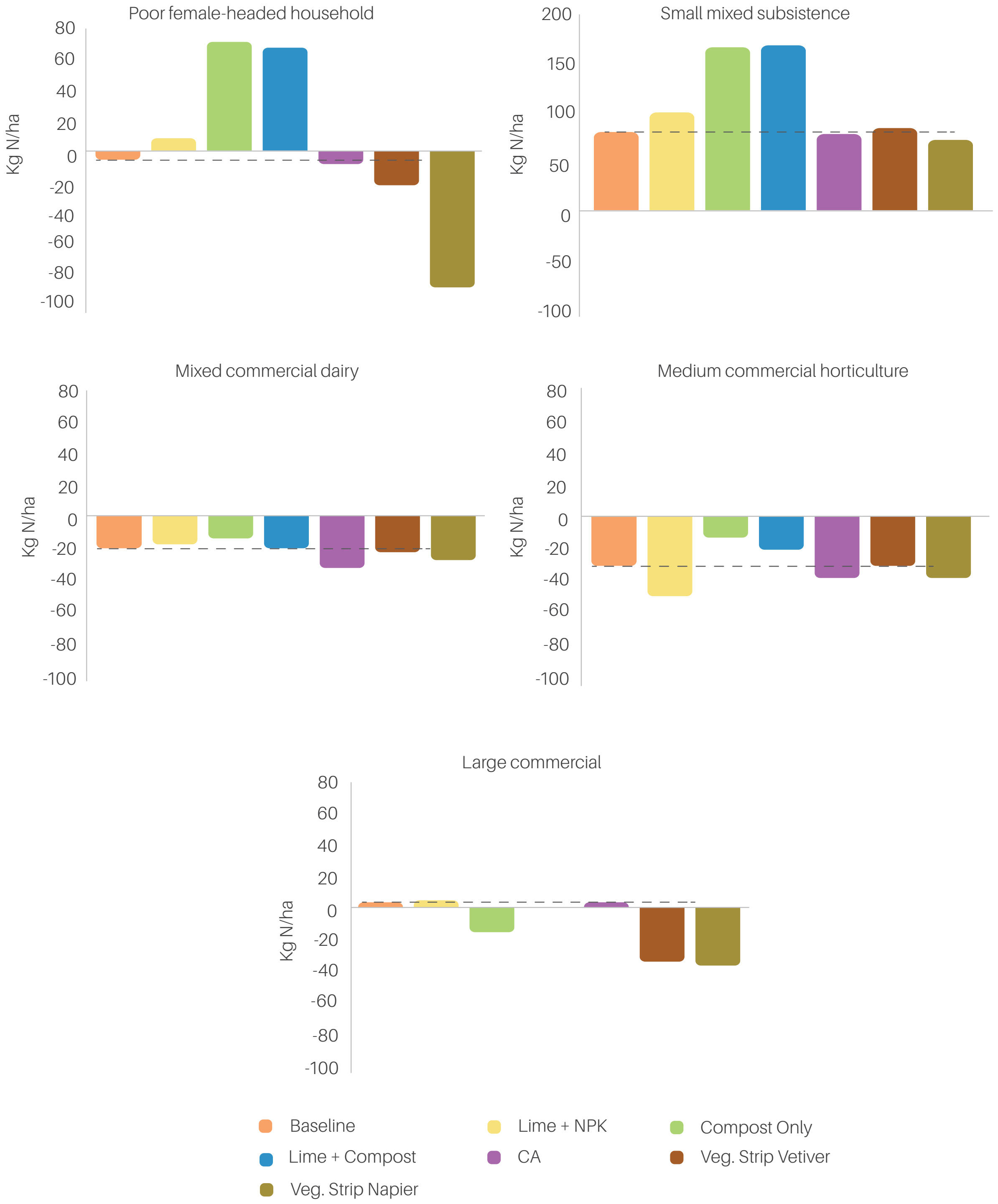


Figure 40: N balance of baselines and scenarios across farms (kg N/ha)

6.4.2.3 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 200 kg soil/ha (Figure 41).

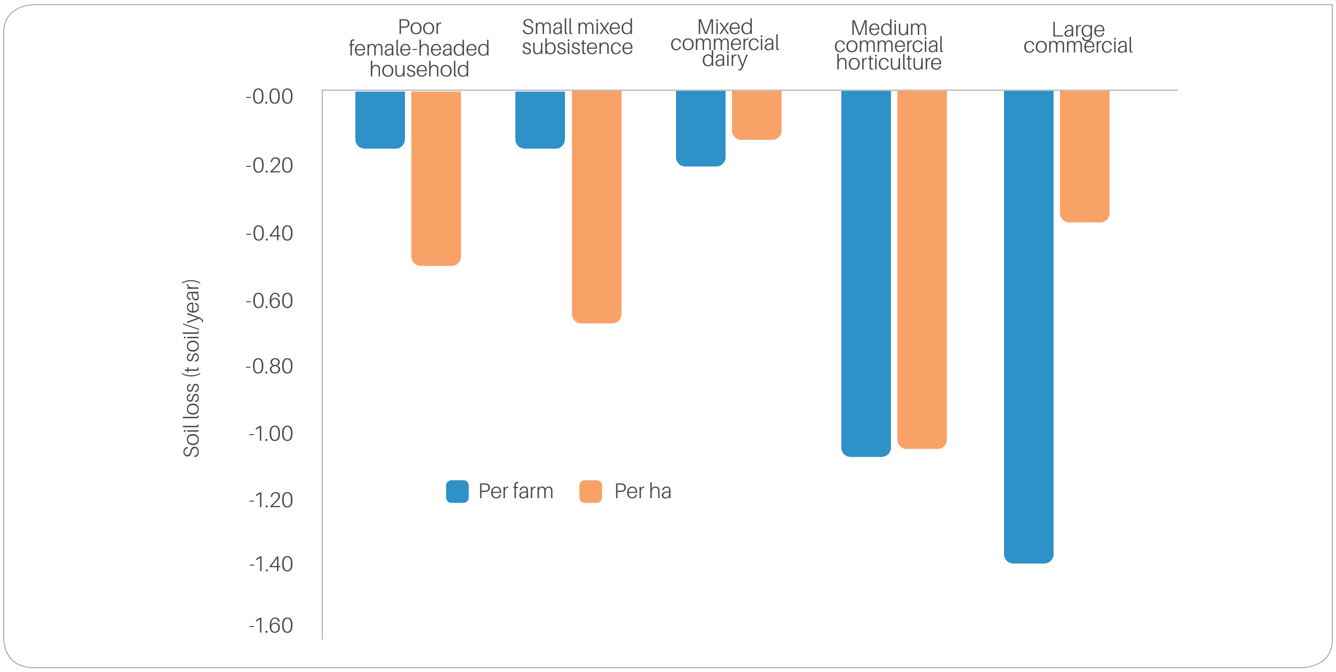
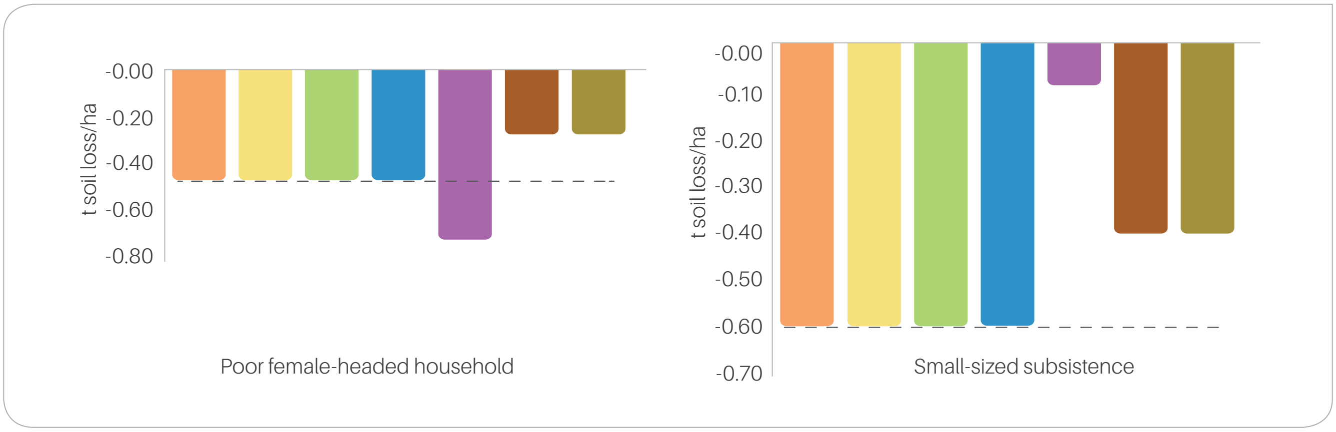


Figure 41: Baseline soil erosion (t soil/year), per farm or per hectare

6.4.2.4 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 42). 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.



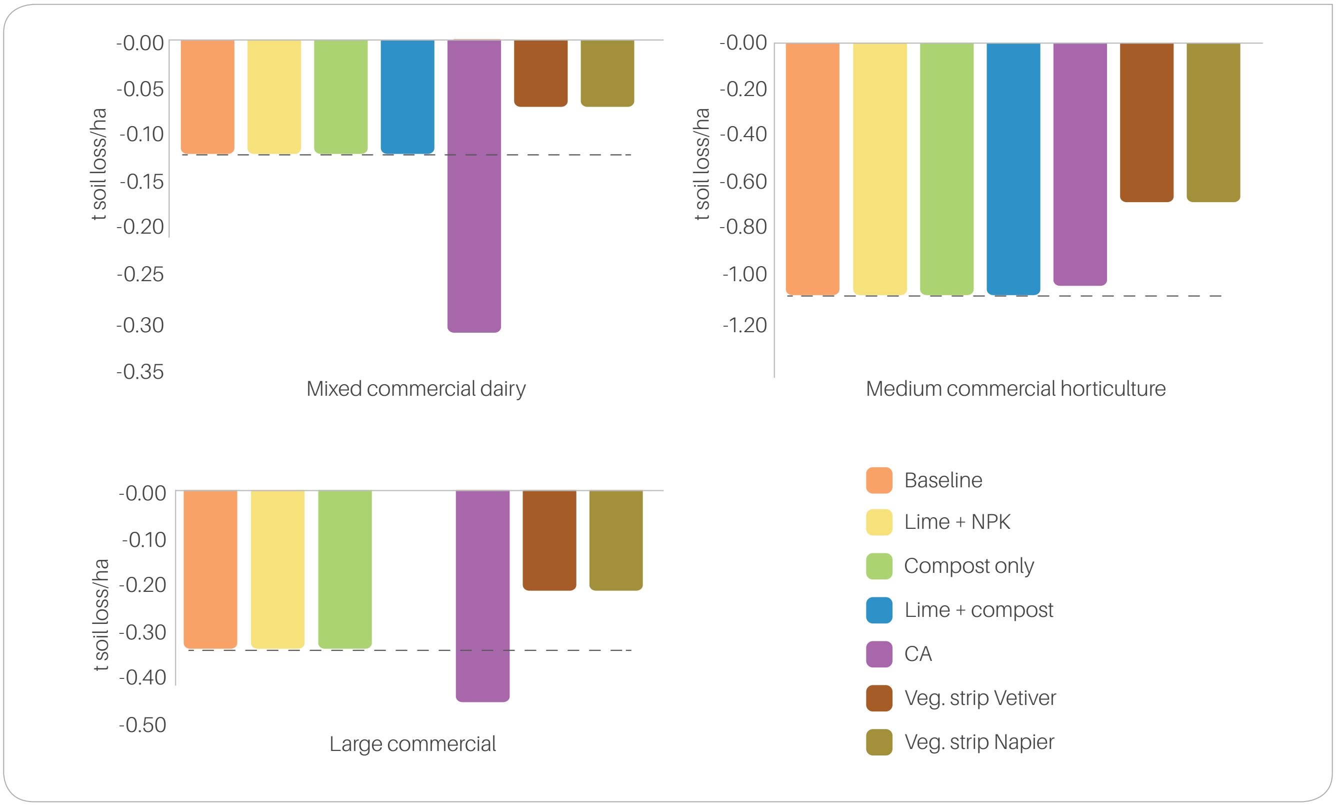


Figure 42: Soil erosion baselines and scenarios across farms (t soil/ha)

6.4.3 Mitigation pillar

6.4.3.1 Baseline greenhouse gas emissions

GHG emissions comprise emissions through enteric fermentation (methane), manure management (methane and nitrous oxide) and soil emissions (nitrous oxide and, if rice is cropped – not in Western Kenya though – methane). For easy comparison, these are converted into equivalents of carbon dioxide emissions (CO_2e).

