Climate smartness of GIZ soil protection and rehabilitation technologies in Zou and Collines counties of Benin

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Rapid Assessment Report

Celine Birnholz, Špela Kalčić, Jessica Koge, Birthe Paul, Juliet Braslow, Rolf Sommer, and An Notenbaert

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RESEARCH PROGRAM ON Water, Land and Ecosystems

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1. Introduction

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).

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 goods such as climate change mitigation (Klapwijk et al., 2014). Although CSA aims at improving food security, resilience and mitigation, it does not imply that every recommended practice should necessarily be a 'triple win'. Mitigation in developing countries is often seen as a co-benefit, while food security and resilience are main priority. Low emission growth paths might have more associated costs than the conventional high emission pathways, thus monitoring can open opportunities for climate finance funds (Lipper et al., 2014).

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" (SEWOH), which invests in sustainable approaches to promoting soil protection and rehabilitation of degraded soil in Kenya, Ethiopia, Benin, Burkina Faso and India. 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. The climate-smart soil protection and rehabilitation research project allows GIZ to widen the scope of information on impacts of soil protection and rehabilitation measures 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, namely the rapid assessment of climate-smartness of some of the ProSOL endorsed soil rehabilitation and protection technologies in the region of Zou/Collines counties in Benin (Kalčić and Birnholz 2016). Subsequently, interviews were conducted in farm households that were deemed representative of the 5 farm types identified during the workshop. The data collected on these farms forms the basis of the baseline calculations of greenhouse gas (GHG) emissions, soil erosion and nitrogen balances for each farm type, as well as scenarios representing soil rehabilitation technologies promoted by GIZ. Section 2 provides more details about the farming systems typologies characterized by various factors that determine diversity. In the following sections we provide more details about the methodology and the sampled farms. Section 4 entails descriptions of the soil rehabilitation scenarios implemented in the 'Kalkulator', whose results have been presented in section 5 in comparison to the baselines.

2. Methodology

Following the participatory workshop that identified 4-6 farming system types per country, potential representative farms were jointly identified by CIAT, GIZ (ProSOL) 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). 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 that used within 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 according to different methodologies:

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 of 2500 kcal per day (AME). Energy from potential 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 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). 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.

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 farm-field balance expressed in kg N per farm. These results are then, again, converted into kg N per ha.

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

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

where,

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

K = Erodibility factor

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

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

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

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

GHG emissions: GHG emissions are calculated at farm level following the guidelines of the International Panel on Climate Change (IPCC, 2006). Emissions from livestock (methane from enteric fermentation), manure (methane and nitrous oxide), and field emissions (nitrous oxide) are taken into account as illustrated in 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).

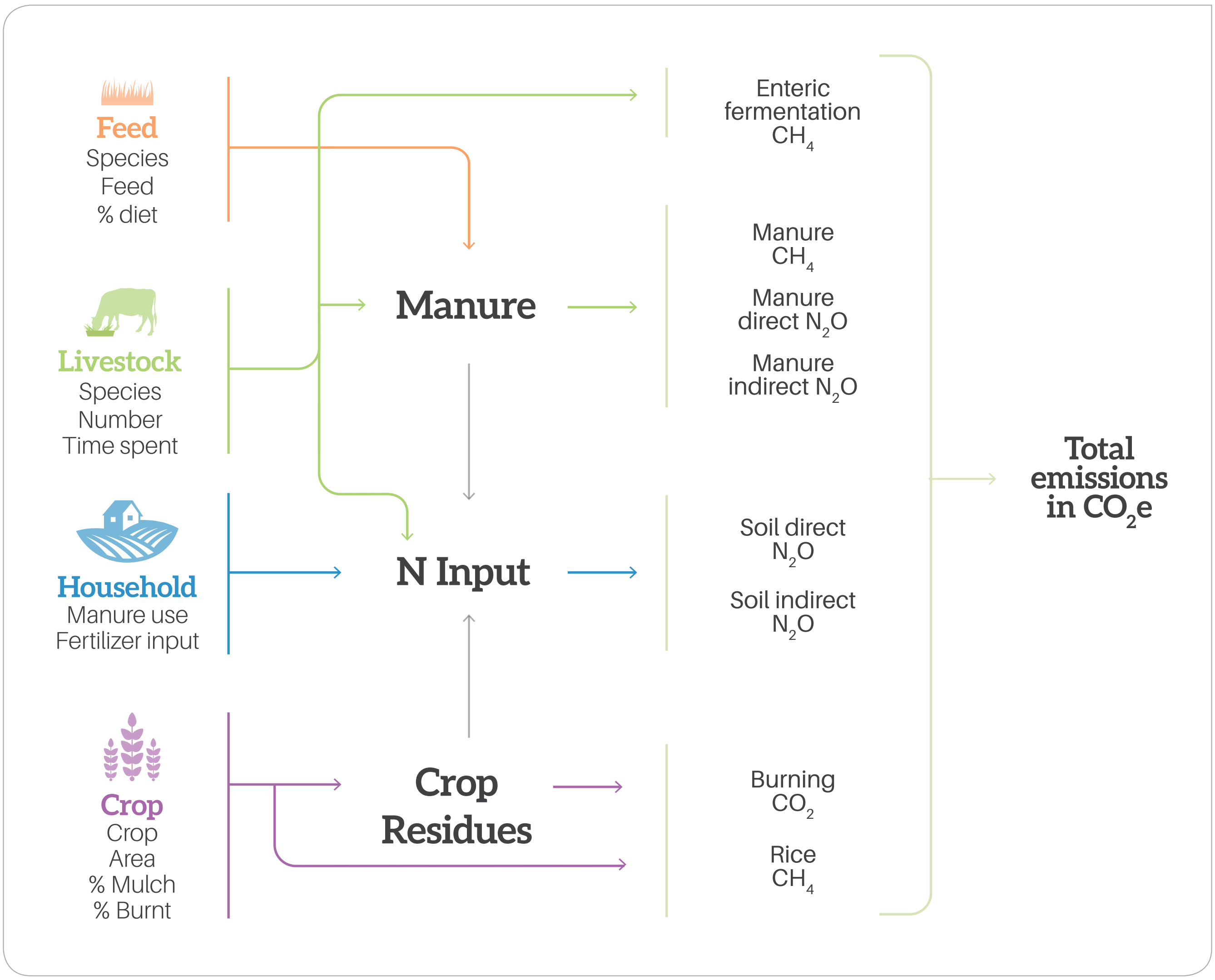

Figure 1. Scheme of GHG emission calculations.

3. 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. Summary of survey techniques used in the economic assessment

Type	Small-scale farming systems	Lowland farming systems	Integrated farming systems	Medium-scale farming systems	Large-scale farming systems
Share	60%	10%	10%	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.

i. **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.

ii. **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.

iii. **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.

iv. **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.

v. **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.

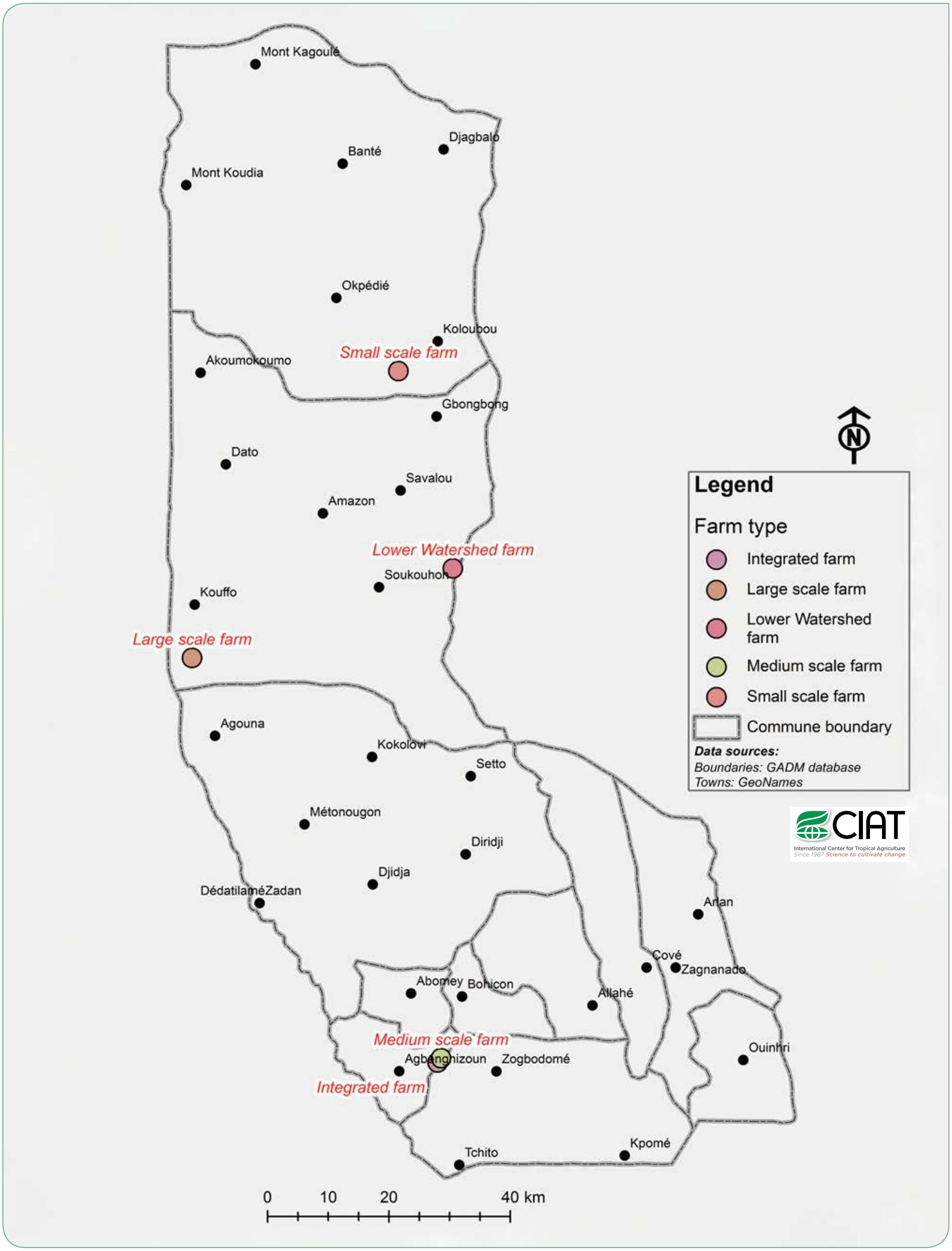

Figure 2. Location of case study farms.

