Climate change impacts of the UK Foreign, Commonwealth & Development Office (FCDO) commercial agriculture portfolio

Working Paper No. 331

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

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About CCAFS

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Abstract

This report provides an initial, rapid assessment of a selection of programmes in the commercial agricultural portfolio of the Department for International Development of the United Kingdom (DfID) (now the Foreign, Commonwealth and Development Offices or FCDO) to demonstrate a range of interventions and their likely net greenhouse gas (GHG) emission impacts. Analysis of crop and livestock value chains in seven countries, representing over four million hectares, shows that the changes in farmers' practices supported by DfID's bilateral investments in commercial agriculture significantly enhance crop and livestock production, while likely reducing net GHG emissions in the near term. The programme value chains increased average crop productivity by 1.0 ton per hectare per year (t ha^{-1} y^{-1}), and reduced net GHG emissions by as much as 5.5 tCO_2e ha^{-1} y^{-1} (cocoa agroforestry) compared to the start of the programme. Cereals demonstrated smaller annual changes, averaging a reduction of 0.80 tCO_2e ha^{-1} y^{-1}. Livestock productivity only increased slightly on average from 1.0 (goats) to 3.0 kg $head^{-1}$ y^{-1} (beef cattle), with corresponding slight reductions in net GHG emissions from 0.001 (goats) to 0.01 (beef cattle) tCO_2e $head^{-1}$ y^{-1}. Increases in emissions across the programmes are commonly due to increased use of nitrogen fertiliser and mechanisation. Reductions are commonly due to carbon sequestration in the soil as a result of manure addition, minimum tillage, crop rotation or reduced burning. These results are consistent with the increased use of inputs expected from market-driven agricultural intensification.

Keywords

Agriculture; climate change; low-emissions development; mitigation; emissions; DfID

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The views expressed in this document cannot be taken to reflect the official opinions of these organisations. We thank all FCDO programme representatives for their assistance and support in providing data, and especially thank Giles Henley for facilitating this work. All omissions and errors are the authors' responsibility.

Contents

Acronyms

AWD	Alternate wetting and drying
BAU	Business-as-usual
C	Carbon
CH_4	Methane
CO_2e	Carbon dioxide equivalents
CCAFS	CGIAR Research Programme on Climate Change, Agriculture and Food Security
CF	Conservation farming
CSA	Climate smart agriculture
DfID	Department for International Development of the United Kingdom
EX-ACT	Ex Ante Assessment tool for agricultural GHG emissions
FCDO	Foreign, Commonwealth & Development Office (formerly DfID)
FAO	Food and Agriculture Organisation of the United Nations
GHG	Greenhouse gas
Gt	Gigaton or billion tonnes
GWP	Global Warming Potential
Ha	Hectare
LED	Low-emission development
LUC	Land use change
LULUCF	Land Use, Land Use Change and Forestry", a category of activities in GHG inventories
L	Litre
M	Million
K	Thousand
MSD	Midseason drainage
N	Nitrogen
NDC	Nationally determined contribution (to the Paris Agreement)
N_2O	Nitrous oxide
PICS	Purdue Improved Crop Storage bags
SOC	Soil organic carbon
t	Tonnes
y	Year

Executive summary

As part of its support to economic development, the UK Foreign, Commonwealth and Development Office (FCDO)[1] supports the commercialisation of agriculture in developing countries, which could serve as a critical driver of agricultural transformation for climate and food security. To date, the potential to harness mitigation co-benefits in the UK Department for International Development (DfID) portfolio has not been analysed comprehensively. Understanding the GHG emissions footprint of current activities and the factors affecting emissions and their reduction could help increase and scale up mitigation and food security impacts in future investments. Many of these interventions also support farmers to adapt to climate shocks and trends.

This report provides an initial, rapid assessment of a selection of programmes in DfID's commercial agricultural portfolio to demonstrate a range of interventions and their likely net GHG emission impacts. The objectives of the assessment were to (i) evaluate the GHG emission impacts of a representative sample of commercial agriculture programmes and selected value chains affected; (ii) identify mitigation options appropriate to the investments; and (iii) support learning among DfID's staff working on agriculture priorities and opportunities for reducing climate impacts.

This rapid assessment of GHG emission impacts shows the significance of investment impacts, provides a baseline for future comparison, and can indicate opportunities for reducing climate change impacts in the future.

Findings

Results from analysis of crop and livestock value chains in seven countries, representing over four million hectares, show that the changes in farmers' practices supported by DfID's bilateral investments in commercial agriculture are estimated to significantly enhance crop and livestock production while likely reducing net GHG emissions in the near term. Overall, the programme value chains increased average crop productivity by 1.0 ton per hectare per year (t ha^{-1} y^{-1}) (ranging from a minimum of -0.20 to a maximum of 3.7 t ha^{-1} y^{-1}). The largest changes in net

[1] This study was undertaken prior to the creation of the UK's Foreign, Commonwealth and Development Office in September 2020. As the programmes analysed were exclusively those of the former Department for International Development, we use this term for sake of clarity in this paper.

GHG emissions were observed for cocoa agroforestry, which reduced net emissions by 5.5 tCO_2e ha^{-1} y^{-1} compared to the start of the programme. Cereals demonstrated smaller annual changes, averaging a reduction of 0.80 tCO_2e ha^{-1} y^{-1} (ranging from a reduction of 1.62 to 0.05 tCO_2e ha^{-1} y^{-1}). For livestock, farmers increased average productivity only slightly from 1.0 (goats) to 3.0 kg $head^{-1}$ y^{-1} (beef cattle), with corresponding slight reductions in net GHG emissions from 0.001 (goats) to 0.01 (beef cattle) tCO_2e $head^{-1}$ y^{-1}. The reductions in livestock emissions predicted by the model used for quantifying emissions, however, should be further monitored as increased productivity can also lead to increases in emissions, depending on weight, productivity gains, feed, type of breed, age and other conditions. For poultry (meat and eggs), emissions (mostly from manure) increased, relative to the start of the programme, by 18.9 KtCOe y^{-1} because of the increase in total number of chickens (over 6 million heads) and productivity since the start of the programme.

Increases in emissions across the programmes are commonly due to increased use of nitrogen fertiliser and mechanisation (Figure E1). Reductions are commonly due to carbon sequestration in the soil as a result of manure addition, minimum tillage, crop rotation or reduced burning. These results are consistent with the increased use of inputs expected from market-driven agricultural intensification.

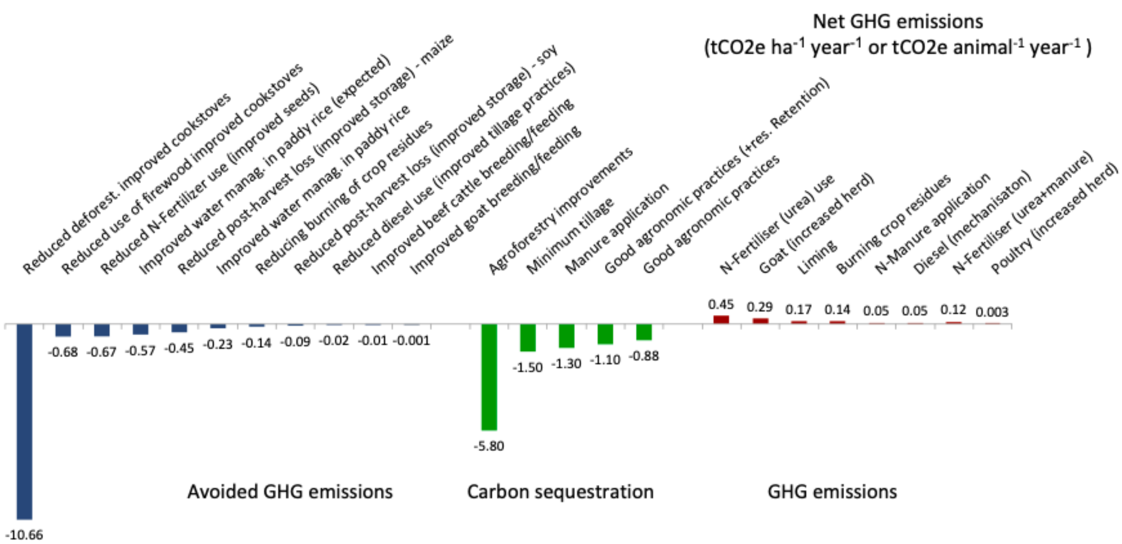

Figure E1. The impact of major agricultural interventions and practices on GHG emissions and carbon sequestration, on an area and animal basis, across supported DfID's programmes in countries in Africa and Asia.

The aggregate impacts of **soil organic carbon (SOC) sequestration outweighed increases in GHG emissions by five times**. The levels of SOC sequestration that could be achieved in practice are highly uncertain, due to variability in local climate, land use history, soil type, topography, and management practices. In addition, SOC builds up slowly - reaching saturation within 20-40 years - but can be lost quickly. Given these caveats, the role of soil carbon in offsetting programmes' emissions should be interpreted carefully and not be the sole means for reducing climate impacts. Soil carbon sequestration is nevertheless a no-regrets strategy due to its benefits for soil health and productivity and short-term carbon sequestration could buy time for transitioning agriculture to lower emissions practices.

Most programme representatives reported land use change associated with interventions, but only two were able to provide quantitative estimates. Multiple factors likely drive land use change in the programme areas, so impacts cannot be attributed to programme interventions alone. Nevertheless, conversion of land with significant stored carbon, such as forest, grasslands, and peatlands, is the single most high-impact driver of emissions and should be avoided if emissions are to be minimized. For that reason, understanding the role that programmes have in land use change is a priority for managing climate impacts.

The GHG impacts of practices reported here are similar to the analysis of the GHG impacts of other overseas development assistance programs in agriculture (Grewer 2018; Richards 2019). Including investments in forestry in the portfolio of programmes, would likely show even higher levels of carbon sequestration and offsetting of emissions from agriculture.

These findings are subject to some caveats. While both at the portfolio and programme level, analysis focussed on activities estimated to have the largest impacts, not all activities were 'in scope' and thus findings (and especially numbers) are indicative rather than definitive. A large share of information came from programme interviewees' expert estimates rather than observable data. Readers should therefore focus on the patterns of activities (e.g., introduction of nitrogen fertilizer, machinery) and the associated rates of emissions with these patterns rather than precise GHG footprints. Estimates of impacts due to land use change (LUC) and, to some extent, programme activities may also reflect a mix of programme interventions and other drivers of intensification and land use change.

Recommendations: To enhance climate change mitigation, **nutrient management interventions** for both cropping and pasture-based livestock production systems are likely to have the most significant effect across the DfID portfolio. The implementation of agroforestry may further enhance carbon sequestration across the portfolio. Improving animal breeding and feeding and promoting water drainage in rice paddies are additional opportunities for mitigation.

Guidance for low-emission pathways relevant to the programmes can initially use best practice checklists relevant to regional production systems, or more generally according to three principles: (1) avoid land use change, (2) improve production efficiency, and (3) offset emissions with carbon storage. Production efficiency should focus on (a) efficient use of energy, fertilizer, and, in the case of paddy rice, water, (b) efficient use and conversion of feed in livestock production, (c) avoided food loss or waste, and (d) recycling of waste. In addition, where possible, fossil fuels should be replaced with alternative renewable energy and the efficiency and quality of production of ruminant livestock should be enhanced before increasing the number of animals. Low-emission pathways are context specific and emissions reflect aggregated net emissions for a production system, so no single practice can guarantee mitigation impacts.

Monitoring: Improving programmes' emissions estimates requires refinements in the activity data related to emissions sources and sinks. Data from existing reports are insufficient and result in low certainty of emissions estimates. Programme reporting could be designed to capture more GHG emission-relevant information, particularly for land use change, cropping and pasture areas, and level of farm inputs.

Introduction

Globally, agriculture is a principal source of climate change, directly contributing ~10-12% of anthropogenic greenhouse gas (GHG) emissions and indirectly contributing an additional ~6-7% through land-use change (Smith et al. 2014).[2] Agriculture also is the source of 80-86% of food system emissions (Vermeulen et al. 2012).[3] Most future increases in agricultural emissions will likely occur in low- to middle-income countries (Metz et al. 2007).

The 2015 Paris Agreement set the goal of limiting warming to no more than 2°C in 2100 and to pursue 1.5°C. To align with a 2°C pathway, agriculture will have to reduce nitrous oxide and methane emissions, the major emissions from the sector, by ~1.5 billion tons of CO_2 equivalents (CO_2e) per year by 2030 or ~20% relative to 2020.[4] In addition, zero deforestation is needed after 2020 (SDG 15.2). A target for carbon sequestration in agricultural soils, based on low-cost options, is ~1.2 billion tons of CO_2e (Bossio et al. 2020).[5] To meet these goals, more than 104 of countries included agriculture in the mitigation targets, polices or measures of their Nationally Determined Contribution (NDC). Another 15 countries committing to economy-wide mitigation action in their NDC, which potentially includes agriculture. National and international policy mandates therefore exist for emissions reductions in agriculture.

While both developing and developed countries must reduce current levels of GHG emissions to meet mitigation targets, developing countries face the extra challenge of increasing food security and incomes, while also reducing net emissions.[6] In this context, Sub-Saharan Africa faces the biggest challenge in meeting food security needs and improving livelihoods, while also avoiding further land use change and minimizing emissions. Between 2010 and 2050, the demand for cereal crops in Sub-Saharan Africa is expected to triple, requiring land use intensification or increased imports to avoid large-scale land use change (van Ittersum et al.

[2] Land use change contributed 7-9% of global anthropogenic GHG emissions 2000-2010 (Smith et al. 2014). Agriculture is responsible for about 80% of deforestation, which is the predominant source of land use change (Kissinger et al. 2012)

[3] 9.8–16.9 GtCO2e, inclusive of land use change

[4] For the 1.5˚C target, emissions will need to be reduced by ~1.9 billion tons of CO2 per year in 2030 or about 24% relative to 2020 levels. Targets for 1.5˚ and 2˚C pathways are based on average values of emissions needed in the AFOLU sector for N2O and CH4 for RCPs 1.9 and 2.6 using integrated assessment scenarios for SSP2. Data available here: https://data.ene.iiasa.ac.at/iamc-1.5c-explorer/#/login (Huppman et al. 2018).