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.

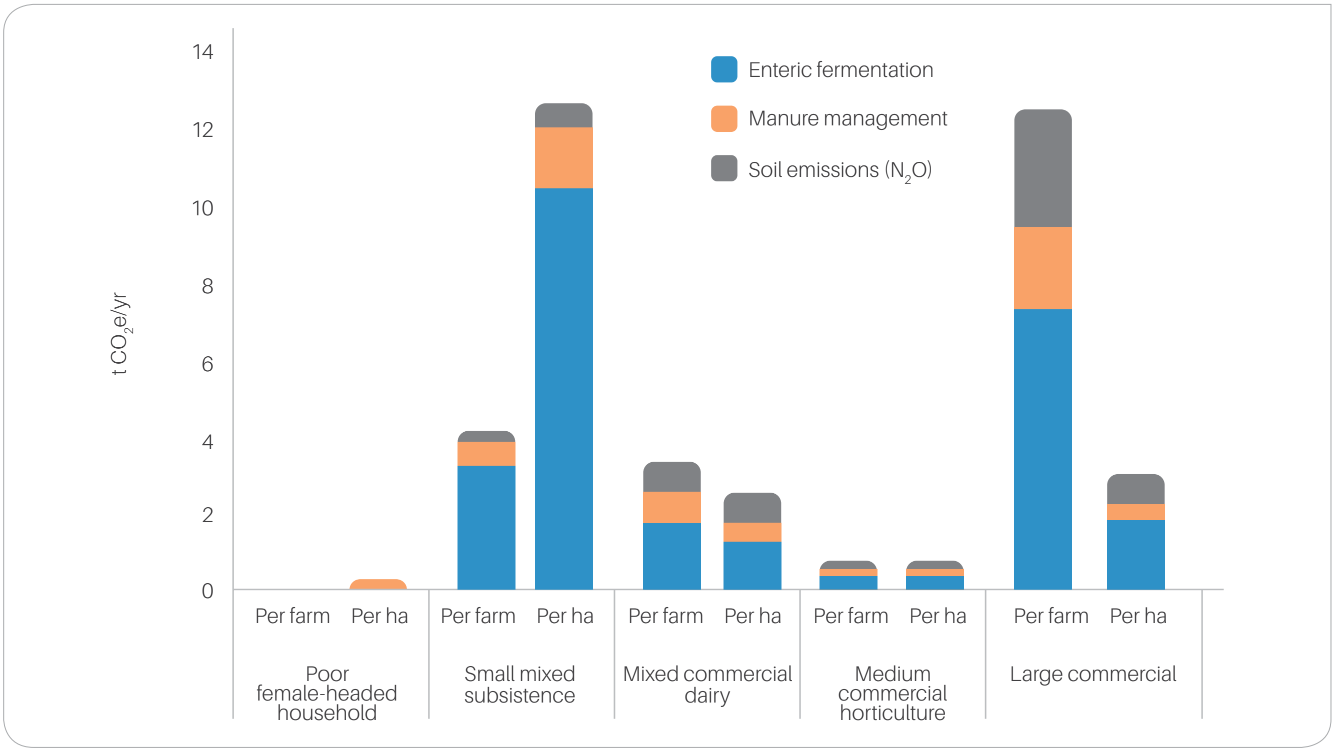
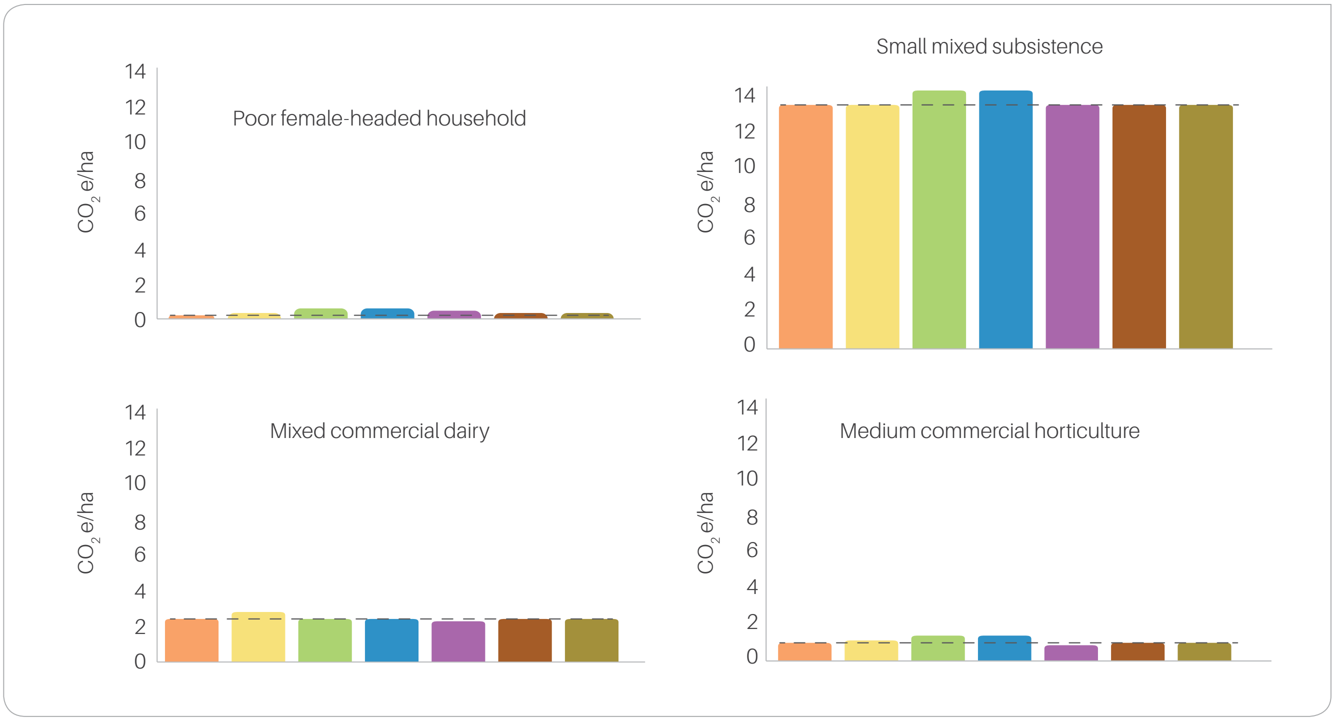


Figure 43: Baseline GHG emissions from enteric fermentation, manure management and soil emissions across farm types

6.4.3.2 Changes in GHG emissions

In the first three 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 43).



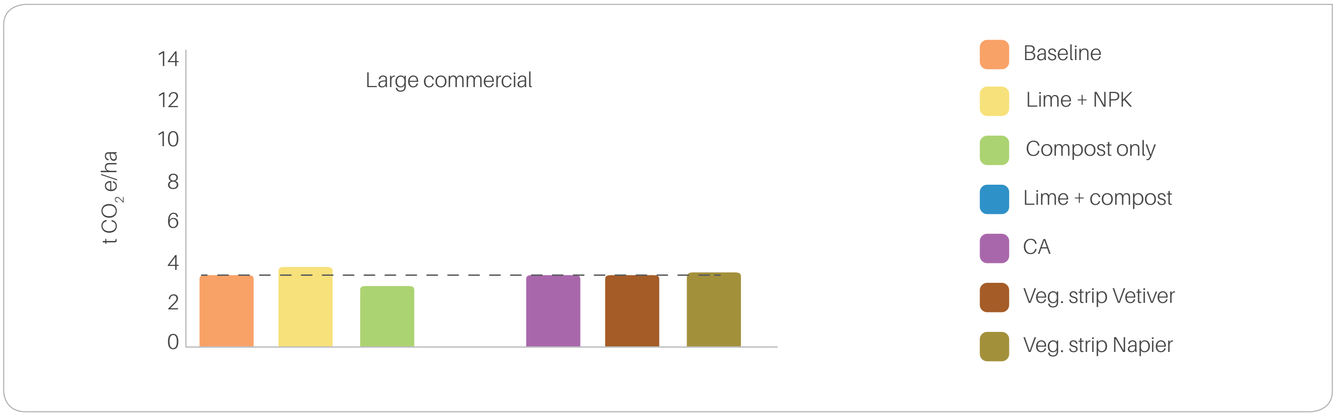


Figure 44: GHG emission intensity baselines and scenarios across farms

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.

6.4.4 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 45) and mitigation (GHG emission intensity, Figure 46). These figures show trade-off and synergy patterns across farm types and soil technology scenarios.

In Figure 45, 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. When looking at synergies and trade-offs between changes in productivity and GHG emissions (Figure 46), 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.

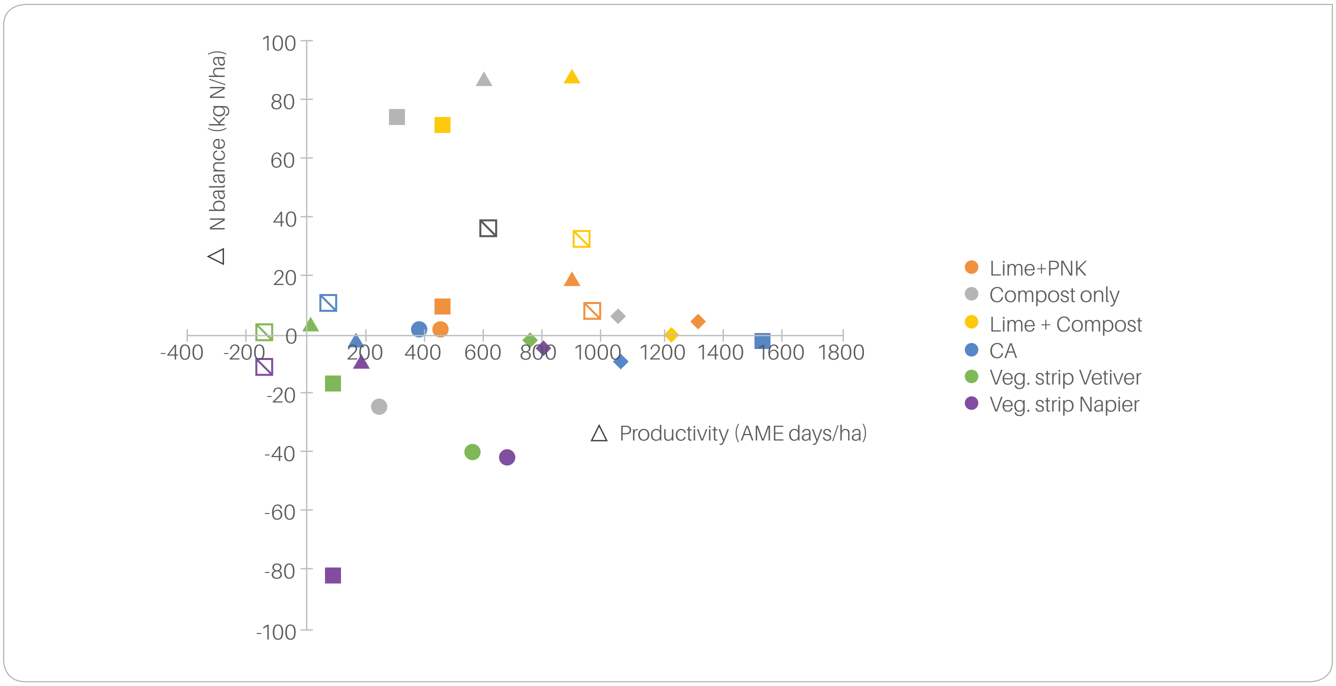


Figure 45: Trade-offs between changes in productivity (AME days/ha) and field N balance (kg N/ha) when moving from baseline to soil conserving technologies. Colours represent the scenario and shape the farm types (□=Poor female-headed household, △=Small mixed subsistence, ◇=Mixed commercial dairy, ⧄ with patterns=Medium commercial horticulture and ○=Large commercial)