4. Technology descriptions and scenarios

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

The interventions fall in five categories:

1. Soil fertility interventions: Intercropping, pigeon pea, mucuna, morenga and many other legumes and soil improving plants, use of compost and manure, management of residus from harvest.
2. Physical measures for better soil and water management (digues filtrantes, cordons pierreux, Zai, Démi-lunes, ploughing along the contour lines etc.).
3. Managing climate change risk interventions: Improved varieties (short cycle and drought-tolerant crops).
4. Agro-forestry interventions: Orchard rehabilitation, planting of legume trees into existing fields, arranging for on farm individual tree plantation (other than cashew and citron).
5. Better integration of animal husbandry and plant production within the farming system (fodder production, use of animal manure).

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 **short cycle** and **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 and soja 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.

5. Results

5.1 Productivity pillar

5.1.1 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.

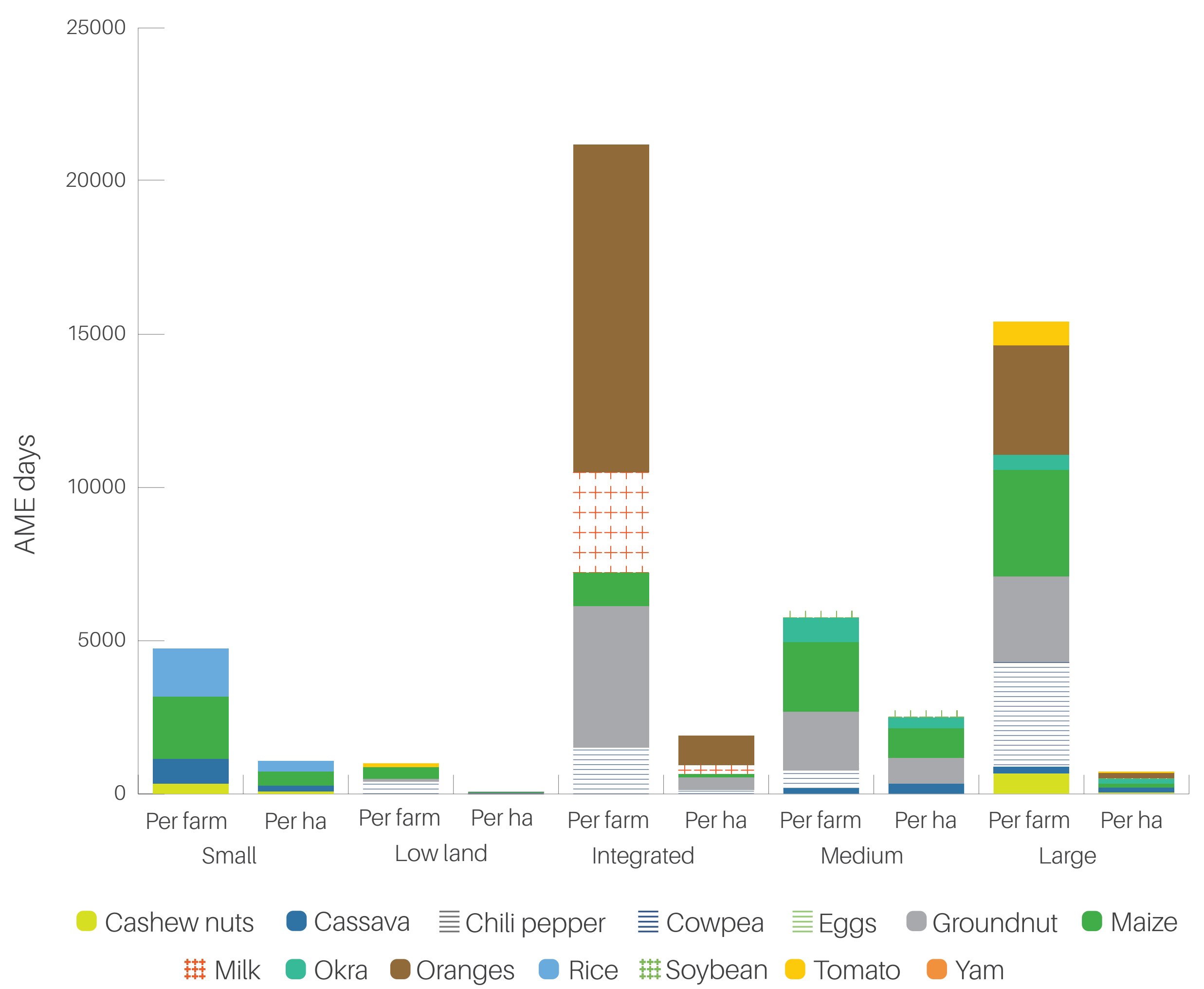

Figure 3. Baseline productivity and contribution from the different products across farm types. *Productivity is expressed as number of days that 1 adult male equivalent (AME) can be fed from livestock and crop products produced on the farm.*

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.

5.1.2 Changes in productivity

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

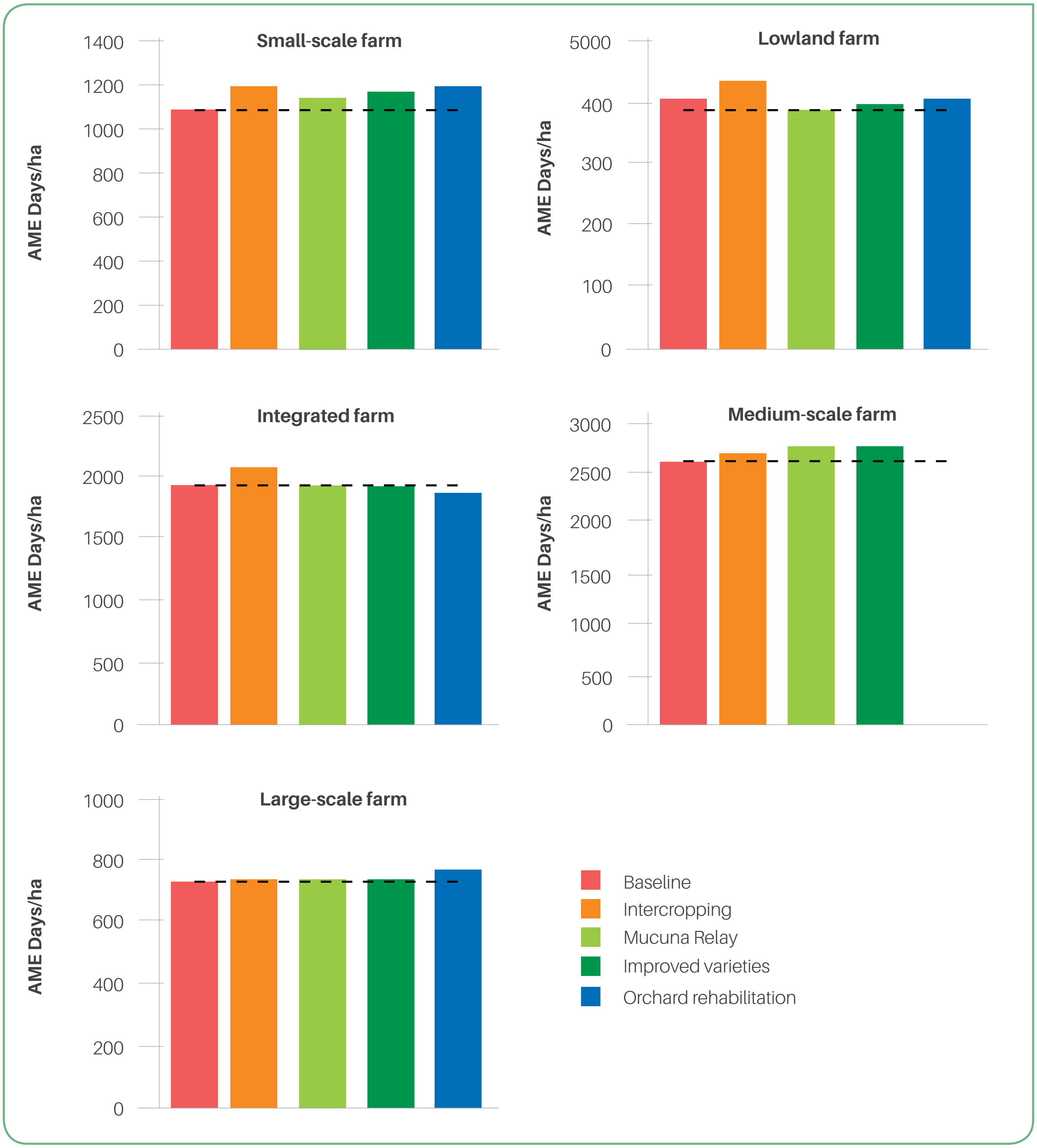

Figure 4. Baseline and scenario productivity per farm type. Results are expressed in days of Adult Male Equivalent calories (AME = 2500 kcal/day) on a per-hectare basis.