[5] i.e., what is feasible at costs up to USD 10 per ton CO2e. The total technical potential of soil carbon sequestration is ~2 to 5 GtCO2, with the range reflecting differences in assumptions about the area of land included in the estimate (Fuss et al. 2018).

[6] Net emissions are the sum of GHG emissions and soil carbon sequestration

2016). Yet, tropical Africa is already experiencing rapid land use change, contributing the highest level of land-based CO_2 emissions in the global tropics (Palmer et al. 2019). Vast parts of Sub-Saharan Africa are also highly vulnerable to extreme climate events, rising temperatures and increased rainfall variability (Searchinger et al. 2018).

Most low-income counties will likely need to increase their agricultural emissions relative to current levels to improve food security. The need for 60% more food production by 2050 (Alexandratos, Bruinsma 2012)[7] will drive agricultural emissions higher and increase the share of the agriculture sector in global emissions, especially as other sectors are decarbonized (Searchinger et al. 2020).[8] For example, to meet 2050 maize demand in Sub-Saharan Africa, nitrogen fertiliser use is expected to increase by 15 times to an average of 140 kg nitrogen (N)/ hectare (ha) relative to 2015 levels (van Ittersum et al. 2019; Jayne et al. 2019).[9]

The contribution to the global carbon balance from agricultural growth could be significant with interventions. Projections for Sub-Saharan Africa indicate that by 2050, agricultural production will contribute ~1 billion tons of CO_2e per year and expand by 200 million hectares relative to 2010, producing an additional 2.1 billion tons of CO_2e per year due to land use change alone (Searchinger et al. 2020).[10,11] Balancing the multiple objectives of food production, livelihood improvement, greenhouse gas emissions, carbon sequestration, and other environmental impacts may require trade-offs in some places until more affordable technical innovations such as more nitrogen efficient crops or feed supplements for livestock are available (Kanter et al. 2016; Searchinger et al. 2018).

Common sources of GHG emissions from intensified production include fertiliser production, fertiliser use, feed production (for livestock), livestock production, mechanisation, manure

[7] Increase is relative to 2005/07. Bruinsma (2009) projected that 90% of new production would have to come from developing countries, with this production coming predominantly from yield increases (71%), expanded land area (21%), and increased crop intensity (8%).

[8] Searchinger et al. (2018) projected that current direct and indirect agricultural emissions of 12 GtCO2e will increase to 15 GtCO2e by 2050, and use “up to 70 percent of the annual allowable emissions budget for all human emissions, including energy, that will be necessary to hold warming to international climate goals.”

[9] These levels of nitrogen fertiliser use are comparable to or less than levels currently in food-secure countries.

[10] Projection assumes that crop yields double and 20% of food needs are met with trade.

[11] Whether such large areas of land will be available in the countries requiring expansion is an issue. Land appropriate for agricultural expansion (not forested, not protected and with populations densities of <25 people/km2) is scarce globally, with only about 445 million hectares available, which is mostly located in a handful of countries (Brazil, Argentina, Sudan, Democratic Republic of the Congo, Mozambique, Tanzania, Madagascar) (Lambin and Meyfroidt, 2011).

management, and irrigation. Irrigation for paddy rice is a major source of emissions. Emissions can also occur along the supply chain for storage, processing and transport. Agricultural expansion is the single most significant source of emissions where land use changes from non-agricultural land uses such as forest, grassland, or shrubland to agriculture.

Low-emission development (LED) in agriculture intentionally reduces, minimizes or offsets emissions in development interventions. As an approach to help countries' meet food and economic security needs, LED treats mitigation as a co-benefit to agricultural income or yields. This contrasts with approaches that prioritize mitigation over agricultural production, such as cropland set asides. In practice, mitigation in most places will need to be a co-benefit of farming.

LED practices relevant to low-income countries include nitrogen fertilizer efficiency, improved feed for livestock, intermittent drainage of rice paddies, soil carbon sequestration, agroforestry, avoided burning of crop residues and avoided land use change. Practices can be compatible with climate change adaptation where they address local climate constraints. For example, soil carbon sequestration can improve the soil's capacity to store water in drought prone areas and agroforestry can buffer extreme heat. Carbon sequestration can help offset emissions (van Ittersum et al. 2019; Hijbeek et al. 2019) and is an important near-term strategy to align with the 2°C mitigation target, however it only provides a net mitigation effect for a finite period, (e.g., up to 20 years for soils), after which, annual emissions will outweigh the carbon saved unless additional sinks are realized. Increases in GHG emissions are thus inevitable to achieve food security in most places over the long-term, but they can be minimized relative to food production.

An LED lens can be applied to, and but is not necessarily integrated with existing production paradigms, such as sustainable intensification, regenerative agriculture, organic agriculture, agroecology or digital and precision agriculture. Some of these approaches make explicit claims to climate change mitigation impacts, such as regenerative agriculture's aim of soil carbon sequestration or climate-smart agriculture's goal of achieving productivity, adaptation and mitigation where possible (see Glossary). Others are less clear. It is beyond the scope of this paper to discuss each of these approaches and their mitigation implications; however, we elaborate here on sustainable intensification as a common development pathway in commercialized agriculture that has a complicated relationship to agricultural land conversion and resulting GHG emissions.

Sustainable intensification, land use change and emissions

Sustainable intensification is a pathway for agricultural development that increases crop or livestock production while reducing ecological impacts (Godfray, Garnett 2014). Impacts can be measured in terms of input-use efficiency (e.g., energy, water, nutrients, land), yields, incomes, and environmental impacts (Cassman, Grassini 2020). Its practices are not necessarily aligned with low-emission development in agriculture or the practices needed for climate change mitigation. Intensification of crop or livestock productivity can reduce GHG emission intensity (emissions per unit product) but increases overall emissions and may not address all significant emission sources.

Most importantly, intensification can influence emissions due to the conversion of land to agriculture. The role of sustainable intensification in the expansion of agriculture in forests and other high-carbon landscapes is complex (Byerlee 2014). At global levels, evidence suggests that historically, intensification has reduced land conversion, likely avoiding significant levels of GHG emissions due to avoided deforestation (Burney et al. 2010). However, at regional and crop levels, intensification has not had predictable impacts on land use change (Rudel et al. 2009). At these levels, agricultural intensification sometimes incentivises further expansion and land conversion (Hertel 2012). This is particularly true where commodity markets can absorb new production, land is readily available, local costs (e.g., in forest areas) are more competitive, and suitable production conditions exist, such as for oil palm in forest areas of Indonesia (Campbell et al. 2014). Indirect impacts on land conversion can also occur. For example, in Brazil, mechanized cultivation of soy displaced pasture, leading to conversion of more forest area for pasture (Nepstad 2014).

Intensification alone, therefore, is not a guarantee of avoided land use change and GHG emissions. A mix of governance and economic incentives is needed in addition to intensification, including land zoning, land tenure security, promoting efficient use of already-cleared lands, monitoring forest clearing, boundary enforcement, supply chain initiatives (e.g., sustainability commitments and disclosure, traceability), incentives for relocating production, or support for alternative livelihoods (Ewers et al. 2009; Nepstad et al. 2014; Macedo et al. 2012; Lambin et al.

2018; Lambin, Meyfroidt, 2011; Wollenberg et al. 2011). These conditions are often inherently weak in remote forest areas, or subject to changes in political will, even in countries with strong national land governance. Intensification far from forest frontiers is less likely to lead to land use conversion (Byerlee et al. 2014).

Purpose and methods of this study

In 2020, the UK Department for International Development (DfID)[12] engaged the CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS) to conduct a rapid analysis of the GHG impact and mitigation opportunities in DfID's agriculture portfolio of investments. To frame a strategic approach to low-emissions development in the agricultural sector, DfID sought to quantify the GHG emissions impacts of a range of representative programmes and identify options for mitigation.

DfID pre-selected seven programmes from their commercial agricultural portfolio for the GHG analysis (Table 1). More details are provided on each programme in the Annex. The criteria for selection of programmes included representativeness of the type of programme and agricultural sector supported by DFID's agriculture portfolio as well as the capacity of programme developers to engage in the GHG analysis exercise. Programmes were located in Sub-Saharan Africa and Asia and had agribusiness, rural market development or livelihood objectives (Table 1). At least one programme had an explicit climate change focus. Programme interventions often operated at the market or investment level and did not necessarily link directly to farm practices affecting the sources and sinks of emissions. Thus, assumptions were made based on trends in farming and supply chain practices reported by programme representatives or 'implementing partners.' Attributing these changes entirely to the programmes may therefore not be appropriate in all sites. Implementing partners were local or locally based organisations with long experience in the agricultural sector and in-depth knowledge about the region and production practices. All selected programmes were still active at the time of the interview. Nearly all programmes had been operating for more than four years, and roughly half were close to ending.

[12] This study was undertaken prior to the creation of the UK's Foreign, Commonwealth and Development Office in September 2020. As the programmes analysed were exclusively those of the former Department for International Development (DfID), we use this term for sake of clarity in this paper.

Table 1. Focus country and core interventions of selected programmes

Programme focus country	Core market and agribusiness interventions relevant to GHG emissions
Uganda	Livestock and soil management
Ghana	Soil and fertiliser management
Nigeria	Soil management and avoided deforestation (cookstove efficiency)
Zimbabwe	Livestock and soil management
Myanmar	Irrigated rice and fertiliser management
Zambia	Soil management, post-harvesting losses
Mozambique	Livestock
Ghana	Agroforestry, soil management and forest conservation

Note: GHG emissions were estimated based on data available in the programme's annual reviews and assumptions based on expert consultation and literature review.

Due to a lack of existing field data and DFID's request for a rapid analysis, the primary method of data collection was based on a limited set of interviews and review of documents13. During March 2020, CCAFS conducted interviews with developers and implementers of the programmes described in Table 1 for collecting data necessary to estimate GHG emissions balance.

We estimated each programme's impacts on GHG emissions and carbon sequestration using the FAO Ex-Ante Carbon Balance Tool (EX-ACT) (Bernoux et al. 2010). EX-ACT is an appraisal system developed by the Food and Agriculture Organisation of the United Nations (FAO) to estimate the impact of agriculture and forestry development programmes and policies on net GHG emissions and carbon sequestration. In all cases, conventional agricultural practices (those employed before programme implementation) provided reference points for a GHG emission baseline. The team described results as increases or reductions in net GHG emissions attributable to changes in agricultural practices as a result of the programme. Impacts were assessed for the time of interview and for an estimated 20 years after the start of the programme to account for carbon sequestration, in line with IPCC emissions accounting for agriculture and land use. Methane, nitrous oxide, and carbon dioxide emissions are expressed in metric tonnes (t) of carbon dioxide equivalent (tCO_2e). If the agricultural practices supported by the programme were estimated to lead to a decrease in net GHG emissions through an increase in GHG removals (e.g., carbon sequestration, emission reductions) or a reduction of GHG emissions, the overall programme

[13]Rapid assessment relies on limited interviews and self-reported information from programme representatives. Improvements in estimates would be possible with more thorough activity data collection, and evidence of conditions before and after interventions at farm-level such as farm records, survey data, statistical reports, remote sensing, reports, photos, videos or other documentation.

impact is represented as a negative (-) value. It is important to note that a negative value does not necessarily indicate a GHG sink, but rather a decrease in emissions relative to the baseline (i.e., practices before programme intervention).

This rapid assessment technique is intended for contexts where aggregate data are available on agricultural land use and management practices, but where field measurements of GHG and carbon stock changes are not available. The method indicates the magnitude of GHG effects among field activities, cropping systems or value chains. As such, the results provide evidence of programme trends in the selected value chains, rather than a comprehensive or precise greenhouse gas footprint for the programme as a whole.

This method is useful for estimates of GHG emissions where data are scarce; however, results should be interpreted based on an understanding of the nature of the data. Error in total GHG emissions per value chain in the programmes is likely due to the use of interview data and the need for key respondents to estimate some information. We urge users of this report to focus on the patterns of activities (e.g., introduction of nitrogen fertilizer, machinery) and the associated rates of emissions with these patterns. Estimates of impacts due to land use change and to some extent programme activities should consider that impacts might reflect a mix of programme interventions and other drivers of intensification.

Results: Programmes' GHG emissions and carbon sequestration

Interviews and data quality analysis

During the interviews, DfID's programme implementers and CCAFS identified predominant farm types and practices in each programme area. We then identified value chains relevant to GHG emissions and for which sufficient information existed to estimate implementation areas and activities. Across programmes these included seven cropping value chains (maize, groundnuts, soybean, sorghum, sugar bean, cotton, and rice) and three livestock value chains (beef cattle, goats, and poultry) directly affected by the programmes' market and agribusiness interventions. Value chain information (post-farmgate) was possible to estimate for one programme on improvements in post-harvesting losses (Zambia) and for one programme on cookstove efficiency (Nigeria).

The 24 value chains sampled in this work were associated with an expected land area of almost 4 million hectares. Of this area, close to 76% of land use was for pasture and 24% for cropping systems. Maize was the largest cropland use area among value chains (53.5%), whereas beef cattle were the largest livestock type among ruminant animals (0.66 million heads) (Figure 2).