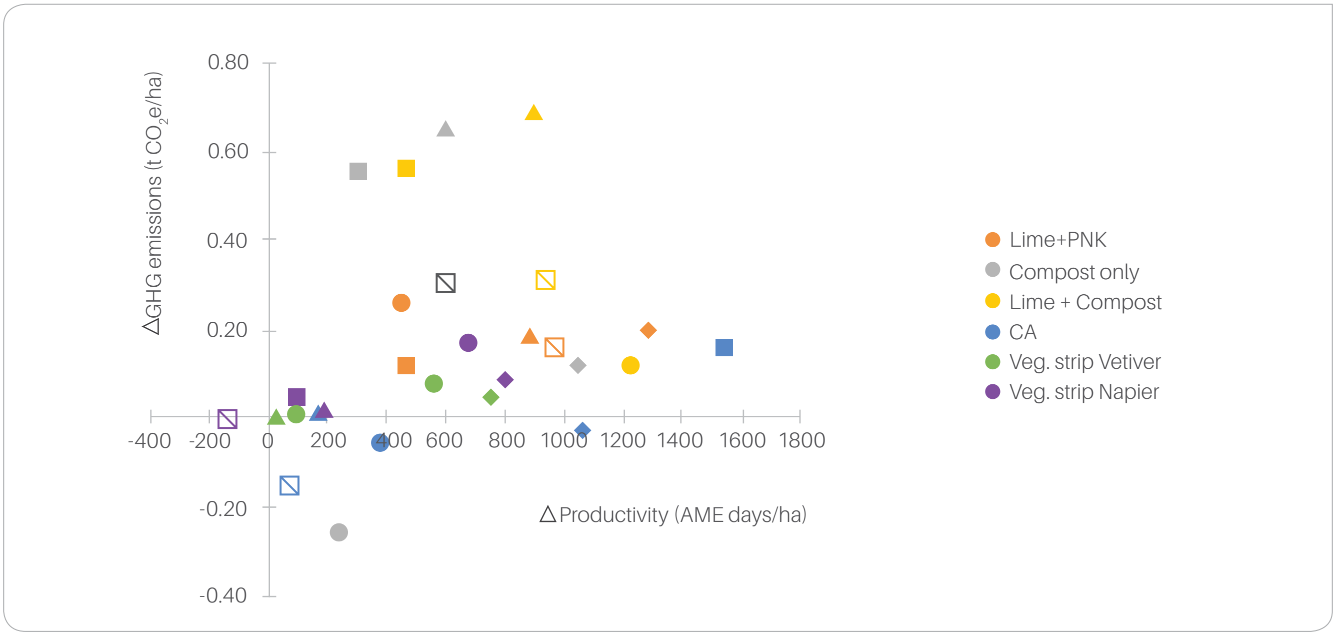


Figure 46: Trade-offs between changes in productivity (AME days/ha) and GHG emissions (t CO_2e/ha) comparing baseline and soil conservation scenarios; Colours represent the scenarios, and shape the farm types (□=Poor female-headed household, △=Small mixed subsistence, ◇=Mixed commercial dairy, ⧄ with patterns=Medium commercial horticulture and ○=Large commercial)

7 India

7.1 Background

As far as India is concerned, “the sustainability of agriculture is the crisis India faces today” (Misra and Prakash, 2013). By 2030, India will have to annually produce 345 million tons (Mt) of food grains against the production of about 265 Mt in 2013–14 (ICAR, 2015). Meanwhile, the average farm holding size declined from 2.26 ha in 1970–71 to 1.6 ha in 2010–11 while the number of farm holdings increased from 71 to 138 million during the same period, mainly due to progressive fragmentation of land holdings (Ganeshamurthy, 2014).

At the same time, soil erosion and loss of soil fertility are affecting crop productivity and food security (Nair, 2014). Climate change could exacerbate the issue, whereas the Indian dry areas, such as in the state of Maharashtra, are especially vulnerable. As rainfall intensities are projected to increase with progressing climate change, so is soil erosion (Mondal et al., 2014). Higher temperatures as well as reduced overall amounts of rainfall have been projected to negatively impact rice (Soora et al., 2013) and wheat (Naresh Kumar et al., 2014) productivity in India; the two major staple food crops of the country. There is little evidence that other crops will not be similarly affected.

India has come a long way, especially concerning the issue of food security and soil protection & health. To start with, the Green Revolution in the late 1960s/early 70s was propelled by the idea that boosting agricultural productivity helped to create a “springboard” out of poverty in Asia and provided the foundation for the broader economic and industrial development (World Bank 2005; Hazell, 2009; Pingali, 2012). The Green Revolution gains in agricultural productivity, food security and reduced poverty were widely associated with irrigated areas, where the benefits of improved seeds and increased use of inorganic fertilizers could be realized, while the majority of the farmers in arid and semi-arid regions could not fully reap the benefits. On the other hand, the massively increased use of chemical (only) fertilizers during the green revolution, had, and is having, negative side-effects. Among others, incentives for judicious use of inputs were, and are, largely absent, the Green Revolution incurred a range of significant hidden ecological and social costs (Shiva, 1991; Dubey and Lal, 2009; Brainerd and Menon, 2014). In response to these issues, as well as to the observed slowdown in increases of agricultural yields threatening long-term food security (Janaiah et al., 2005; Manna et al., 2005), some re-thinking took place over the past 10 to 20 years. Increasingly, the value of agricultural sustainability, as well as the fundamental importance of soil protection, uniting productivity and the integrity of the natural resource base, came into focus. Claims were made towards initiating a new, second (or 2.0) or real green revolution (Horlings and Marsden, 2011) that, among others, “embraces the concept of agroecology, i.e. the application of ecological science to the study, design, and management of sustainable agriculture” (De Schutter and Vanloqueren, 2012).

In line with this trend, organic agriculture, though still somewhat underappreciated in India, is gaining incredible momentum. In 2013, according to Willer and Lernoud (2016), 99.2 million hectares of cereals were produced organically, making India the number 1 organic producer of cereals as far as acreage is concerned.

Recently, the importance of social inclusion and participation has been added, and authors like Srivastava et al. (2016) "propose a «commercial ecological agriculture» which should be an amalgamation of sustainable agricultural practices and supported by a progressive coordination among all the stakeholders."

Within this context, 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) 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 CIAT-led project 'Climate-smart soil protection and rehabilitation in Benin, Burkina Faso, Ethiopia, India and Kenya', supports the BMZ-GIZ Soil program, and intends to widen the scope of soil protection and rehabilitation for food security by aligning with the goals of CSA. The project builds on CIAT's expertise in both soil science and CSA. It assesses the climate smartness of selected, GIZ-endorsed soil protection and rehabilitation measures in the five countries because, 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 strong potential to contribute to all three pillars of CSA. There is a need to align soil protection and climate-smart agriculture, in implementation of agricultural innovation practices that address soil degradation issues and climate change mitigation and adaptation.

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, as well as potential to increase the climate smartness of these measures.

This report focuses on the GIZ-supported soil protection and rehabilitation work ongoing in India, and summarizes the result of a first, rapid assessment of the climate smartness of suggested, best-bet technologies to protect or rehabilitate soils.

7.2 The case study farms

Four farm types were identified during the initial participatory workshop held on 5–6 April, 2016, in Darewadi, India. Workshop participants identified the dryland famers, the dryland diversified farmers, the rice farmers and the specialized irrigation farmers. A complete description of the different farm types can be found in the workshop report by Braslow et al. (2016). The percentage distribution of farm types per research region is shown in Table 3. Not only does this distribution vary, so does also the distribution within regions by clusters (Table 4). One case study farm was selected for each of the farm types. The farms chosen were typical farms that could be used as a representative of the farmers within each farm type. These farms were visited and detailed information was collected for the use as input data to model GHG emissions, nitrogen balance, erosion and farm production. The location of the sampled farms is shown in Figure 47.

Table 3: Percentages of farm types per research region

District	Dryland farmer	Dryland diversified farmer	Rice farmer	Specialized irrigation farmer
	%	%	%	%
Ahmednagar	23	5	7	65
Dhule	50	5	35	10
Jalna	60	35	0	5
Yavatmal	15	70	0	15
Amaravati	10	75	0	15
Overall project area	5	50	20	25

Table 4: Percentages of farm types per cluster

District	Dryland farmer	Dryland diversified farmer	Rice farmer	Specialized irrigation farmer
	%	%	%	%
Bhalawani (Ahmednagar)	25	5	0	70
Pimpalner (Dhule)	10	5	75	10
Bhokardan (Jalna)	70	20	0	10
Dhamangaon (Amaravati)	10	75	0	15
Asoli, Devdhari & Atmurdi (Yavatmal)	10	75	0	15

1. Dryland farmer: This farm is 3.24 ha in size and is all under cultivation including rented land (2.42 ha) and there are 6 household members. Crops grown are cotton, pigeon pea and soybean, with pigeon pea occupying the largest areas i.e. 1.62 ha. This household mostly depends on hired labour for crop activities and family labour (male household head) for livestock activities. Urea, NPK and DAP are applied on crop fields. Crop residues are mostly fed to livestock. There are 8 local cattle (3 dairy, 2 bulls, 1 calf, 1 heifer and 1 young male) and no non-ruminants on the farm. Crop residues make up the largest portion of the feed basket. The livestock spend of their time in the stable, yard, on crop fields and off-farm and manure collected is applied on crop fields.
2. Diversified dryland farmer: This farm is 8.9 ha in size ha and is all under cultivation, including rented land (2.42 ha) and there are 6 household members. Crops grown are cotton, pigeon pea, traditional vegetables, wheat, soybean and sorghum, with pigeon pea and cotton occupying the largest areas, i.e. 4.13 ha and 3.52 ha respectively. This household depends on hired labour and a permanent worker for all crop activities and the permanent worker alone for all livestock activities. Urea, NPK and DAP are applied on crop fields. Crop residues are mostly fed to livestock. There are 8 local cattle (3 dairy, 2 bulls, 1 calf, 1 heifer and 1 young male) and no non-ruminants on the farm. Crop residues make up the largest portion of the feed basket. The livestock spend of their time in the stable, on crop fields and off-farm and manure collected is applied on crop fields.
3. Rice farmer: This farm is 2.02 ha in size ha and is all under cultivation and there are 6 household members. Rice is the main crop and is mostly grown for household consumption though some of it is sold. Groundnut, millet and mango trees are also grown. This household depends on hired labour and family and hired labour for crop and livestock activities. No fertilizers are applied to crop fields, only manure collected from the animals' stables and from the yard. Crop residues are mostly fed to livestock. There are 18 local cattle (12 dairy, 4 bulls and 2 calves), 5 goats of which 3 are dairy goats and 12 chicken. Crop residues make up the largest portion of the feed basket in the dry season whereas in the wet season the livestock mostly feed on off-farm pasture. The livestock spend of their time in the stable, yard, on crop fields and off-farm and manure collected is applied on crop fields.
4. Specialized irrigation farmer: This farm is 2.43 ha in size ha and is all under cultivation and there are five household members. Maize, marigold, green gram, horse bean, moth bean, pigeon pea, chick pea, sorghum and onion are grown on the farm. This household depends on hired labour and family and hired labour for crop and livestock activities. NPK fertilizer and manure collected from the animals' stables and from the yard are applied on crop fields. Crop residues are mostly fed to livestock. There are 30 chicken, 2 local bulls and 24 goats, 2 of which are dairy goats. Crop residues make up the largest portion of the feed basket. The livestock spend of their time in the stable, yard, on crop fields and off-farm and manure collected in the stable and yard is applied on crop fields.

