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Climate smartness of GIZ soil protection and rehabilitation technologies in Ethiopia

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Climate smartness of GIZ soil protection and rehabilitation technologies in Ethiopia

Rapid Assessment Report

Celine Birnholz, Jessica Koge, Katherine Snyder, An Notenbaert, Juliet Braslow, Biyensa Gurmessa, Rolf Sommer, and Birthe Paul

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CIAT Publication No. 428
January 2017

Birnholz C; Koge J; Snyder K; Notenbaert A; Braslow J; Gurmessa B; Sommer R; Paul B. 2017. Climate smartness of GIZ soil protection and rehabilitation technologies in Ethiopia - Rapid Assessment Report. Working Paper. CIAT Publication No. 428. International Center for Tropical Agriculture (CIAT), Nairobi, Kenya. 37 p.

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Acknowledgements

This report is an output of the project 'Climate-smart soil protection and rehabilitation in Benin, Burkina Faso, Ethiopia, India and Kenya', led by the International Center for Tropical Agriculture (CIAT) and with funding from the German Federal Ministry for Economic Cooperation and Development (BMZ) / Deutsche Gesellschaft fuer Internationale Zusammenarbeit (GIZ) under Contract # 81194110.

We thank Christine Ketter from GIZ in Bonn for helping us fine-tune research ideas and her valuable logistic support. Special acknowledgement to the stakeholder workshop participants for their engagement and wealth of insights and information. We would especially like to thank Steffen Schulz and Haile Deressa from GIZ in Addis Ababa for guiding the workshop, assisting in identifying and inviting stakeholders, and actively participating.

Wheat (CIMMYT/P. Lowe)

Sorghum

1. Introduction

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.

Globally, agriculture is a principal source of climate change, directly contributing 14% of anthropogenic GHG emissions, and another 17% through land use change; the latter mostly in developing countries. The majority of future increase in agricultural emissions is expected to take place in low- to middle-income countries (Smith et al., 2007). While industrialized countries must dramatically reduce current levels of GHG emissions, developing countries face the challenge of finding alternative, low carbon or green growth development pathways. In this sense, climate-smart agriculture (CSA) aims at transforming agricultural systems to sustain food security under climate change. Although CSA aims at improving food security, 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). 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).

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-endorsed soil protection and rehabilitation measures in the five countries. Soil rehabilitation is often evaluated for productivity and food security benefits, with little attention to 'climate smartness'. Likewise, 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," 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.

Community member, Debre Berhan

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. Appendix III contains 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.

This report focuses on the results from the first activity of the project. The objective of the rapid assessment of climate smartness of GIZ endorsed soil rehabilitation and protection technologies in Ethiopia, 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 CSA pillars – food security, adaptation and mitigation. During a participatory workshop in Addis Ababa, five distinct farming types were identified (Gurmessa et al., 2016). Subsequently, four household interviews were conducted in farm households that were deemed representative of the five farm types identified during the workshop. The data collected on these farms forms the basis of the baseline calculations of productivity, nitrogen (N) balances, erosion, and greenhouse gas (GHG) emissions, as suitable (rapid) indicators representing the three CSA pillars – food security, adaptation and mitigation.

Check dams, Debre Berhan

Debre Berhan, central Ethiopia

Community leader, Debre Berhan

2. Methodology

Following the participatory workshop that delineated farming system types, potential representative farms were jointly identified by CIAT and GIZ 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 spreadsheet model calculates the following indicators.

Productivity: Farm productivity was calculated based on the energy (calories) produced on farm – crop and livestock products – and compared to the energy requirement of an adult male equivalent to 2500 kcal per day (AME). Energy from direct consumption of on-farm produce was calculated by multiplying the energy content of every crop and livestock product with the produced amount. It is thus important to note that the indicator only represents food/energy production from the own farm, not funds that the household might use to purchase additional food. Energy contents were based on a standard product list developed by the US Department of Agriculture USDA (source: http://bit.ly/1g33Puq). The total amount of energy produced on the farm was then divided by 2500 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).

$$\text{Soil loss (t/ha/year)} = R*K*LS*C*P$$

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://bit.ly/2gL0rhb

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

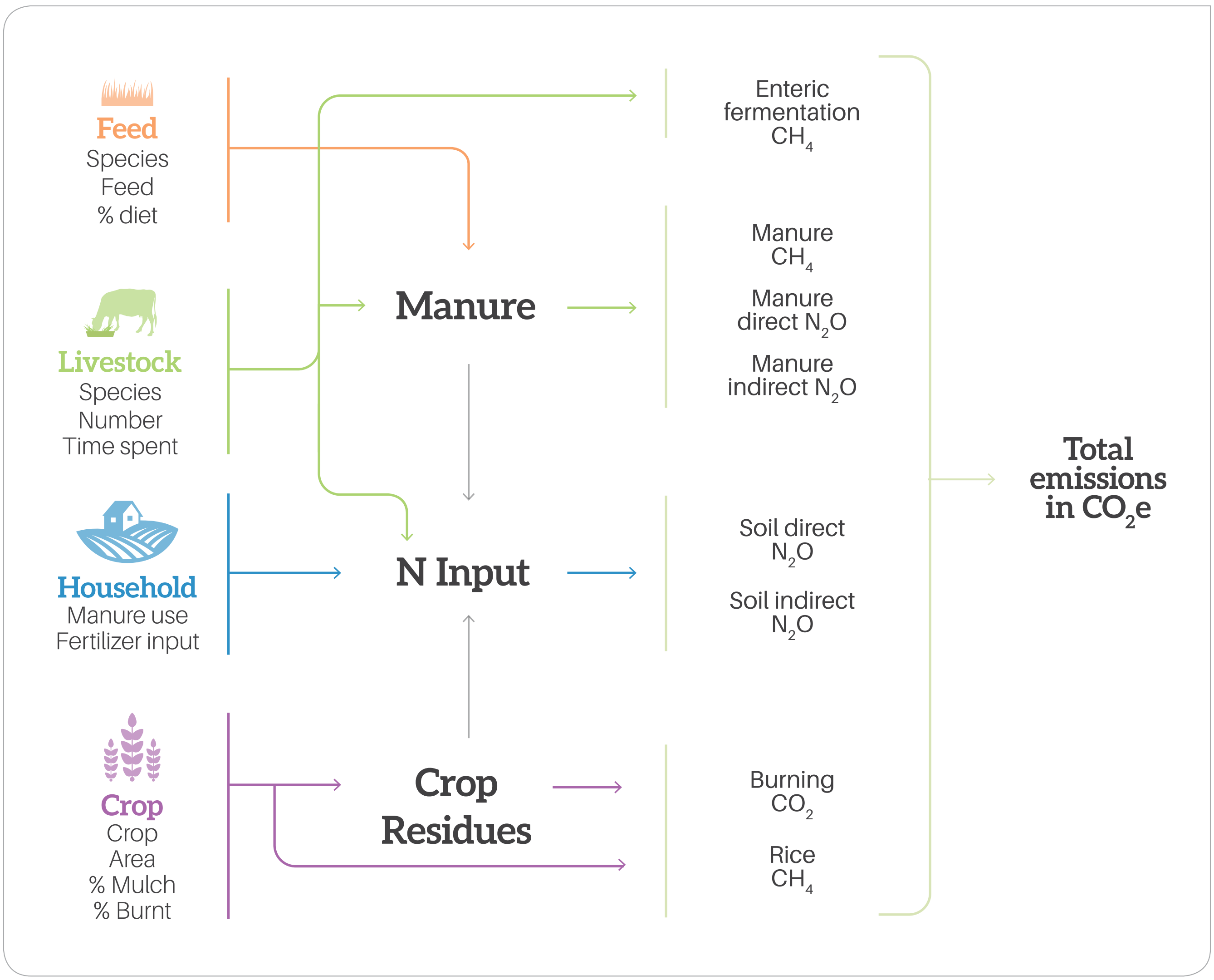


Figure 1. Scheme of the GHG emission calculations.

Farmers in Ethiopia

3. Farming system types

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).

1. **Poorest farmer:** About 8% of the farmers in Oromia and 12% of the farmers in Amhara fall in this category. They have less than 0.5 hectares of land, and have no oxen for ploughing, and not more than 4 heads of livestock. The land is much less productive than that of the other farm types. Farmers mainly grow potatoes and some little maize or Enset around their homestead. Farmers in this category often rent out family labour and land to wealthier farmers.

2. **Small mixed cereal farmer:** About 60% of the farmers in Amhara and 23% of the farmers in Oromia fall in this type. Land size is between 0.5 and 1 hectare, and farmers have about 2-4 cattle with at least one ox for ploughing and some sheep and goats. These farmers produce teff and wheat for sale and also grow maize and Eucalyptus trees. They also produce livestock products (honey, butter, live animals and eggs). They have low levels of education and have adopted more innovation technologies than the 'poorest farmer' type. They apply fertilizer below the recommended amount.

3. **Medium mixed cereal farmer:** These are medium farmers who have 1-3 ha of land, up to 10 heads of livestock, and oxen to plough their land. They produce teff, wheat and maize and livestock products (butter, honey live animals and eggs). Fertilizer application rates are higher than that of the small mixed cereal farmers. The number of households in this category is higher in Oromia (42%) than Amhara (20%). Most of the farmers in this category depend on cereal for their livelihood. These farmers are the main suppliers of maize and teff to the country's market at large.

4. **Double cropping farmer:** Most farming in Ethiopia, in general, and in the GIZ-Integrated Soil Fertility Management areas, in particular, is rain-fed. However, during the long rainy season which varies from year to year, farmers use residual moisture to produce early maturing crops (mostly chickpea) after harvesting the main crop. This farming system exists in some areas of the central highlands, including Ambo (Woreda of Oromia). The percentage of such farmers is small, about 7% in Oromia and 2% in Amhara region. The primary crops in these areas are cereals, though pulses such as chickpea and grass pea are also grown. This is possible either with residual moisture at the end of the long rainy season or in the short rainy season.

5. **Coffee commercial mixed farmer:** These farmers are typical to Western Oromia region. Their livelihoods largely depend on coffee. However, they still produce maize and teff. Land allocated to coffee is much higher (70%) than that to food crops. The main food crops grown are maize and teff, which are mostly for household consumption. Fruit production is also common to this region. Farmers produce mango, avocado and papaya either as (coffee) shade trees or in home-gardens. These fruit trees are for consumption and sale. Khat is also common in home-gardens and is another source of income. Farmers in these areas have more diverse livestock such as cows, sheep and/or goats, poultry and donkeys than any other regions due to the favourable environment and better sources of feeds.