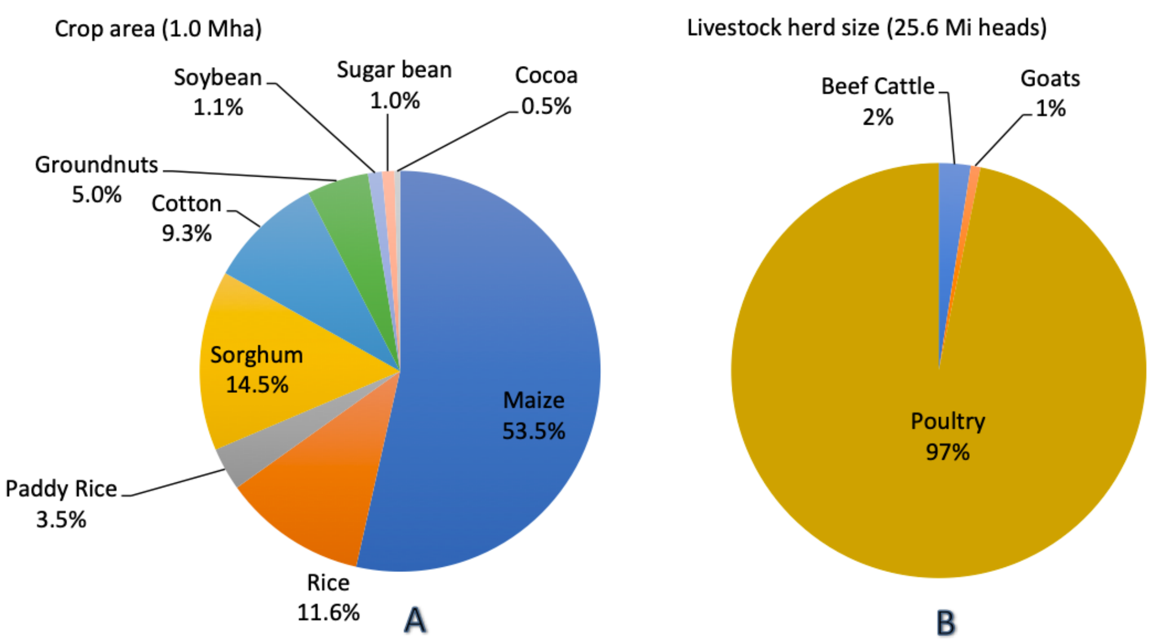

Figure 2. Land area (A) and livestock herd size (B) associated with the interventions of agricultural programmes in the DfID portfolio of investments.

About 85% of the data was collected from interviews with DfID's programme representatives and 15% from literature reviewed by the CCAFS team or based on assumptions using expert judgement. We characterized the certainty of the data based on the source of the information used in this assessment (Table 2).

Table 2. Certainty related to the data necessary to estimate GHG emissions and carbon sequestration from programmes within DfID's agriculture portfolio of investments.

Annual Cropping System	Certainty Interviewed Programmes
Predominant crop type	High
Total area (ha):	Medium
Yield (t $ha^{-1}y^{-1}$)	High
Cropping system	Medium
Tillage system	High
Residue management	High
N-Fertiliser	Medium
Liming	High
On-farm fossil fuel use	High
Off-farm interventions	Medium

Livestock System	Certainty Interviewed Programmes
Predominant livestock type	High
Total area (ha):	Medium
Herd size (animals)	Medium
Yield (t $ha^{-1}y^{-1}$/ t $animal^{-1}y^{-1}$)	Low
Livestock management	Medium
Manure management	Medium
Pasture management	Medium
Soil inputs (i.e., lime and fertiliser)	-
On-farm fossil fuel use	-
Off-farm interventions	-

Data quality criteria	Certainty
Programme records (auto-declaratory information provided by programme representatives)	High
Assumptions based on programme expertise, expert consultation or literature review	Medium
Assumptions based on similar programmes or arbitrarily assumed, or source not considered	Low

Agricultural practices influencing GHG emissions and carbon sequestration in cropping systems

As a result of DfID programme interventions, farmers made one or more of the following improvements: (a) soil management, (b) crop residue retention (reduced burning of crop residues), (c) nitrogen fertiliser management, (d) soil liming, (e) improved seed varieties, and (f) mechanisation (Table 3). Land use change involving conversion of native vegetation was reported in five programmes, but only two programmes, both in Ghana, were able to provide quantitative estimates.14

[14] For the programmes that promoted the nitrogen fertiliser use (urea and manure) application rates across value chains ranged from ~5 to 100 kg N $ha^{-1}y^{-1}$. Mechanisation required diesel consumption at a rate of 15-23 L ha^{-1} y^{-1}. Burning of crop residues occurred in a few programmes, but for most programmes, open burning was banned or reduced to support the implementation of minimum tillage. In some cases, residues were removed for animal feed or composted.

This set of agricultural interventions has allowed farmers to increase the average yields of cereal crops by 1.0 t ha^{-1} y^{-1} (from -0.20 to 3.7 t ha^{-1} y^{-1})[15], and reduce current average net GHG emission per hectare by 0.80 tCO_2e ha^{-1} y^{-1} (mitigation of 1.62 to 0.05 tCO_2e ha^{-1} y^{-1}). Interventions reduced the greenhouse gas emission intensity by 0.88 tCO_2e ha^{-1} t $product^{-1}$ (0.01 to 2.88 tCO_2e ha^{-1} t $product^{-1}$). As these practices continue, programme staff expect a further increase in productivity and reduction in GHG emission intensities (Table 3; A2; Figure 6).

The use of nitrogen fertiliser was a significant GHG emission source across programmes, increasing GHG emissions by approximately 0.02-0.5 tCO_2e ha^{-1} y^{-1}. Other significant sources were the use of lime (~0.17 tCO_2e ha^{-1} y^{-1}), burning of crop residues (~0.14 tCO_2e ha^{-1} y^{-1}) and use of fossil fuel (~0.05 tCO_2e ha^{-1} y^{-1}), respectively (Figure 2).

The use of improved seeds (short growing season and high-quality varieties) and good agronomic practices reduced use of nitrogen fertiliser (urea) by 50% (or 0.67 tCO_2e ha^{-1} y^{-1}) and paddy rice flooding periods, from 140 to 120 days, enabling a further emission reduction of 0.23 tCO_2e ha^{-1} y^{-1} (Figure 3; Table 3).

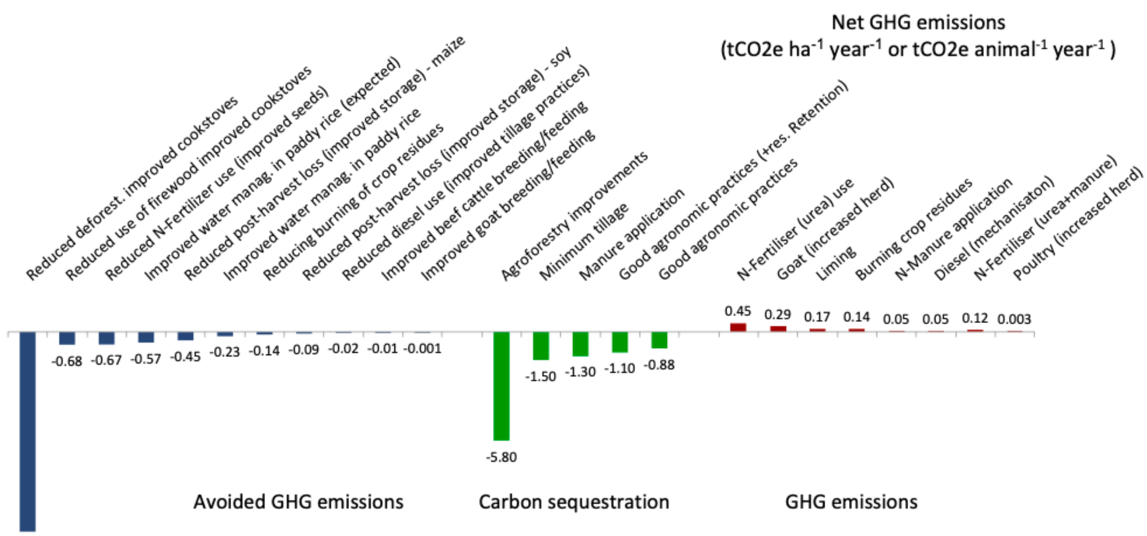

Figure 3. The impact of major current and expected agricultural interventions and practices on GHG emissions and carbon sequestration, on an area and animal basis, supported by DfID's programmes in countries in Africa and Asia.

[15]Compared to the baseline scenario (before programme start), agricultural interventions were reported to change yields of cereal crops from -33% to 196% (see Annex 2).

New soil management practices improved soil carbon sequestration by 0.88 to 1.5 tCO_2e ha^{-1} y^{-1}, offsetting more than 100% of emissions caused by the use of soil inputs and mechanisation in most of the programmes (Figure 3, Table 3). Practices that supported increases in soil carbon included improved seeds, crop rotation, reducing crop burning, and nutrient management. These practices induced higher biomass production, supplying increased organic matter to soils and, consequently, leading to soil carbon sequestration.

Cocoa cropping systems were a significant source of carbon sequestration. By enriching cocoa plantations with other perennial crops (multi-strata agroforestry), we estimate new carbon sequestration in the aboveground biomass at a rate of 5.8 tCO_2e ha^{-1} y^{-1} (Figure 3). These benefits will accrue until the trees reach maturity, after which carbon sequestration in aboveground biomass levels off.

Table 3. Major agriculture value chains, major interventions, and current and expected impacts on productivity and GHG emissions of seven selected market and agribusiness programmes in DfID's investment portfolio.

Value chain	Major implemented practices	Area**	Productivity*	Current* Effect on net GHG emissions		Expected (programme end)* Productivity	Effect on net GHG emissions	
		ha	t/ha	$tCO_2e/ha/y$	tCO_2e/t product	t/ha	$tCO_2e/ha/y$	tCO_2e/t product
Ghana								
Maize	Minimum tillage; use of soil inputs; mechanisation	27,700	2.2	-0.25	-0.09	2.8	-0.69	-0.17
Rice	Use of soil inputs; minimum tillage	13,643	3.7	-0.62	-0.10	4.9	-0.62	-0.08
Groundnuts	Use of soil inputs; mechanisation	10,515	0.7	-0.51	-0.32	1.6	-0.51	-0.20
Soybean	Use of soil inputs; minimum tillage	11,424	1.5	-0.70	-0.22	2	-0.70	-0.19
Land use change	Cropland expansion over set aside area	23,732	-	3.10	-	-	3.10	-
Land use change	Cropland expansion over new land	7,911	-	12.20	-	-	12.20	-
Zambia								
Maize	Min.till; reduc. burning crop res.; mechanisation	93,597	0.68	-1.38	-0.79	0.68	-1.38	-0.79
Soybean	Min.till; reduc. burning crop res.; mechanisation	93,597	0.39	-1.36	-1.43	0.39	-1.36	-1.43
Cotton	Min.till; reduc. burning res.; mechanisation	93,597	0.75	-1.33	-1.70	0.75	-1.33	-1.70
Maize (*Off-farm*)	Post-harvesting losses: storing improvements		-65% losses	-0.45	-1.38	-65% losses	-0.45	-1.38
Soybean (*Off-farm*)	Post-harvesting losses: storing improvements		-60% losses	-0.09	-1.43	-60% losses	-0.09	-1.43
Burma								
Paddy rice	Improved seeds and water and nutrient management	35,317	0.52	-1.62	-1.44	0.52	-1.96	-1.61
Zimbabwe								
Maize	Crop rotation; fertiliser (synthetic + manure), min. till	332,500	0.1	-0.74	-1.34	0.5	-1.05	-1.37
Groundnuts	Crop rotation; fertiliser (synthetic + manure), min. till	40,000	-0.2	-0.61	-1.51	0	-0.87	-1.45
Sugar-bean	Crop rotation; fertiliser (synthetic + manure), min. till	10,000	0.2	-0.67	-1.35	0.4	-1.27	-1.94
Sorghum	Crop rotation; fertiliser (synthetic + manure), min. till	45,000	-0.1	-0.58	-2.88	0.3	-1.00	-1.68
Beef cattle	Breeding, feeding, sanitation	0.66 Mi heads	3.0 kg $heads^{-1}$	-0.01 head-1	-	3.9 kg	-0.01 $head^{-1}$	-
Poultry (broilers)	Breeding, feeding, sanitation	NA	NA	18.4 $KtCO_2e\ y^{-1\dagger}$	NA	NA	46 $KtCO_2e\ y^{-1}$	NA
Goat	Breeding, feeding, sanitation	0.20 Mi heads	1.0 kg $heads^{-1}$	-0.001 $head^{-1}$	-	1.9 kg	-0.001 $head^{-1}$	-
Uganda								
Rice	Min.till; reduc. burning crop res.; mechanisation	48,000	0.99	-0.96	-0.45	0.99	-1.32	-0.59
Poultry (broilers)	Breeding, feeding, sanitation	0.17 Mi heads	NA	0.49 $KtCO_2e\ y^{-1}$	NA	NA	0.49 KtCO2e y^{-1}	NA
Poultry (layers)	Breeding, feeding, sanitation	0.019 Mi heads	NA	0.05 $KtCO_2e\ y^{-1}$	NA	NA	0.05 KtCO2e y^{-1}	NA
Nigeria								
Maize	Min. till; reduced burning crop resid.; crop rotation	85,575	0.36	-0.78	-0.58	2.06	-0.87	-0.67
Upland rice	Min. till; reduced burning crop resid.; crop rotation	55,892	1.02	-0.89	-0.24	1.37	-0.92	-0.25
Improved cookstove	Avoided deforestation	NA	-	0.63 (-60%)	(per beneficiary)	-	0.63 (-60%)	(per beneficiary)
Improved cookstove	Improved fuel use (firewood)	NA	-	0.04 (-50%)	(per beneficiary)	-	0.04 (-50%)	(per beneficiary)
Ghana								
Cocoa	Multistrata agroforestry; intercropping	5,520	0.42	-5.46	-	0.42	-5.46	-
Maize	Crop rotation; use of inputs; minimum tillage	356	3.5	-0.05	-0.01	3.5	-0.05	-0.01
Sorghum	Crop rotation; use of inputs; minimum tillage	1,600	0.66	-0.57	-0.52	0.66	-0.57	-0.52
Land use change	Cropland expansion over new land	356	-	31.47	-	-	31.47	-
Forest management	Avoided forest burning	376	-	-7.17	-	-	-7.17	-
Mozambique								
Goat††	Breeding, feeding, sanitation	3,000 heads	6 kg (LWG)	-0.001 $head^{-1}$	-2.9kg/kgLWG	6 kg (LWG)	-0.001 $head^{-1}$	-2.9kg/kgLWG

*values represent the difference compared to baseline scenario (see Table A2). **expected by programme end (see Table A2). †Refers to changes in net emissions where the baseline was assumed to be zero. See Table A2. ††Pasture area not provided. Productivity expressed in animal live weight gain (LWG) rather tons of meat produced. NA: not applicable.

