# Agricultural GHGs in East and West Africa

## Baseline Emissions and Mitigation Potential

Working Paper No. 13

Sandra Brown
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Stephen Ambagis
Timothy Pearson

CLIMATE CHANGE
AGRICULTURE AND
FOOD SECURITY

Working Paper

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# Abstract

The main question behind the work presented here is: How can agricultural greenhouse gas emissions be reduced or sequestration enhanced while maintaining and even increasing food supply. To address this question, we first estimated the business-as-usual emissions of greenhouse gases from the agricultural sector using the IPCC framework and land cover datasets based satellite imagery for the base year 2006 for four East African countries—Ethiopia, Kenya, Tanzania, and Uganda, and five West African countries—Burkina Faso, Ghana, Mali, Niger, and Senegal. We found the total emissions to be in the order of about 129 million t $CO_2$e/yr., with emissions from activities related to livestock dominating (84% of the total). Then, we estimated the annual quantity of $CO_2$e/ha that could be sequestered in soil and vegetation (agroforests and native ecosystems) above business-as-usual for several potential mitigation options across the nine countries by four climatic zones. We found that the change in practices included soil only resulted in carbon sequestration rates of about 0.4 to 5 t $CO_2$e/ha/yr and for changes that included in soil and vegetation of about 6 to 22 t $CO_2$e/ha/yr.

## Keywords

Agriculture, Baselines, Burkina Faso, Carbon Sequestration, Climate Change, East Africa, Ethiopia, Ghana, Green House Gas Emissions, Kenya, Mali, Mitigation, Niger, Senegal, Soil Carbon, Tanzania, Uganda, West Africa

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# Contents

# Acronyms

| | |
|---|---|
| AFOLU | Agriculture, Forestry, and Other Land Uses |
| $CH_4$ | Methane |
| $CO_2$ | Carbon Dioxide |
| EF | Emission Factor |
| ESA | European Space Agency platform |
| FAO | Food and Agriculture Organization |
| FracLEACH | Fraction lost by leaching and runoff |
| GH | Growth Habitat |
| GHG | Greenhouse Gas |
| IGBP | International Geosphere-Biosphere Programme |
| IPCC | Intergovernmental Panel on Climate Change |
| MERIS | Medium Resolution Imaging Spectrometer on board |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| NASA | National Aeronautics and Space Administration |
| NC | National Communications |
| $N_2O$ | Nitrous Oxide |
| SD | Stand Density |
| SOC | Soil Organic Carbon |
| SQ | Site Quality |
| UNFCCC | United Nation Framework Convention on Climate Change |
| USAID | United States Agency for International Development |

# Executive Summary

The main question behind the work presented here is: How can agricultural greenhouse gas emissions be reduced or sequestration enhanced while maintaining and even increasing food supply. To address this question we first estimate the business-as-usual emissions of greenhouse gases from the agricultural sector using the IPCC framework for four East African countries—Ethiopia, Kenya, Tanzania, and Uganda, and five West African countries—Burkina Faso, Ghana, Mali, Niger, and Senegal. This is followed by an analysis of mitigation options in the agricultural sector for the nine focal countries with estimations of the quantity of $CO_2e$/ha that could be sequestered above business-as-usual for each potential mitigation option.

Previous estimates of greenhouse gases reported for the agricultural sector by the nine countries in their National Communications used national statistics for land cover areas that were not based on remote sensing data. To obtain more recent and independent estimates of the area of agricultural lands in each country, we used land cover datasets produced from both the NASA MODIS (Moderate Resolution Imaging Spectroradiometer) and ESA MERIS (Medium Resolution Imaging Spectrometer on board the European Space Agency platform) satellite sensors for the base year 2006. We used these products to produce a composite map delineating the current extent of croplands and grazing lands for the nine West and East African countries. We used four MERIS land cover classes for cropland (post-flooding or irrigated croplands, rainfed croplands, and two mosaic classes of cropland and mixed vegetation of grassland, shrubland, and forest that were assumed to be lands under the forest-fallow cycle) and two MODIS land cover classes for grazing land (grassland and savanna were assumed to be those classes that have attributes capable of supporting livestock) to produce one map showing the distribution of these areas in the nine focus countries. As part of the processing of the imagery, the resolution of the two products was standardized to about 500 m pixel size, with an actual area of the pixels of 23.5 ha.