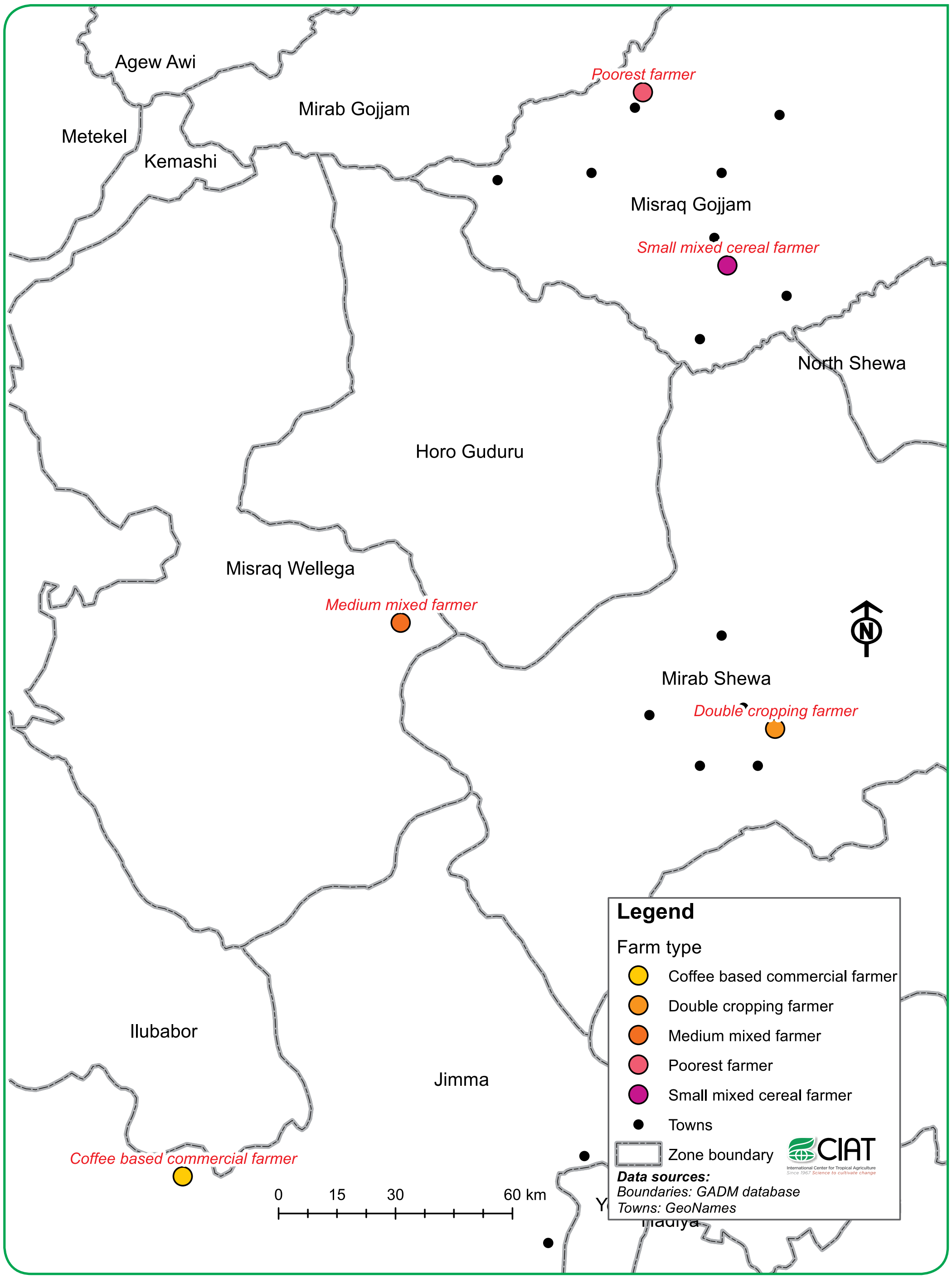


Figure 2. Location of the case study farms in Ethiopia.

Experiment to determine soil loss

4. 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.


Wheat (CIMMYT/P. Lowe)

Community leader with CIAT researcher

5. Results

5.1 Productivity pillar

5.1.1 Baseline productivity

On farm productivity was calculated by summing up all the calories from crop and livestock produced on farm (excluding meat) and dividing by the equivalent calorie requirements of an average adult male (AME: Adult Male Equivalent; 2500 k cal/day). Productivity is thus expressed in number of AME days (Figure 3).

The poorest farm has the highest productivity per hectare followed by the small mixed cereal farm. 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.

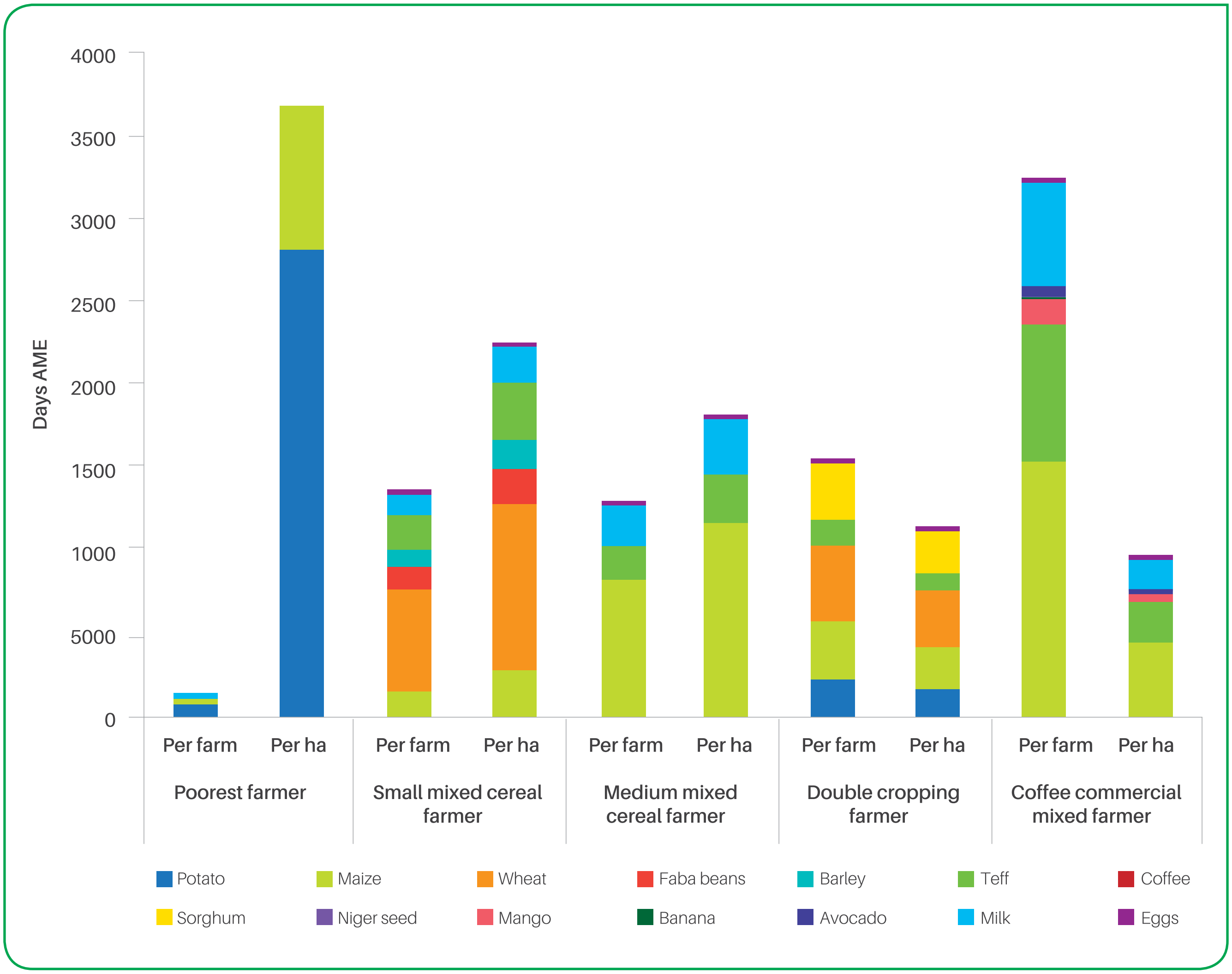


Figure 3. Baseline productivity and contribution from the different products across farm types. *Productivity is expressed as number of days that 1 adult male equivalent (AME) can be fed from livestock and crop products produced on the farm.*

5.1.2 Changes in productivity

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 4), 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.

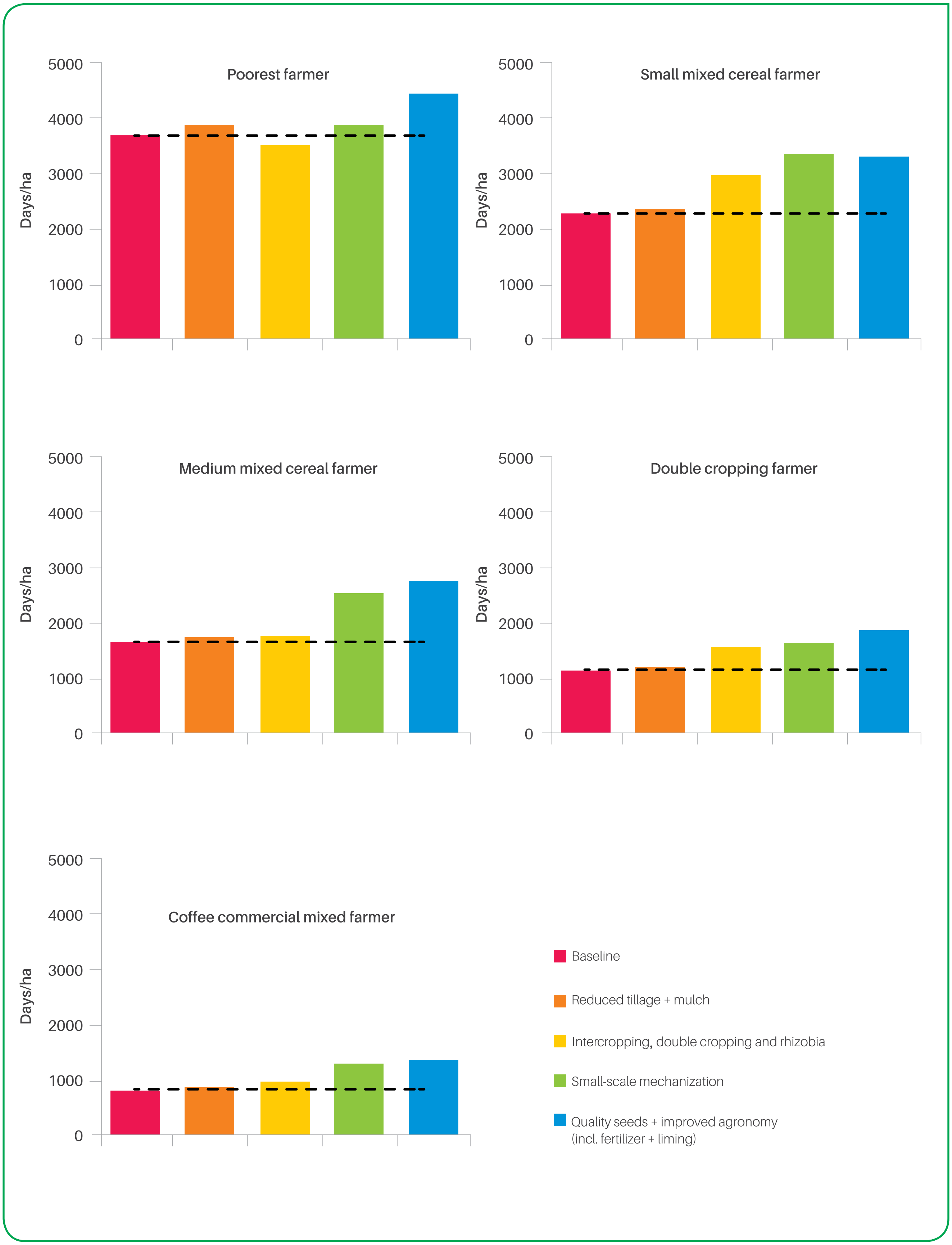


Figure 4. Baseline and scenario productivity per farm type. *Productivity is expressed as number of days that 1 adult male equivalent (AME) can be fed from livestock and crop products produced on the farm.*

5.2 Resilience pillar

5.2.1 Baseline nitrogen balance

The nitrogen (N) balance is calculated for each of the fields found on the farm. The "per farm" N balance is the sum of field level N balance of the individual plots. Reference can be made to Section 2 for further details on the calculations.

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 5). 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. 30kg 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.