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.

5.2 Resilience pillar

5.2.1 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 5). As the use of inorganic fertilizers is limited, manure 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.[2] 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.

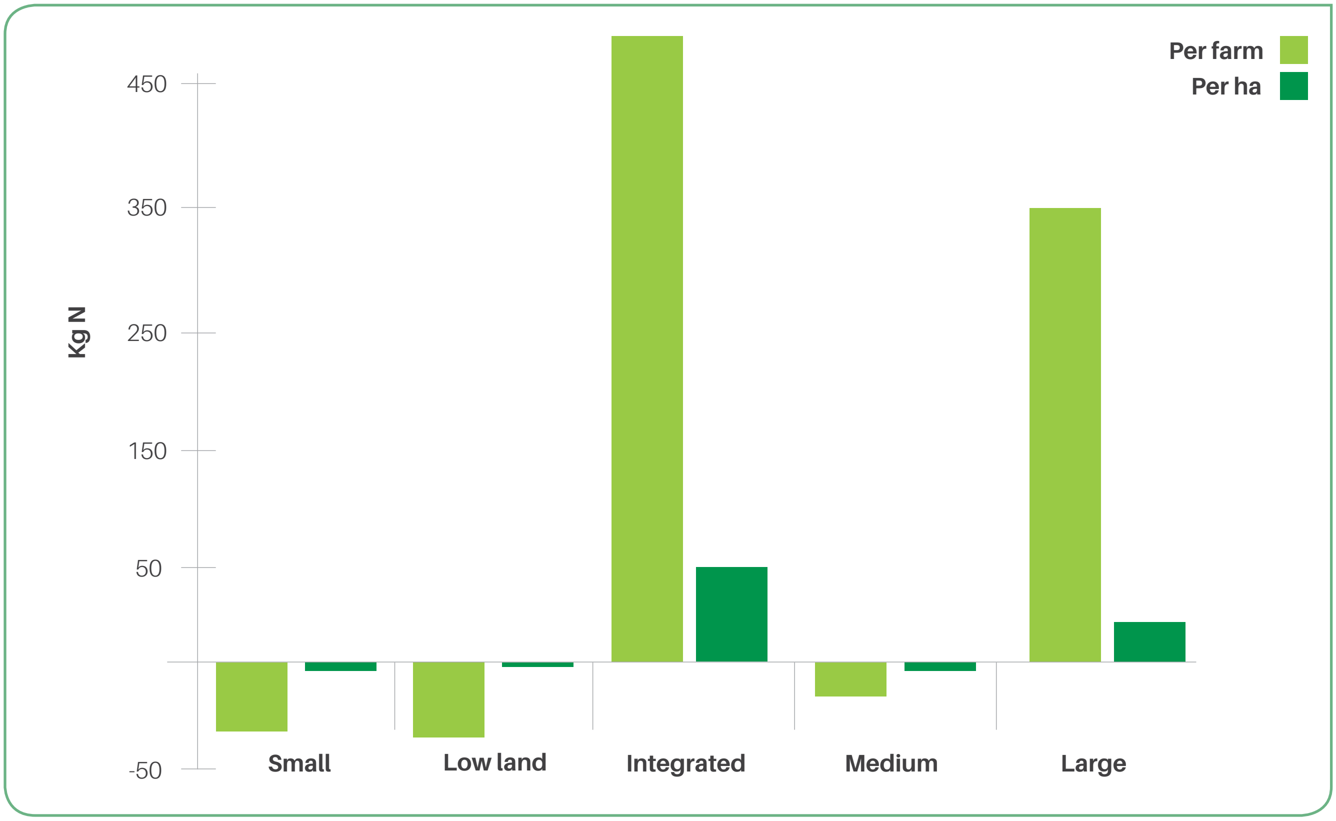

Figure 5. Baseline N balance at field level per farm and hectare across farm types.

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

5.2.2 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.

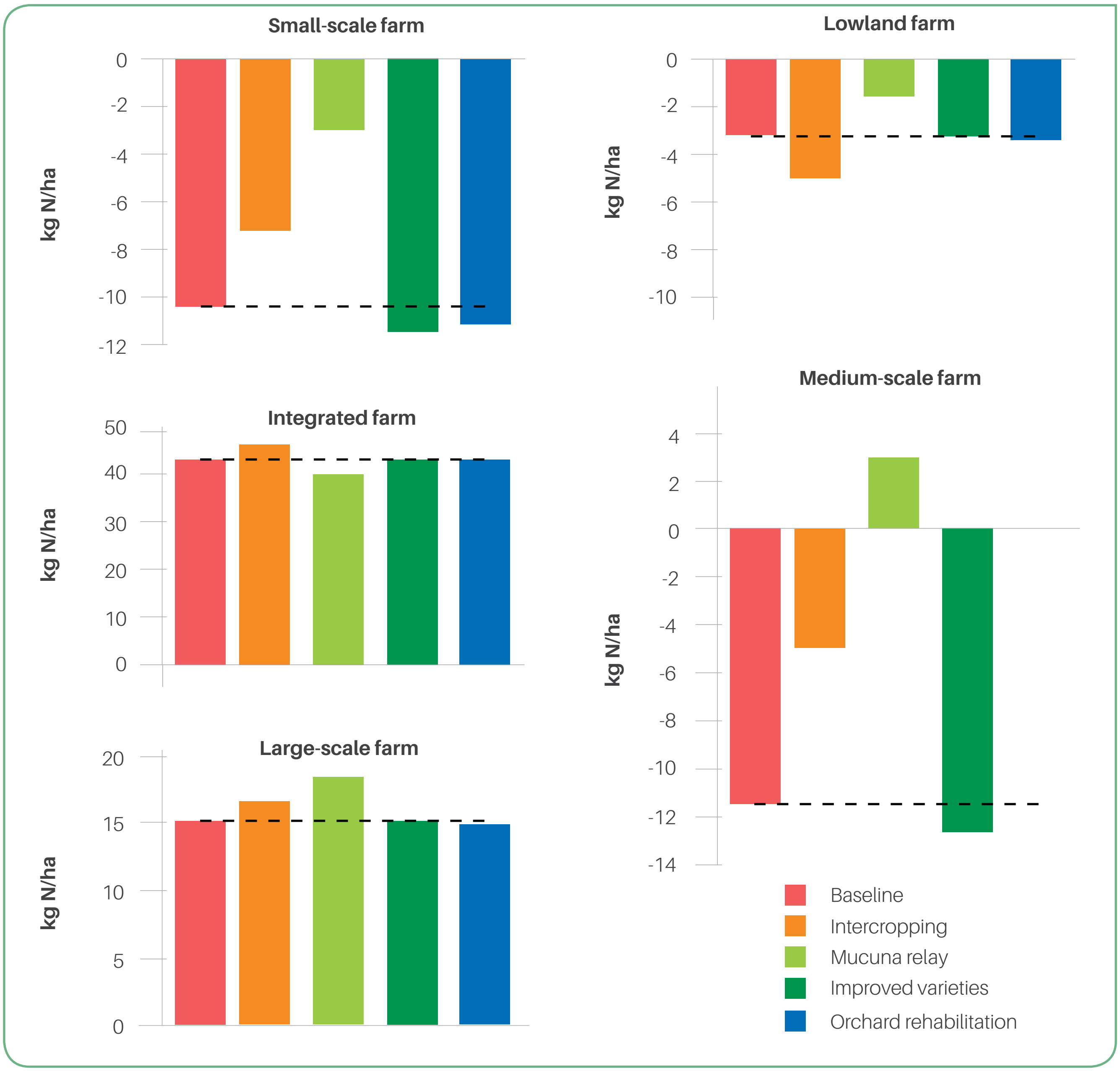

Figure 6. Baseline and scenario soil N balance per farm type (kg N/ha).

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.

5.3 Mitigation pillar

5.3.1 Baseline GHG 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 source of GHG emissions, contributing more than half of on-farm emissions in all four cases. Soil emissions are the second largest source of GHG on those farms.