Agricultural practices influencing GHG emissions and carbon sequestration in livestock systems

The livestock value chains assessed in this work implemented improved breeding, feeding, and health (e.g., vaccination) in Zimbabwe, Uganda, and Mozambique (Table 3, A2; Figure 3). Farmers increased average productivity only slightly from 1.0 (goats) to 3.0 kg head^{-1} y^{-1} (beef cattle). On an animal basis, according to the EX-ACT tool, improvements in livestock production across programmes decreased emissions by 0.01 tCO_2e animal^{-1} y^{-1} for beef cattle and 0.001 tCO_2e animal^{-1} y^{-1} for goat (Figure 3). The change in emissions should be investigated further with more detailed models, as increases in productivity can also lead to increases in emissions, depending on weight, productivity gains, feed, type of breed, age and other conditions.

In the poultry sector, vaccination and improved animal feeding promoted by the programmes made it possible for farmers to expand chicken numbers significantly. An increase in chicken population of more than 6 million heads was reported across programmes, which increased GHG emissions relative to the baseline by 18.9 KtCOe y^{-1} (0.003 tCO2e per poultry head) (Table 3; Table A2). After implementing a programme for better poultry management in Zimbabwe, for example, poultry meat production increased almost 50% and an increase of 110% is expected by the end of the programme (Table 3, A2). If chicken consumption displaces consumption of higher emissions meat products such as beef, poultry production will help reduce overall emissions. The annual emissions of one head of cattle raised for beef, for example, is equivalent to the emissions of approximately 600 chickens. Consumption patterns would need to be monitored to confirm any displacement effect.

GHG emissions intensities for livestock meat (emissions per kg beef, mutton or chicken), however, were not assessed due to the lack of data collected on livestock production and productivity before and after the programme interventions.

Net GHG emissions impacts of crop and livestock interventions

The seven DfID programmes evaluated in this work reduced net GHG emissions in 24 value chains by 1.01 Mt CO_2e y^{-1} in crop systems and increased net GHG emissions slightly by 0.015 Mt CO_2e y^{-1} in livestock systems, during the period from programmes' start dates to the present. By the programmes' end dates, mitigation is expected to increase to a total cumulative value of 1.20 Mt CO_2e y^{-1} in crop systems, suggesting that the largest GHG mitigation from cropland, mostly due to soil carbon sequestration, has already been achieved. For livestock systems, programme interventions are expected to increase to 0.041 Mt CO_2e y^{-1} due to increases in livestock population (Figure 5; Table 3, A2).

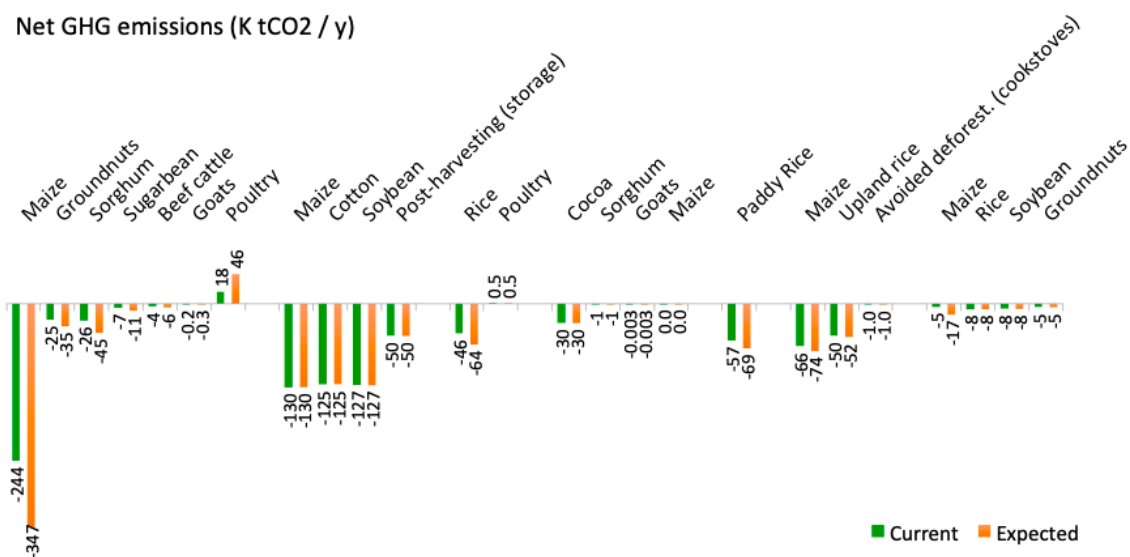

Figure 5. Total current and expected GHG emissions impact of agricultural practices of seven selected market and agribusiness programmes in DfID's investment portfolio.

Land use change due to the programmes

Of the seven programme representatives interviewed, five mentioned occurrence of land use change in the area of influence of the programme. However, only two programmes, both in Ghana, were able to provide estimates of how much land had been converted for agriculture expansion since the start of the project. Identified land use change in Ghana due to the two programmes comprised an estimated area of approximately 32,000 ha in Ghana.

Almost all land use change was due to one programme expanding cropland in the northern savannah region, with 75% of the expansion occurring on areas previously fallow, and 25% involving clearing of tropical shrubland in native savanna. Although the latter is a relatively low-carbon density forest type, the conversion of one hectare of native savanna is estimated to emit close to 240 tCO_2e ha^{-1}, which contributes GHG emissions for the programme of 1.9 $MtCO_2e$ or 12.2 tCO_2e ha^{-1} y^{-1} (over 20 years). The conversion of one hectare of fallow area is estimated to emit close to 60.0 tCO_2e ha^{-1}, which impacts GHG emissions for the programme by 1.47 $MtCO_2e$ or 3.1 tCO_2e ha^{-1} y^{-1}. Thus, emissions associated with land use change (3.4 $MtCO_2e$ or 170.0 K tCO_2e y^{-1}) are almost 4.5 times higher than the expected GHG emission reduction by the end of the programme (38.9 K tCO_2e y^{-1}) (Table 3).

In the second case in Ghana, land clearing of native tropical moist deciduous forest for cropping production expanded over 356 ha (to produce maize) was estimated to emit close to 630.0 $tCO_2e\ ha^{-1}$, which impacts GHG emissions for the programme by 0.22 $MtCO_2e$ or 31.47 $tCO_2e\ ha^{-1}$ $year^{-1}$ (over 20 years) (Table 3).

However, land use conversion is driven by multiple factors such as: (a) demographic (population growth, urbanisation and migration), (b) economic incentives (changes in prices, shifts in demands, and infrastructure development), and (c) policy (tenure rights, access to loans) (Ciao, Sarpong 2007; Geist, Lambin 2002). Addressing the drivers of cropland expansion over natural woodlands and sensitive areas (e.g., forest, mangroves, grasslands, wetlands, and peatlands) is an important opportunity to curb GHG emissions in the region of programme influence. At the same time, the converted land supported an almost quadrupling of grain production (Table A2), so consideration of trade-offs and whether alternative land use choices were available is necessary.

Land sparing potential

We analysed the potential land sparing due to agriculture intensification supported by DfID's programme interventions. To achieve the same level of production without agricultural intensification (Table 3) would have required an additional land area of approximately 4.1 million hectares, which is equivalent to 97% of the area of influence of the programmes evaluated in this work (Table 4).[16]

While most programmes likely contributed to land sparing, it is possible that further expansion of agriculture and land use change will occur with the growth of markets and input efficiencies. Measures to slow land use change include:

- Avoid locating programmes in the frontier zones of carbon-sensitive areas, such as forest land, grassland, peatland, or wetlands (create incentives for use of already cleared areas, restricted areas, road and market infrastructure choices).
- Encourage sustainable sourcing commitments by corporate actors (labelling, certification, impact investment funds, disclosure agreements)

[16] This analysis was based on the amount of land necessary to achieve equivalent production of intensified agriculture under baseline practices.

- Foster programmes that also promote rule of law and strong governance for the protection of carbon-sensitive areas (including environmental protection policy, monitoring, third-party watch dogs, national-level adjudication and enforcement).
- Strengthen compliance of private sector action with public policy commitments for climate change and environment (e.g., through local and national government, emissions reporting requirements, conditional finance, traceability and labelling).

Table 4. Potential land sparing from agriculture intensification within the DfID portfolio of investments in agriculture.

Programme/value chain	Expected scenario (at programme end)		
	Area	Increase in productivity	Potential land sparing
	ha	t/ha	ha
Ghana	**63,282**		**94,116**
Maize	27,700	127%	35,179
Rice	13,643	196%	26,740
Groundnuts	10,515	178%	18,717
Soybean	11,424	118%	13,480
Zambia	**280,791**		**202,905**
Maize	93,597	40%	37,439
Soybean	93,597	60%	56,158
Cotton	93,597	100%	93,597
Post-harvest losses (PICS)	-	-65% losses	8,691
Post-harvest losses (PICS)	-	-60% losses	7,020
Myanmar	**35,317**		**12,361**
Improved rice	35,317	35%	12,361
Zimbabwe	**3,627,500**		**3,597,500**
Maize	332,500	100%	332,500
Groundnuts	40,000	0%	0
Sugar-bean	10,000	100%	10,000
Sorghum	45,000	100%	45,000
Beef cattle	2,200,000	130%	2,860,000
Goat	1,000,000	35%	350,000
Uganda	**48,000**		**32,160**
Rice	48,000	67%	32,160
Nigeria	**141,567**		**140,816**
Maize	85,575	143%	122,372
Upland rice	55,892	33%	18,444
Ghana and Mozambique	**7,476**		**5,921**
Cocoa	5,520	84%	4,637
Maize	356	100%	356
Sorghum	1,600	58%	928
Total potential land sparing (Mha)	**4.20**		**4.09**

Forest conservation

Interventions to reduce forest burning and promote forest conservation have been taking place in Ghana. The project has reduced the occurrence of forest burning by an estimated 50%. This action has avoided degradation of 376 ha of tropical moist deciduous forest in Ghana (Table 3), reducing emissions by 85% (from 8.47 to 1.30 tCO_2e ha^{-1} y^{-1}), which is equivalent to 53.95 K tCO_2e or 2.70 K tCO_2e y^{-1} (Table 3, A2).

Off-farm interventions: post-harvest loss

Through the help of a local partner company, the programme in Zambia is also facilitating interventions to reduce maize and soybean post-harvest losses through storage bag improvements. At the start of the programme, maize and soybean grain losses were approximately 20%. With off-farm interventions to improve technologies for packing and storing, called Purdue Improved Crop Storage (PICS) bags, maize and soybean grain losses have dropped to about 5%. PICS are designed to store crops and reduce post-harvest losses from pests such as weevils (Hohenberger 2016).

PICS, therefore, results in savings in maize and soybean production equivalent to 0.22 and 0.08 t y^{-1}, respectively. According to the GHG emission estimated in this work (Table 3), PICS implementation has avoided emissions equivalent to 0.45 and 0.09 tCO_2 ha^{-1} y^{-1} for maize and soybean, respectively, totalling about 0.05 Mt tCO_2e y^{-1} for these value chains combined (Figure 3; A2). Reduced food loss does not necessarily lead to reduced production however, so these reductions may be best thought of as avoided emission increases.

Off-farm interventions: avoided deforestation through improved cookstoves

By improving cookstove efficiency, the programme in Nigeria is reducing deforestation and consequently, baseline GHG emissions by 60% as a result of reduced firewood use. Traditional cookstoves require 1.9 kg of firewood per day, whereas improved cookstoves only require 0.75 kg of firewood per day. Currently, 1,438 beneficiaries have received improved cookstoves, meaning that total firewood consumption has potentially decreased from 492 to 197 t firewood y^{-1}, avoiding the deforestation of 4.3 ha of forest (shrubland) per year (considering 69.3 t of harvested wood product per ha per year). Consequently, the adoption of improved cookstoves has avoided the emissions of 0.63 and 0.04 tCO_2e $beneficiary^{-1}$ y^{-1} from forest degradation and firewood use, respectively, totalling -963.5 tCO_2e y^{-1} (Figure 3; Table 3, A2).

Summary of impacts and mitigation opportunities across programme interventions

The selected crop and livestock value chains of the seven programmes (Table 1) comprise an area of slightly more than four million hectares. Results show that improving farming management practices and technologies due to these DfID investments are expected to lead to a significant increase in crop and livestock productivity while reducing net total GHG emissions by 1 MtCO_2e/year for the first 20 years (Table 3, A2). This number should be interpreted with caution as it reflects only a subset of programmes' activities and has high uncertainty.

The largest changes were observed for cocoa agroforestry systems, which resulted in a net GHG change of -5.5 tCO_2e ha^{-1} y^{-1} (Figure 6; Table 3, A2). Cereals and other annual crops demonstrated smaller annual changes, currently averaging -0.80 tCO_2e ha^{-1} y^{-1} (from -1.62 to -0.05 tCO_2e ha^{-1} y^{-1}; see rice in Myanmar and maize in Ghana), with a slight change to -0.97 tCO_2e ha^{-1} y^{-1} expected by the programmes' end (Figure 6; Table A2). Interventions in livestock production systems decreased net GHG emissions from 0.001 (goat) to 0.01 (beef) tCO_2e head^{-1} y^{-1}, with no further changes expected by the programmes' end (Figure 3; Table A2). Overall, programmes promoting more use of nitrogen fertiliser (synthetic and organic sources) or improved soil management (e.g., minimum tillage) tended to increase or decrease emissions respectively compared to their baseline scenarios (Figure 2).

The trends found in this work are similar to those reported in evaluations of other agriculture development interventions. Analysis of agriculture interventions in more than 30 crop value chains across Africa, Asia, and Latin America showed average annual net GHG impacts of -6.14 tCO_2e ha^{-1} in agroforestry and -0.78 tCO_2e ha^{-1} for cereals (Grewer et al. 2018). On-farm emissions increased due to more use of nitrogen fertiliser, and reductions in emissions by soil carbon sequestration (Grewer et al. 2018; Richards et al. 2019).

The baseline scenario and the acreage also mattered. DfID programmes in Zambia and Ghana, for example, have similar programme structure (soil and fertiliser management interventions). However, farmers in the Zambia programme used fertiliser inputs more intensively before the start of the programme, while soil inputs used by farmers before the start of the Ghana programme were negligible. Thus, Zambia's increase in fertiliser emissions was lower and soil carbon sequestration had a higher offset impact (Figure 2; Table 3). On the other hand, the adoption of fertiliser through the Ghana programme helped farmers to increase crop production and narrow differences in crop productivity compared to Zambia (see Table 3 for maize).