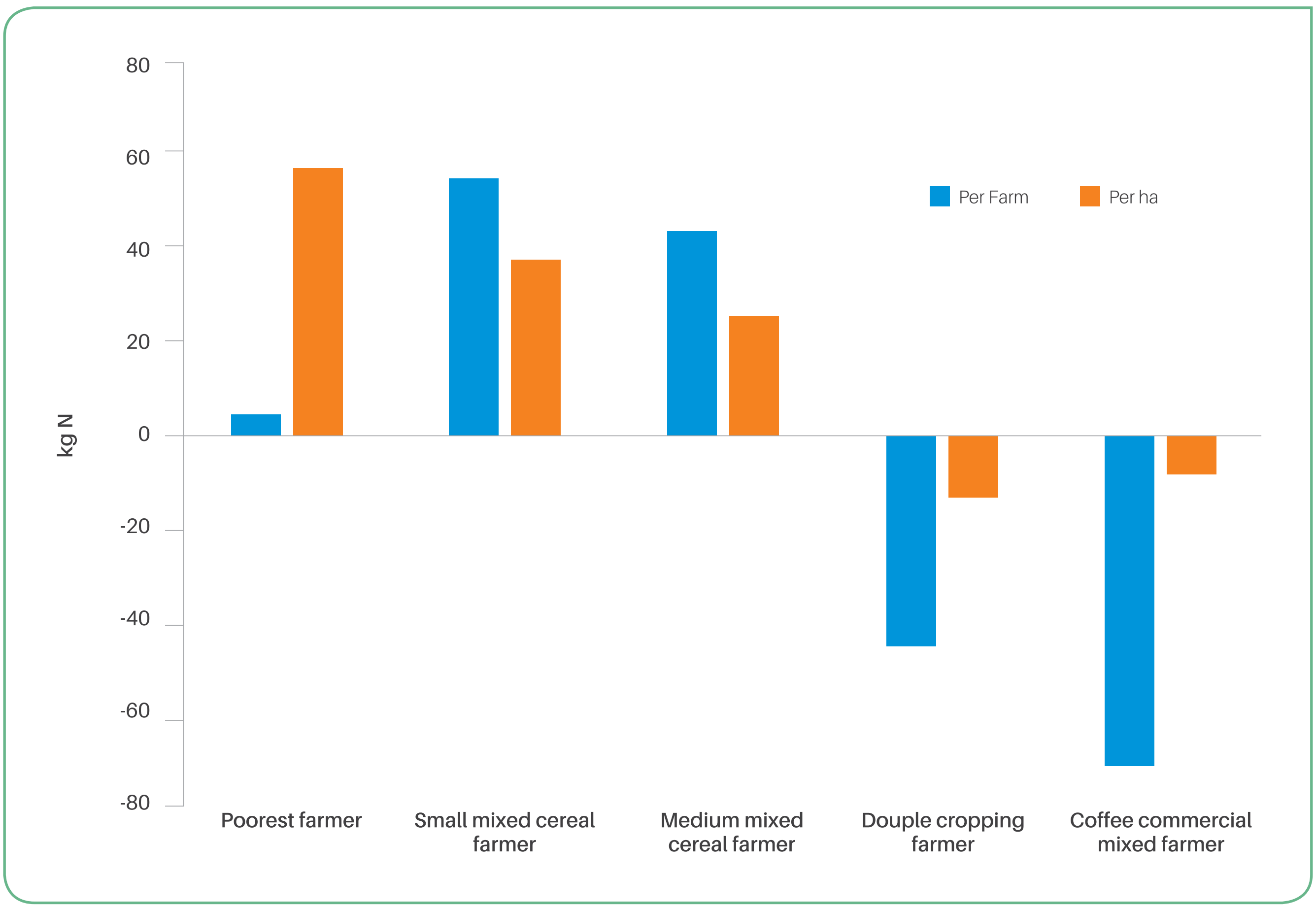


Figure 5. Baseline nitrogen balance at field level per farm and hectare across farm types.

5.2.2 Changes in nitrogen balance

Implementing the different technologies would affect the N balance differently across the farms (Figure 6; 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.

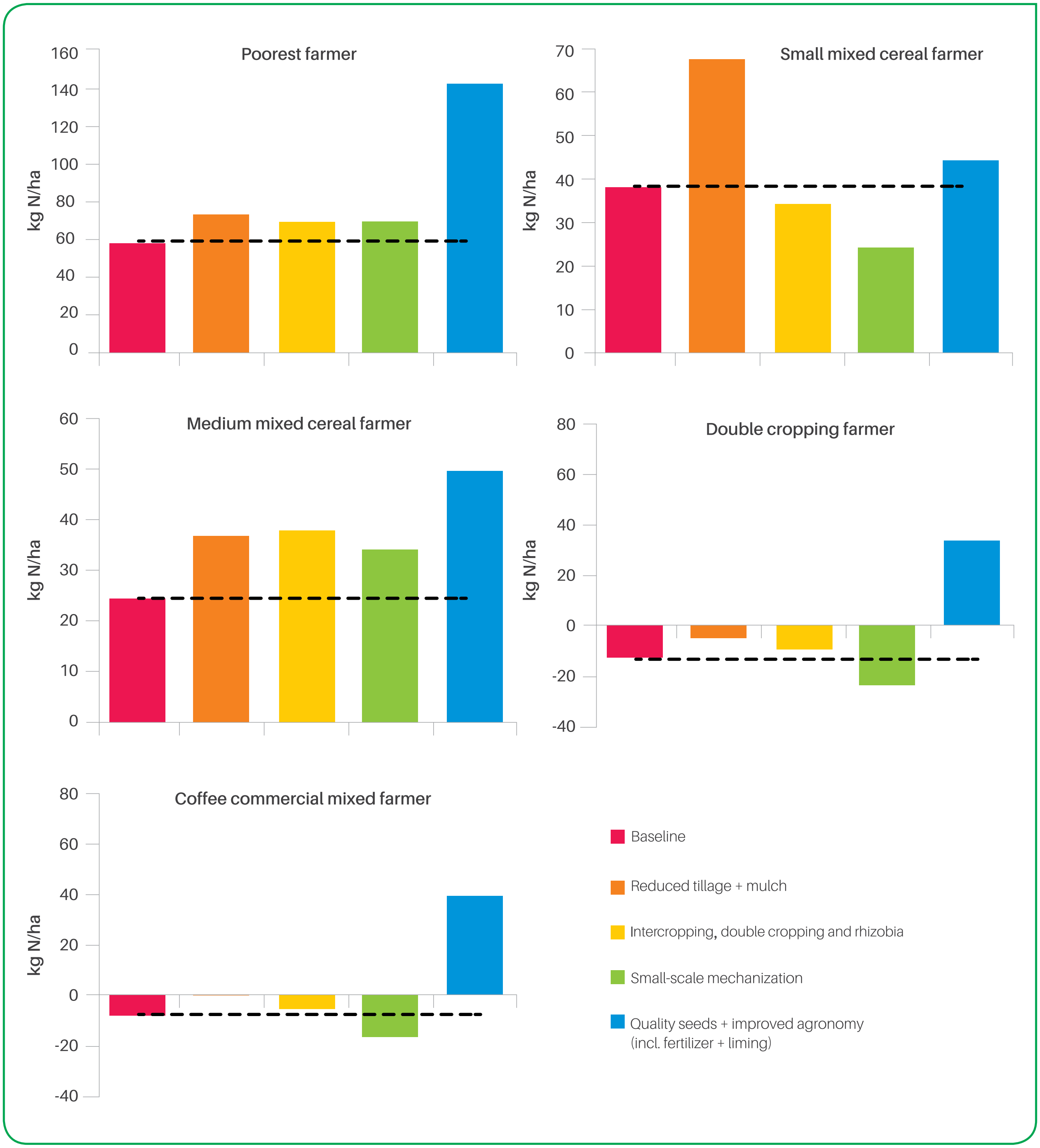


Figure 6. Nitrogen balance baselines and scenarios across farms (kg N/ha).

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.

5.2.3 Erosion baselines

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 7). 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.

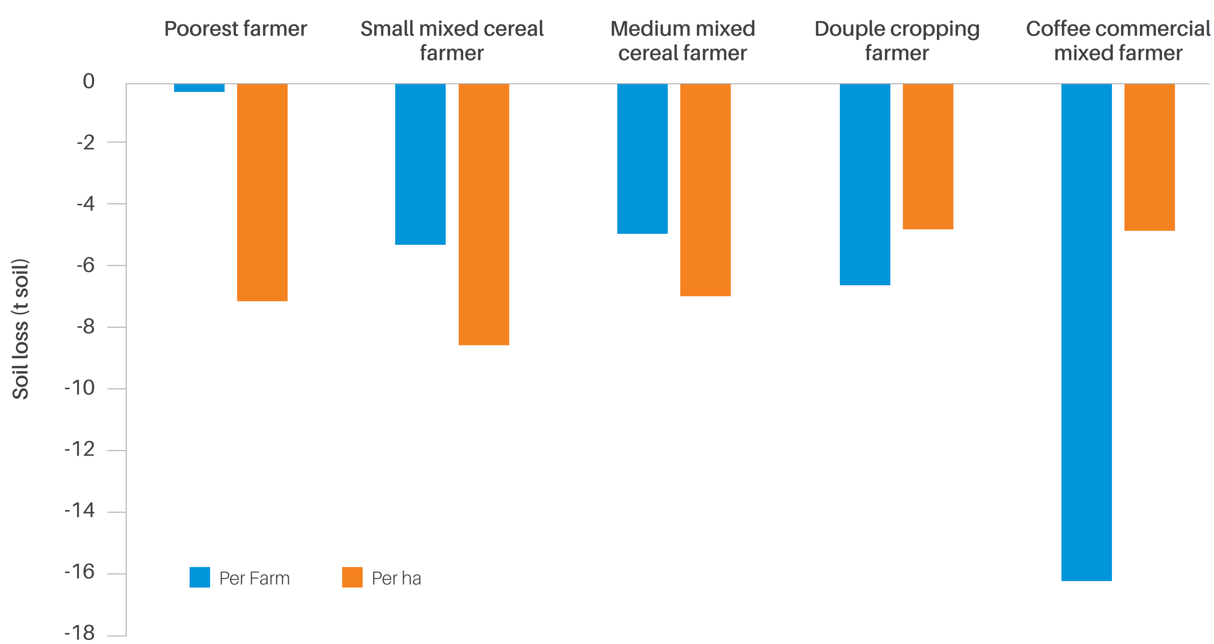


Figure 7. Baseline soil erosion per farm and per hectare across farm types.

5.2.4 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 8). 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.

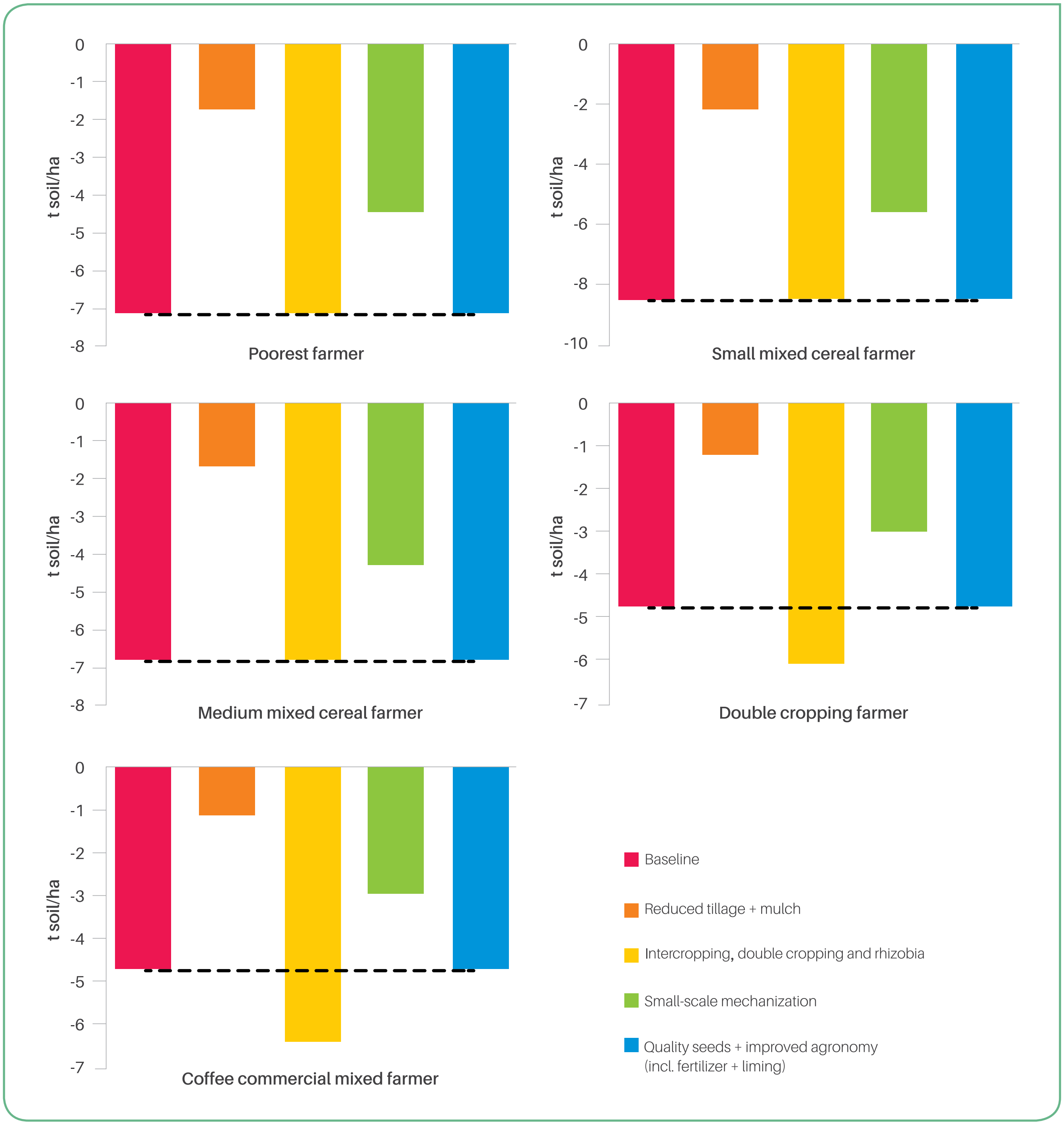


Figure 8. Soil erosion baselines and scenarios across farms (t soil loss/ha).