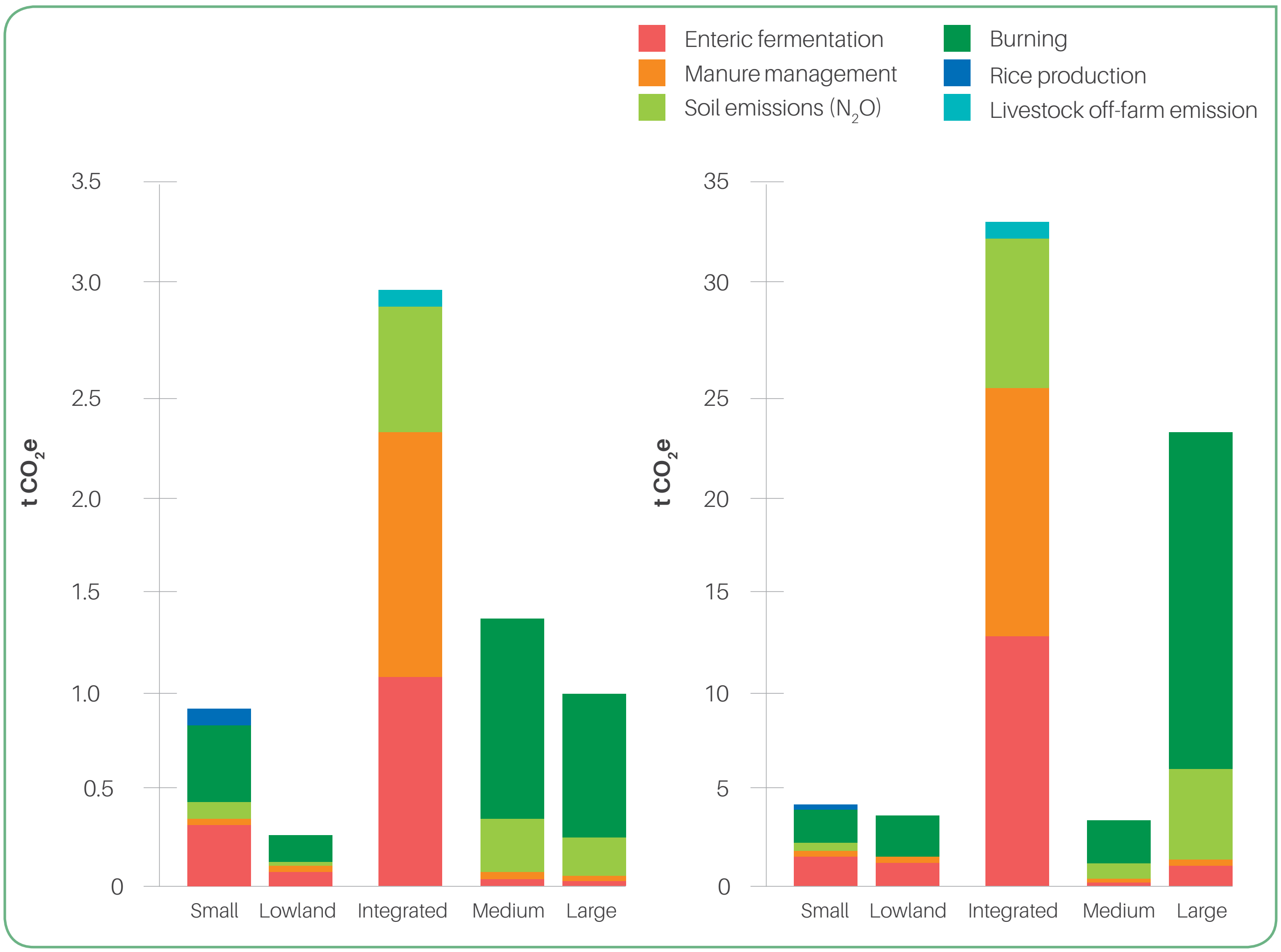

Figure 7. Baseline GHG emissions across farm types per hectare (left) and farm (right). Emission sources include enteric fermentation, manure management, burning of residues, rice production and soil emissions.

5.3.2 Changes in GHG 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).

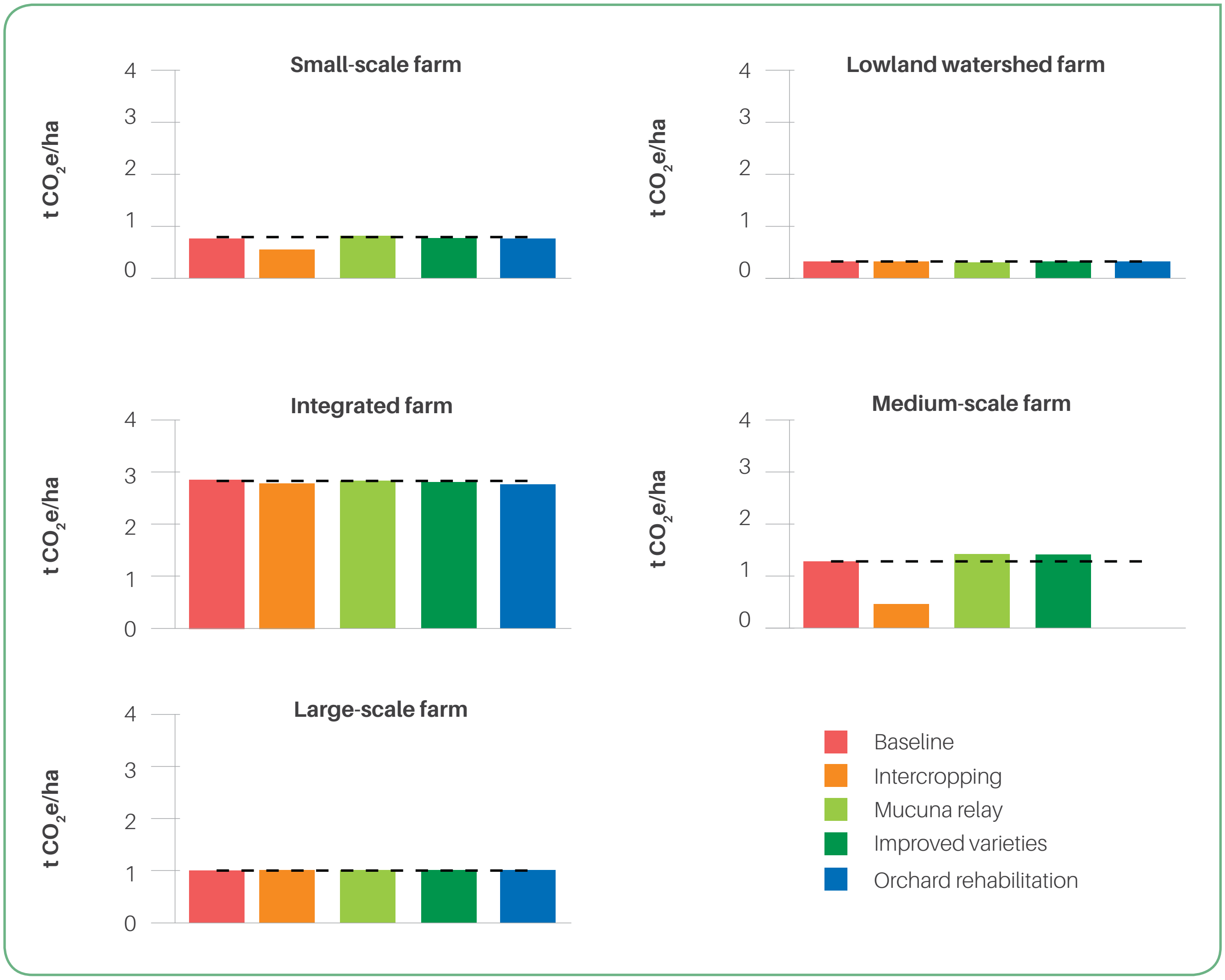

Figure 8. Baseline and scenarios GHG emission intensity per farm type (t CO_2e/ha).

5.4 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 small, medium and to a certain extent the integrated farm.