Zambia is also achieving further emissions reductions per unit of food through post-harvesting loss interventions (Table 3; Figure 3). Similarly, soil management in Uganda has a baseline and programme scenarios with low use of soil inputs. Still, with improvements in soil management, the soil carbon sequestration largely offsets the programme interventions.

The programme in Myanmar is an exception among the programmes evaluated. This programme reduced emissions by 46% with the use of improved seeds and good agronomic practices (GAP), while increasing rice productivity (35%) – also potentially lowering production costs (Figure 3; Table 3). The use of improved seeds (short growing season and high quality varieties) and good agricultural practices have promoted reduced use of nitrogen fertiliser (urea) by 50% (or 0.67 tCO_2e ha^{-1} y^{-1}) and shorter paddy rice flooding periods, from 140 to 120 days, promoting a further emission reduction of 0.23 tCO_2e ha^{-1} y^{-1}. In addition, the Myanmar programme expects a further reduction in the flooding period (to 90 days) in the coming years once new short growing varieties are introduced, which will lead to a GHG emission reduction of 0.57 tCO_2e ha^{-1} y^{-1} (Figure 3; Table 3).

We assessed the relationship between productivity increases associated with intensification and emissions across value chains for all programmes and found no significant relationship, which may reflect the small number of value chains sampled. We did not include cocoa agroforestry and selected livestock interventions, which were outliers with emission values over 4 tCO_2e ha^{-1} y^{-1}, only a few observations (n=3), and with data of medium to low certainty.

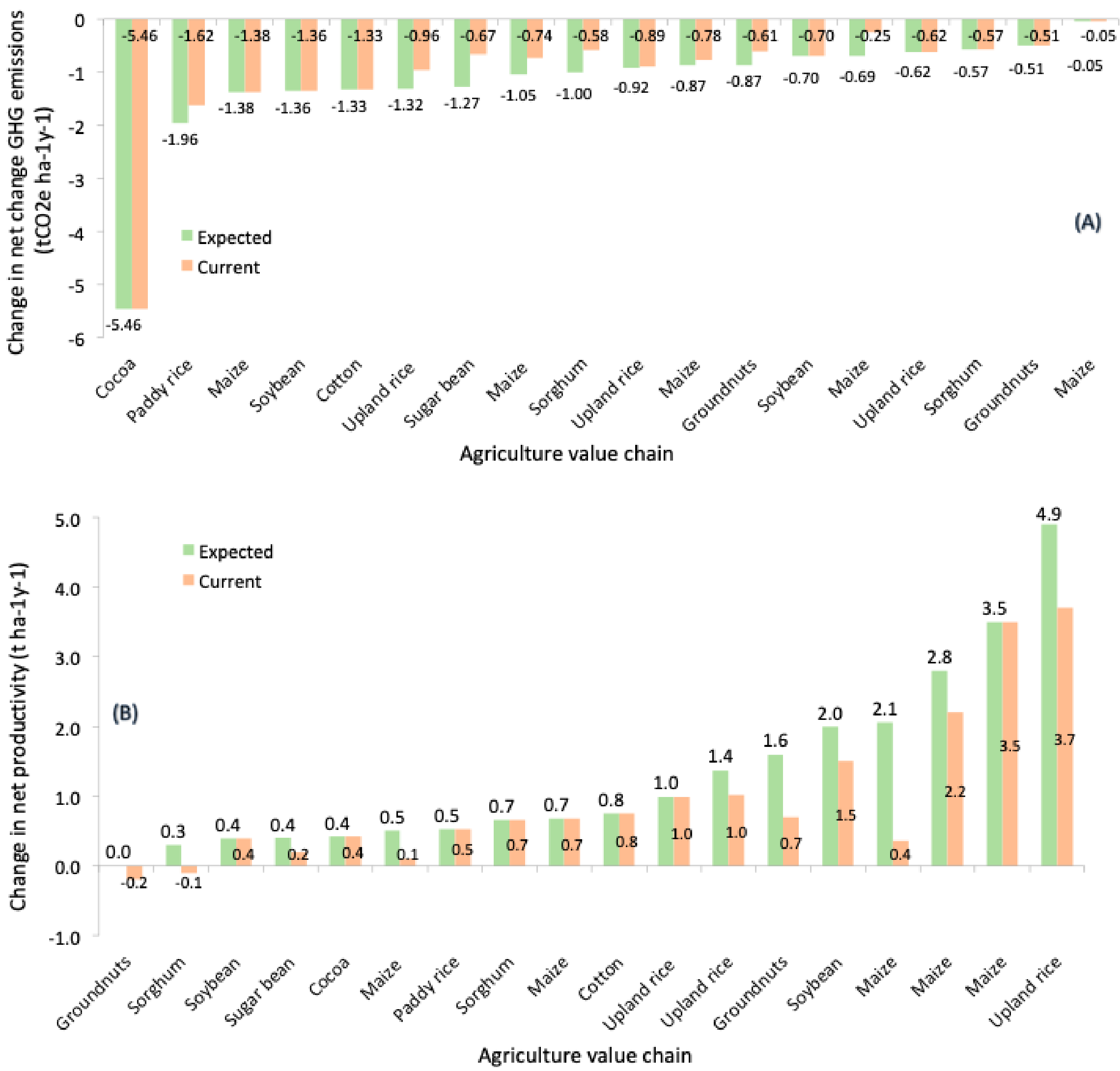

Figure 6. Changes in net GHG emissions (A) and productivity (B) of selected interventions and agriculture value chains supported by DfID's programmes in countries in Africa and Asia compared to baseline scenario.

Importantly, carbon sequestration, especially in soil, comprises the majority of the GHG mitigation potential in the programmes assessed – over 80% for most of the programmes, except for Myanmar (Table 5, 6). Minimum tillage, manure additions, and crop rotation were the major interventions leading to soil carbon sequestration across programmes (Table 3, 5; Figure 2, 3). However, in Myanmar, soil carbon sequestration contributed to less than 50% as interventions focused on using improved seed and good agronomic practices reduced the use of nitrogen fertiliser application and the period paddy rice remains flooded, which decreased associated emissions by 46% (Table 3, A2; Figure 2, 3).

Excluding soil carbon sequestration, reduced burning of crop residues was the main intervention reducing net GHG emission of the programmes. On the other hand, increased use of nitrogen fertiliser and, to a lesser extent, mechanisation use in most programmes were the main drivers of increases in emissions. This suggests that the net mitigation effect of programme interventions is likely in the short term (e.g., over 20 to 40 years) or until carbon sequestration reaches equilibrium. Without the adoption of interventions leading to new emission reductions and carbon sequestration, we estimate that, under a scenario of saturation of carbon sequestration, the programme interventions would increase net GHG emissions from 45% to 161%. In the absence of carbon sequestration, aggregated emissions of the total area evaluated in this work would approximately shift from -0.19 to 0.05 $tCO_2e\ ha^{-1}\ y^{-1}$ or from -0.81 to 0.22 $MtCO_2e\ y^{-1}$ (Table 5). The eventual annual increase in GHG emissions would be a trade-off of securing food security benefits.

Table 5. Summary of current and expected impacts from a sample of agricultural programmes interventions within the DfID portfolio of investments

Programme focus country	Core market and agribusiness interventions at the farm-level evaluated	Area	Net GHG Impact (inc. carbon sequestration*)		Removals/net emissions††	Net GHG Impact (exc. carbon sequestration)		Removals/net emissions††
		ha	tCO_2e/ ha/y	$KtCO_2e$/ y†	%	tCO_2e/ ha/y	$KtCO_2e$/ y†	%
Mozambique and Ghana	Agroforestry, livestock, soil management	12,965	-2.39	-31.0	103%	0.07	0.9	103%
Uganda	Livestock, Soil management, post-harvesting losses	48,000	-0.95	-45.8	96%	-0.04	-1.9	93%
Ghana	Soil and fertilizer management	63,520	-0.42	-26.7	161%	0.27	16.9	128%
Nigeria	Livestock and soil management	141,200	-0.83	-116.9	82%	-0.15	-20.6	75%
Zambia	Soil management, post-harvesting losses	280,800	-1.54	-431.4	99%	-0.01	-3.8	99%
Zimbabwe	Livestock and soil management	3,627,500	-0.08	-287.0	121%	0.02	77.2	74%
Myanmar	Irrigated rice	35,000	-1.64	-57.3	45%	-0.91	-31.7	37%
Total		**4,208,985**	**-0.24**	**-996.10**		**0.01**	**37.05**	
Land use change (LUC)**		32,158	5.67	181.28		5.67	182.34	
Net GHG balance			**-0.19**	**-814.82**		**0.05**	**219.39**	

*20 year time-period after the start of the programme; **Land use change was associated with agriculture expansion and deforestation.

† Reflects total area of the programme; †† Values over 100% mean that removals, primarily through soil carbon sequestration, are higher than the total GHG emissions of the programme.

Table 6. Primary emissions and mitigation sources across agricultural programmes in DfID's portfolio of investments

Programme focus country	Major emission source	Major mitigation source
Ghana	Use of N-fertiliser / land use change	Soil carbon sequestration
Zambia	Use of N-fertiliser	Soil carbon sequestration
Uganda	Livestock – poultry	Soil carbon sequestration
Nigeria	Use of N-fertiliser	Soil carbon sequestration
Zimbabwe	Use of N-fertiliser and livestock-beef	Soil carbon sequestration
Mozambique + Ghana	Use of N-fertiliser	Aboveground carbon sequestration
Myanmar	Crop rotation and use of N-fertiliser	Reduction in N-fertiliser application and paddy rice flooding period

Table 7. Core interventions for enhancing mitigation and carbon sequestration in agricultural systems*

Additional GHG emission reduction
Avoid land conversion by curbing land expansion over native shrublands.
Animal management practices such as improved health, genetics and live weight gain, and reduced mortality.
Improved animal feeding with the inclusion of cereal grains in feed to improve feed quality.
Improved rice cultivation with the adoption of water management techniques such as alternate wetting and drying (AWD) and midseason drainage (MSD), residue incorporation and improved fertiliser management.
Nutrient management focused on reducing excessive fertiliser use and improve application methods such as improving the timing, placement, and form of fertiliser application, replacing synthetics by organic sources without negatively impacting crop yields.
Replacement of fossil fuels by solar panels and other co-generation as a source of electricity and transportation.
Additional carbon sequestration
Planting cover crops during the part of the year when the main crop is not growing and shifting soil ploughing to reduced-tillage or zero-tillage systems.
Integrating trees into croplands at levels that do not reduce crop yields. It includes windbreaks and alley cropping.
Adopting silvopastoral systems integrating livestock, forage production, and forestry on the same land-management unit.
Implementing agroforestry systems that combine coffee, tea or cocoa shrubs with multi-purpose shade species.
Sowing legumes in planted pastures.
Grazing optimization on rangeland and planted pastures.
Other interventions
Avoid deforestation by improving cook-stoves efficiency.
Reduce post-harvesting loss by improving handling, storage and transport practices.
Grazing optimization on rangeland and planted pastures.

*Griscom et al. 2018; IPCC, 2006.

Fortunately, there are several options to minimize and avoid higher emissions scenarios in future investments. We identified core value-chain interventions that may enable programmes to enhance future emissions reduction and carbon sequestration while presenting economic feasibility and yield crop productivity benefits (Table 7).

As stated above, the highest impact intervention for mitigation is to avoid conversion of lands with significant carbon stored in vegetative cover or soil due to its relatively high impact compared to emission reductions of agriculture practices. This is followed by on-farm methods focused on livestock and cropping systems and off-farm practices that reduce post-harvesting loss (Table 7).

Among the mitigation opportunities listed in Table 7, improving nutrient efficiency in both cropping and pasture-based livestock production systems is likely to have the most significant effect across the DfID portfolio. The implementation of agroforestry may further enhance carbon sequestration across the portfolio. Improving animal breeding and feeding and promoting water drainage in rice paddies are additional opportunities for mitigation (Figure 7).

Guidance toward low-emission pathways relevant to the programmes may be initiated through use of best-practice checklists or, more generally, by applying three principles: (1) avoid land use change, (2) improve production efficiency, and (3) offset emissions with carbon storage. Production efficiency should focus on:

(a) efficient use of energy, fertilizer, in the case of paddy rice, water;

(b) efficient use and conversion of feed in livestock production;

(c) avoided food loss or waste; and

(d) recycling of waste.

In addition, where possible, fossil fuels should be replaced with alternative renewable energy and the efficiency and quality of production of ruminant livestock should be enhanced before increasing the number of animals. Low-emission pathways are context specific and emissions reflect aggregated net emissions for a production system, so no single practice can guarantee mitigation impacts.