5.3 Mitigation pillar

5.3.1 Baseline 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 9).

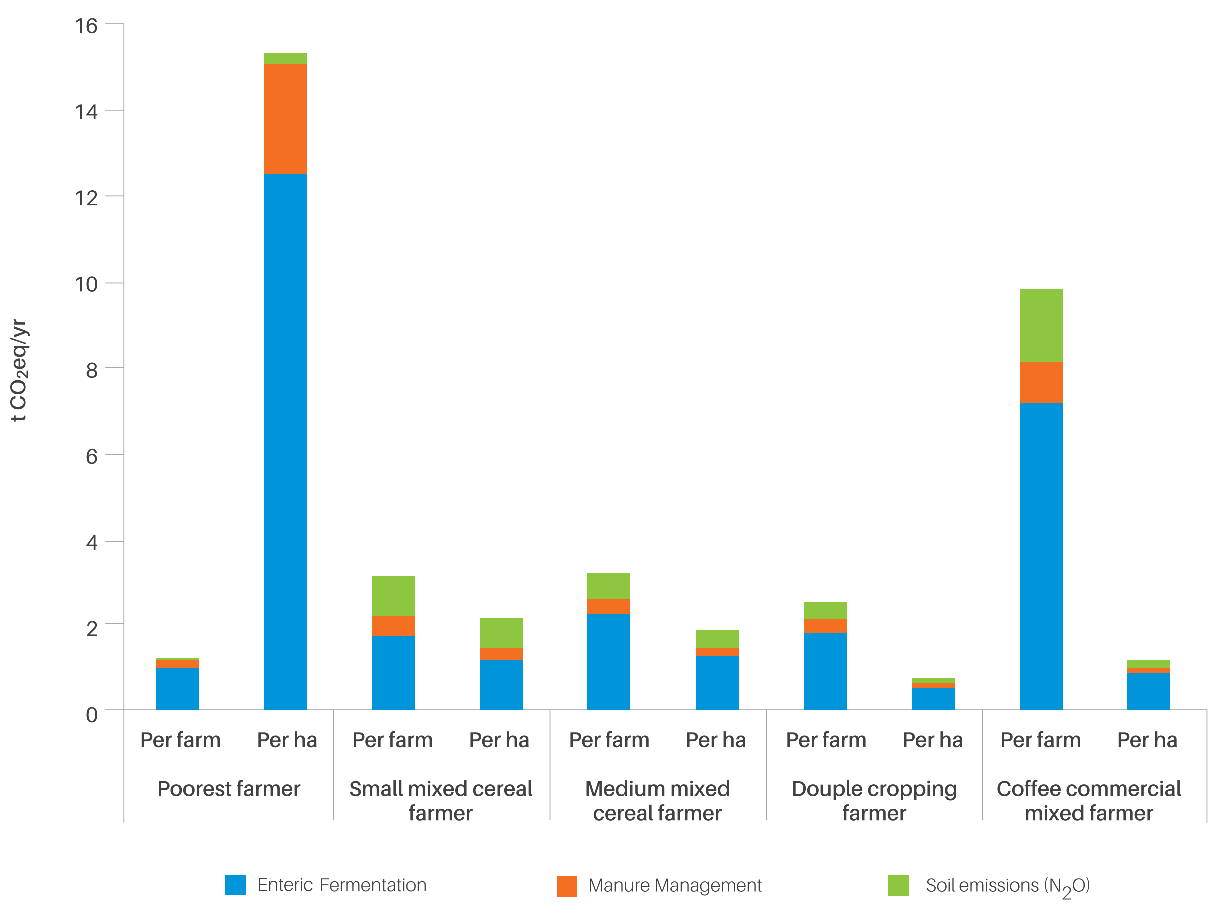


Figure 9. Baseline GHG emissions from enteric fermentation, manure management and soil emissions across farm types.

5.3.2 Changes in GHG emissions

There is generally little to no change in GHG intensity from the baseline across the technologies in all farms (Figure 10). 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_20 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_2e/ha from the baseline.

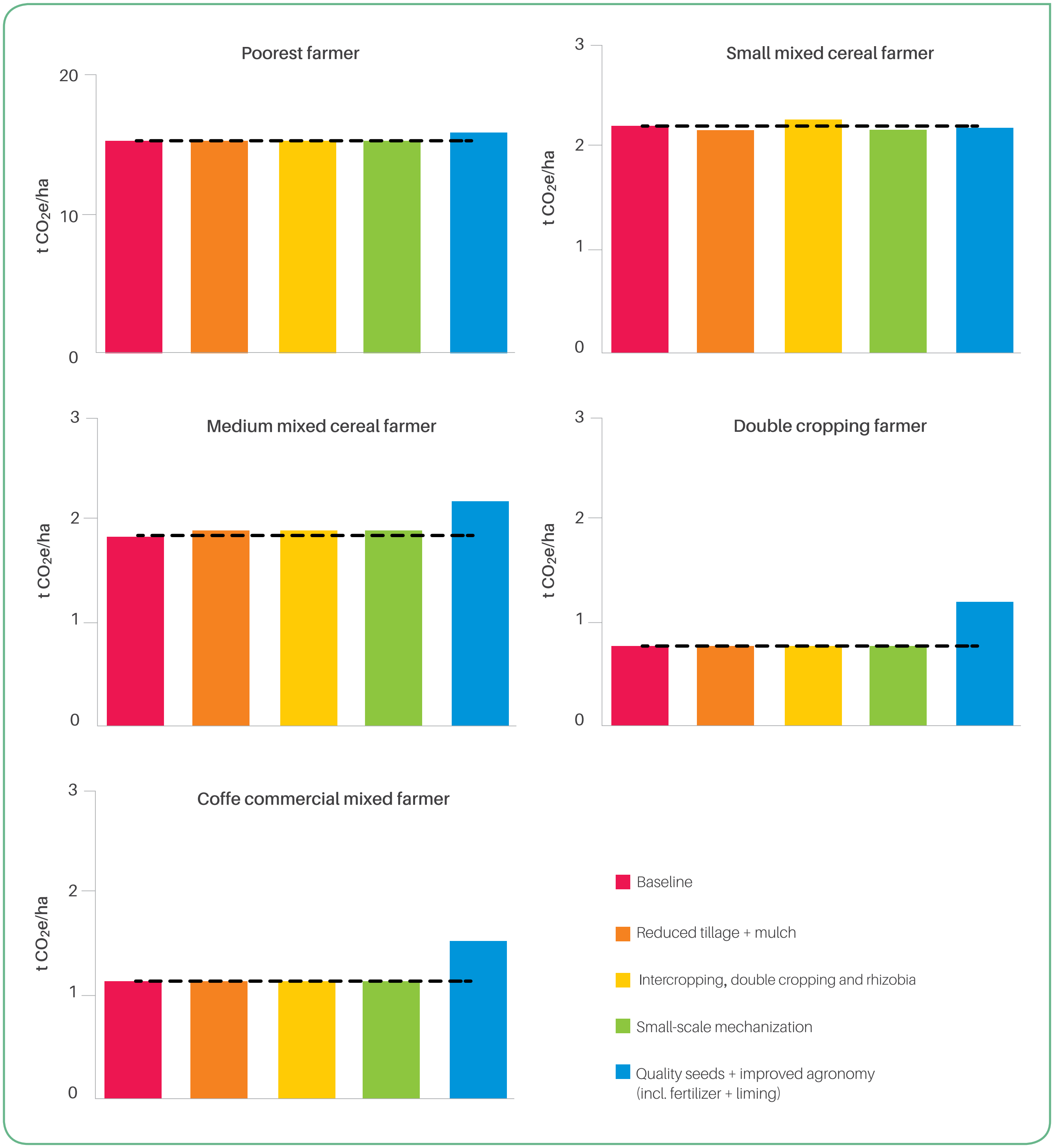


Figure 10. GHG emission intensity baselines and scenarios per farm type. Colours represent different scenarios.

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 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 11) and mitigation (GHG emission intensity, Figure 12). In addition, we plotted changes in mitigation (GHG emission intensity) against the changes in resilience (N balance) (Figure 13). These figures show trade-off and synergy patterns across farm types and soil technology scenarios.

Plotting changes in productivity against changes in N balances allows for a few insights (Figure 11). 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.

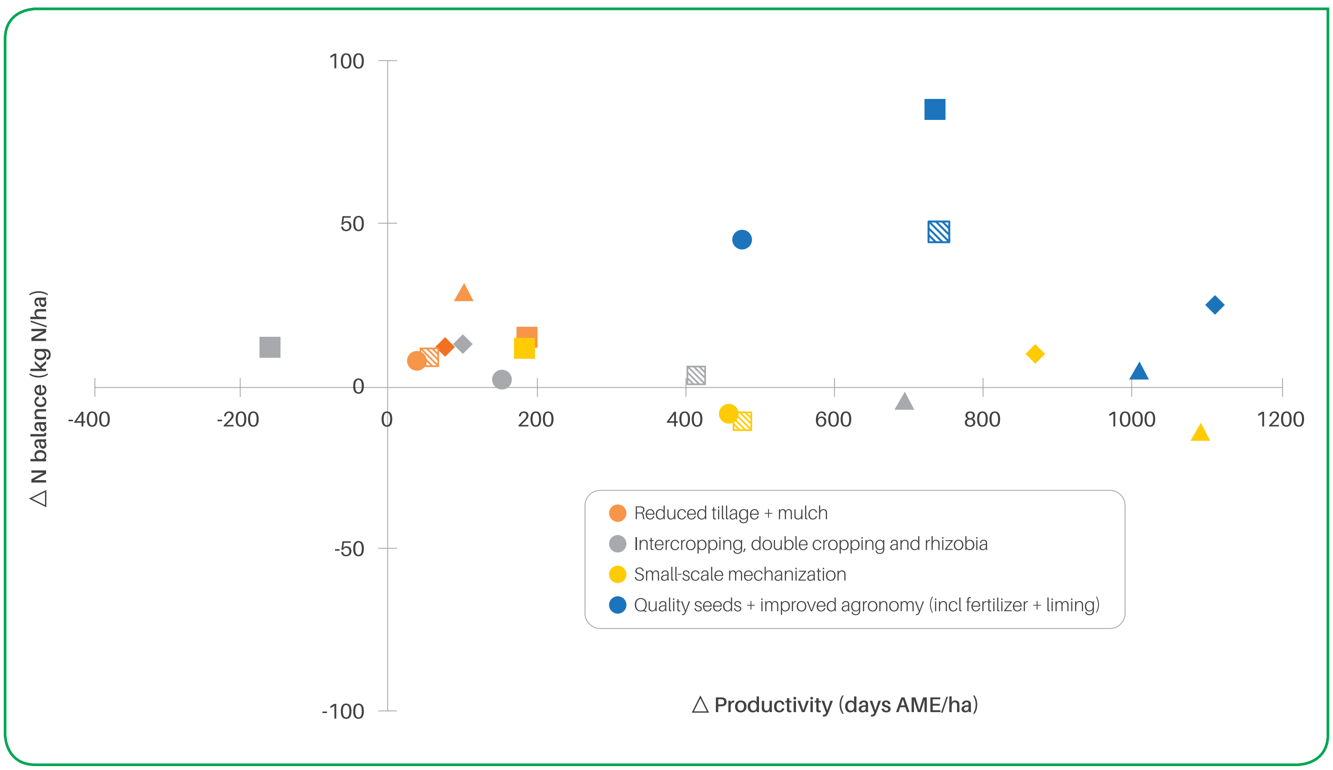


Figure 11. Trade-offs between productivity (days/ha) and field N balance (kg N/ha). *Colour represents the scenario and shape the farm types (□=poorest farm, △=Small mixed cereal farm, ◇=Medium mixed cereal farm, ▧with patterns=Double cropping farm and ○=Coffee commercial mixed farm).*

Different patterns appear when comparing changes in GHG emissions with changes in productivity (Figure 12). 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.