To provide an estimate of the GHG emission in the agriculture sector for the nine countries in question, this study employed Tier 1 methodologies from the *IPCC 2006 Guidelines for the Agriculture, Forestry, and Other Land Uses (AFOLU)*, by using country-specific activity data and default emission factors provided in the *2006 Guidelines*. The GHG sources covered here are: methane from enteric fermentation and manure management, carbon dioxide from soils caused by land-use change from native ecosystems to rainfed/irrigated cropland and combined mosaic agriculture, direct and indirect nitrous oxide from fertilizer use, and methane and nitrous oxide from fires in gazing lands.

For the analysis on emissions from soil due to land use change, we identified areas that changed from forest/shrubland classes in the MODIS 2001 image to cropland classes in the MERIS 2006 image (most recent year of available data at time of the analysis). We used the IPCC soil carbon tool and the soil carbon data in the Harmonized World Soil Database to select the country, the climate zone (using the IPCC climate zone map), the initial soil carbon stock, the soil type (soils in the nine countries fell into one of three classes: high activity clay, low activity clay or sandy based on the Harmonized World Soil Database) and our land use change analysis. The soil carbon tool used these inputs to produce estimates of the annual carbon stock change for the given land-use change.

The total area of croplands and grazing lands covers about 52% of the East African countries' lands and 39% of the West African countries' lands in 2006 (Figure S-1). The area of grazing lands exceeded the area of cropland in West African countries (53% of total agricultural land area) but in East African countries cropland covered a larger area than grazing lands (54% of total agricultural land area). Most of the croplands in the nine countries were rainfed (about 65% of all croplands). And, from our analysis is it not clear how much of the irrigated croplands are covered by rice and so any methane emissions from this land use are not included in our analysis.

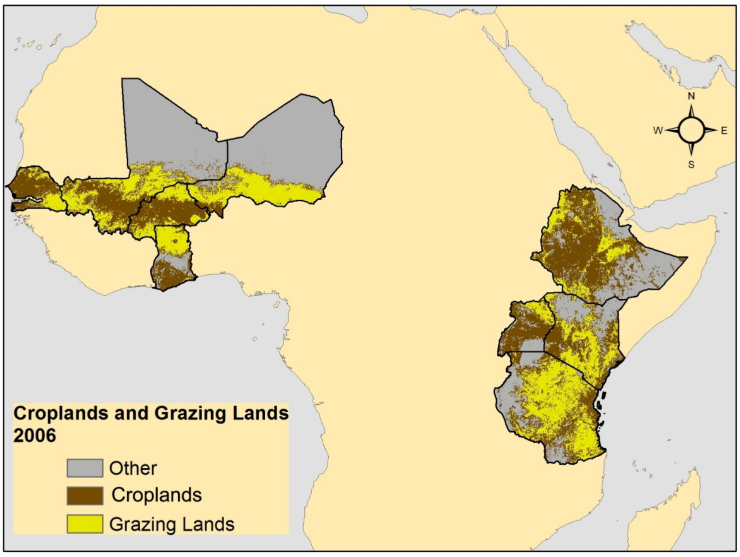

**Figure S-1 Distribution of grazing lands from the MODIS landcover map and croplands from MERIS landcover map for 2006**

The total amount of GHG emissions from the nine African countries was almost 129 million t $CO_2$e/yr in the mid-2000s (Table S-1). The largest amount of GHG emissions was from the livestock sector, mostly methane from enteric fermentation as expected (83% of the total), followed by emissions from soil only from due to the conversion of native ecosystems to cropland (11% of the total). Emissions from use of fertilizer are lower than all other sources and represent just 0.7% of the total emissions. Despite the large area of grazing lands burned each year (about 9 million ha), the emissions of $CH_4$ and $N_2O$, as $CO_2$e, represent about 4% of total emissions.