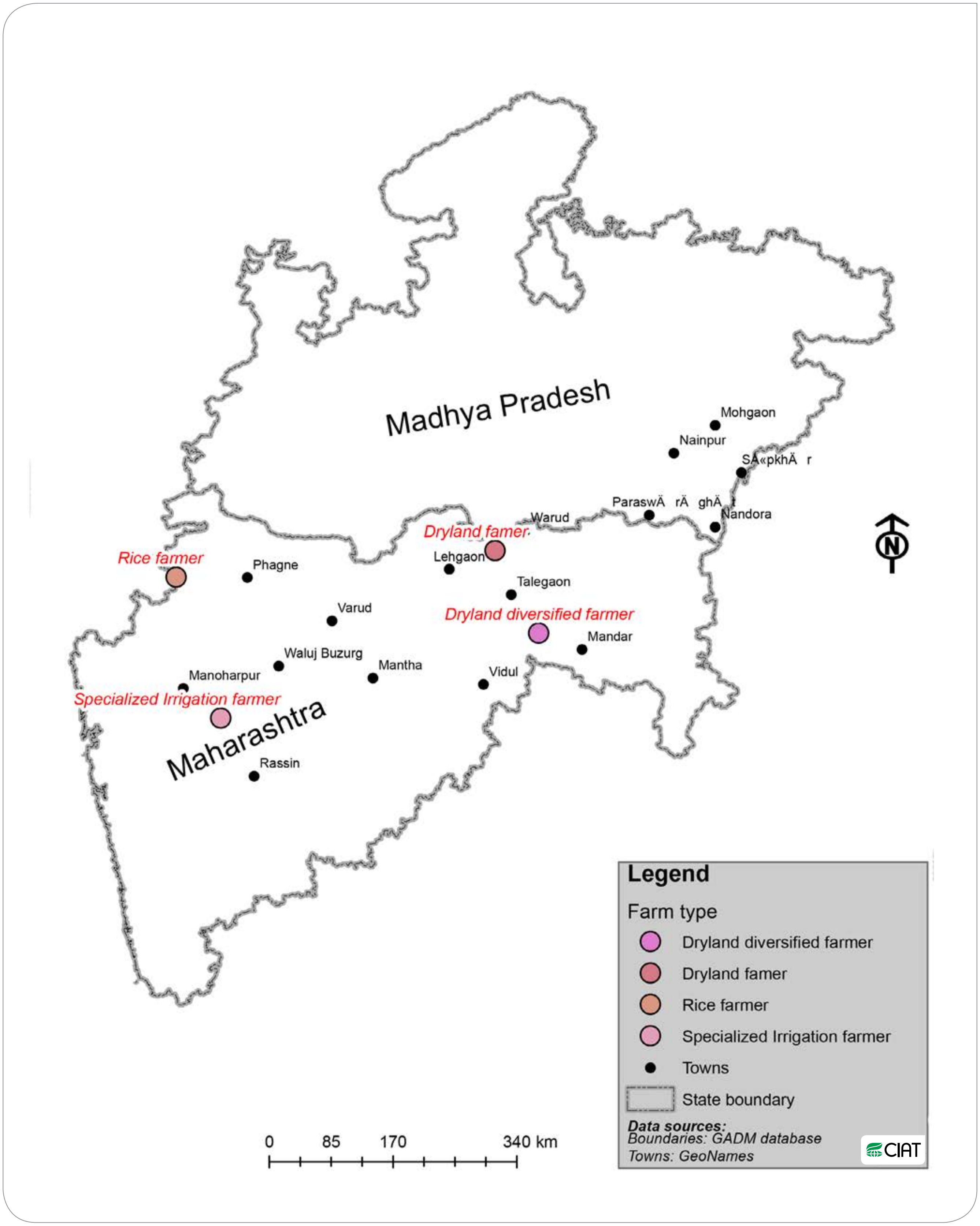


Figure 47: Case study farms location in Maharashtra

7.3 Technology description and scenarios

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

i. Composting/green manure/farm yard manure

ii. Intercropping/ crop rotation and rhizobium inoculation

iii. Reduced tillage + mulch (dryland farms only), or mulching only (rice farmer and specialized irrigation farmer only)

iv. System of rice intensification (rice farmer only)

Soil fertility improvement technologies comprised two components, composting/green manure application and rhizobia inoculation, of which the latter was merged with intercropping/double cropping.

In the composting/green manure/farm yard manure scenario, two thirds of the crop residues were removed from the fields after harvest for composting. The amount of compost or farm yard manure (FYM) applied to the fields ranged between 2.5 and 7 t/ha across the farms. Further assumptions on the impact dimensions of composting included reduction in manure application by 20% and increase in crop yield by 7–25% across the farms.

In the intercropping/double cropping with rhizobia inoculation scenario, cereal crop yields were assumed to reduce by 15% due to the competition with the intercropped beans, and fields that were left fallow during the short rainy season were instead rotated with chickpea. Rhizobia inoculation was done on all legumes, and assumed to have no impact on yields, but instead imply savings in mineral N fertilizer application by 5–20%.

The reduced tillage and mulch scenario entailed a 67% residue retention on crop fields, 10% reduction in organic and inorganic fertilizer application, and increase in crop productivity by 5–22.5%. As a result, milk production was estimated to increase by 5% in the specialized farm, while the anticipated in increase in crop yields in the other farm types were assumed too little to have any effect on milk production.

The System of Rice Intensification (SRI) scenario was assumed to increase rice yields by 10%, without any associated change in milk production, as rice straw feed is of only poor quality.

7.4 Results

7.4.1 Productivity pillar

7.4.1.1 Baseline productivity

On farm productivity was calculated by summing up all the calories from crop and livestock products produced on farm and dividing by the calorie requirements of an average adult (AME: Adult Male Equivalent; 2500 kcal/day). Productivity is thus expressed in number of AME days (Figure 48).

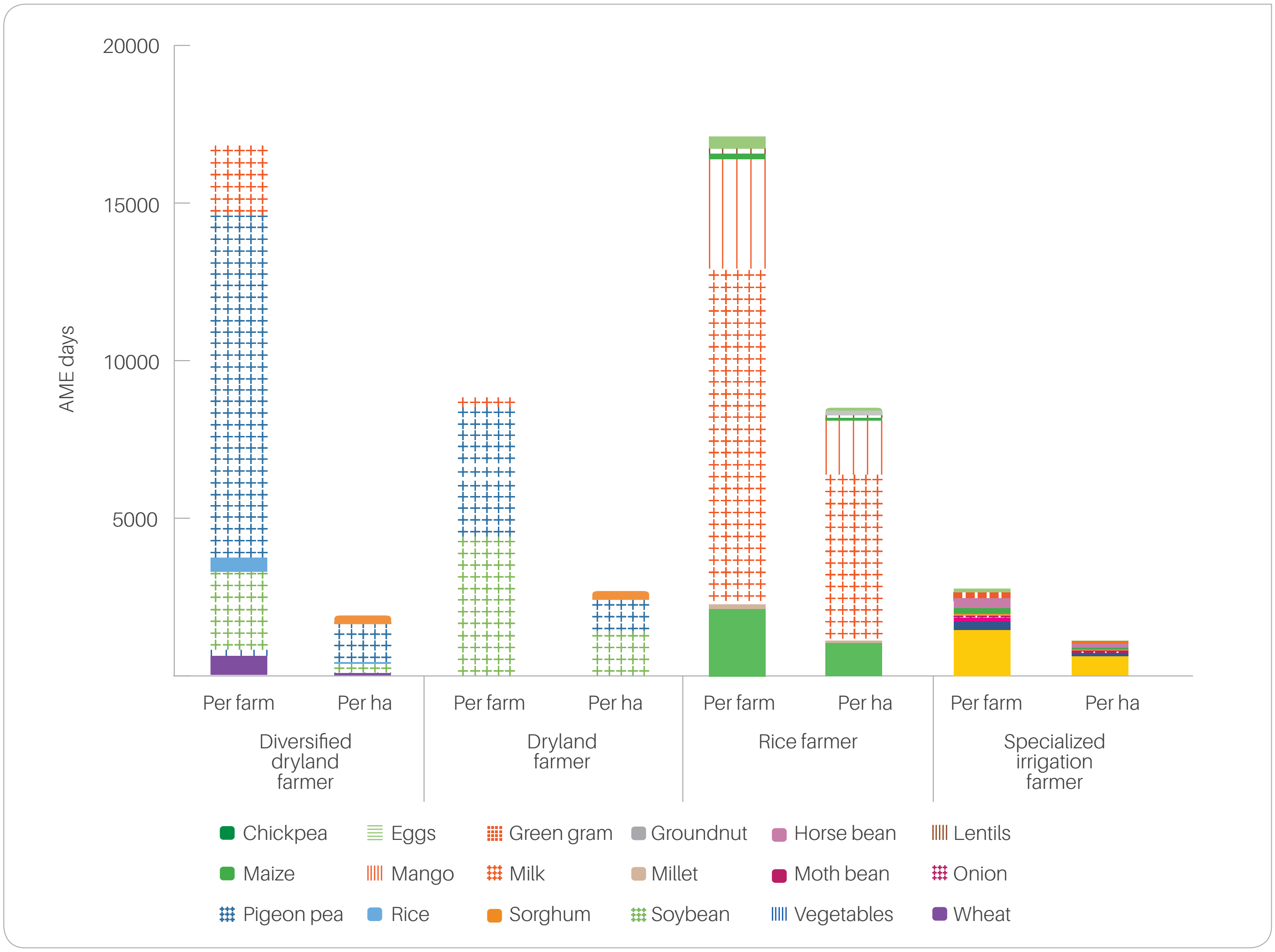


Figure 48: Baseline productivity and contribution from the different products across farm types. *Productivity is expressed in days of equivalent calories an adult male (AME)*

The rice farm has the highest productivity – per farm and per hectare, mainly because of the significant addition of calories from milk from the (exceptionally) high numbers of dairy cows. Interestingly here, rice ranks only third in terms of calories added, despite the fact that the farm type is named for the activity of rice cultivation. Pigeon pea and soybean add notably to the productivity of the two dryland farms. The specialized irrigation farm has the lowest productivity, whereas sorghum is the most important source of calories, while milk from the 2 goats adds only little. However, it must be noted that the interviewed farmer of this type had 22 goats – only the aforementioned (on average) 2 producing milk. The meat production from these animals will add to the overall farm productivity, but has not been included in this report.