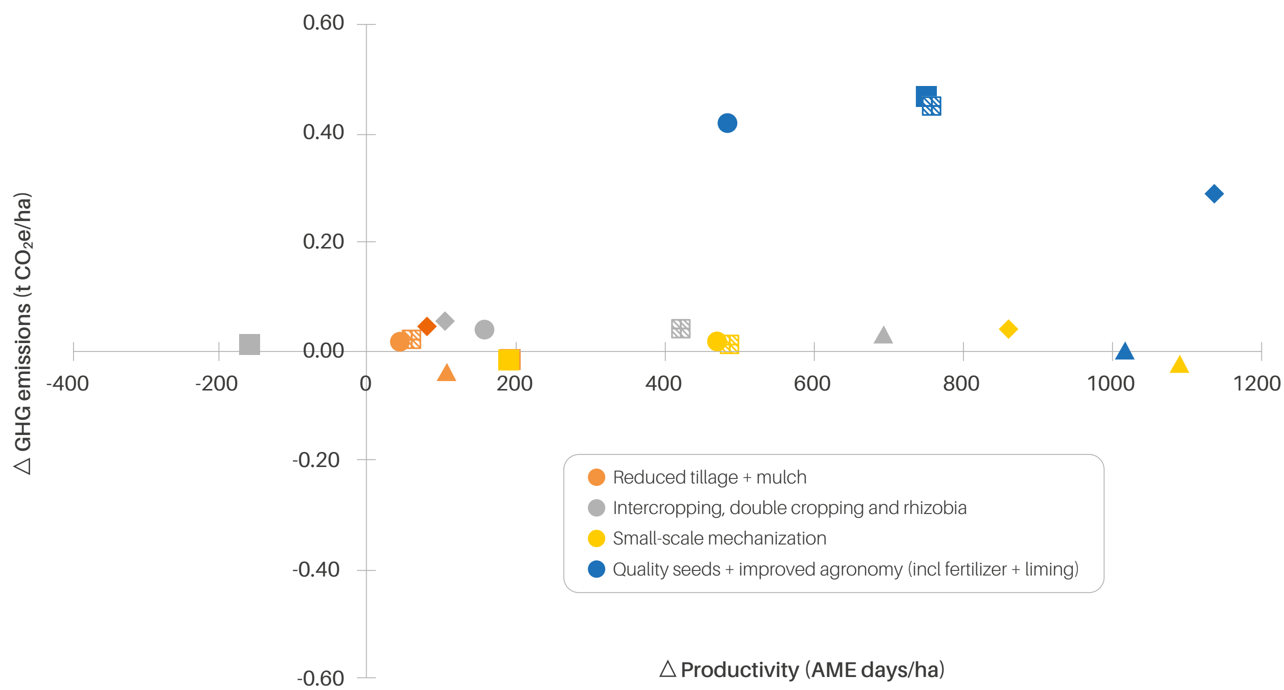


Figure 12. Trade-offs between productivity (days/ha) and GHG emissions (t CO_2e/ha). *Colour represents the scenarios, and shape the farm types (□=poorest farm, △=Small mixed cereal farm, ◇=Medium mixed cereal farm, ▧ with patterns=Double cropping farm and ○=Coffee commercial mixed farm).*

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. Again, the increase in GHG emissions in general are not large, especially in all technologies except the quality seeds plus improved agronomy.

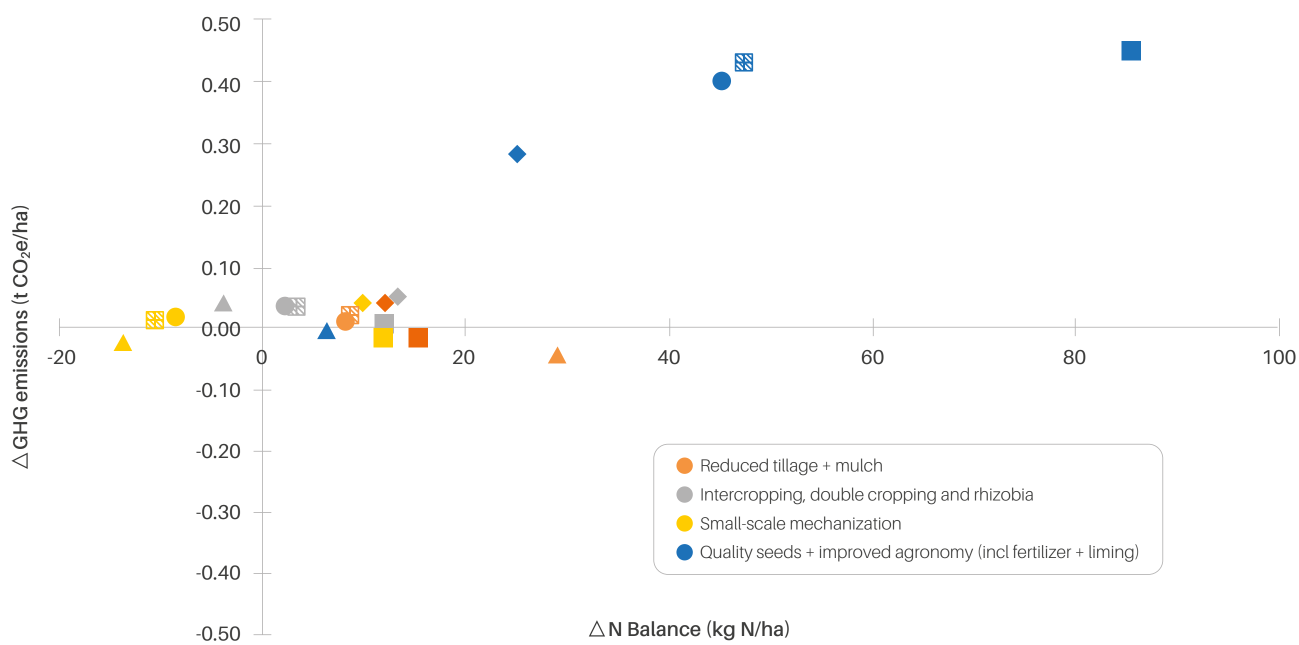


Figure 13. Trade-offs between GHG emissions (t CO_2e/ha) and change in N balance (kg N/ha). *Colour represents the scenarios, and shape the farm types (☐=poorest farm, △=Small mixed cereal farm, ◇=Medium mixed cereal farm, ▧ with patterns=Double cropping farm and ○=Coffee commercial mixed farm).*

Maize

6. Conclusions and recommendations

In this study, a fairly simple set of four indicators was used for assessing the climate smartness of farm types and soil protection and rehabilitation measures in Ethiopia. Furthermore, the analysis relied on minimum data: farming systems and soil technologies and impacts identified during a participatory stakeholder workshop, and questionnaire interviews with case study farmers deemed representative of the farming system types. This approach allowed for a truly rapid assessment that can feed into decision-making processes in the on-going GIZ Soil Protection and Rehabilitation for Food Security Program. However, both the choice of indicators and the case study approach has its limitations. Firstly, the use of calorie-based productivity indicator lacks the importance of nutritional security, to which livestock products add significantly. Moreover, such calorie calculation excludes food that is purchased with income generated by on-farm (cash crops) or off-farm activities. However, adding up calories produced from the various crops and livestock products and comparing business-as-usual with best-bets, is a simple and easy-to-grasp way of indicating changes. Focusing on soil fertility as the adaptation/resilience indicators excludes a large number of important issues that contribute to farmers' resilience to climate change, such as income stability, access to skills, capital and information, crop/livestock diversity, etc. Secondly, identifying farming systems types during a stakeholder workshop and choosing representative case study farms for data collection has possible limitations in representativeness of the chosen farms. This risk was tried to be mitigated by involving several CIAT, GIZ and if possible ministry staff in the choice, but highest representativeness could not always be reached. Despite the shortcomings of the indicators and approach used, the rapid assessment clearly shows that there is some variation in the baseline climate-smartness across different farm types. 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 on 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 + mulch provide win-win synergies across all farm types when comparing GHG emissions and N balance, but only small-scale mechanization provides synergies across most farm types in regards to productivity and N balance. Quality seeds and improved agronomy highly increased productivity, but also increased GHG intensity. However, the increases in GHG emissions in general are not alarmingly large. Adopting any of the tested technologies should not be of concern in terms of negatively affecting the third pillar, mitigation, of climate smartness, if food security and resilience objectives are met. This highlights on the one hand the diversity of farm types in this region, which is difficult to capture with a limited set of rapid single-household assessments, but on the other hand, also shows that similar performance regarding certain CSA indicators may have very different drivers and consequences.

Positive N balances need to be examined and discussed further, as some case study farms seem to deviate from the norm. The positive N balances on the poor and small farms might not be representative of these farms types throughout the target area due to above average manure and fertilizer application. However, they do indicate that with adequate amount of supply of N (from manure and/or inorganic fertilizers), there can be a potential accumulation of nitrogen in the fields. On the other hand, the double cropping and coffee farms highlight some slightly negative balances that however overtime could contribute to significant soil mining. Nutrient management remains a key concern across different farm types.

Livestock is the major cause of GHG emissions, followed by nitrous oxide emissions from soils. The latter is a direct consequence of the application of N-fertilizer. However, our rapid assessment analysis could not account for carbon (C) sequestration in soils as a consequence of reduced tillage and surface residue retention. Such C-sequestration has the potential to completely offset nitrous oxide emissions from soils. As mentioned earlier, livestock often plays a crucial role in securing farm household livelihoods and nutrition, and reducing their numbers is most likely not a feasible nor desirable climate change mitigation option. This is especially true for Ethiopia, which has the highest population of livestock of any country in Africa. They are highly valued for tilling, threshing and providing manure for both fertilizer and fuel. 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. 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 the region.

The assessment thus shows that the impact of the interventions varies across the farm types, pointing to the importance of targeting not only to bio-physical/agro-ecological environments but also taking into account the socio-economic context and associated farming practices.

Debre Berhan, central Ethiopia

APPENDIX I: Surveyed farm details

Table 1. Household size (no.), land sizes (ha).

Farm type	Farm size	Area under cultivation*	Household members
Poorest farmer	0.08	0.08	3
Small mixed cereal farmer	0.50	1.50	6
Medium mixed cereal farmer	1.69	1.75	5
Double cropping farmer	2.63	3.38	11
Coffee based commercial farmer	9.33	8.33	5

* Area under cultivation may exceed farm size if the farm rents land.

Table 2. Crops yields per farm type. Not applicable (NA) indicates that the respective crop is not grown on the farm. All yields are reported in fresh weight (FW/ha/year).

Farm type	Maize	Wheat	Barley	Sorghum	Avocado	Mango	Banana	Coffee	Faba bean	Teff	Potatoes	Niger seed
Poorest farmer	1250	NA	NA	NA	NA	NA	NA	NA	NA	NA	5000	NA
Small mixed cereal farmer	2800	9200	2222	NA	NA	NA	NA	NA	1563	1000	NA	NA
Medium mixed cereal farmer	968	NA	NA	NA	NA	NA	NA	491	NA	500	NA	NA
Double cropping farmer	700	667	NA	533	NA	NA	NA	NA	NA	1467	2000	89
Coffee-based commercial farmer	3864	NA	NA	NA	7200	9600	2400	304	NA	650	NA	NA

Table 3. Fertilizer application rates (kg N/ha).

Farm type	Cereals				Pulses		Trees				Grass	Tuber
	Maize	Barley	Sorghum	Wheat	Faba bean	Niger seed	Coffee	Mango	Banana	Avocado	Teff	Irish potato
Poorest farmer	0	NA	0	NA	NA	0	NA	NA	NA	NA	NA	0
Small mixed cereal farmer	22	50	NA	155	28	NA	NA	NA	NA	NA	27	NA
Medium mixed cereal farmer	15.15	NA	NA	NA	NA	NA	0	0	0	0	89.3	NA
Double cropping farmer	41	NA	0	20.48	NA	0	NA	NA	NA	NA	0	12.8
Coffee commercialized farmer	20.45	NA	NA	NA	NA	NA	0	0	0	0	20.5	NA

Table 4. Livestock herd composition (no.) and total tropical livestock unit (TLU).

Farm type	Local dairy cattle	Improved dairy cattle	Other cattle (male and heifers)	Calves	Sheep	Poultry	Donkey	TLU
Poorest farmer	0	0	2	0	0	0	0	1.0
Small mixed cereal farmer	1	0	2	0	4	4	1	1.8
Medium mixed cereal farmer	2	0	2	1	2	7	1	3.1
Double cropping farmer	0	0	3	0	0	5	1	1.9
Coffee-based commercial farmer	3	0	8	1	9	7	1	7.2

Table 5. Ruminants (cows and sheep) feed basket (%).