**Table S-1 Total annual GHG emissions, in 1,000 t CO2e, from land-use change, livestock, nitrogen fertilizer consumption and fires in grazing lands in the nine East and West African Countries**

| Region | Country | Land-Use Change | Livestock | Nitrogen Fertilizer | Grazing Area Burned | Total | Total from NC* |
|---|---|---|---|---|---|---|---|
| East Africa | Ethiopia | 7,339 | 41,966 | 356 | 1,254 | 50,915 | 32,728 |
| | Kenya | 1,812 | 11,988 | 339 | 232 | 14,372 | 12,088 |
| | Tanzania | 1,833 | 13,935 | 44 | 1,736 | 17,548 | 28,017 |
| | Uganda | 1,112 | 6,204 | 23 | 524 | 7,863 | 5,797 |
| | ***Subtotal*** | ***12,097*** | ***74,093*** | ***762*** | ***3,745*** | ***90,697*** | ***78,629*** |
| West Africa | Burkina Faso | 273 | 8,779 | 19 | 306 | 9,377 | 4,501 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Ghana | 1,664 | 1,865 | 58 | 491 | 4,079 | 4,637 |
| | Mali | 440 | 9,270 | 65 | 241 | 10,016 | 7,036 |
| | Niger | 31 | 10,405 | 15 | 9 | 10,461 | 6,231 |
| | Senegal | 369 | 3,364 | 88 | 249 | 4,070 | 4,514 |
| | ***Subtotal*** | ***2,778*** | ***33,683*** | ***245*** | ***1,297*** | ***38,003*** | ***26,919*** |
| | **Total** | **14,874** | **107,776** | **1,009** | **5,043** | **128,699** | **105,548** |

**National Communications*

Although we used a consistent set of data and methodologies, the uncertainty around these estimated GHG emissions is likely to be large. First, given the resolution of the remote sensing data sets (about 500 m resolution) it is likely that the uncertainty in the area estimates used in the soil emissions from land use change and in the fire emissions could be high. Also, the data used for the livestock and nitrogen emissions, although from reputable sources (e.g. FAO), they ultimately originate from country reports, the quality of which varies by country. The consumption of nitrogen fertilizer is particularly uncertain given the low rates of application per unit area of land it translates to.

There are many other ways by which this analysis could be improved and are mainly related to the need to improve the data behind the calculations. For example;

- It would be beneficial to reduce the scale of analysis to key agricultural areas of each country,
- Use higher resolution remote sensing data to obtain more accurate data on land cover/land use and area burned;
- Improvements in monitoring the number of ruminant animals,
- Improvements in estimates of quantity of N fertilizer used by agricultural practices;
- The carbon stocks of burned areas of grazing lands would reduce the uncertainty and lead to improved methods and emission factors for these sources of GHG emissions.

These will be key steps needed to develop improved baselines for GHG emissions from agricultural practices against which any future improvements in practices could be monitored.

Emissions of GHGs from agriculture are substantial and beg the question—what opportunities exist to reduce these emissions or even to increase sequestration? Given the common practices and magnitude of GHG emissions from livestock (and fire which is often set to improve the forage for grazing animals) in all of these countries, it is unlikely that very much can be done in the near future to reduce these emissions. There appears to be no opportunity to reduce nitrous oxide emissions from fertilizer application either given the generally low intensity of use. However, given the low rate of N application per ha, there is an opportunity to increase the rate of application to improve crop production and at the same time reduce the need to clear native ecosystems for new croplands (the second largest source of $CO_2$ emissions). **What is needed is more research on the relationship between increases in crop production for the variety of crops grown in these countries versus increases in N fertilizer application and the related $N_2O$ emissions**. If increasing fertilizer can double productivity (as has been seen in the US for example) then each improved hectare of agriculture will reduce the need to clear forest with their associated emissions. However, to maintain enhance crop production will mean fertilizer will need to be added continually through time and there will likely be a point where cumulative $N_2O$ emissions will outweigh advantages from stopping clearing of native ecosystems.