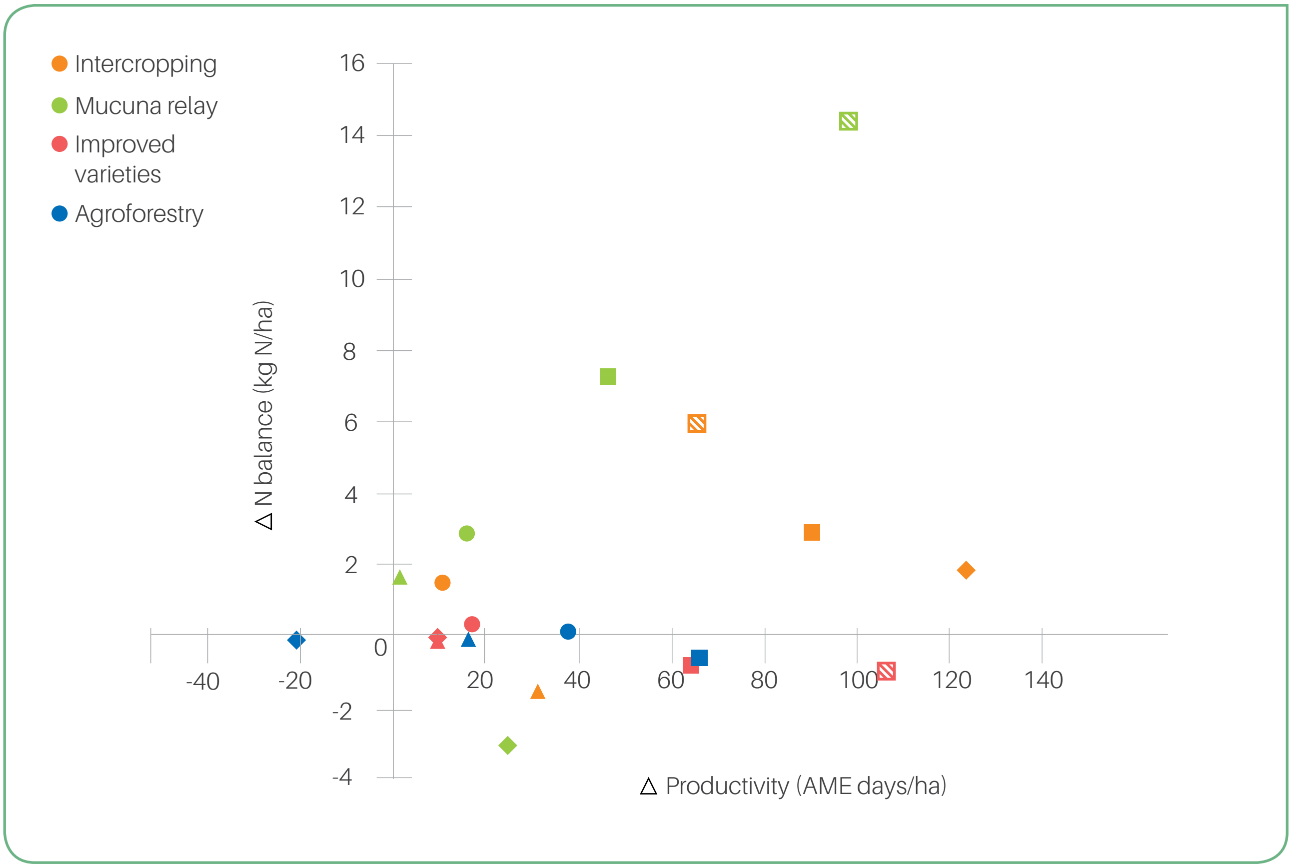

Figure 9. Tradeoffs between productivity (AME days/ha) and field N balance (kg N/ha) change from baseline. Colours represent the scenarios, and shape the farm types (□=Small-scale farm, △=Lowland farm, ◇=Integrated farm, ▧ with patterns=Medium-scale farm and ○=Large-scale farm).

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.

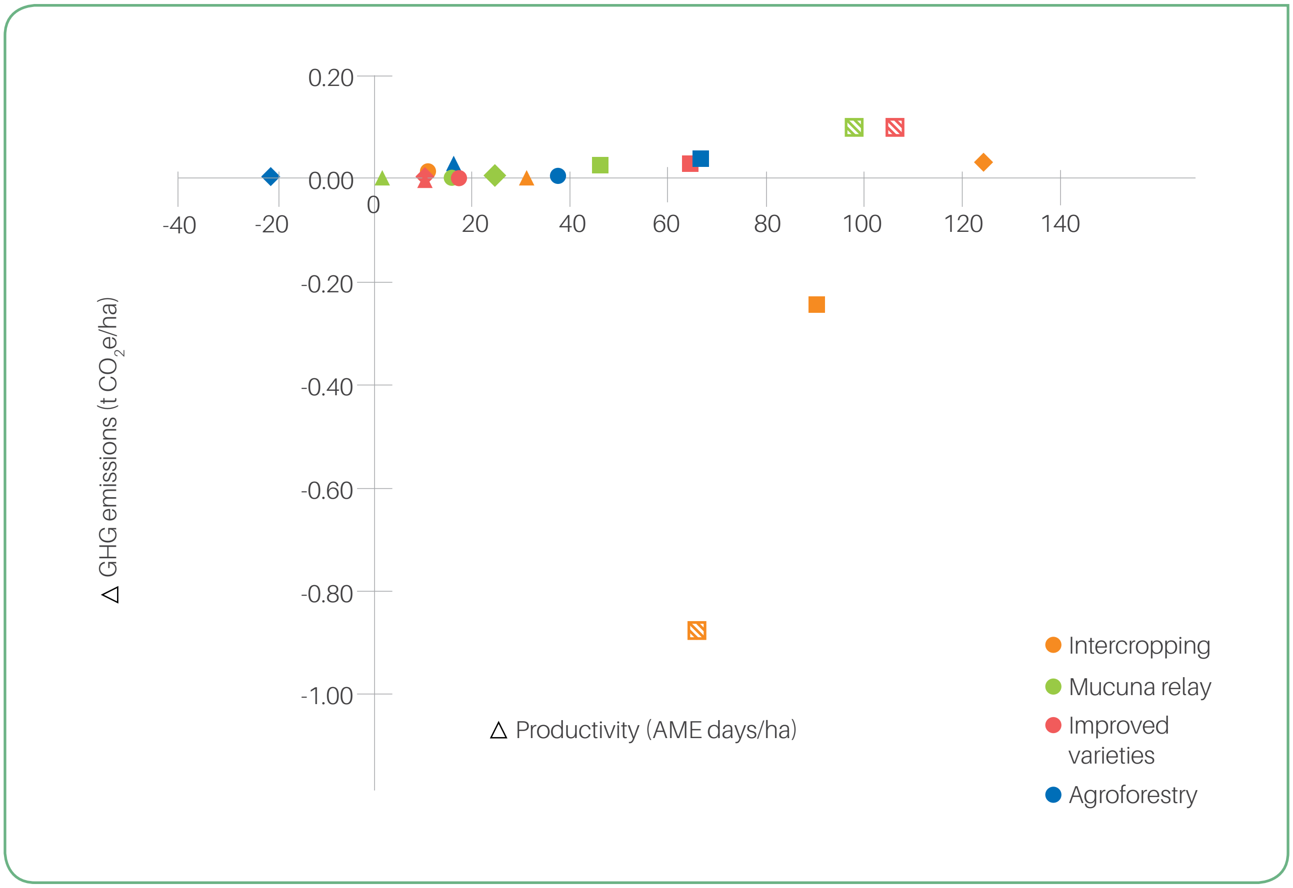

Figure 10. Tradeoffs between productivity (AME days/ha) and GHG emissions (t CO_2e/ha) change from baseline. Colours represent the scenarios, and shape the farm types (□=Small-scale farm, △ =Lowland farm, ◇ =Integrated farm, ▧with patterns=Medium-scale farm and ○ =Large-scale farm).

6. Conclusions and recommendations

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

The choice of indicators has its limitations. The use of calorie-based production as a productivity indicator disadvantages farms with higher importance of livestock production as compared to staple crops. The high protein content of meat and milk renders them however very important for nutrition security, especially so for young children and pregnant women. This should be kept in mind when evaluating production. 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 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.

Despite the shortcomings of the indicators used, the rapid assessment clearly shows that there is a huge variation in the baseline climate-smartness across different farm types. The increases in productivity in response to the implemented scenarios are quite varied and in many cases, limited. 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, fertilizer and manure use is very low to start with. Productivity increasing measures, unless accompanied with higher levels of inputs (i.e. manure, residues…), may thus result 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, except for intercropping where residues were not burned. Most of the farms could easily reduce emission by better manure management as well as by abolishing burning of all residues.

As mentioned earlier, orchards as well as teak and cashew 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. Overall, the assessment shows that the impact of the interventions varies across the farm types and also are sensitive to the assumed changes. This points 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.

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Appendix II. Surveyed farm details

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

Farm Type	Household members (number)	Farm size (ha)	Area managed (ha)	Area cultivated (ha)
Small	11	4	4	4.0
Lowland	9	12.5	12.5	12.5
Integrated	11	11.2	11.2	11.2
Medium	7	6.8	4.81	2.3
Large	10	31.5	20.5	20.5

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

Farm Type	Grain yields of cereal crops (kg FW/ha/year)			Yields of legume crops (kg FW/ha/year)			Yield of tree crops (kg FW/ha/year)				Yield of tubers (kg FW/ha/year)		Yield of vegetables (kg FW/ha/year)		
	Maize	Rice	Cotton	Cowpea	Groundnut	Soybean	Cashew	Orange	Palm oil	Teak**	Cassava	yam	Tomato	Chili peppers	Okra
Small	1214	2000*	NA	NA	NA	NA	150	NA	20	NA	1667	NA	NA	NA	NA
Lowland	200	NA	NA	300	107	281	150	NA	Unknown	5000	1667	1400	10000	500	4000
Integrated	453	NA	NA	303	471	NA	NA	12 500	Unknown	5000	NA	NA	NA	NA	NA
Medium	1324	NA	NA	233	1107	400	NA	NA	NA	NA	NA	NA	NA	NA	4000
Large	1320	NA	950	240	320	NA	150	12500	NA	5000	1667	NA	10000	600	4000

* Yields in italics are from national/regional averages. These were used instead of farmer reported yields either because they were unknown to the farmer or because the crop had failed this past year.

** Teak: density =980 kg/m^3; and average year yield 5 m^3/ha/year.

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

Farm Type	Maize		Cotton		Vegetables
	NPK 14%	Urea	NPK 14%	Urea	NPK 14%
Small	21	23	NA	NA	NA
Lowland	1.2	1.2	NA	NA	NA
Integrated	NA	NA	NA	NA	NA
Medium	NA	NA	NA	NA	NA
Large	7	23	21	23	17

Table 5. Livestock herd composition (no.) and total TLU.

Farm type	Local female cattle (no.)	Improved cattle (no.)	Other cattle (male and heifers) (no.)	Calves (no.)	Sheep (no.)	Goats (no.)	pigs (no.)	Poultry (no.)	Total TLU (no.)
Small	0	0	0	0	7	5	0	120	2.4
Lowland	0	0	0	0	0	8	0	10	0.9
Integrated	14	0	4	8	14	7	85	347	129
Medium	0	0	0	0	0	1	0	54	0.64
Large	2	0	2	1	0	6	0	50	17.2

Table 6. Livestock herd composition (no.) and total TLU.