Farm type	Natural grasses (pasture)	Teff	Maize stover	Wheat straw
Poorest farmer	75	0	25	0
Small mixed cereal farmer	5	50	5	40
Medium mixed cereal farmer	90	10	0	0
Double cropping farmer	30	40	20	10
Coffee-based commercial farmer	95	0	5	0

Table 6. Fraction of crop residue removed from the field.

Farm type	Maize	Wheat	Barley	Sorghum	Avocado	Mango	Banana	Coffee	Faba bean	Teff	Potatoes	Niger seed
Poorest farmer	1.0										0.0	
Small mixed cereal farmer	1.0	0.7	0.5						0.0	1.0		
Medium mixed cereal farmer	1.0							1.0		0.8		
Double cropping farmer	1.0	0.8		0.5						0.9		
Coffee-based commercial farmer	1.0				0	0	0	1			0.0	0.0

Table 7. Livestock whereabouts in fraction of day (0-1).

Farm type	Cattle				Sheep				Chicken			
	Stable	Yard	Pasture	Off-farm	Stable	Yard	Pasture	Off-farm	Stable	Yard	Pasture	Off-farm
Poorest farmer	0.54	0.46	0.00	0.00	NA	NA	NA	NA	NA	NA	NA	NA
Small mixed cereal farmer	0.46	0.21	0.00	0.33	0.50	0.17	0.00	0.33	0.58	0.42	0.00	0.00
Medium mixed cereal farmer	0.33	0.33	0.08	0.25	0.58	0.00	0.08	0.33	0.63	0.38	0.00	0.00
Double cropping farmer	0.58	0.25	0.04	0.13	NA	NA	NA	NA	0.75	0.25	0.00	0.00
Coffee-based commercial farmer	0.29	0.29	0.21	0.21	0.58	0.00	0.21	0.21	0.54	0.46	0.00	0.00

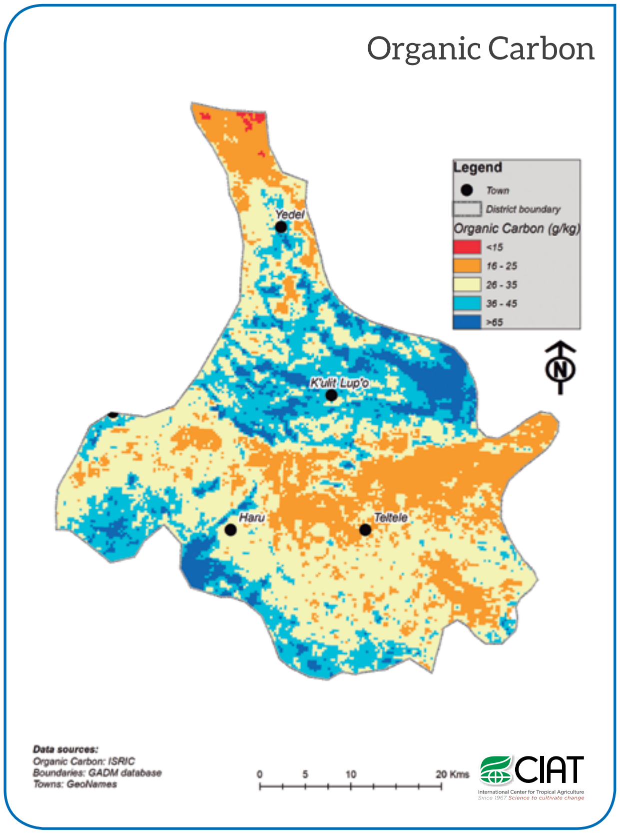
APPENDIX II: Scenario assumptions

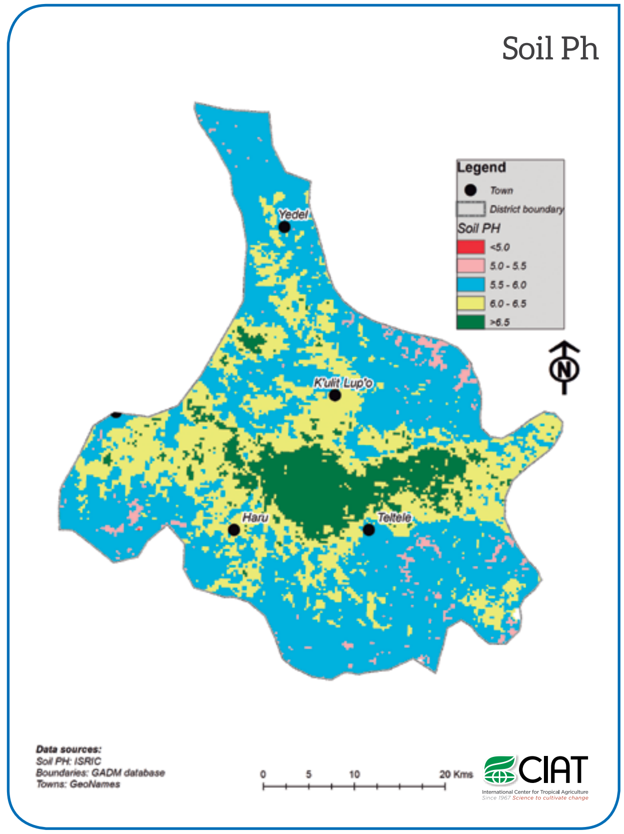
Farm type	Impact dimension	SC1 Reduced tillage + mulch	SC2 Intercropping, double cropping and rhizobia	SC3 Small-scale mechanization	SC4 Quality seeds + improved agronomy (incl. fertilizer + liming)
Poorest farmer	Land use change	No change	Reducing maize area by **15**% for beans	No change	No change
Small mixed cereal farmer	Land use change	No change	⁎Double cropping: Introduced chickpea (500kg/ha) on wheat, teff and barley plots after harvest *(Kassie et al., 2009)* ⁎Reducing maize areas by **20**% for beans	No change	No change
Medium mixed cereal farmer	Land use change	No change	⁎Double cropping: Introduced chickpea (500kg/ha) on teff plot after harvest *(Kassie et al., 2009)* ⁎Reducing maize area by **20**% for beans	No change	No change
Double cropping farmer	Land use change	No change	⁎Double cropping: Introduced chickpea (500kg/ha) on teff and wheat plots after harvest. *(Kassie et al, 2009)* ⁎Reducing sorghum and maize areas by **20**% each for beans	No change	No change
Coffee commercial mixed farmer	Land use change	No change	⁎Double cropping: Introduced chickpea (500kg/ha) on teff plot after harvest. ⁎Reducing maize area by **20**% for beans	No change	No change
Poorest farmer	Mineral fertilizer application	No change (no fertilizer applied baseline)	No change (no fertilizer applied baseline)	No change (no fertilizer applied baseline)	**87** kg N/ha/crop applied to all crops
Small mixed cereal farmers	Mineral fertilizer application	No change (Gurmessa et al., 2016)	Reduced by **35**% *(Gurmessa et al., 2016)*	No change	**87** kg N/ha/crop applied to all crops
Medium mixed cereal farmer	Mineral fertilizer application	No change (Gurmessa et al., 2016)	Reduced by **30**% *(Gurmessa et al., 2016)*	No change	**87** kg N/ha/crop applied to all crops
Double cropping farmer	Mineral fertilizer application	No change (Gurmessa et al., 2016)	Reduced by **25**% *(Gurmessa et al., 2016)*	No change	**87** kg N/ha/crop applied to all crops
Coffee commercial mixed farmer	Mineral fertilizer application	No change (Gurmessa et al., 2016)	Reduced by **25**% *(Gurmessa et al., 2016)*	No change	No change (Gurmessa et al., 2016) - already using this
Poorest farmers	Manure application	Reduced by **5**%	Increased by **10**% *(Gurmessa et al., 2016)*	No change	10% increase
Small mixed cereal farmer	Manure application	Reduced by **5**%	Increased by **20**% *(Gurmessa et al., 2016)*	No change	10% increase
Medium mixed cereal farmer	Manure application	Reduced by **5**%	Increased by **30**% *(Gurmessa et al., 2016)*	No change	10% increase
Double cropping farmer	Manure application	Reduced by **5**%	Increased by **30**% *(Gurmessa et al., 2016)*	No change	10% increase
Coffee commercial mixed farmer	Manure application	Reduced by **5**%	Increased by **15**% *(Gurmessa et al., 2016)*	No change	No change - already applying 200kg manure
Poorest farmer	Crop yield	Increased in all yields by **5**%	Intercropping: No change Rhizobia: Increased legume yields by **30**%	Increased by 5% due to reduction of post-harvest losses.	Increased all yields by **20**% (Gurmessa et al., 2016)
Small mixed cereal farmer	Crop yield	Increased in all yields by **5**%	Double cropping: **500** kg/ha chickpea added Intercropping: No change Rhizobia: Increased legume yields by **30**%	Increased all yields by 50% due to either irrigation or reducing post harvest losses	Increased all yields by **50**%

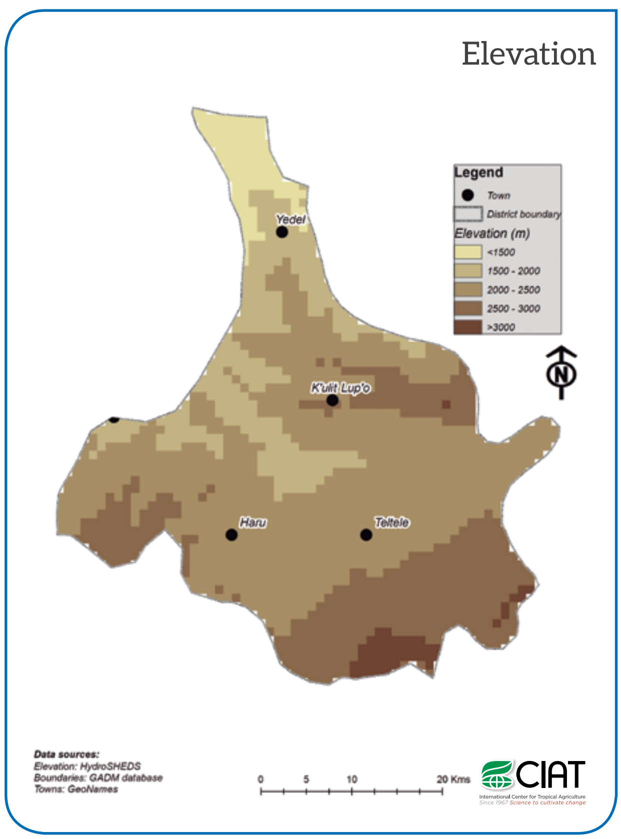
Farm type	Impact dimension	SC1 Reduced tillage + mulch	SC2 Intercropping, double cropping and rhizobia	SC3 Small-scale mechanization	SC4 Quality seeds + improved agronomy (incl. fertilizer + liming)
Medium mixed cereal farmer	Crop yield	Increased in all yields by **5**%	Double cropping: **500** kg/ha chickpea added Intercropping: No change Rhizobia: Increased legume yields by **30**%	Increased all yields by 50% due to either irrigation or reducing post harvest losses	Increased all yields by **75**%
Double cropping farmer	Crop yield	Increased in all yields by **5**%	Double cropping: **500** kg/ha chickpea added Intercropping: No change Rhizobia: Increased legume yields by **30**%	Increased all yields by 50% due to either irrigation or reducing post harvest losses	Increased all yields by **75%**
Coffee commercial mixed farmer	Crop yield	Increased in all yields by **5**%	Double cropping: **500** kg/ha chickpea added Intercropping: No change Rhizobia: Increased legume yields by **30**%	Increased all yields by 50% due to either irrigation or reducing post harvest losses	Increased all yields by **75**%
Poorest farmer	Milk yield	No dairy cattle on the farm	No dairy cattle on the farm	No dairy cattle on the farm	No dairy cattle on the farm
Small mixed cereal farmer	Milk yield	**5**% increase	**40**% increase *(Gurmessa et al., 2016)*	100% increase due to increased feed production	**5**% increase *(Gurmessa et al., 2016)*
Medium mixed cereal farmer	Milk yield	**5**% increase	**40**% increase *(Gurmessa et al., 2016)*	100% increase due to increased feed production	**10**% increase *(Gurmessa et al., 2016)*
Double cropping farmer	Milk yield	No dairy cattle on the farm	No dairy cattle on the farm	No dairy cattle on the farm	No dairy cattle on the farm
Coffee commercial mixed farmer	Milk yield	**5**% increase	**25**% increase *(Gurmesa et al. 2016)*	100% increase due to increased feed production	**20**% increase *(Gurmessa et al., 2016)*
Poorest farmer	Residue management	2/3 residue left on the field	Incorporating bean residue from the double/inter cropping back into the soil	No change	No change
Small mixed cereal farmer	Residue management	2/3 residue left on the field	Incorporating chickpea residue and beans residue from the double/inter cropping back into the soil	No change	No change
Medium mixed cereal farmer	Residue management	2/3 residue left on the field	Incorporating chickpea residue and beans residue from the double/inter cropping back into the soil	No change	No change
Double cropping farmer	Residue management	2/3 residue left on the field	Incorporating chickpea residue and beans residue from the double/inter cropping back into the soil	No change	No change
Coffee commercial mixed farmer	Residue management	2/3 residue left on the field	Incorporating chickpea residue and beans residue from the double/inter cropping back into the soil	No change	No change
Poorest farmer	Soil erosion	Reduced soil conservation factor (P) to 0.2	No change	Reduced soil conservation factor (P) to 0.5	No change
Small mixed cereal farmer	Soil erosion	Reduced soil conservation factor (P) to 0.2	No change	Reduced soil conservation factor (P) to 0.5	No change
Medium mixed cereal farmer	Soil erosion	Reduced soil conservation factor (P) to 0.2	No change	Reduced soil conservation factor (P) to 0.5	No change
Double cropping farmer	Soil erosion	Reduced soil conservation factor (P) to 0.2	No change	Reduced soil conservation factor (P) to 0.5	No change
Coffee commercial mixed farmer	Soil erosion	Reduced soil conservation factor (P) to 0.2	No change	Reduced soil conservation factor (P) to 0.5	No change