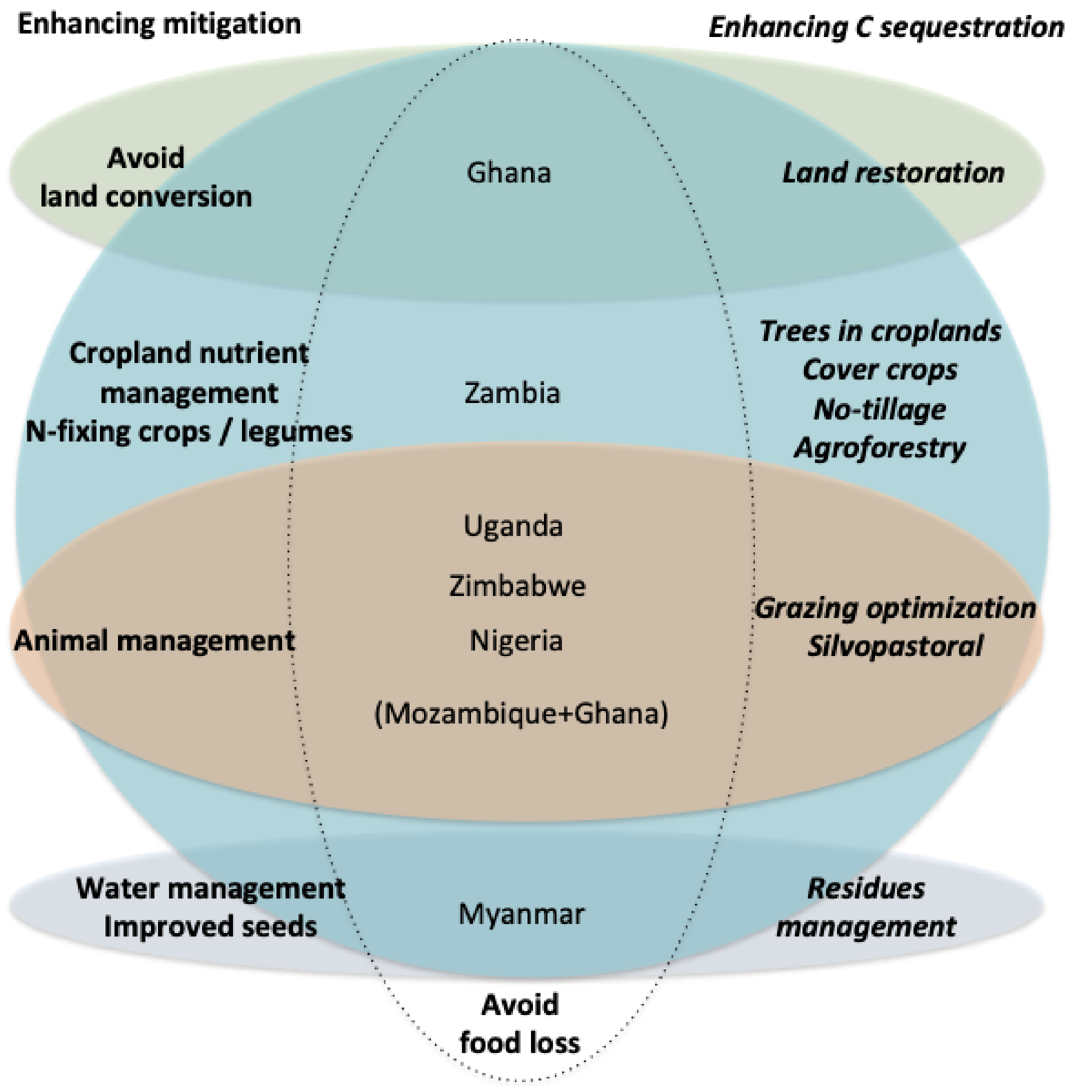

Figure 7. Core interventions for enhancing mitigation and carbon sequestration across agricultural programmes in seven focus country within DfID portfolio of investments.

Reducing uncertainties and gaps in understanding emission and mitigation potentials

Overall, the certainty of the net GHG emissions estimates in this work, based on the methods used, ranged from medium to low. Emission factors used in this work were mostly default Tier 1 emission factors provided by the IPCC. A Tier 1 emission factor has medium to low certainties (IPCC 2006). The only Tier 2 emission factors (which provide higher certainty than Tier 1) available were related to the soil carbon sequestration potential in cropping systems (World Bank 2012; Fan et al. 2015) and emissions from ruminant enteric fermentation (IPCC database) for the adoption of improved interventions.

Activity data accessed in this work relied mostly on programme interviews and, therefore, should be understood as having medium certainty. Data collected based on assumptions and literature not related to the programme has low certainty. Improving activity data collection is the best means to generate a more precise and low-cost evaluation of DfID programmes in the short-term. Improving relevant emission factors depends on the development of controlled and long-term experiments, which is out of the scope of most development programmes.

Figure 8 presents a decision tree for guiding programme developers to prioritize and improve data collection for estimating emissions. Across programme interventions, the data that are most important to improve net GHG emission estimates are quantitative information on the risk and expected level of land-use change, the land area of programme implementation, and the number of animal heads, water management in paddy rice and the amount of N-fertiliser applied to soils before and after the programme. By following this guidance, estimates will have more certainty and better guide future decision-making for low-emissions agriculture.

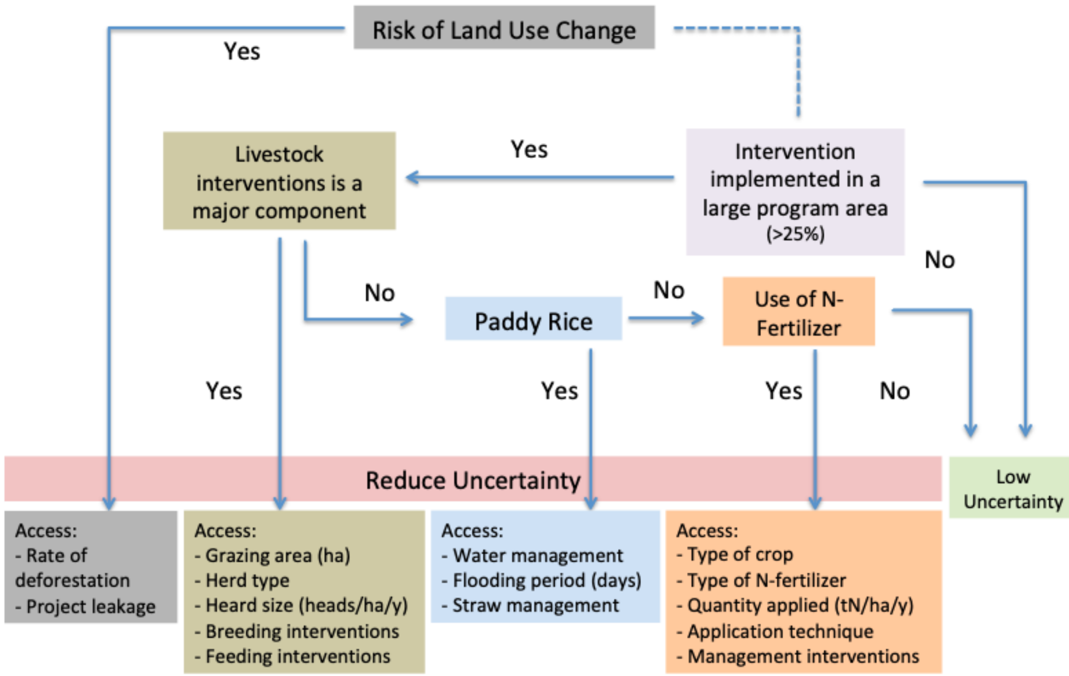

Figure 8. Decision tree to improve data collection and the GHG footprint certainty of DfID's agriculture portfolio of investments.

Conclusions

The adoption of enhanced agronomic interventions is expected to significantly enhance crop and livestock productivity across DfID's programme investments in commercial agriculture in Africa and Asia while reducing net GHG emissions.

Carbon sequestration, especially in the soil, comprises the majority of the GHG mitigation potential in the sampled value chains in the programmes. Minimum tillage, pasture management, crop rotation, and nutrient management were the major interventions leading to soil carbon sequestration.

Across programmes, the use of nitrogen fertiliser will likely lead to an overall increase in emissions over time, despite the impacts of fertiliser use on increasing soil carbon sequestration. The net mitigation effect from soil carbon sequestration is only likely in the short term (up to 20 to 40 years), until soil carbon sequestration reaches equilibrium.

However, there are several opportunities to minimize and avoid higher emissions scenarios from future investments. The most important of these is to prevent the conversion of land with significant vegetation or organic soils (e.g., peatlands), as the level of carbon loss will likely outweigh the emission reductions possible using agriculture practices. Among the most significant agronomic interventions for mitigation are nitrogen fertilizer efficiency, crop rotation, no-tillage, agroforestry, animal management, and water-saving irrigation in paddy rice (Table 6).

Finally, practices and policies that promote efficient and improved nutrient use, with a focus on balanced nutrient inputs and optimal use of organic resources, as well as those that promote high-yielding and improved seeds, are crucial for future low-emissions development. For example, as seen in the Myanmar programme, the use of improved rice seeds and adoption of good agronomic practices helped reduce the use of nitrogen fertiliser by 50%.

Annex 1 Material and methods

Selection of programmes for analysis

DfID selected seven programmes from their commercial agricultural portfolio for review based on programmes' objectives and the likelihood of significant effects on net GHG emissions (Table 1). Programmes had agribusiness, rural market development or livelihoods objectives located in Sub-Saharan Africa and Asia. Implementing partners were local or locally based organisations with long experience in the agricultural sector and in-depth knowledge about the region. All selected programmes were still active at the time of the interview. Nearly all programmes had been operating for more than five years, and roughly half were close to ending.

Scope

The scope of this work is on-farm and off-farm greenhouse gas emissions and removals as a result of interventions of the programme. The primary sources and sinks of GHG emissions at farm level (i.e., on-farm) are:

1) methane (CH_4) emissions caused by enteric fermentation and flooded rice systems as well as direct and indirect nitrous oxide (N_2O) emissions caused by livestock waste management systems.

2) N_2O emissions from the decomposition of crop residues and direct and indirect emissions of N_2O and CO_2 emissions caused by the application to soils of (synthetic and organic) nitrogen fertilisers and limestone, respectively.

3) CO_2 emissions caused by the burning of fossil fuels.

4) CO_2, N_2O and CH_4 related to land-use change.

5) CO_2 removal (C sequestration) in reforestation, afforestation, well-managed cropped soils and implementation of trees in croplands (e.g., agroforestry systems) (Figure 8).

Off-farm GHG sources and sinks are more diverse. Still, major sources are transportation and manufacturing of farm inputs and energy generation as well as avoided emissions from post-harvest losses and land-use change.

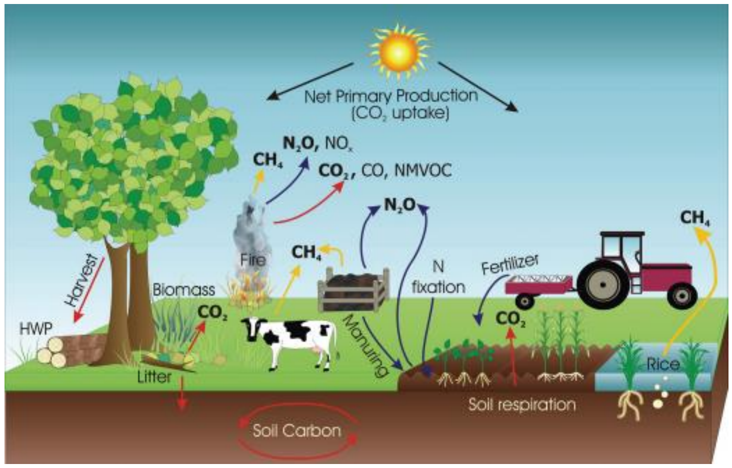

Figure 8. The primary greenhouse gas emission sources, removals and processes in managed ecosystems (IPCC, 2006).

Estimating GHG emissions and removals

Estimating GHG emissions and removals requires two sets of data: *activity data* and *emission factors*. *Activity data* is the information related to the activities or interventions of a given scope (e.g., quantity of fertiliser applied to the soil, heads of animals, type of soil tillage). An *emission factor* is the amount of GHG emitted or removed by a unit of activity data (e.g., a kilogram of N_2O emitted by the application of 1 kilogram of urea). In the next two sections, we describe the process of acquiring activity data from selected programmes as well as associated emission factors.

Activity data collection

The process of collecting *activity data* for the selected DfID programmes consisted of four steps:

1. *Review of programme documentation*: We examined and collected qualitative and quantitative data for the selected applications by reviewing programmes' design documents and annual reports. These documents were provided by implementing organisations and available in a dedicated DfID's investments platform (DevTracker). The objective of this step was to identify significant value chains and interventions promoted by the programmes and their status under three scenarios: situation at the start of programme implementation (baseline year), the current state of programme implementation, and expected results at the programme completion. For programmes with large portfolios, we selected a sample of programmes most likely to have emissions and mitigation impacts.

2. *Completion of a written questionnaire by programme implementing organisations*: Each implementing organisation completed a detailed survey tailored to specific programme activities pre-filled by the research team with the data collected in Step 1. The questionnaires considered a comprehensive range of programme's direct and indirect impacts related to GHG emissions and carbon sequestration in agriculture, forestry, and land use identified based on IPCC (2006).

3. *Interviews with implementing organisations*: We conducted interviews by teleconference with programme implementing organisations to complement and double-check the information gathered in Steps 1 and 2. During interviews and follow-up calls, priority production systems and value chains were confirmed and implementing organisations were asked to characterise in detail the type of improved practices and technologies directly and indirectly supported under the three scenarios described in Step 1.

4. *Interview follow-up*: We set up follow-up interviews with implementing organisations to collect quantitative programme data that were not available during the first round of interviews (Step 3).

In order to ensure data in this assessment were of sufficiently quality to draw robust conclusions, we employed the following data quality management measures:

- We flagged data provided by implementing organisations as subject to low certainty, unaccompanied by a reasonable amount of monitoring data and assumed values. For those, we arbitrarily assumed low, medium and low certainty, respectively.
- We crosschecked data provided by implementing organisations with agriculture experts, literature consultation, and global databases for precision (e.g., FAO-Stat for agriculture yields and use of soil inputs), excluding data when no reliable data documentation was available.

Emission factor selection

The IPCC (2006) methodology allows the combined use of Tier 1 and Tier 2 emission factors data. Tier 1 emission factors are default values readily available national or international factors such as those provided by the IPCC and therefore should be feasible for all countries, but low certainty. Tier 2 emission factors are country-specific developed by considering country-specific data and, consequently, they have higher certainty compared to Tier 1 emission factors. We used country- and programme-specific Tier 2 factors wherever available (i.e., soil carbons sequestration rates), otherwise relying on default Tier 1 factors. Coefficients from published reviews or international databases were used where appropriate.

Emission factors used in this report relating to rates of soil carbon sequestration (t CO_2 ha^{-1} y^{-1}) in Africa were adopted from The World Bank report on Carbon Sequestration in Agricultural Soils (report number: 67395-GLB). The report provides soil carbon sequestration rates (kg C ha^{-1} y^{-1}) for a range of continents and agronomic practices and further provides an averaged soil carbon sequestration rate based on several observations (number of observations range from 11 to 125 per region and agronomic practice). To determine the soil carbon sequestration rates for different value chains at baseline, current, and expected programme scenarios, we calculated an average rate for the agronomic practices of interest. For the programme in Myanmar, we adopted a soil carbon sequestration rate from similar agronomic practices and study region.