7.4.1.2 Changes in productivity

Productivity changes little across all farms in response to the implementation of the five different technologies (Figure 49). This is by large a result of the technology selection per se. Selected technologies primarily aim at protecting and rehabilitating soils. On the other hand, it is noteworthy that none of the technologies had a negative impact on farm productivity overall. Composting sticks out somewhat, which should not be surprising given the notable amounts of compost and farm yard manure added to the fields in this scenario.

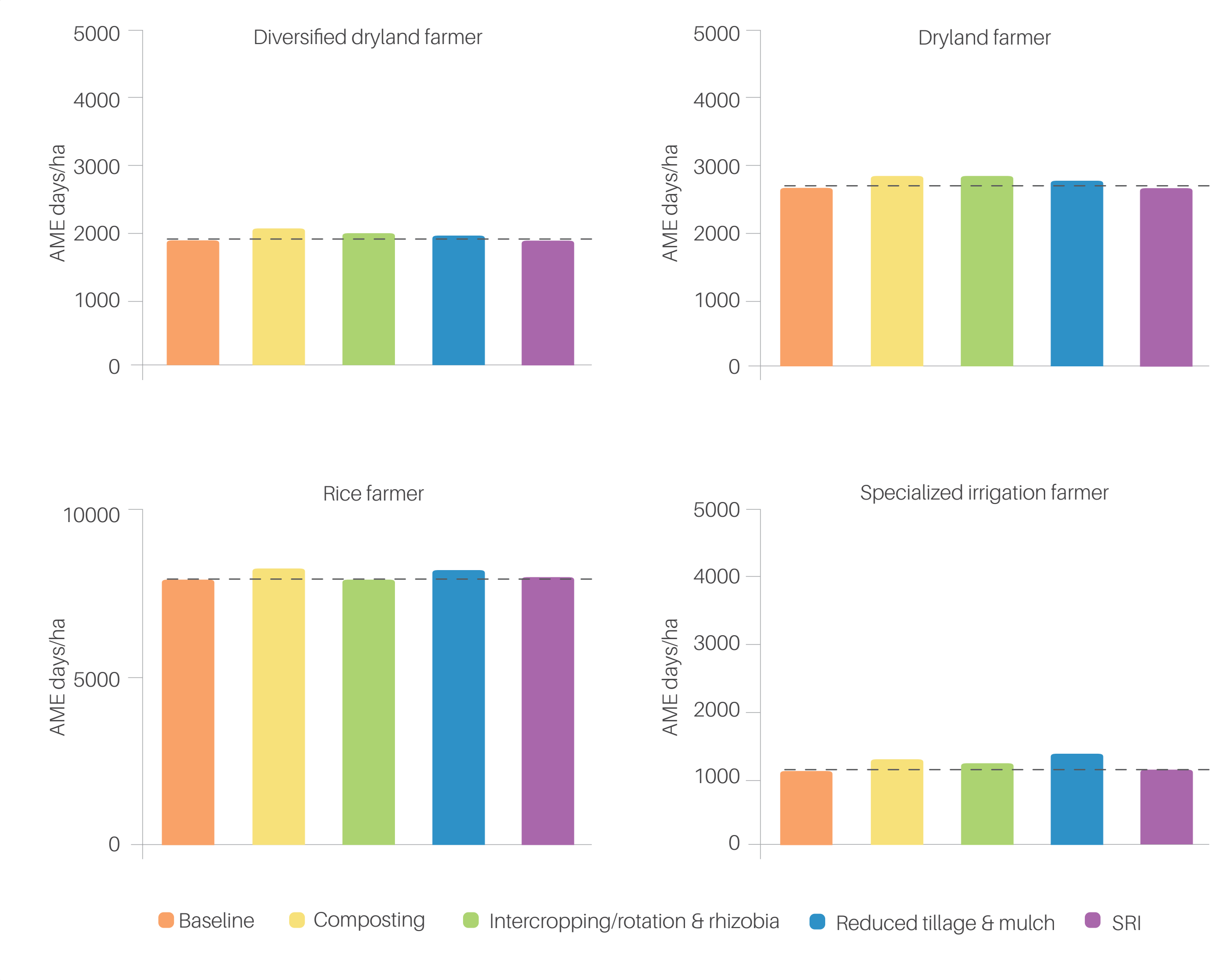


Figure 49: Baseline and scenario productivity per farm type. *Results are expressed in days of Adult Male Equivalent calories (AME = 2500 kcal/day) on a per hectare basis*

7.4.2 Resilience pillar

7.4.2.1 Baseline N balances

The nitrogen (N) balance is calculated at the field level (please refer to the appendix for further details on the calculations). The per-farm N balance is the sum of N balance of the individual fields, and the per hectare balance equal to the per-farm balance divided by the acreage of the farm.

The N balance is positive on all farms (Figure 50). Excessive fertilizer application to cotton and pigeon pea are mostly responsible for the positive balance of the diversified dryland farm and the dryland farm. Soybean production with more N fertilizer applied than N withdrawn during harvest adds to the positive balance of the latter farm. The addition of about 300 kg N/ha (most of it coming from manure) to the rice crop that yields only 2 t/ha grains, is also more N than required, and thus results in a positive overall N balance on the rice farm. In the case of the specialized irrigation farmer, N inputs hardly compensate for the N extracted with the harvested products for all crops grown in the Rabi season, and all but onions (receiving 160 kg N/ha through mineral fertilizer) in the Kharif season. In total, this farm is thus very close to a fully balanced N-budget.

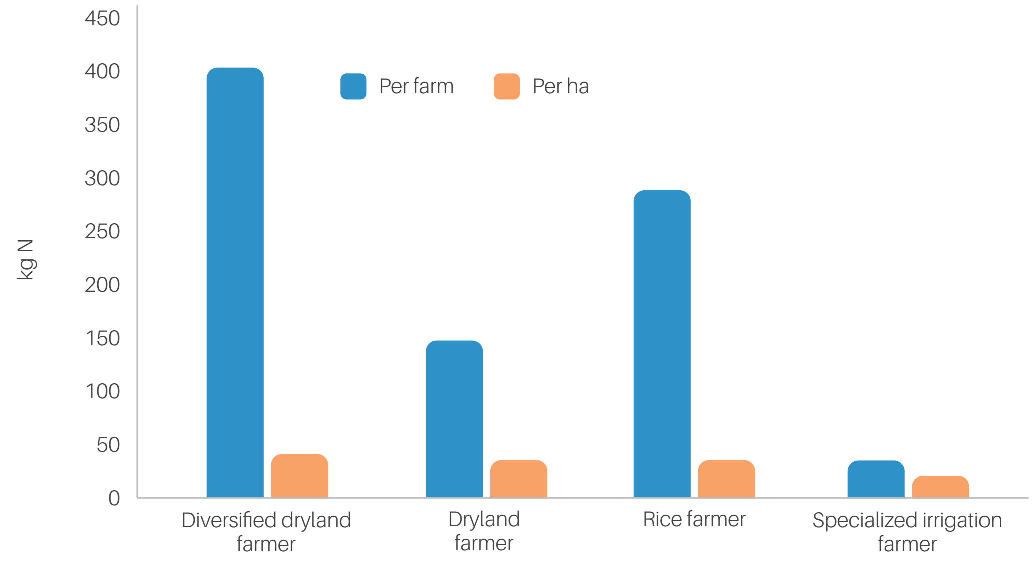
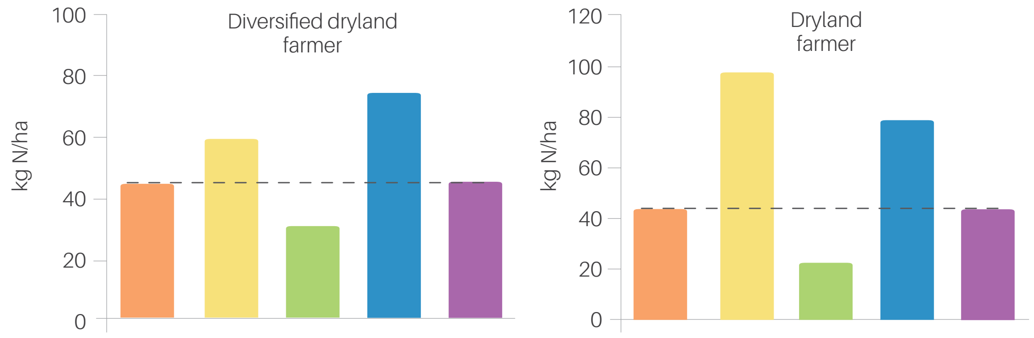


Figure 50: Baseline N balance at field level per farm and hectare across farm types

7.4.2.2 Changes in N balance

Composting results in the highest increase in N balance across most farm types, because too much N is added in the form of compost in comparison to the anticipated increases in yield and the foreseen reduction in mineral N fertilizer rates (Figure 51). This is especially visible in the specialized irrigation farm, where a) assumed rates of compost or farmyard manure as in the case of all the specialized farm types (7.5 t/ha) were the highest in comparison to the other farms, and b) compost addition was very high in comparison to baseline N-inputs. Thus, there is scope to re-evaluate/optimize the way this technology is implemented against the anticipated impacts. Reduced tillage in combination with mulch ranks second and increases the N balance by 22 kg N/ha (rice farm) to maximum 37 kg N/ha (dryland farm), which is largely due to increased residue retention as opposed to the conventional residue management system of removing all crop residue from the field. However, this technology reduces the N balance by 7 kg N/ha on the specialized irrigation farmer, yet the balance remains positive. Introducing the System of rice intensification (SRI) and intercropping/double cropping with rhizobia inoculation affect the N balance the least. The accompanying reduction in mineral N fertilizer rates decreases the surpluses of N added to the system, while the (humble) assumed increases in yields increase N use efficiency. This seems most beneficial for systems, where N balance surpluses are already present in the baseline, and a reduction rather than increase of N-inputs is required.



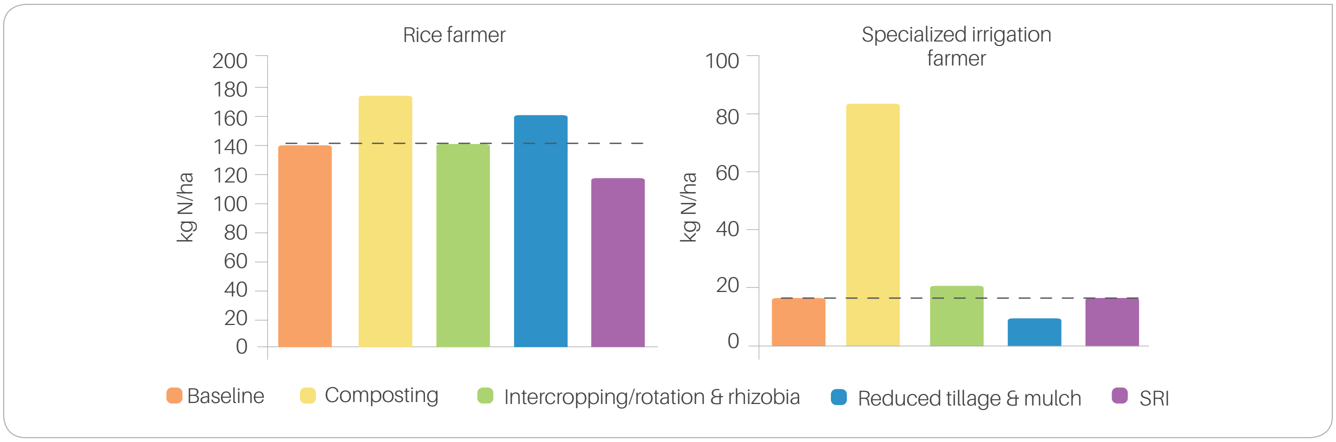


Figure 51: Nitrogen balance baselines and scenarios across farms (kg/ha)

7.4.2.3 Baseline erosion

Soil erosion is negligible with all farms losing less than 2.5 t/ha/year except the diversified dryland farm, which loses about 5 t/ha/year (Figure 52). This is attributed to the fact that the land is rather flat.