APPENDIX III: Reference maps of study sites

Ambo

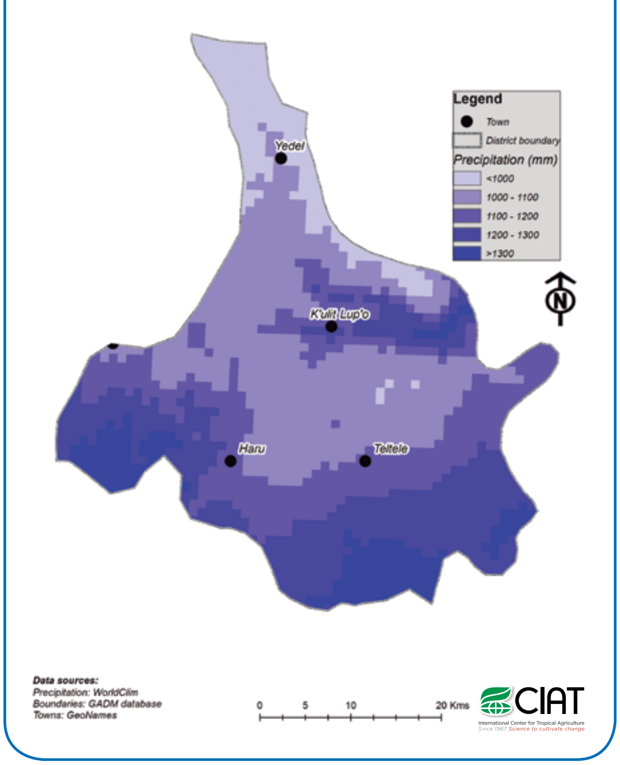






Ambo

Annual Precipitation



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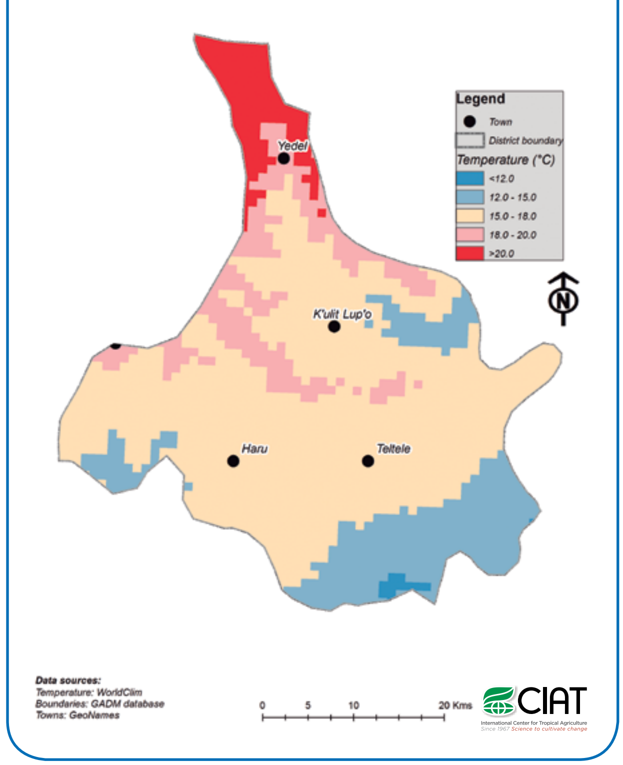
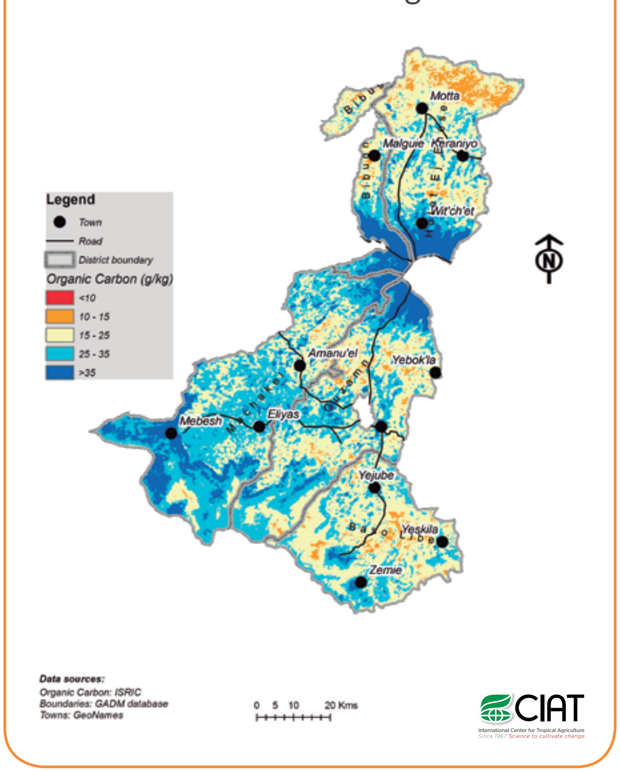
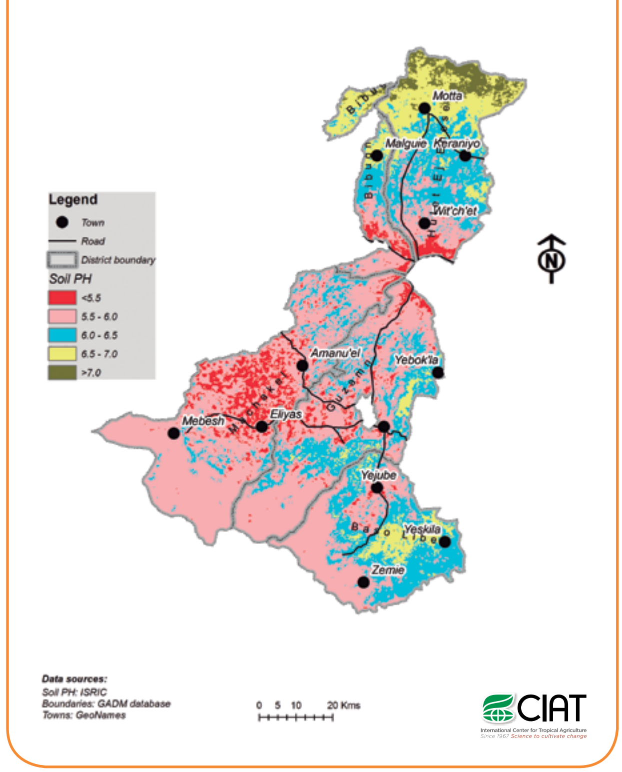