GHG emission estimate framework

Calculating the GHG impact of each programme accounted for GHG emissions and carbon sequestration resulting from the programme interventions using the EX-ACT tool of the UN Food and Agriculture Organisation (FAO). The EX-ACT tool was built based on the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). And was selected because of its ability to evaluate the primary sources of GHG emissions and removals in agriculture, forestry, and land use as compared with a business-as-usual (BAU) scenario; it also allows for the combined use of Tier 1 and Tier 2 emission factors.

Expected and monitored programme outcomes were used as input data to the EX-ACT tool to estimate (i) the total GHG impact of agricultural production systems by area; (ii) the GHG impact of individual agricultural practices as compared with BAU practices; and (iii) the GHG emission intensity of production systems before and after programme implementation. Results were converted to CO_2e using Global Warming Potential (GWP) factors provided by the IPCC (2013).

Temporal setting

We estimated the influence of programmes' agricultural interventions on average annual GHG emissions over 20 years following programme initiation, consistent with time frames commonly considered for carbon stocks to reach equilibrium (IPCC 2006). We assumed an implementation and a capitalization period of 7 and 13 years, respectively. This approach assumes that farmers continue to use agricultural practices introduced by development programmes over 20 years, often a more extended period than the development assistance.

Leakage

Programmes can influence land-use beyond the target area, which can influence GHG emissions accordingly. When an activity promotes emission increases in another area, it is called leakage. These dynamics are challenging to estimate in ex-ante analyses because their causal pathways depend strongly on context. In interviews, we limited ourselves to explore with interviewees any land-use change that was related to the programme activities.

Annex 2: Table A2

Table A2. Major agriculture value chains, interventions and impacts on productivity and GHG emissions promoted by selected market and agribusiness programmes within DfID's investment portfolio (detailed table).

								Effect on GHG emissions (tCO2e)			
Country focus	**Value chain**	**Implemented Practices**	**Scenario**	**Area (ha)/Head**		**Productivity**		**Area/Head/Beneficiary**		**Product**	
Ghana	Maize	Minimum tillage; residue retention; use of soil inputs (urea); improved nutrient management; improved agronomic practices; and machinery; crop burning reduction	Baseline	13,850	ha	2.2	t /ha/y	0.14	tCO_2e ha/y	0.06	tCO_2e
			Current	27,700	ha	4.4	t /ha/y	-0.11	tCO_2e ha/y	-0.03	tCO_2e
			Difference*			**2.20**	**t /ha/y**	**-0.25**	**tCO_2e ha/y**	**-0.09**	**tCO_2e**
			Expected	27,700	ha	5.0	t /ha/y	-0.55	tCO_2e ha/y	-0.11	tCO_2e
			Difference**			**2.80**	**t /ha/y**	**-0.69**	**tCO_2e ha/y**	**-0.17**	**tCO_2e**
	Upland rice	Use of soil inputs (urea); improved nutrient management; improved agronomic practices; and machinery	Baseline	6,821	ha	2.5	t /ha/y	0.00	tCO_2e ha/y	0.00	tCO_2e
			Current	13,643	ha	6.2	t /ha/y	-0.62	tCO_2e ha/y	-0.10	tCO_2e
			Difference			**3.70**	**t /ha/y**	**-0.62**	**tCO_2e ha/y**	**-0.10**	**tCO_2e**
			Expected	13,643	ha	7.4	t /ha/y	-0.62	tCO_2e ha/y	-0.08	tCO_2e
			Difference			**4.90**	**t /ha/y**	**-0.62**	**tCO_2e ha/y**	**-0.08**	**tCO_2e**
	Groundnuts	Use of soil inputs (urea); improved nutrient management; improved agronomic practices; and machinery	Baseline	5,257	ha	0.9	t /ha/y	0.00	tCO_2e ha/y	0.00	tCO_2e
			Current	10,515	ha	1.6	t /ha/y	-0.51	tCO_2e ha/y	-0.32	tCO_2e
			Difference			**0.70**	**t /ha/y**	**-0.51**	**tCO_2e ha/y**	**-0.32**	**tCO_2e**
			Expected	10,515	ha	2.5	t /ha/y	-0.51	tCO_2e ha/y	-0.20	tCO_2e
			Difference			**1.60**	**t /ha/y**	**-0.51**	**tCO_2e ha/y**	**-0.20**	**tCO_2e**
	Soybean	Machinery; improved nutrient management; improved agronomic practices	Baseline	5,712	ha	1.7	t /ha/y	0.00	tCO_2e ha/y	0.00	tCO_2e
			Current	11,424	ha	3.2	t /ha/y	-0.70	tCO_2e ha/y	-0.22	tCO_2e
			Difference			**1.50**	**t /ha/y**	**-0.70**	**tCO_2e ha/y**	**-0.22**	**tCO_2e**
			Expected	11,424	ha	3.7	t /ha/y	-0.70	tCO_2e ha/y	-0.19	tCO_2e
			Difference			**2.00**	**t /ha/y**	**-0.70**	**tCO_2e ha/y**	**-0.19**	**tCO_2e**
	LUC	Cropland expansion over set aside area	Baseline	0	ha			0.00	tCO_2e ha/y		
			Current	23,732	ha			3.10	tCO_2e ha/y		
			Difference					-			
			Expected	23,732	ha			3.10	tCO_2e ha/y		
			Difference					-			
		Cropland expansion over new land	Baseline	0	ha			0.0	tCO_2e ha/y		
			Current	7,911	ha			12.20	tCO_2e ha/y		
			Difference					-			
			Expected	7,911	ha			12.20	tCO_2e ha/y		
			Difference								
Zambia	Maize	Improved seeds; minimum tillage; crop rotation; machinery; and inputs	Baseline	93,597	ha	1.70	t /ha/y	1.28	tCO_2e ha/y	0.75	tCO_2e
			Current	93,597	ha	2.38	t /ha/y	-0.10	tCO_2e ha/y	-0.04	tCO_2e

Country focus	Value chain	Implemented Practices	Scenario	Area (ha)/Head		Productivity		Effect on GHG emissions (tCO2e)			
								Area/Head/Beneficiary		Product	
		(nitrogen fertiliser and lime); crop burning reduction	**Difference**			**0.68**	**t /ha/y**	**-1.38**	**tCO_2e ha/y**	**-0.79**	**tCO_2e**
			Expected	93,597	ha	2.38	t /ha/y	-0.10	tCO_2e ha/y	-0.04	tCO_2e
			Difference	**93,597**	**ha**	**0.68**	**t /ha/y**	**-1.38**	**tCO_2e ha/y**	**-0.79**	**tCO_2e**
	Soybean	Improved seeds; minimum tillage; crop rotation; machinery; and inputs (nitrogen fertiliser and lime); crop burning reduction	Baseline	93,597	ha	0.65	t /ha/y	0.22	tCO_2e ha/y	0.34	tCO_2e
			Current	93,597	ha	1.04	t /ha/y	-1.14	tCO_2e ha/y	-1.10	tCO_2e
			Difference			**0.39**	**t /ha/y**	**-1.36**	**tCO_2e ha/y**	**-1.43**	**tCO_2e**
			Expected	93,597	ha	1.04	t /ha/y	-1.14	tCO_2e ha/y	-1.10	tCO_2e
			Difference	**93,597**	**ha**	**0.39**	**t /ha/y**	**-1.36**	**tCO_2e ha/y**	**-1.43**	**tCO_2e**
	Cotton	Improved seeds; minimum tillage; crop rotation; machinery; and inputs (nitrogen fertiliser and lime); crop burning reduction	Baseline	93,597	ha	0.75	t /ha/y	1.22	tCO_2e ha/y	1.63	tCO_2e
			Current	93,597	ha	1.5	t /ha/y	-0.11	tCO_2e ha/y	-0.07	tCO_2e
			Difference			**0.75**	**t /ha/y**	**-1.33**	**tCO_2e ha/y**	**-1.70**	**tCO_2e**
			Expected	93,597	ha	1.5	t /ha/y	-0.11	tCO_2e ha/y	-0.07	tCO_2e
			Difference	**93,597**	**ha**	**0.75**	**t /ha/y**	**-1.33**	**tCO_2e ha/y**	**-1.70**	**tCO_2e**
	Maize	*Off-farm*									
		Post-harvesting losses improvements; Storage (PICS)	Baseline			0.34	t/ha/y (losses)	0.44	tCO_2e ha/y	0.26	tCO_2e
			Current			0.12	t/ha/y (losses)	-0.01	tCO_2e ha/y	-0.01	tCO_2e
			Difference			**0.22**	**t/ha/y (avoided)**	**-0.45**	**tCO_2e ha/y**	**-0.27**	**tCO_2e**
			Expected			0.12	t/ha/y (losses)	-0.01	tCO_2e ha/y	-0.01	tCO_2e
			Difference			**0.22**	**t/ha/y (avoided)**	**-0.45**	**tCO_2e ha/y**	**-0.27**	**tCO_2e**
	Soybean	Post-harvesting losses improvements; Storage (PICS)	Baseline			0.13	t/ha/y (losses)	0.03	tCO_2e ha/y	0.04	tCO_2e
			Current			0.05	t/ha/y (losses)	-0.06	tCO_2e ha/y	-0.06	tCO_2e
			Difference			**0.08**	**t/ha/y (avoided)**	**-0.09**	**tCO_2e ha/y**	**-0.10**	**tCO_2e**
			Expected			0.05	t/ha/y (losses)	-0.06	tCO_2e ha/y	-0.06	tCO_2e
			Difference			**0.08**	**t/ha/y (avoided)**	**-0.09**	**tCO_2e ha/y**	**-0.10**	**tCO_2e**
Myanmar	Improved Rice	Improved seeds; improved agronomic practice; shorter flooding period	Baseline	35,317	ha	1.47	t/ha/y	3.54	tCO_2e ha/y	2.41	tCO_2e
			Current	35,317	ha	1.99	t/ha/y	1.92	tCO_2e ha/y	0.96	tCO_2e
			Difference			**0.52**	**t/ha/y**	**-1.62**	**tCO_2e ha/y**	**-1.44**	**tCO_2e**
			Expected	35,317	ha	1.99	t/ha/y	1.58	tCO_2e ha/y	0.79	tCO_2e
			Difference			**0.52**	**t/ha/y**	**-1.96**	**tCO_2e ha/y**	**-1.61**	**tCO_2e**
Zimbabwe	Maize	Crop rotation with legumes; N-Fertiliser (synthetic + manure); minimum tillage; and residues management	Baseline	332,500	ha	0.5	t/ha/y	0.32	tCO_2e ha/y	0.64	tCO_2e
			Current	332,500	ha	0.6	t/ha/y	-0.42	tCO_2e ha/y	-0.70	tCO_2e
			Difference			**0.10**	**t/ha/y**	**-0.74**	**tCO_2e ha/y**	**-1.34**	**tCO_2e**
			Expected	332,500	ha	1	t/ha/y	-0.73	tCO_2e ha/y	-0.73	tCO_2e
			Difference			**0.50**	**t/ha/y**	**-1.05**	**tCO_2e ha/y**	**-1.37**	**tCO_2e**
	Groundnuts	N-Fertiliser (synthetic + manure); and use of inputs (lime)	Baseline	40,000	ha	0.6	t/ha/y	0.02	tCO_2e ha/y	0.03	tCO_2e
			Current	40,000	ha	0.4	t/ha/y	-0.59	tCO_2e ha/y	-1.48	tCO_2e
			Difference			**-0.20**	**t/ha/y**	**-0.61**	**tCO_2e ha/y**	**-1.51**	**tCO_2e**
			Expected	40,000	ha	0.6	t/ha/y	-0.85	tCO_2e ha/y	-1.42	tCO_2e
			Difference			**0%**	**t/ha/y**	**-0.87**	**tCO_2e ha/y**	**-1.45**	**tCO_2e**
	Sugar bean		Baseline	10,000	ha	0.4	t/ha/y	0.28	tCO_2e ha/y	0.70	tCO_2e

Country focus	Value chain	Implemented Practices	Scenario	Area (ha)/Head		Productivity		Effect on GHG emissions (tCO2e)			
								Area/Head/Beneficiary		Product	
		N-Fertiliser (synthetic + manure); and use of inputs (lime)	Current	10,000	ha	0.6	t/ha/y	-0.39	tCO_2e ha/y	-0.65	tCO_2e
			Difference			**0.20**	**t/ha/y**	**-0.67**	**tCO_2e ha/y**	**-1.35**	**tCO_2e**
			Expected	10,000	ha	0.8	t/ha/y	-0.99	tCO_2e ha/y	-1.24	tCO_2e
			Difference			**0.40**	**t/ha/y**	**-1.27**	**tCO_2e ha/y**	**-1.94**	**tCO_2e**
	Sorghum	Crop rotation; N-Fertiliser (synthetic + manure); minimum tillage; and use of inputs (lime)	Baseline	45,000	ha	0.3	t/ha/y	0.01	tCO_2e ha/y	0.03	tCO_2e
			Current	45,000	ha	0.2	t/ha/y	-0.57	tCO_2e ha/y	-2.85	**tCO_2e**
			Difference			**-0.10**	**t/ha/y**	**-0.58**	**tCO_2e ha/y**	**-2.88**	**tCO_2e**
			Expected	45,000	ha	0.6	t/ha/y	-0.99	tCO_2e ha/y	-1.65	tCO_2e
			Difference			**0.30**	**t/ha/y**	**-1.00**	**tCO_2e ha/y**	**-1.68**	**tCO_2e**
	Beef cattle	Breeding, feeding, and vaccination; manure composting; and use of manure as fertiliser	Baseline	660K	heads	3.0	$kghead^{-1}y^{-1}$	1.52	$head^{-1}$		
			Current	660K	heads	6.0	$kghead^{-1}y^{-1}$	1.51	$head^{-1}$		
			Difference			**3.0**	**$kghead^{-1}y^{-1}$**	**-0.01**	**$head^{-1}$**		
			Expected	660K	heads	6.9	$kghead^{-1}y^{-1}$	1.51	$head^{-1}$		
			Difference			**3.9**	**$kghead^{-1}y^{-1}$**	**-0.01**	**$head^{-1}$**		
	Poultry	Breeding, feeding, and vaccination	Baseline	9.6 mi	heads			33.5 K	total emis. y^{-1}		
			Current	16.0mi	heads			51.9 K	total emis. y^{-1}		
			Difference					**18.4 K**	**total emis. y^{-1}**		
			Expected	25.6mi	heads			79.5 K	total emis. y^{-1}		
			Difference					**46.0 K**	**total emis. y^{-1}**		
	Goat	Breeding, feeding, and vaccination	Baseline	200K	heads	5.5	$kghead^{-1}y^{-1}$	0.288	$head^{-1}$		
			Current	200K	heads	6.4	$kghead^{-1}y^{-1}$	0.287	$head^{-1}$		
			Difference			**0.9**	**$kghead^{-1}y^{-1}$**	**0.001**	**$head^{-1}$**		
			Expected	200K	heads	7.4	$kghead^{-1}y^{-1}$	0.287	$head^{-1}$		
			Difference			**1.9**	**$kghead^{-1}y^{-1}$**	**0.001**	**$head^{-1}$**		
Uganda	Upland rice	Crop rotation; minimum tillage; drought resistant seeds; and residue management; crop burning reduction	Baseline	48,000	ha	1.48	t/ha/y	0.22	tCO_2e ha/y	0.15	tCO_2e
			Current	48,000	ha	2.47	t/ha/y	-0.74	tCO_2e ha/y	-0.30	tCO_2e
			Difference			**0.99**	**t/ha/y**	**-0.96**	**tCO_2e ha/y**	**-0.45**	**tCO_2e**
			Expected	48,000	ha	2.47	t/ha/y	-1.10	tCO_2e ha/y	-0.45	tCO_2e
			Difference			**0.99**	**t/ha/y**	**-1.32**	**tCO_2e ha/y**	**-0.59**	**tCO_2e**
	Poultry (broilers)	Breeding, feeding, sanitation	Baseline	0	ha			0.00	total emis. y^{-1}		
			Current	172,800	heads			0.49 K	total emis. y^{-1}		
			Difference	**172,800**	**heads**			**0.49 K**	**total emis. y^{-1}**		
			Expected	172,800	heads			0.49 K	total emis. y^{-1}		
			Difference	**172,800**	**heads**			**0.49 K**	**total emis. y^{-1}**		
	Poultry (layers)	Breeding, feeding, sanitation	Baseline	0	heads			0.00	total emis. y^{-1}		
			Current	19,200	heads			0.05 K	total emis. y^{-1}		
			Difference	**19,200**	**heads**			**0.05 K**	**total emis. y^{-1}**		
			Expected	19,200	heads			0.05 K	total emis. y^{-1}		
			Difference	**19,200**	**heads**			**0.05 K**	**total emis. y^{-1}**		