Due to the limitations in terms of activities that can immediately impact emissions from livestock and from fire use, and the limited use of fertilizers in the focal countries, we focused on those potential mitigation activities that enhance soil carbon. We analyzed the following scenarios, using the IPCC soil carbon tool, for three categories of lands assumed to undergo the following changes in land use practices: switching from severely degraded grazing lands to those with improved management; switching from rainfed cultivation with full tillage to reduced tillage and with different level of nutrient inputs; switching from reduced tillage rainfed cultivation to native ecosystems, and converting combined mosaic vegetation (assumed to be shifting cultivation cycle) to native ecosystems. We found that the range of changes in land use activities across the nine countries and four climatic zones (with initial soil carbon stocks based on soil type for each country/climatic zone) resulted in carbon sequestration rates in the top 30 cm of soil (recommended depth for such analysis and likely to persist for 20 yr only; according to the IPCC 2006) of 0.5 to 5 t $CO_2$e/ha/yr for croplands and 2 to 6 t $CO_2$e/ha/yr for degraded grazing lands. Converting combined mosaic cultivation to native ecosystem shows the highest potential in annual soil carbon stock change of 1-8 t $CO_2$e/ha/yr, and with inclusion of carbon sequestration in the vegetation raises the total to 5-22 t $CO_2$e/ha/yr. Further analyses are needed to improve the estimates of the mitigation potential through additional activities that include application and monitoring of existing methods known to enhance carbon sequestration, further scientific research, and developing country-specific information on current practices.

# 1 Introduction

As populations grow worldwide, the demand for food rises. This will be exacerbated by potential changes in climate that will likely impact traditional agricultural production systems. Simultaneously there is a demand for mitigating climate change through actions that decrease emissions or increase sequestration relative to business as usual. These actions to decrease emissions or increase sequestration indirectly and directly affect agricultural production.

The internationally proposed REDD+ mechanism[1] indirectly affects agriculture because a major driver of deforestation in many countries is expansion of agriculture. Efforts to reduce emissions from deforestation will clearly lead to the need to reduce conversion of forests to agricultural lands, thus implying the need to increase production on existing lands. The very large areas occupied by agriculture, and the attraction of an additional source of income for farmers, have led to the demand for agricultural inclusion in greenhouse gas emission offsetting schemes. However, in the light of global demand for food it is an increasingly accepted principle that greenhouse gas offsets should not be at the expense of food production.

The main question behind the work presented here is: How can agricultural greenhouse gas emissions be reduced or sequestration enhanced while maintaining and even increasing food supply[2]. To address this question on a meaningful level it is necessary to first understand business-as-usual emissions of greenhouse gases from the agricultural sector.

In this report we focus on nine African countries: Ethiopia, Kenya, Tanzania, and Uganda in East Africa; and Mali, Niger, Ghana, Burkina Faso and Senegal in West Arica. The report has the following key components:

1. Methodological description of the framework and steps used for the regional analyses of the agricultural activities and their associated greenhouse gas (GHG) emissions for the 5-year period 2001-2006, including:
    - Details of the specific steps used to identify the agricultural area and the relative coverage of different crops and commodities using remote sensing products;
    - The steps used to obtain the appropriate data and emission factors; and
    - Methods for combining the data sets to arrive at estimates of the baseline GHG emissions from the agriculture sector;
2. For each country, results showing greenhouse gas emissions by agricultural activity;
3. Discussion of mitigation options in the agricultural sector; and
4. First order estimations of the quantity of $CO_2$e/ha that could be sequestered above business-as-usual for each potential mitigation option.

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[1] Reducing emissions from deforestation and degradation, in developing countries; and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks

[2] The work reported on in this report is supported by the CGIAR Challenge Program on Climate Change, Agriculture, and Food Security (CCAFS).