Farm type	Maize	Sorghum	Rice	Cotton	Sesame	Cowpea	Groundnut	Soybean	Cashew	Orange	Palm oil	Teak	Cassava	yam	Tomato	Chili peppers	Okra
Small	0	NA	0	NA	NA	NA	NA	NA	0	NA	0	NA	0	NA	NA	NA	NA
Lowland	0	NA	NA	NA	NA	0	0	0	0	NA	0	0	0	0	0	0	0
Integrated	0	NA	NA	NA	NA	0	0	NA	NA	0	0	0	NA	NA	NA	NA	NA
Medium	0	NA	NA	NA	NA	0	0	0	NA	NA	NA	NA	NA	NA	NA	NA	0
Large	0	NA	NA	0	NA	0	0	NA	0	0	NA	0	0	NA	0	0	0

All residues are burned (unknown for tree crops) although most residues are left on a mulch, most of it eaten by transhumant cattle herds.

Table 7. Whereabouts of ruminants and manure collection and use.

Farm type	Cattle (fraction of the day)				Sheep (fraction of day)				Goats (fraction of day)				Manure collection (%)		Manure collected used for fertilization
	Stable	Yard	Pasture	Off-farm	Stable	Yard	Pasture	Off-farm	Stable	Yard	Pasture	Off-farm	Stable	Yard	
Small	NA	NA	NA	NA	0	1	0	0	0	1	0	0	NA	0%	0%
Lowland	NA	NA	NA	NA	NA	NA	NA	NA	0	1	0	0	NA	0%	0%
Integrated	0.5	0	0.25	0.25	0.5	0.5	0	0	0.5	0.5	0	0	85%	75%	100%
Medium	NA	NA	NA	NA	NA	NA	NA	NA	0.5	0	0.5	0	85%	0%	100%
Large	0	0	0	1	NA	NA	NA	NA	0	0.5	0.5	0	0%	0%	0%

Table 8. Whereabouts of non-ruminants.

Farm type	Poultry				Pigs			
	Stable	Yard (free range)	Pasture	Off-farm	Stable	Yard	Pasture	Off-farm
Small	0	1	0	0	NA	NA	NA	NA
Lowland	0	1	0	0	NA	NA	NA	NA
Integrated	1	0	0	0	1	0	0	0
Medium	0.5	0	0.5	0	NA	NA	NA	NA
Large	0	0.5	0.5	0	NA	NA	NA	NA

Appendix III. Scenario assumptions

Table 9. Whereabouts of non-ruminants.

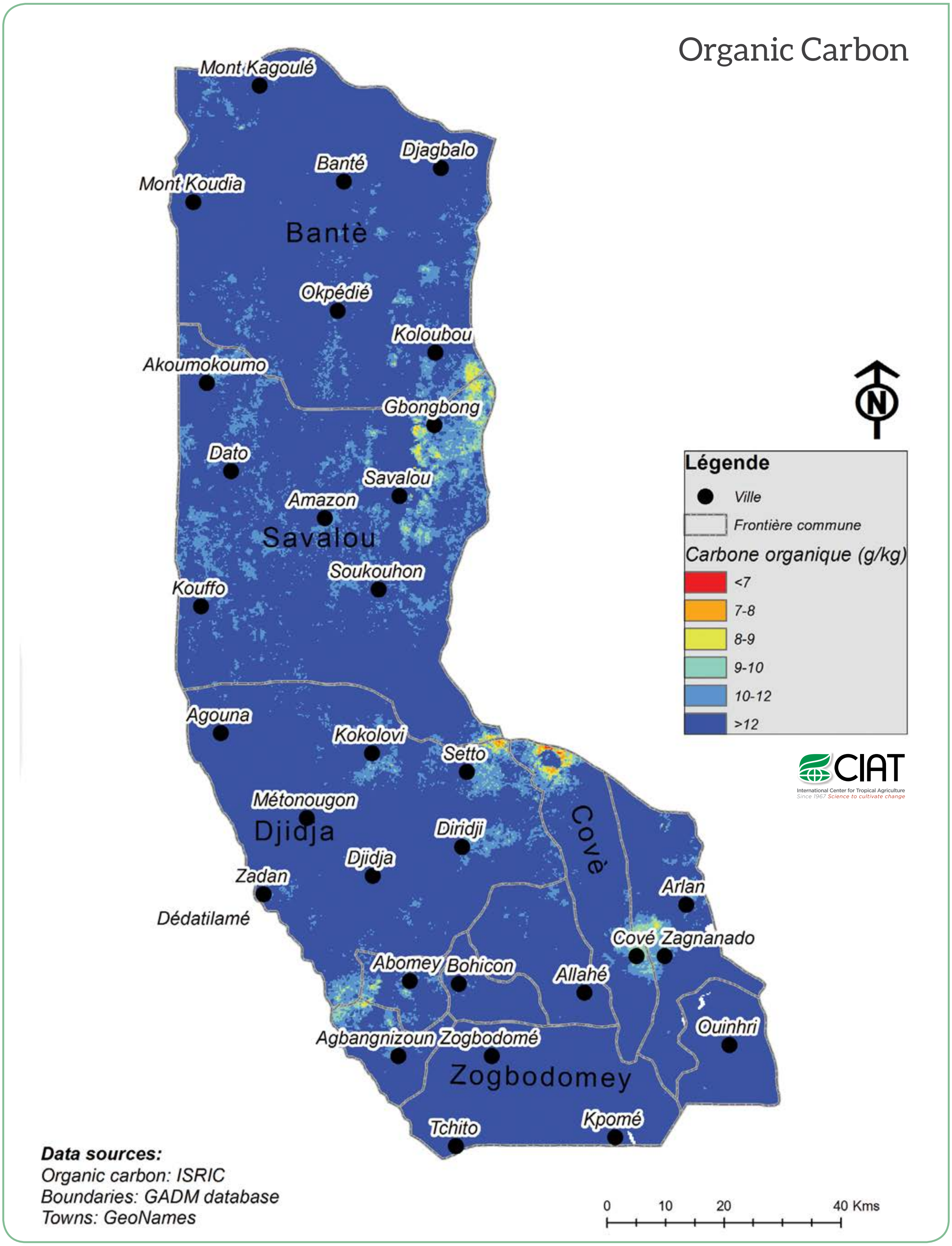
Farms	Impact Dimension	SC1: Intercrop with pigeon pea (with Maize)	SC2: Mucuna intercropping and relay cropping	SC3: Drought tolerant crop varieties (Maize and Cassava)	SC4: Agroforestry - rehabilitate orchard (Cashew tree plantations and orange orchards)
Small	Land-use change	1.3 ha maize intercropped with PP	Relay on 1.3 ha maize	no change	decrease cashew tree plots by 10%; incorporate maize
Lowland	Land-use change	0.8 ha maize intercropped with PP	Relay on 0.8 ha maize	no change	decrease cashew tree plots by 10%; incorporate maize
Integrated	Land-use change	1.25 ha maize intercropped with PP	Relay on 1.25 ha maize	no change	decrease cashew and orange tree plots by 10%; incorporate maize
Medium	Land-use change	1.3 ha maize intercropped with PP	Relay on 1.3 ha maize	no change	N/A
Large	Land-use change	2 ha maize intercropped with PP	Relay on 2 ha maize	no change	decrease cashew and orange tree plots by 10%; incorporate maize
Small	Fertilizer application	no change	no change	no change	no change
Lowland	Fertilizer application	no change	no change	no change	no change
Integrated	Fertilizer application	no change	no change	no change	no change
Medium	Fertilizer application	no change	no change	no change	N/A
Large	Fertilizer application	no change	no change	no change	no change
Small	Manure Application	no change	no change	no change	no change
Lowland	Manure Application	no change	no change	no change	no change
Integrated	Manure Application	no change	no change	no change	no change
Medium	Manure Application	no change	no change	no change	N/A
Large	Manure Application	no change	no change	no change	no change

(continues)

(continued)

Farms	Impact Dimension	SC1: Intercrop with pigeon pea (with Maize)	SC2: Mucuna intercropping and relay cropping	SC3: Drought tolerant crop varieties (Maize and Cassava)	SC4: Agroforestry - rehabilitate orchard (Cashew tree plantations and orange orchards)
Small	Crop yield	Reduce maize yield by 20% and PP yield of 300 kg DM/ha	Increase Maize yield by 10% (we assume that Mucuna there the previous year)	Increase maize and cassava yield by 10%	Increase in tree crops by 5%; Decrease cereal cropped in between trees by 10%
Lowland	Crop yield	No maize reduction because already so low and PP yield of 300 kg DM/ha	Increase Maize yield by 10% (we assume that Mucuna there the previous year)	Increase maize and cassava yield by 10%	Increase in tree crops by 5%; no decrease in maize because so low already
Integrated	Crop yield	No maize reduction because already so low and PP yield of 300 kg DM/ha	Increase Maize yield by 10% (we assume that Mucuna there the previous year)	Increase maize yield by 10% - no cassava	Increase in tree crops by 5%; decrease cereal cropped in between trees by 10%
Medium	Crop yield	Reduce maize yield by 20% and PP yield of 300 kg DM/ha	Increase Maize yield by 10% (we assume that Mucuna there the previous year)	Increase maize and cassava yield by 10%	N/A
Large	Crop yield	Reduce maize yield by 20% and PP yield of 300 kg DM/ha	Increase Maize yield by 10% (we assume that Mucuna there the previous year)	Increase maize and cassava yield by 10%	Increase in tree crops by 5%; decrease cereal cropped in between trees by 10%
Small	Animal productivity	no change	no cattle	no change	no change
Lowland	Animal productivity	no change	no cattle	no change	no change
Integrated	Animal productivity	no change	Mucuna fed to dairy cows; 5% increase in milk	no change	no change
Medium	Animal productivity	no change	no change	no change	N/A
Large	Animal productivity	no change	no change	no change	no change
Small	Residue management	Stops burning the cereal residues intercropped with pigeon pea	Residues remain on field	no change	no change
Lowland	Residue management	Stops burning the cereal residues intercropped with pigeon pea	Residues remain on field	no change	no change
Integrated	Residue management	no change - was not burning residues	Mucuna residues fed to livestock; removed from field (grazing or stall fed)	no change	no change
Medium	Residue management	Stops burning the cereal residues intercropped with pigeon pea	Residues remain on field	no change	N/A
Large	Residue management	no change - only burns cotton residues	Residues remain on field	no change	no change
Small	Soil erosion	Reduce P to 0.6	Reduce p to 0.7	no change	no change
Lowland	Soil erosion	Reduce P to 0.6	Reduce p to 0.7	no change	no change
Integrated	Soil erosion	Reduce P to 0.6	Reduce p to 0.7	no change	no change
Medium	Soil erosion	Reduce P to 0.6	Reduce p to 0.7	no change	N/A
Large	Soil erosion	Reduce P to 0.6	Reduce p to 0.7	no change	no change