Country focus	Value chain	Implemented Practices	Scenario	Area (ha)/Head		Productivity		Effect on GHG emissions (tCO2e): Area/Head/Beneficiary		Effect on GHG emissions (tCO2e): Product	
Nigeria	Maize	Crop rotation; use of inputs (synthetic fertiliser); and mechanisation for land preparation; crop burning reduction	Baseline	85,575	ha	1.44	t/ha/y	1.03	ha/y	0.72	tCO_2e
			Current	85,575	ha	1.8	t/ha/y	0.25	ha/y	0.14	tCO_2e
			Difference			**0.36**	**t/ha/y**	**-0.78**	**ha/y**	**-0.58**	**tCO_2e**
			Expected	85,575	ha	3.5	t/ha/y	0.16	ha/y	0.05	tCO_2e
			Difference			**2.06**	**t/ha/y**	**-0.87**	**ha/y**	**-0.67**	**tCO_2e**
	Upland rice	Crop rotation; use of inputs (synthetic fertiliser); and mechanisation for land preparation; crop burning reduction	Baseline	55,892	ha	4.13	t/ha/y	1.32	tCO_2e ha/y	0.32	tCO_2e
			Current	55,892	ha	5.15	t/ha/y	0.43	tCO_2e ha/y	0.08	tCO_2e
			Difference			**1.02**	**t/ha/y**	**-0.89**	**tCO_2e ha/y**	**-0.24**	**tCO_2e**
			Expected	55,892	ha	5.5	t/ha/y	0.40	tCO_2e ha/y	0.07	tCO_2e
			Difference			**1.37**	**t/ha/y**	**-0.92**	**tCO_2e ha/y**	**-0.25**	**tCO_2e**
	Improved cookstoves	Avoided deforestation	Baseline	7.1	ha deforested			1.05	per beneficiary		
			Current	2.84	ha deforested			0.42	per beneficiary		
			Difference					**0.63**	**per beneficiary**		
			Expected	2.84	ha deforested			0.42	per beneficiary		
			Difference					**0.63**	**per beneficiary**		
		Improved fuel use	Baseline	492	Tons total firewood use			0.08	per beneficiary		
			Current	197	Tons total firewood use			0.04	per beneficiary		
			Difference					**0.04**	**per beneficiary**		
			Expected	197	Tons total firewood use			0.04	per beneficiary		
			Difference					**0.04**	**per beneficiary**		
Ghana	Cocoa	Multistrata agroforestry; Intercropping; Irrigation; Use of inputs*	Baseline	5,520	ha	0.5	t/ha/y	-9.79	tCO_2e ha/y	-	
			Current	5,520	ha	0.92	t/ha/y	-15.25	tCO_2e ha/y	-	
			Difference			**0.42**	**t/ha/y**	**-5.46**	**tCO_2e ha/y**	-	
			Expected	5,520	ha	0.92	t/ha/y	-15.25	tCO_2e ha/y	-	
			Difference			**0.42**	**t/ha/y**	**-5.46**	**tCO_2e ha/y**	**-**	
	Maize	Crop rotation; use of inputs; and minimum tillage	Baseline	356	ha	-		-		-	
			Current	356	ha	3.5	t/ha/y	-0.05	tCO_2e ha/y	-0.01	
			Difference			-		-		-	
			Expected	356	ha	3.5	t/ha/y	-0.05	tCO_2e ha/y	-0.01	
			Difference			-		-		-	
	Sorghum	Crop rotation; use of inputs; and minimum tillage	Baseline	1,600	ha	1.13	t/ha/y	0.63	tCO_2e ha/y	0.56	
			Current	1,600	ha	1.79	t/ha/y	0.06	tCO_2e ha/y	0.03	
			Difference			**0.66**	**t/ha/y**	**-0.57**	**tCO_2e ha/y**	**-0.52**	
			Expected	1,600	ha	1.79	t/ha/y	0.06	tCO_2e ha/y	0.03	
			Difference			**0.66**	**t/ha/y**	**-0.57**	**tCO_2e ha/y**	**-0.52**	
Mozambique	Goat	Breeding and feeding; pasture management; and use of inputs	Baseline	0		22	LWG	0.288	$head^{-1}$	13.1	kg/kgLWG
			Current	3,000	heads	28	LWG	0.287	$head^{-1}$	10.2	kg/kgLWG
			Difference	**3,000**	**heads**	**6**	**LWG**	**0.001**	**$head^{-1}$**	**-2.9**	**kg/kgLWG**
			Expected	3,000	heads	28	LWG	0.287	$head^{-1}$	10.2	kg/kgLWG
			Difference	**3,000**	**heads**	**6**	**LWG**	**0.001**	**$head^{-1}$**	**-2.9**	**kg/kgLWG**

Country focus	Value chain	Implemented Practices	Scenario	Area (ha)/Head		Productivity		Effect on GHG emissions ($tCO2e$)			
								Area/Head/Beneficiary		Product	
Ghana	Deforestation	Land expansion	Baseline	0	ha			0.00	tCO_2e ha/y		
			Current	356	ha			31.47	tCO_2e ha/y		
			Difference					**31.47**	**tCO_2e ha/y**		
			Expected	356	ha			31.47	tCO_2e ha/y		
			Difference	-				**31.47**	**tCO_2e ha/y**		
	Forest management	Reducing occurrence of fires	Baseline	0	ha			8.47	tCO_2e ha/y		
			Current	376	ha			1.30	tCO_2e ha/y		
			Difference					**-7.17**	**tCO_2e ha/y**		
			Expected	376	ha			1.30	tCO_2e ha/y		
			Difference					**-7.17**	**tCO_2e ha/y**		

*Difference between expected and baseline scenarios.

**Difference between current and baseline scenarios.

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Glossary

Activity data: Data on the magnitude of a human activity resulting in emissions or removals taking place during a given period of time. Data on energy use, land areas, management systems, lime and fertilizer uses are examples of activity data.

Afforestation: Planting of new forests on lands that historically have not contained forests.

Agroecology: An approach to agriculture that applies ecological concepts to the design and management of food, seeking for example, increased diversity, synergy, resilience, and recycling.

Anthropogenic: Refers to greenhouse gas emissions and removals that are a direct result of human activities or are the result of natural processes that have been affected by human activities.

Baseline emissions: A baseline is a measurement, calculation, or time used as a basis for comparison. Baseline emissions are the level of emissions that would occur without policy intervention or without implementation of a project. Baseline estimates are needed to determine the effectiveness of emission reduction programs (also called mitigation strategies). Also known as business-as-usual emissions.

Biogenic: Produced by the biological processes of living organisms. Note that the term "biogenic" refers only to recently produced (that is non-fossil) material of biological origin. IPCC guidelines recommend that peat be treated as a fossil carbon because it takes a long time to replace harvested peat.

Carbon dioxide (CO_2): A naturally occurring gas, and also a by-product of burning fossil fuels and biomass, as well as land-use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1.

Carbon dioxide equivalent (CO_2e): A metric used to compare emissions of various greenhouse gases. It is the mass of carbon dioxide that would produce the same estimated radiative forcing as a given mass of another greenhouse gas. Carbon dioxide equivalents are computed by multiplying the mass of the gas emitted by its global warming potential.

Carbon intensity: The amount of carbon by weight emitted per unit of activity data.

Carbon sequestration: In the land use sector, removal of carbon dioxide from the atmosphere in biomass or the soil.

Climate smart agriculture (CSA): Agriculture that sustainably increases productivity, enhances adaptive capacity, and reduces or removes greenhouse gas emissions where possible.

Conservation farming (CF): A farming system that promotes minimum soil disturbance (i.e. no tillage), maintenance of a permanent soil cover, and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production.

Deforestation: Practices or processes that result in the change of forested lands to non-forest uses. This is often cited as one of the major causes of the enhanced greenhouse effect for two reasons: 1) the burning or decomposition of the wood releases carbon dioxide; and 2) trees that once removed carbon dioxide from the atmosphere in the process of photosynthesis are no longer present and contributing to carbon storage.

Emissions: The release of a substance (usually a gas when referring to the subject of climate change) into the atmosphere.

Emission factor: A coefficient that quantifies the emissions or removals of a gas per unit activity. Emission factors are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions.

Emission intensity: Emissions per unit produced, in contrast to emissions per hectare. Can be considered a metric of the emission efficiency of a production system.

Fossil Fuel: Geologic deposits of hydrocarbons from ancient biological origin, such as coal, petroleum and natural gas.

Fuel combustion: Fuel combustion is the intentional oxidation of materials within an apparatus that is designed to provide heat or mechanical work to a process, or for use away from the apparatus.

Global warming potential (GWP): An index, based upon radiative properties of different greenhouse gases relative to carbon dioxide. The GWP represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing thermal infrared radiation.

Greenhouse gas: Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include, but are not limited to, water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrochlorofluorocarbons (HCFCs), ozone (O_3), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

Hectare (ha): a metric unit of square measure, equal to 10,000 square meters.

High-carbon landscapes: Land areas with high stocks of carbon in the biomass or soil. These typically include forests, grasslands, peatlands or wetlands.

Intergovernmental Panel on Climate Change (IPCC): Established jointly by the United Nations Environment Programme and the World Meteorological Organization in 1988, the purpose of the IPCC is to assess information in the scientific and technical literature related to the issue of climate change. With its capacity for reporting on climate change, its consequences, and the viability of adaptation and mitigation measures, the IPCC is also looked to as the official advisory body to the world's governments on the state of the science of the climate change issue. For example, the IPCC organized the development of internationally accepted methods for conducting national greenhouse gas emission inventories.

Land Use and Land Use Change: Land use refers to the total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction and conservation). Land use change refers to a change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land use change may have an impact on sources and sinks of greenhouse gases, or other properties of the climate system and may thus have a radiative forcing and/or other impacts on climate, locally or globally.

Low-emission agriculture: Agriculture that reduces emissions relative to a future baseline projection rather than a past base year.

Low-emission development: Development that reduces emissions relative to a future baseline projection rather than a past base year.

Methane (CH_4): A hydrocarbon that is a greenhouse gas with a global warming potential most recently estimated at 25 times that of carbon dioxide (CO_2). Methane is produced through anaerobic (without oxygen) decomposition of waste in landfills, flooded rice fields, animal digestion, decomposition of animal wastes, production and distribution of natural gas and petroleum, coal production, and incomplete fossil fuel combustion. The GWP is from the IPCC's Fourth Assessment Report (AR4).

Net GHG emissions: The sum of GHG emissions less the amount of carbon sequestration, usually expressed in tCO_2e.

Nitrogen fixation: Conversion of atmospheric nitrogen gas into forms useful to plants and other organisms by lightning, bacteria, and blue-green algae; it is part of the nitrogen cycle.

Nitrous oxide (N_2O): A powerful greenhouse gas with a global warming potential of 298 times that of carbon dioxide (CO_2). Major sources of nitrous oxide include soil cultivation practices, especially the use of commercial and organic fertilizers, manure management, fossil fuel combustion, nitric acid production, and biomass burning. The GWP is from the IPCC's Fourth Assessment Report (AR4).

Reforestation: Planting of forests on lands that have previously contained forests but that have been converted to some other use.

Regenerative agriculture: Agriculture that seeks to improve an ecosystem's capacity to self-sustain itself, for example, by increasing biodiversity, capturing carbon in the soil and biomass, improving resilience to climate change, improving soil health, and improving ecosystem services.

Sink: Any process, activity or mechanism that removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas or aerosol from the atmosphere.

Sustainable intensification: Agriculture that increases crop or livestock production, usually by increasing inputs per unit land, while reducing ecological impacts.

RESEARCH PROGRAM ON
Climate Change, Agriculture and Food Security

The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) brings together some of the world's best researchers in agricultural science, development research, climate science and Earth system science, to identify and address the most important interactions, synergies and tradeoffs between climate change, agriculture and food security. For more information, visit us at **https://ccafs.cgiar.org/.**

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