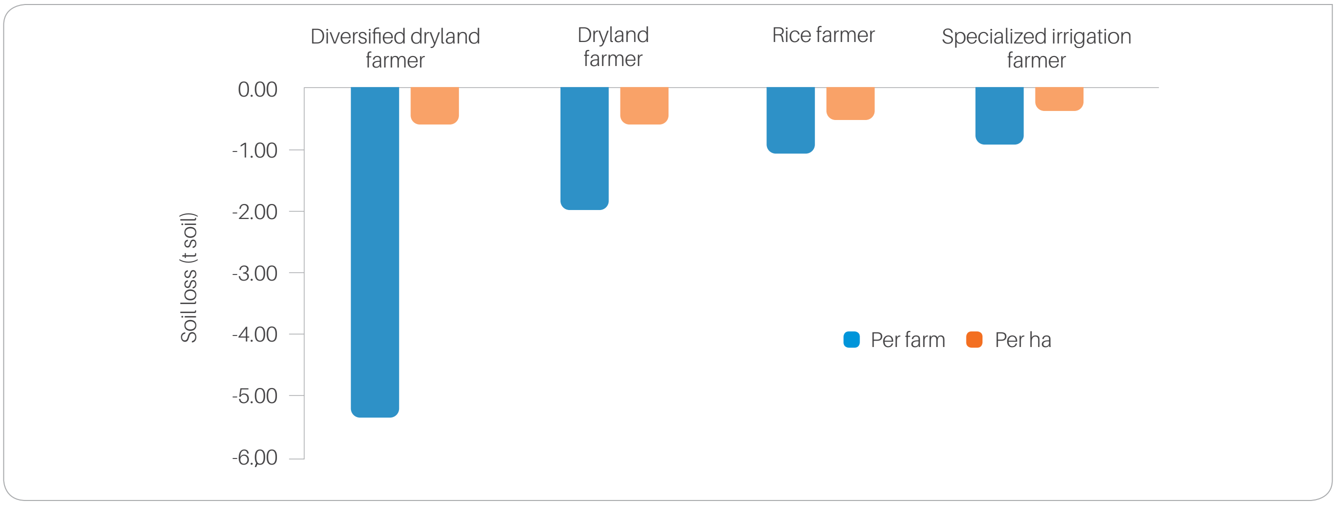
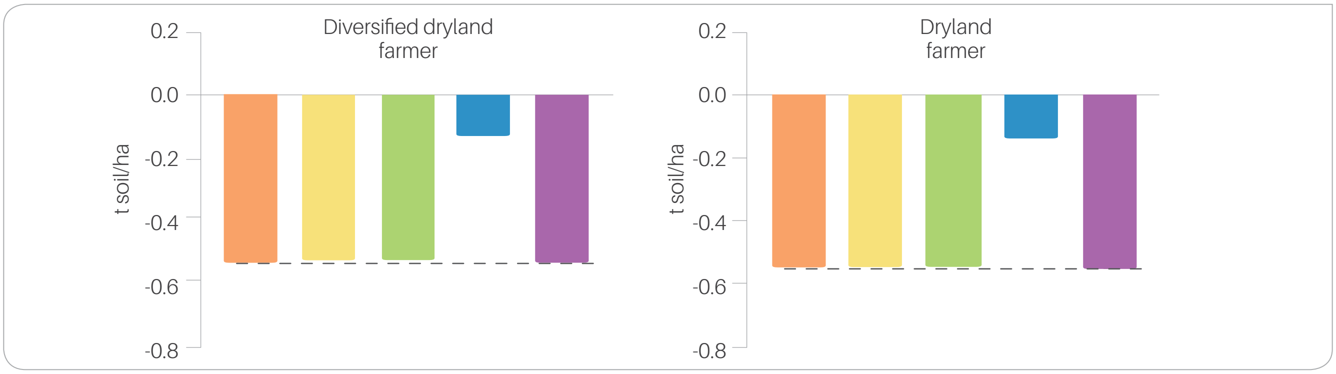


Figure 52: Baseline soil erosion (t soil/year) per farm and per hectare

7.4.2.4 Change in erosion

Erosion rate remains the same across all technologies in all farm types except reduced tillage which reduces erosion by 0.4 t/ha (Figure 53).



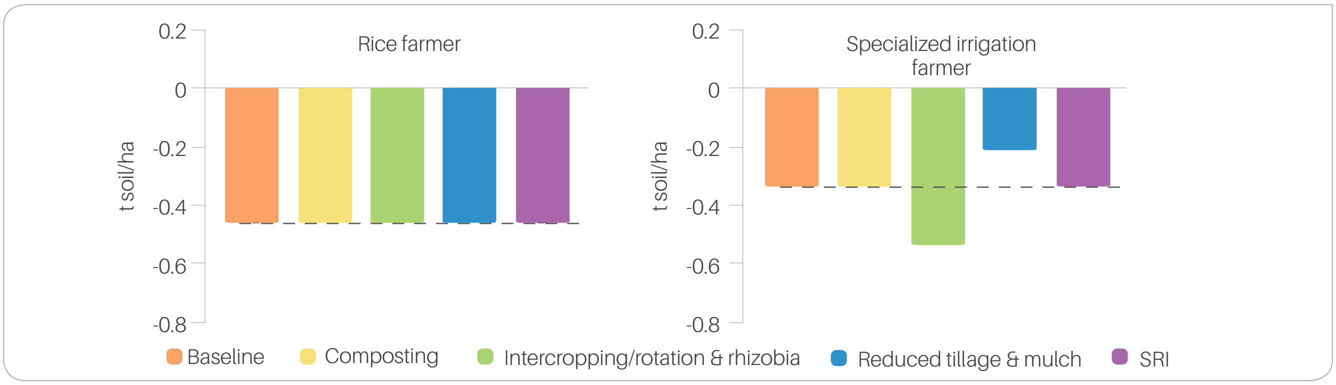


Figure 53: Soil erosion baselines and scenarios across farms (t soil/ha)

7.4.3 Mitigation pillar

7.4.3.1 Baseline greenhouse gas emissions

Soil emissions of nitrous oxide (N_2O) constitute the major share of total GHG emissions in the two drylands farms (Figure 54). Even though, for instance, in the diversified dryland farm these are less than 2 kg N_2O N/ha on average, as N_2O is a very potent GHG (~310 times more detrimental than CO_2), small emissions translate into notable CO_2 equivalents.

Enteric fermentation of ruminants and related emissions of methane contributes further, and constitutes the highest share in the rice farm (with its 12 dairy cows). Methane emissions from rice fields is also an important GHG contributor, while GHG emissions from manure adds comparably little.

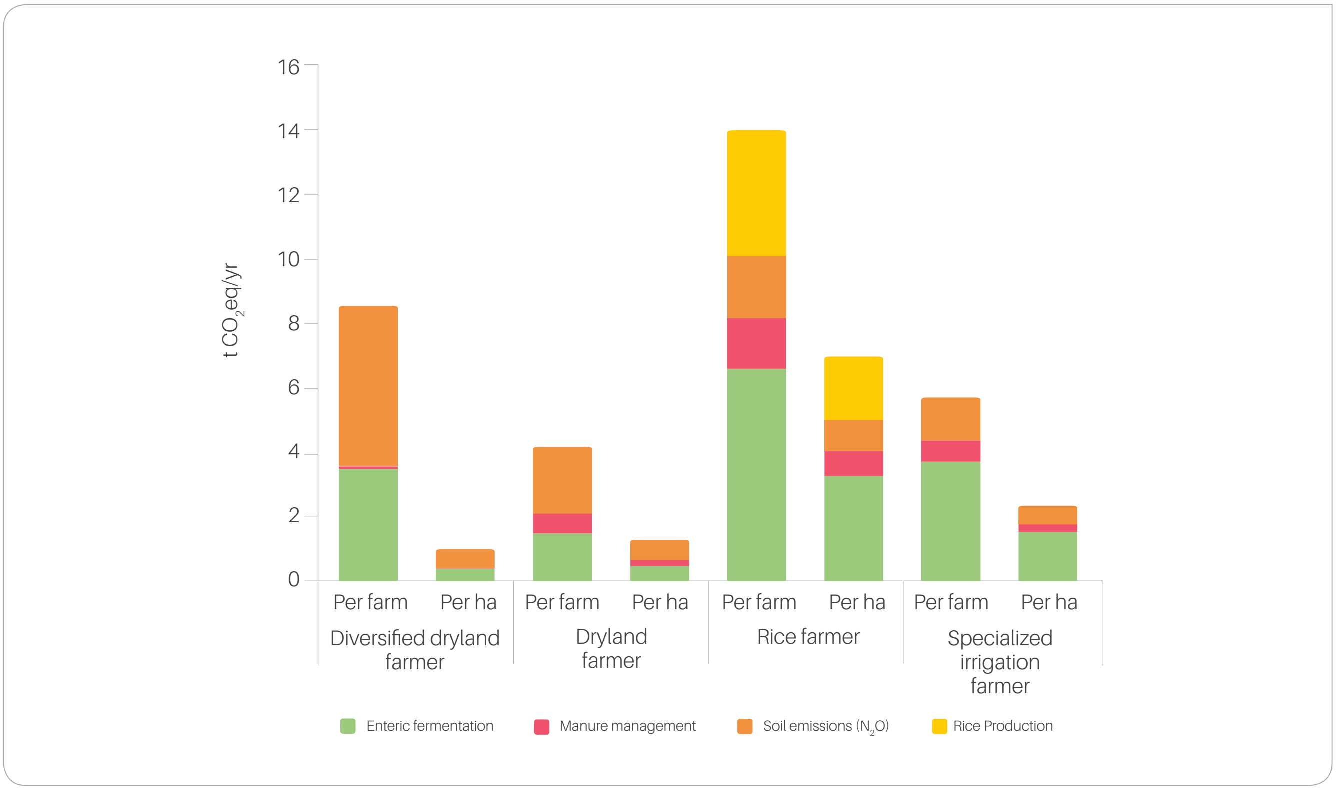


Figure 54: Baseline GHG emissions from enteric fermentation, manure management and soils across farm types

7.4.3.2 Changes in greenhouse gas emissions

Technologies impact GHG emission relatively little overall with the exception of composting for the specialized irrigation farm (Figure 55). Composting and addition of manure, on the one hand, increased N-addition to the soil and thus N_2O emissions of most farm types. This, on the other hand, was more or less counterbalanced by less methane (CH_4) emissions from rice fields (where compost results in comparably less CH_4 emissions than manure) and livestock, as composting competes for residues and less is thus available for livestock feed.