Appendix IV. Reference maps of study sites



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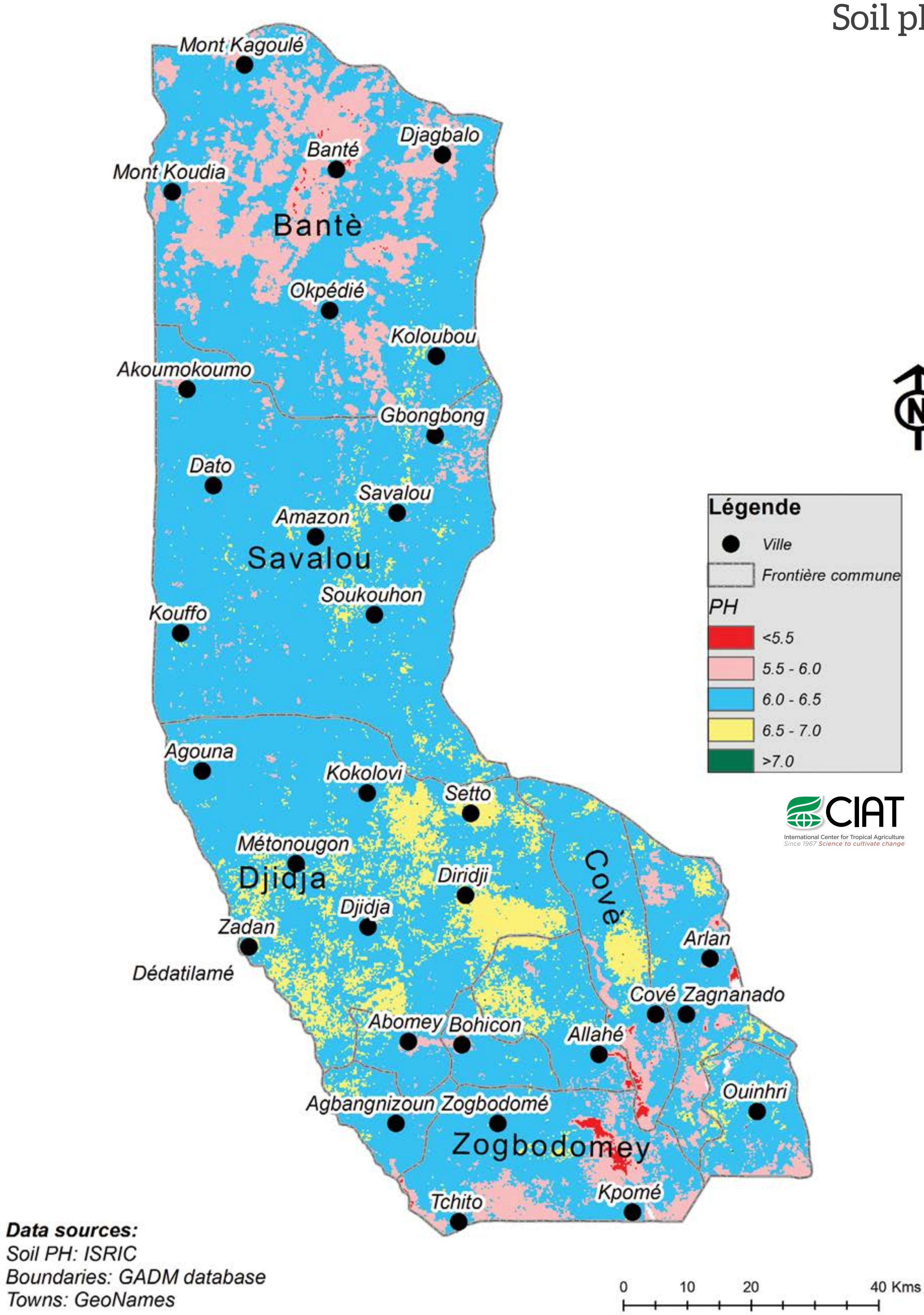
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Banté
Mont Koudia
Bantè
Okpédié
Koloubou
Akoumokoumo
Gbongbong
Dato
Savalou
Amazon
Savalou
Soukouhon
Kouffo
Agouna
Kokolovi
Setto
Métonougon
Djidja
Diridji
Djidja
Zadan
Dédatilamé
Covè
Arlan
Covè
Zagnanado
Abomey
Bohicon
Allahé
Ouinhri
Agbangnizoun
Zogbodomé
Zogbodomey
Tchito
Kpomé
Légende
Ville
Frontière commune
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6.0 - 6.5
6.5 - 7.0
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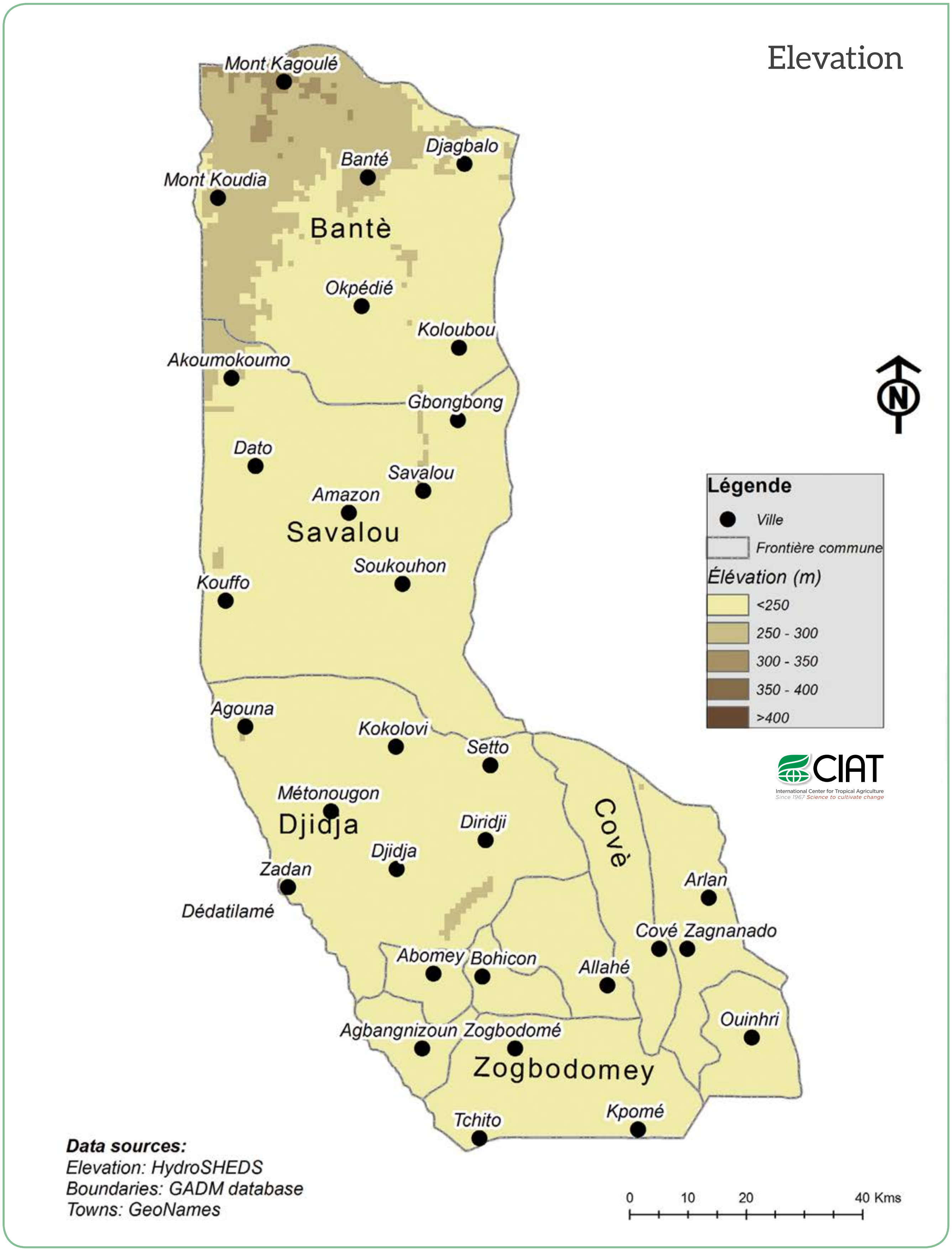
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Okpédié
Koloubou
Akoumokoumo
Gbongbong
Dato
Savalou
Amazon
Savalou
Soukouhon
Kouffo
Agouna
Kokolovi
Setto
Métonougon
Djidja
Diridji
Djidja
Zadan
Dédatilamé
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Arlan