Amhara

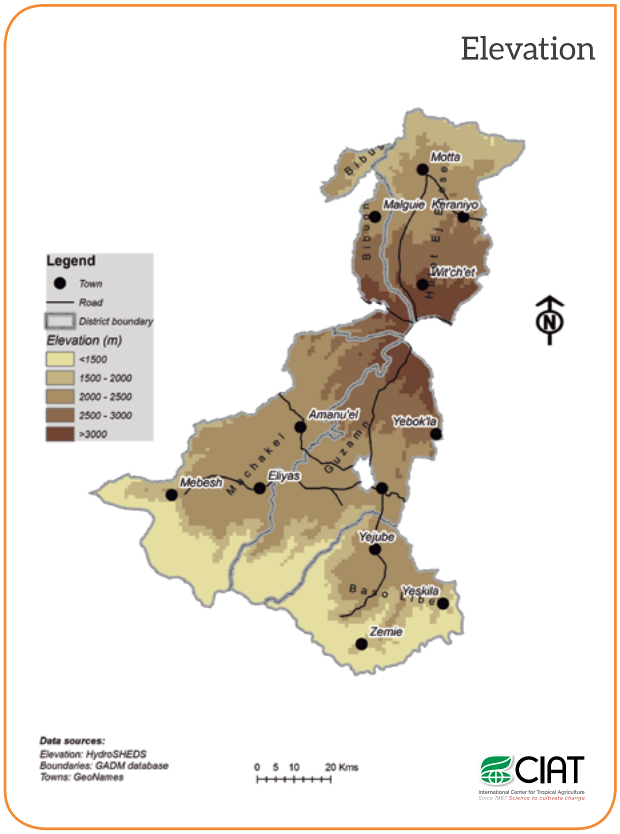
Organic Carbon

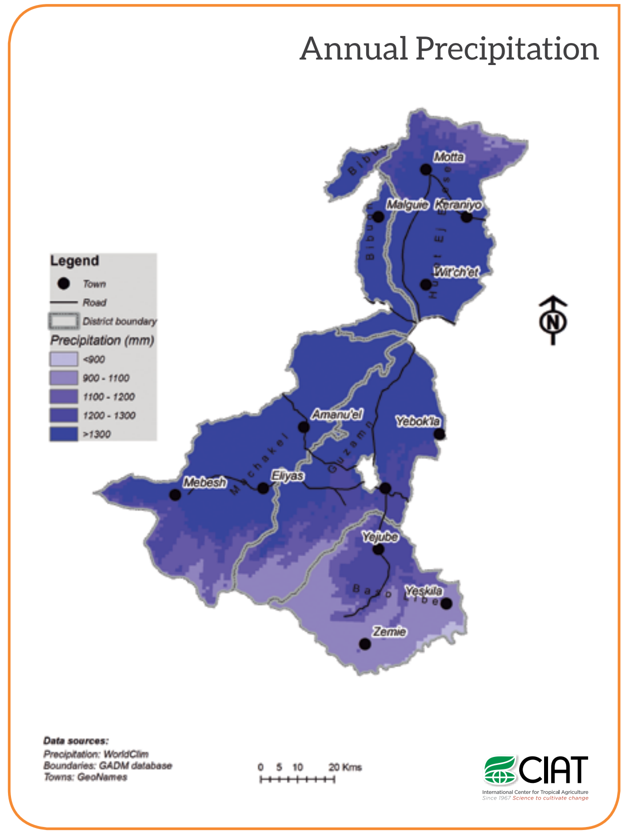


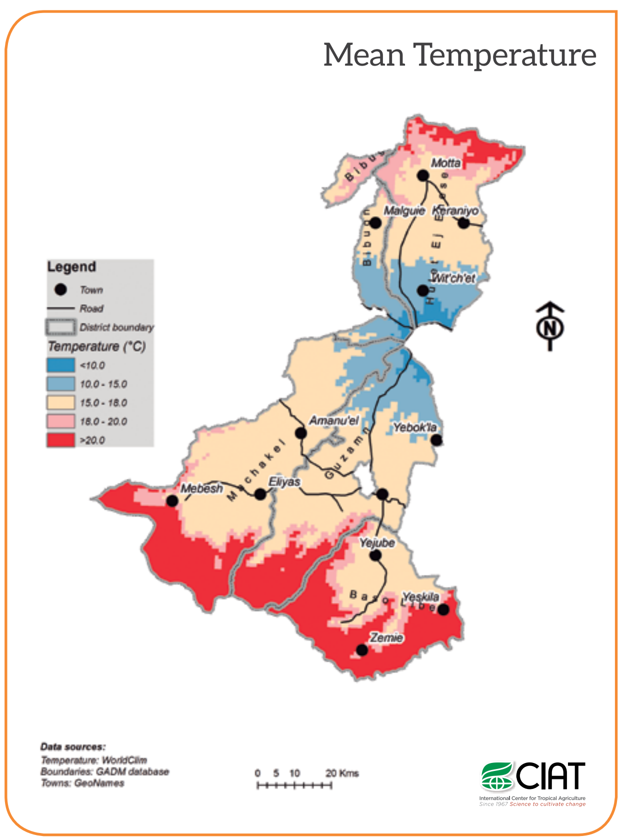
Soil Ph



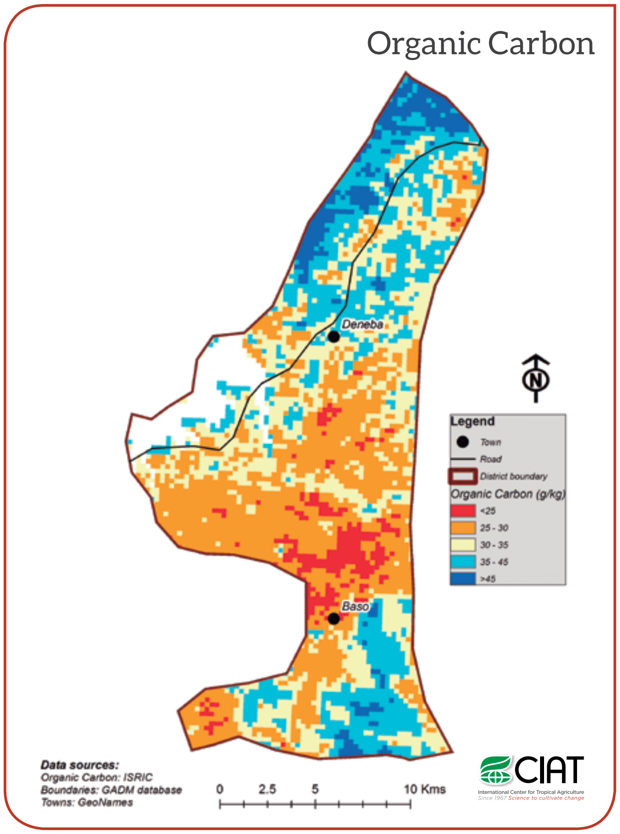
Amhara


Elevation
Legend
Town
Road
District boundary
Elevation (m)
<1500
1500 - 2000
2000 - 2500
2500 - 3000
>3000
Motta
Malguie
Keraniyo
Wit'ch'et
Amanu'el
Yebok'la
Mebesh
Eliyas
Yejube
Yeskila
Zemie
Data sources:
Elevation: HydroSHEDS
Boundaries: GADM database
Towns: GeoNames
0 5 10 20 Kms
CIAT

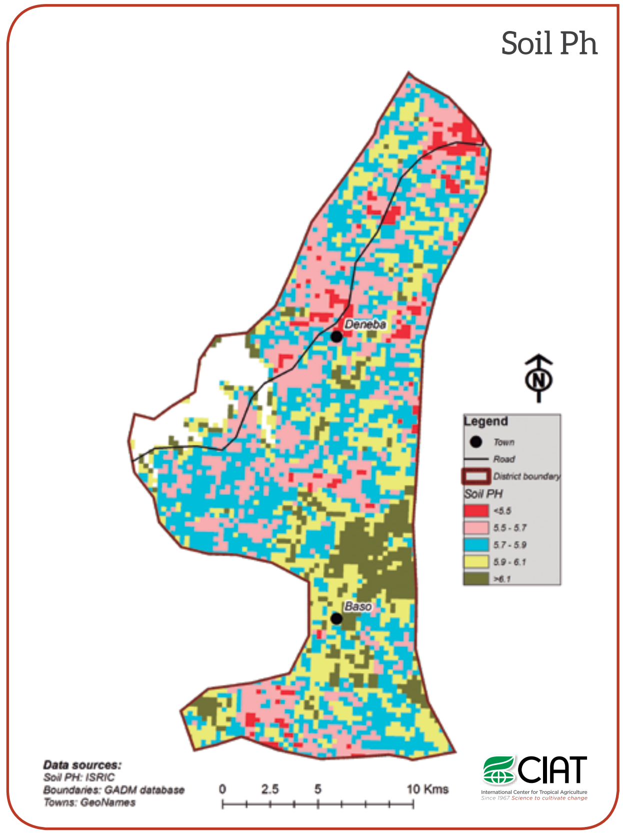

Annual Precipitation
Legend
Town
Road
District boundary
Precipitation (mm)
<900
900 - 1100
1100 - 1200
1200 - 1300
>1300
Motta
Malguie
Keraniyo
Wit'ch'et
Amanu'el
Yebok'la
Mebesh
Eliyas
Yejube
Yeskila
Zemie
Data sources:
Precipitation: WorldClim
Boundaries: GADM database
Towns: GeoNames
0 5 10 20 Kms
CIAT


Mean Temperature
Legend
Town
Road
District boundary
Temperature (°C)
<10.0
10.0 - 15.0
15.0 - 18.0
18.0 - 20.0
>20.0
Motta
Malguie
Keraniyo
Wit'ch'et
Amanu'el
Yebok'la
Mebesh
Eliyas
Yejube
Yeskila
Zemie
Data sources:
Temperature: WorldClim
Boundaries: GADM database
Towns: GeoNames
0 5 10 20 Kms
CIAT

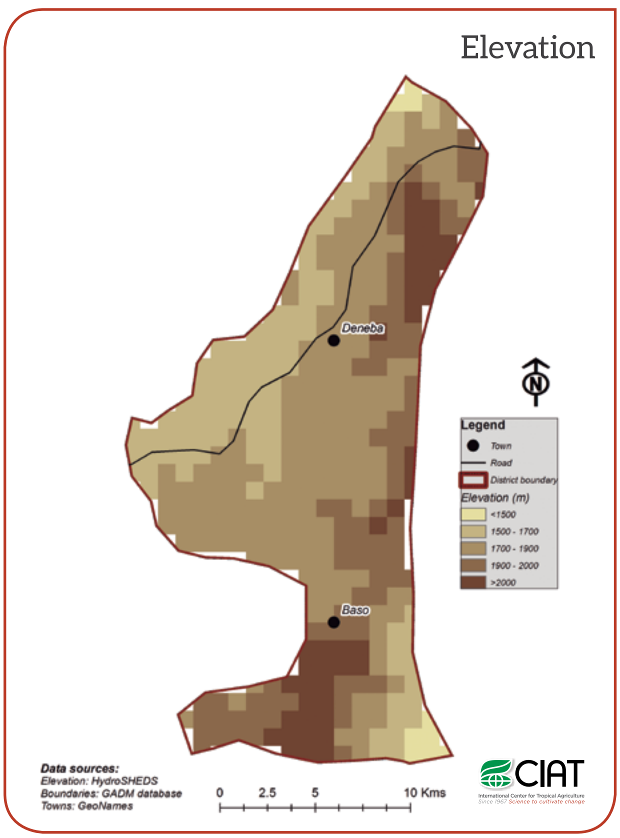
Sekoru



Organic Carbon
Deneba
Baso
Legend
Town
Road
District boundary
Organic Carbon (g/kg)
<25
25 - 30
30 - 35
35 - 45
>45
Data sources:
Organic Carbon: ISRIC
Boundaries: GADM database
Towns: GeoNames
0 2.5 5 10 Kms
CIAT

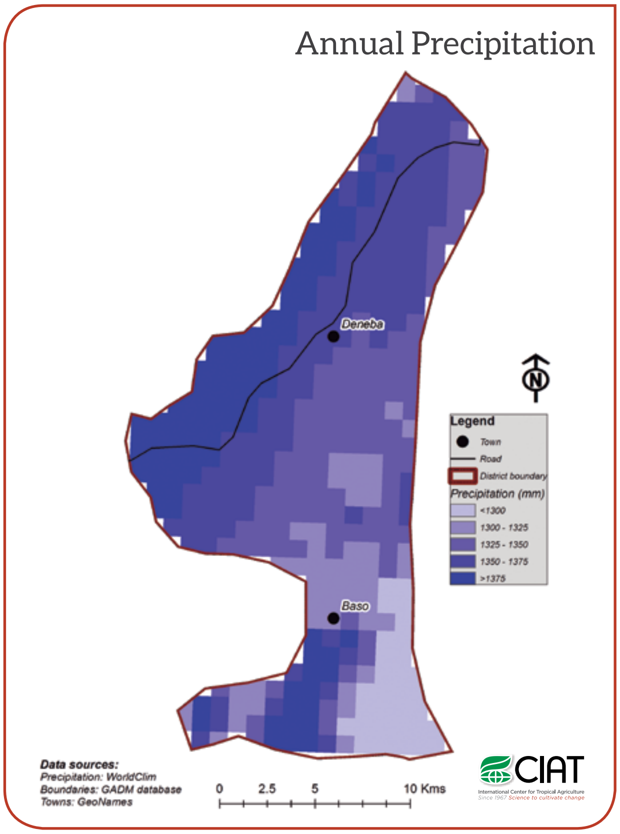


Soil Ph
Deneba
Baso
Legend
Town
Road
District boundary
Soil PH
<5.5
5.5 - 5.7
5.7 - 5.9
5.9 - 6.1
>6.1
Data sources:
Soil PH: ISRIC
Boundaries: GADM database
Towns: GeoNames
0 2.5 5 10 Kms
CIAT



Elevation
Deneba
Baso
Legend
Town
Road
District boundary
Elevation (m)
<1500
1500 - 1700
1700 - 1900
1900 - 2000
>2000
Data sources:
Elevation: HydroSHEDS
Boundaries: GADM database
Towns: GeoNames
0 2.5 5 10 Kms
CIAT

Sekoru


Annual Precipitation
Deneba
Baso
N
Legend
Town
Road
District boundary
Precipitation (mm)
<1300
1300 - 1325
1325 - 1350
1350 - 1375
>1375
Data sources:
Precipitation: WorldClim
Boundaries: GADM database
Towns: GeoNames
0 2.5 5 10 Kms
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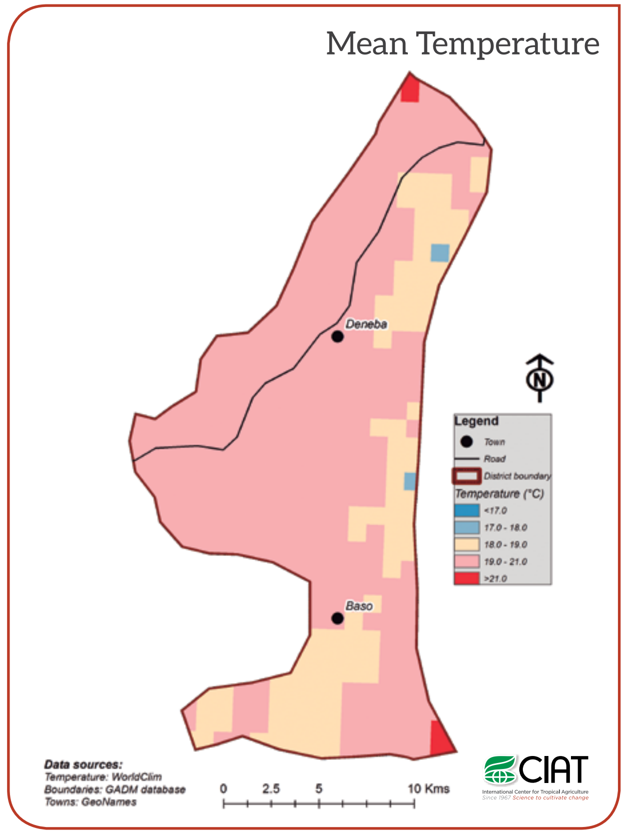
Mean Temperature
Deneba
Baso
N
Legend
Town
Road
District boundary
Temperature (°C)
<17.0
17.0 - 18.0
18.0 - 19.0
19.0 - 21.0
>21.0
Data sources:
Temperature: WorldClim
Boundaries: GADM database
Towns: GeoNames
0 2.5 5 10 Kms
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Community in Debre Berhan, central Ethiopia

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