Reduced tillage and mulching had also a moderate mitigating impact on GHG emissions for both dryland farm types, because this was assumed to be implemented along with a reduction in mineral N fertilizer, and thus lower N_2O emissions from soils.

Intercropping/double cropping with rhizobia inoculation results in very little reduction in GHG emissions, which can be attributed to decreased use of inorganic fertilizers against an increase in incorporation of N-fixing legumes into the cropping systems.

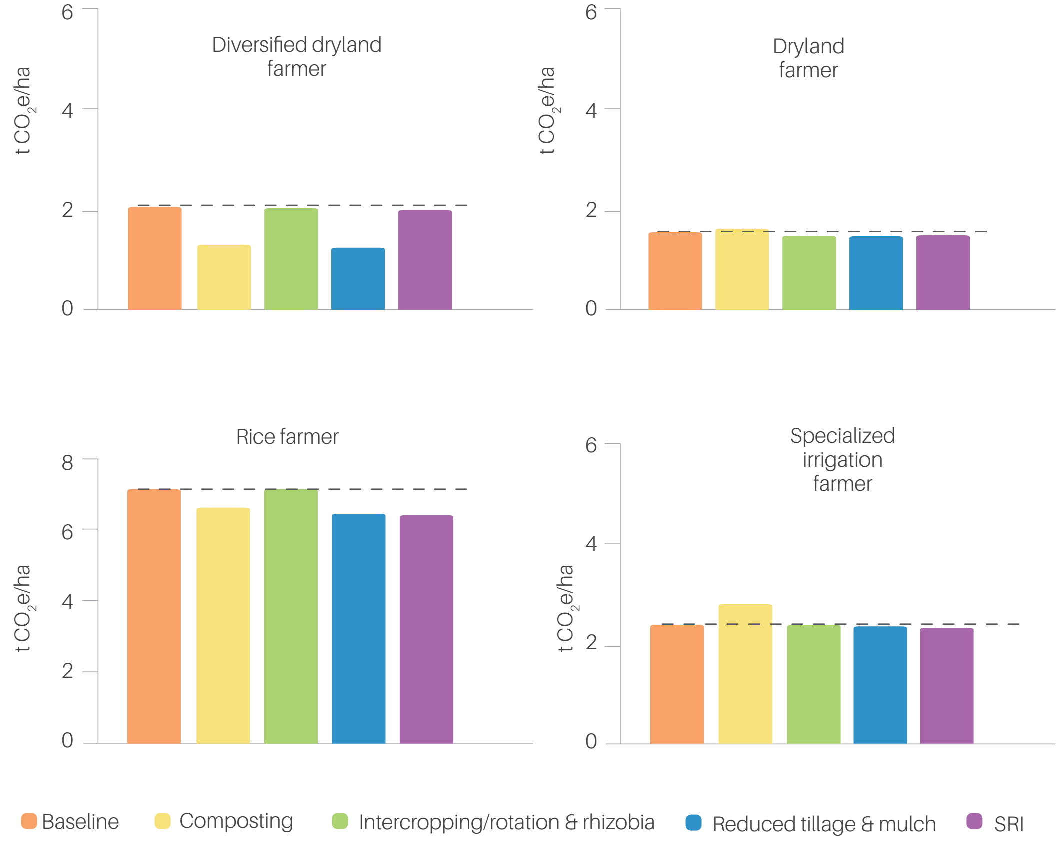


Figure 55: Greenhouse gas emission intensity baselines and scenarios per farm type (CO_2e/ha)

7.4.4 Trade-offs between productivity, N balance and GHG emission intensity

Trade-offs occur when improvement in one dimension of farm performance cause deterioration in another dimension. We plotted changes in productivity – as a food security indicator – against the changes in adaptation (N balance, Figure 56) and mitigation (GHG emission intensity, Figure 57). These figures show trade-off and synergy patterns across farm types and soil technology scenarios.

Usually, in a trade-off analysis, when comparing two indicators/impact dimensions and plotting one against the other, win-win situations are described by data points located in the upper right quadrant of the figure (i.e. positive changes in both impact dimensions).

This is the case for most of the scenarios comparing changes in the N balance against changes in productivity (Figure 56). However, in the particular case of India, further increases in the overall N balances, are less desirable, as N balances are already positive to start with. Thus, selecting soil protection and rehabilitation solutions that aim at reducing such N balance surpluses seems to be a (climate) smarter way to go. This is the case for the intercropping/rotation plus rhizobia inoculation scenarios in most farm types.

Similar patterns appear when comparing changes GHG emissions with changes in productivity (Figure 57).

In this case, we are looking for win-win situations in the lower right quadrant where productivity increases and GHG emissions decrease. Here it is certainly desirable to reject options that come with a large increase in GHG emissions. Reduced tillage + mulch is one such technology in the case of the specialized irrigation farmer. But, the increases in GHG emissions in general are not alarmingly large, which means that adapting any of the tested technologies should not be of concern in terms of negatively affecting the third pillar, mitigation, of climate smartness.

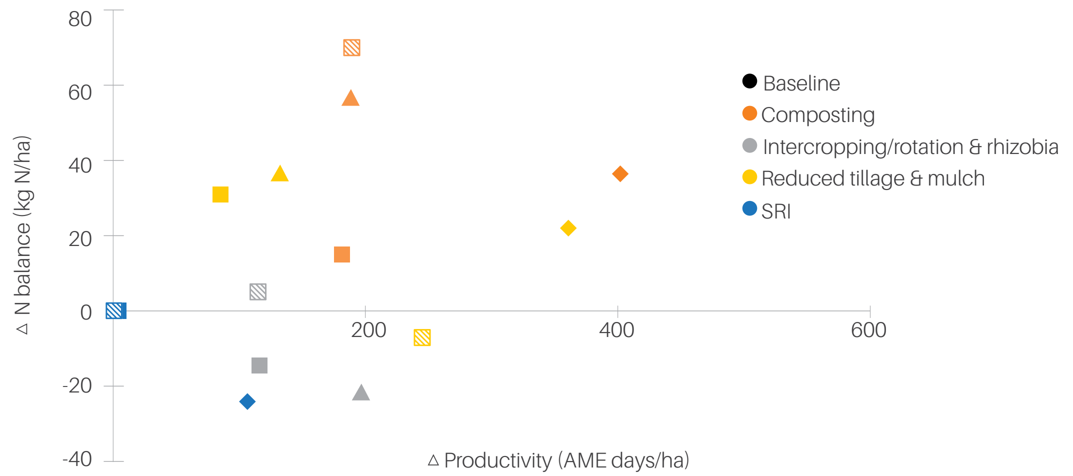


Figure 56: Trade-offs between changes in productivity (days/ha) and changes in N balance (kg N/ha). Colour represents the scenarios (see legend) and shapes the farm types (☐=diversified dryland farm, △=Dryland farm, ◇=Rice farm, ▧ with patterns=Specialized irrigation farm)

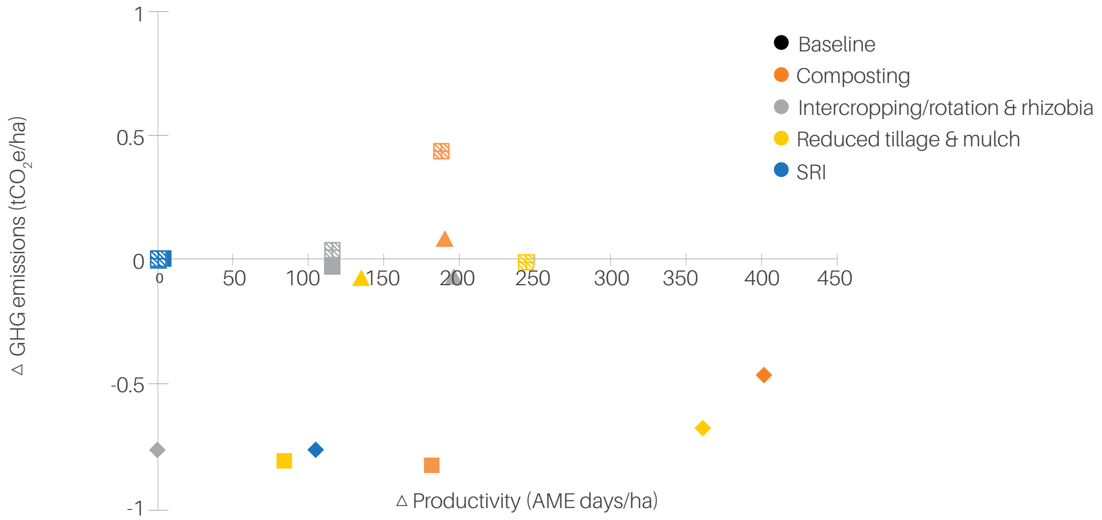


Figure 57: Trade-offs between changes in productivity (AME days/ha) and changes GHG emissions (t CO_2e/ha). Colour represents the scenarios (see legend) and shape the farm types (☐=diversified dryland farm, △=Dryland farm, ◇=Rice farm, ▧ with patterns=Specialized irrigation farm)

Climate-smart soils: testing soil health in Western Kenya (G. Smith/CIAT) - http://bit.ly/2liFywl

8 Discussion

8.1 Benin

Estimated increases in productivity in response to the implemented scenarios vary and in many cases, of limited magnitude. This, on the one hand, is not surprising in the case of orchard rehabilitation and Mucuna relay cropping, as the purpose of these measures is to primarily increase farm income and soil protection/fertility, respectively. Intercropping adds the most to farm productivity, simply because a second crop (pigeon pea) is added. Drought tolerant maize varieties are meant to increase resilience – targeting to mitigate severe reduction in crop yields or even crop failure in dry years – and thus the anticipated increase in average farm productivity, again, is limited. When drought tolerance is achieved through shortening the cropping season (short season varieties) with the aim to evade late-season drought, introducing drought tolerant varieties may even come at a cost of reduced productivity in favourable rainfall year. In such years, planting a long(er)-season variety may outperform such drought tolerant varieties.

Across the different farms in Zou and Collines counties, baseline fertilizer and manure use is very low. Productivity increasing measures, unless accompanied with higher levels of inputs, may thus results in increased soil nutrient mining. However, the observed N balances – slightly negative (small scale, lowland and medium-scale farm) or positive (large scale farm) – are still rather close to breaking even, and, given the uncertainty of this rapid assessment, not too concerning. Also, due to the extensive nature of livestock rearing, a lot of the manure that is produced is not used for crop production. Increased integration of crop-livestock growing, manure management and abolishing residue burning are alternative interventions that would have a positive impact on soil fertility and GHG mitigation.

GHG emission intensities (CO_2e/ha) are not very high at baseline, and none of the tested scenarios affects these markedly. Again, this is because the selected technologies did not target GHG emission reduction in the first place. Most of the farms could easily reduce emission by better manure management as well as by abolishing residues burning.

As mentioned earlier, orchards as well as teak plantations aim at increasing farmer's income, not calories produced. They also add diversity to the farm which usually goes hand in hand with increased resilience. Teak, or tree plantation and afforestation in general, adds to climate change mitigation through aboveground carbon sequestration. If such C-sinks were included into the GHG balances, these would turn out much more favourable for the integrated and large-scale farm – probably even positive overall (i.e. negative in terms of GHG emission CO_2e). Therewith there is little to argue about the climate footprint of the five farm types basically, nor about the selected technologies.