Covè
Zagnanado
Abomey
Bohicon
Allahé
Ouinhri
Agbangnizoun
Zogbodomé
Zogbodomey
Tchito
Kpomé
N
Légende
Ville
Frontière commune
Élévation (m)
<250
250 - 300
300 - 350
350 - 400
>400
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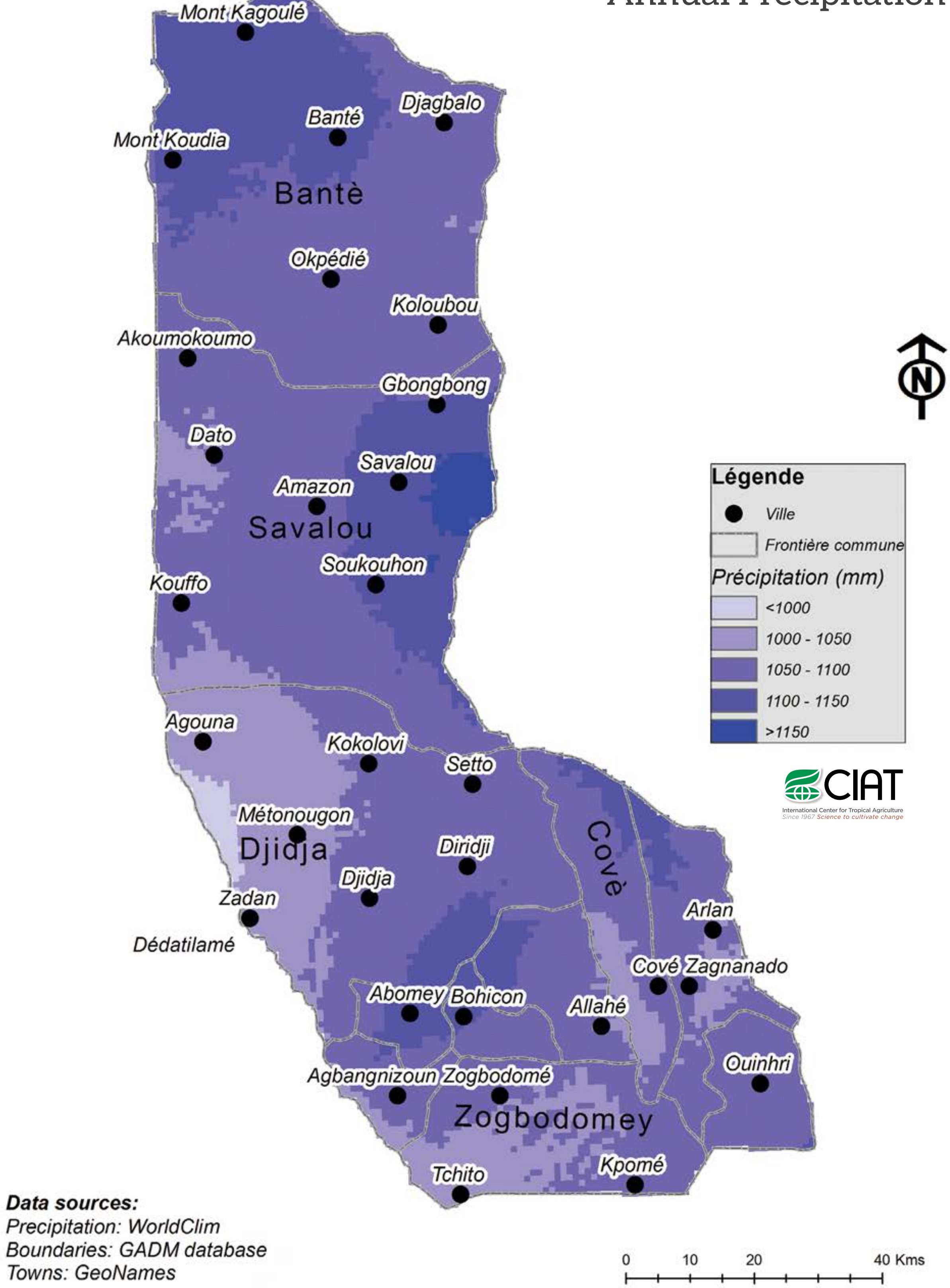
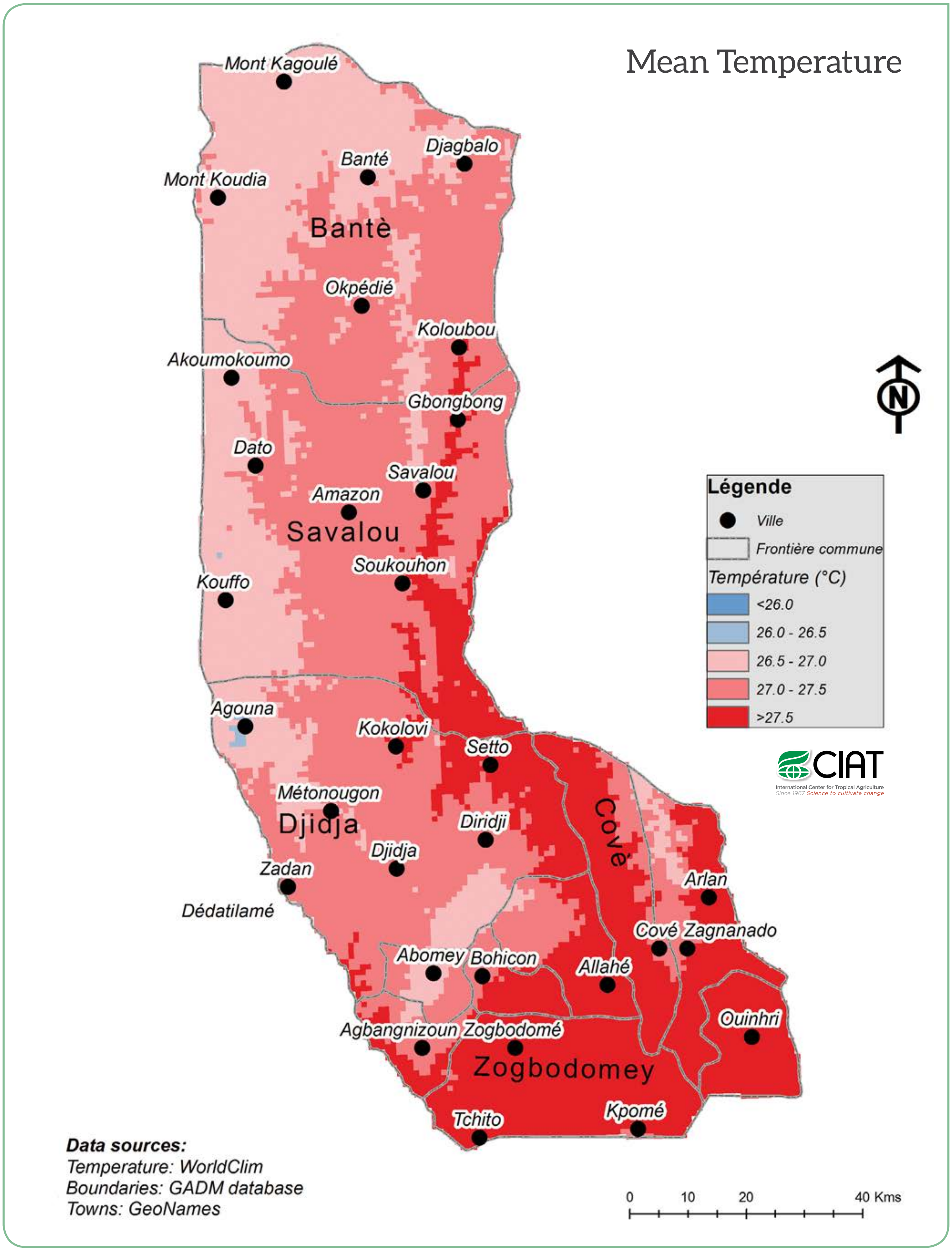
Boundaries: GADM database
Towns: GeoNames
0
10
20
40 Kms

Annual Precipitation




Mean Temperature
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Dato
Savalou
Amazon
Savalou
Soukouhon
Kouffo
Agouna
Kokolovi
Setto
Métonougon
Djidja
Diridji
Djidja
Zadan
Dédatilamé
Covè
Arlan
Covè
Zagnanado
Abomey
Bohicon
Allahé
Ouinhri
Agbangnizoun
Zogbodomé
Zogbodomey
Tchito
Kpomé
N
Légende
Ville
Frontière commune
Température (°C)
<26.0
26.0 - 26.5
26.5 - 27.0
27.0 - 27.5
>27.5
Data sources:
Temperature: WorldClim
Boundaries: GADM database
Towns: GeoNames
0 10 20 40 Kms

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