8.2 Burkina Faso

We find a notable variation in the baseline climate smartness as well as the impact of interventions across the different farm types in Burkina Faso. In the case study farms, the small farms have a very low productivity, negative N balance, but also a very low GHG emission intensity. The higher input use in the medium- to large-scale farms improves their productivity and N balance, but comes with a trade-off in the form of higher GHG emission intensities. On the other hand, increasing the input use on the small farms through compost and manure improves their productivity as well as N balance without increasing soil erosion. Even as GHG emissions increase, their intensities would still remain very low. Increasing the productivity on the medium- and large-scale farms e.g. through compost or intercropping are expected to come with GHG emission intensity reductions but also impacting the N balance negatively, if these are sought to be implemented as a way of reducing the need to purchase and apply mineral N fertilizer. If there are alternatives to burning cotton branches at the end of the season, this would further reduce GHG emissions. As seen earlier on the cotton growing farms, the burning of residues (as common practice for cleaning the plots) is one of the largest sources of GHG next to enteric fermentation from ruminants.

Increasing the use of manure across the farm types especially on the small scale ones, does imply sourcing of manure. Recommended rates of organic amendments reach up to 5 t per ha. To achieve this, farmers have to either start collecting manure much more than is currently done, or to purchase manure which would come at substantial cost especially for small scale farmers who do not have livestock. There are practical limitations to the first options as livestock grazes off-farms to some extent.

In conclusion, the diversity of observed impact highlights the importance of targeting not only by bio-physical/agro-ecological environments but also taking into account the socio-economic context and associated farming practices.

8.3 Ethiopia

As was the case for Burkina Faso, there is some variation in the baseline climate smartness across different farm types in Ethiopia. For example, the poorest farmer shows a significantly lower farm level productivity compared with all other farm types, while at the same time exhibits the highest N balance per hectare, and relatively high GHG emission intensity. This is due to the high organic manure inputs – animals grazing off-farm and are kept overnight on-farm – on a very small farm area. The production of milk and manure, larger land holding size, and diversity of crops grown in the various farm types affect all three of the indicators in this assessment. This variation is also apparent when considering trade-offs between the three CSA pillars. True triple-win technologies are rare. For example, small-scale mechanization and reduced tillage and mulching provide win-win synergies across all farm types when comparing GHG emissions and N balance, but only small-scale mechanization provides synergies in regards to productivity and N balance. Quality seeds and improved agronomy highly increases productivity, but also GHG intensity. However, the increases in GHG emissions in general are not alarmingly large. Thus, if food security and resilience objectives are met, promotion of any of the tested technologies should not be abandoned for the negatively affected third CSA pillar, mitigation.

Some of the N balances need to be re-assessed. The positive N balances on the poor and small farms might not be representative for these farms types throughout the target area given the above-average application of manure and use of mineral fertilizer observed on the case study farms. However, they do indicate that on small farms like these there is a risk that N-deficits quickly turn into excess inputs. On the other hand, the slightly negative balances of the double cropping and coffee farms overtime could contribute to significant soil mining. Thus, appropriate and balanced nutrient management remains a key concern across different farm types in Ethiopia.

Small-scale mechanization, as well as minimum tillage offers an entry point for reducing the number of oxen that have no other purpose than being used for soil tillage, and thus reduce the GHG emission from farms that are mostly coming from the livestock sector. Furthermore, emission intensities can be addressed, by producing more livestock products while not increasing emissions. This is usually achieved through feeding higher-quality feed/forages grown on-farm. Investigating option for forages production could be an interesting addition to the set of technologies tested in Ethiopia.

8.4 Kenya

Livestock numbers and the efficiency of the livestock production influence the climate smartness the most. Livestock production depends on comparably large land sizes (for feed production) and therefore scores quite low in terms of production and productivity. Manure, however, has the potential to contribute considerably to improving soil fertility in Western Kenya, as this is underutilized/poorly managed unnecessarily contributing to GHG emissions. We therefore recommend to include better manure management as one of the intervention scenarios to be looked at in the in-depth assessment. However, while manure management is a promising strategy for nutrient cycling, it is less so for soil organic matter balances (Paul et al. 2015). The poor female headed household cannot not sustain the family from on-farm production (calories) at baseline. Such household often depend on off-farm income to provide for the food requirement of the family. As this farm has no livestock it is not surprising that it also did not emit any notable amounts of GHGs. Large commercial specialized farms contribute less to food production – not surprising as in our case the selected farm had focused on coffee production. For three out of the five farm types the N balances are negative but not excessively. These balances thus can be improved easily by better N-use efficiency/management (see above) and recycling, and, if required, slightly increase (mineral) N-inputs. Grass buffer strips contribute to nutrient mining if not adequately fertilized. Soil erosion is of no concern, which is less of a general statement but rather the consequence of the selected households farming on fairly flat land.

8.5 India

The rice farm sticks out in terms of poor CSA performance, which is mainly due to some farm-specific peculiarities, such as high number of dairy cows adding significantly to productivity and GHG emissions, and notable addition of calories from mango fruits. Furthermore, such a high livestock density translates into large amounts of manure available for fertilization on small acreage. This high amount of manure applied to the rice fields of this particular farm explain the high N balance, causing significant methane emissions from paddy fields. Hence, optimizing the use of on-farm manure seems advisable. For example, surpluses of manure could be sold. Without these two components, the rice farmer would rank lowest in productivity per hectare – together with the specialized irrigation farmer. The rice farm type actually describes potentially food insecure and poor farm households. This is not the case for the specialized irrigation farm type. Specialized irrigation farms are usually better off, have specialized in the production of high-value crops, and thus, even though they are not producing large amounts of calories themselves, are certainly in a position to purchase food if required. This issue highlights on the one hand the diversity of farm types in this region, which is difficult to capture with a limited set of single-household assessments, but on the other hand also shows that similar performance regarding certain CSA indicators may have very different drivers and consequences. The mostly positive N balances leave room for optimizing farm nutrient recommendations, towards “less is possible” for desired production levels. Here, the compost technology in particular could be optimized: if the goal is really to add up to 7.5 t of compost per hectare – which is certainly desirable as far as soil health and soil organic matter/carbon build up is concerned – then this should entail a more drastic reduction in accompanying application of mineral fertilizer. This especially applies to rainfed-only production systems, where water rather than nutrients may be the limiting factor for growth. Better alignment of recommendation for compost rates with expected yields and associated withdrawals of nutrients seems advisable.

9 Conclusion and recommendations

In this report a set of four indicators is used for assessing the climate smartness of different farm types, and selected GIZ-supported soil protection and rehabilitation measures in Benin, Burkina Faso, Ethiopia, Kenya, and India. This allows for a rapid assessment that can feed into decision-making processes in the on-going GIZ Soil Program. However, the choice of indicators has its limitations. The use of a 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 comparably 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 children and pregnant women. This should be kept in mind when evaluating production. In other words: "It is not only about calories produced." 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 and erosion 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.

The rapid assessment shows that there is some variation in the baseline climate smartness across different case study farms representing different farm types. The case study approach allows for a rapid analysis, but that comes at the cost of an increased context-specificity of results which warrants cautions to draw general conclusions. Nevertheless, a few insights can be gained:

1. Farming system diversity across and within the target countries and sites was large, both in terms of socio-economic and agro-ecological factors. This hugely impacts farms' productivity and environmental performance. For example, on-farm food production ranged from 150 – 50,000 adult male equivalent days/farm/year. Productivity per hectare ranges from less than 500 up to 3700 AME days/ha. The exception where the rice farm in India that produces up to 8000 AME days/ha.
2. The "smallest" farms types across countries do not necessarily have the lowest productivity. In fact, in Ethiopia the smallest farm is among the most productive.
3. Cash crops, such as timber and coffee, do not add calories to the production figures, thus indicating low productivity on farms that have specialized towards these, i.e. coffee farmer in Ethiopia. Yet, cash crops are an important source of income.

4. Productivity increases may come at the cost of nutrient mining, if not carefully planned. Appropriate measures for replacing extracted nutrient need to be adopted that take into account the current state of the soil.

5. N balances are in general low and close to 0 in West Africa with a few exceptions only (1 farm type in Benin; one large farm in Burkina Faso). Intercropping with N-fixing legumes alone is not enough to narrow negative N balances, but supplementation of organic and inorganic fertilizers is often required. In India, balances are (very) positive because of such high use of inorganic fertilizers. This is another concern because of possible environmental damages. In such cases we must be cautious when promoting interventions that will further increase the N balance and rather look into interventions that will "replace" the N provided by inorganic fertilizers while providing other benefits/functions to soil health. Similarly in Ethiopia, soil N balances are on the positive side because of the use of inorganic fertilizers.

6. The diversity of farms is also reflected in their greenhouse gas (GHG) emissions which range from 0.2 to 43 t CO_2e/farm/year. Also the impact of the interventions varies greatly across the farm types. This underlines the importance of careful targeting of technologies to regions and farming systems to ensure sustainable intensification.

7. Livestock is an important asset of the majority of farms, distinguished by major farm types in the five countries. It often defines the livelihoods of these farms, provides draught power, adds to food production and is key to nutrient cycling. But, it is also a major source of GHG emissions. Our assessment shows that there is scope for improving the integration of livestock into farms through better manure management, as well as improved feeds and forages, husbandry and health care to improve livestock productivity and hence decrease emission intensities.

8. Paddy rice (India) and residue burning (Benin) are two further contributors to GHG emissions in some farm types. An alternative residue management would be first entry points to decrease GHG quantities in the first case. Alternating wetting and drying cycles as part of a System of Rice Intensification (SRI) is the most promising technology to lower methane emissions from rice, safe water while maintaining or even increasing yields.

9. The level to which the supported technologies/interventions address the core idea of soil protection and rehabilitation varies significantly between the GIZ soil programs in the five countries. Intercropping is part of the portfolio of identified technologies in all five countries. It certainly has a potential to contribute to improving soil fertility, but stand-alone, without additional measures, it is unlikely to do so. The same is true for other technologies, e.g. cross-slope barriers (grass buffer strips, stone bunds). Their prime purpose is soil erosion reduction. However, maintaining or increasing soil fertility goes beyond mere physical protection – notwithstanding that the latter is of major importance. In tropical agro-ecosystems where nutrient mining is the major driver of chemical soil degradation, replenishing and recycling of nutrients as well as organic matter management are key to maintain soil fertility and health long-term.

10. The rapid assessment analysis does not account for carbon sequestration in soils as a consequence of reduced tillage, surface residue retention or other inputs of organic matter to the soil. Such sequestration has the potential to completely offset nitrous oxide emissions from soils, but is a slow process that is difficult to monitor short-term.

11. True triple-win climate-smart solutions, i.e. interventions that increase productivity, improve resilience and reduce GHG emissions, are rare. Instead, implementing soil conservation and rehabilitation measures often has a positive impact on just one or two of the CSA pillars but a negative effect on the remainder(s); i.e. trade-offs have to be made. None of the proposed technologies addresses climate change mitigation (reducing GHG emissions from agriculture) directly. Whether this should indeed be the focus of the GIZ Soil Program, especially in Sub-Sahara Africa, should be further debated.

Rapid ex-ante impact assessments like this can contribute to program design, despite their inherently limited choice of indicators and data collection. However, the feasibility of tested technologies in terms of farmer's accessibility, economics and preferences, and related decision making requires further attention. The idea, for instance, to retain crop residues and/or to apply significant amounts of compost or manure to improve soil fertility is valid, but not seldom outside the possibilities of the farmers, especially if at subsistence level with significant resource constraints. To address these constraints, we have carried out participatory evaluation of land management options with farmers of all farm types in the five countries, which will be presented in a separate document.

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