# 2 Framework for Estimation of Baseline Emissions

Countries complete National Communications to the UNFCCC detailing estimated emissions from their agricultural sector (among others). However, such communications have not been completed for all non-Annex 1 countries and are very rarely updated. In addition, they typically do not rely on a remote sensing analysis to give actual spatial coverage of agricultural lands nor to give country-specific emission factors.  The first step in this analysis was to update and improve the input data as much as possible via the following steps:

For a complete regional analysis, we adopted the following approach for each country:

1. Examine the most recent UNFCCC National Communication (summarized in Annex B of this report)
2. Estimate up-to-date area of agriculture and relative coverage of different crops / commodities and fires based on the most recent remote sensing products for the countries of interest (activity data)
3. Compile the most recent data on GHG emitting sources including livestock population and fertilizer consumption (activity data)
4. Estimate emission factors for all GHG sources in the agricultural sector using the same methods for all countries
5. Combine activity data with emission factors to produce estimates of GHG emissions for the agricultural sector

# 3 Analytical Methods and Approaches

## 3.1 Identify Up-to-Date Area of Agriculture

Using land cover datasets produced from both the NASA MODIS (Moderate Resolution Imaging Spectroradiometer) and ESA MERIS (Medium Resolution Imaging Spectrometer on board the European Space Agency platform) satellite sensors, we produced a composite map delineating the current extent of croplands and grazing lands for the nine West and East African countries. From an initial analysis it was determined that neither dataset alone had cover classes that would consistently identify both land uses over the entire region. Therefore portions of each product were used to produce the resulting map of land use / land cover.

Each of the original data sets was produced using data from 2006 but with significantly different methodologies and imagery products. The resulting maps therefore frequently had discrepancies between cover class types. It was determined that a case-by-case assessment of the classes of interest was needed to determine which ones were best suited to the required result. Expert knowledge of the regions was applied in this assessment to arrive at the closest approximation to what is observed on the ground.

### 3.1.1 Assessment and Analysis of the MODIS Derived Product

The land cover map derived from MODIS satellite data was produced by NASA. This product incorporates five different land cover classification schemes derived through a supervised decision-tree classification method. There are 17 classes defined by the International Geosphere-Biosphere Programme (IGBP). This includes 11 natural vegetation classes, three human-altered classes, and three non-vegetated classes.

These data were evaluated for both areas under agricultural production and areas of grazing lands. When compared to known areas of croplands, specifically in the sub-Saharan region of West Africa, we found that the data were not accurate. It was therefore decided that an alternate product (MERIS) was needed to produce the estimate of cropland areas for the region as a whole.

For the classes best suited to represent grazing lands, the MODIS product had more concise classes to define this area than MERIS. While much of the cultivation that happens in Africa tends to be subsistence and shifting agriculture, livestock grazing tends to be consistently nomadic in nature. This means that those areas that can support livestock usually do at some point in time. As a result it was determined that the best approach was to include all of those classes that were defined as having attributes capable of supporting livestock. This approach does not mean that all the area falling into these classes is used for grazing every year but rather is just potentially available. In the case of the 17 classes of the MODIS data set, two were found to represent the potential range of grazing land over the area of interest. The class Grassland was consistent with known grazing lands across the region and the class Savanna also covered known areas of grazing lands. Because of the nature of animal grazing in the region, the estimated of area of grazing lands is likely on the liberal side and is also variable from year to year.

### 3.1.2 Assessment and Analysis of the MERIS Derived Product

The MERIS data set has the objective of generating a land cover map of the world using an automated processing chain from the 300m MERIS time series. The resulting Globcover Land Cover map is derived from an automatic and regionally-tuned classification of a MERIS FR time series. There are 22 land cover classes that are defined with the UN Land Cover Classification System.

Our assessment of this dataset in known regions indicated that it contained cover classes well suited in defining the range of croplands in the areas of interest. The area defined by the classes containing the term "cropland" in this map showed a much broader area under cultivation than that shown by the MODIS product. This was in agreement with what was known from expert knowledge on the ground for specific areas. It was decided to use this data product for defining the class "croplands" and to include the following four classes from the original MERIS classified map:

- 11. Post-flooding or irrigated croplands
- 14. Rainfed croplands
- 20. Mosaic Cropland (50-70%) / Vegetation (grassland, shrubland, forest) (20-50%)
- 30. Mosaic Vegetation (grassland, shrubland, forest) (50-70%) / Cropland (20-50%)

The last two classes likely represent lands under the forest-fallow cycle, with class 20 dominated by the cultivated and young fallow part of the cycle and class 30 dominated by the older fallow and secondary forests. We therefore consider this product as a range with temporal variability that spans the time period for fallow cycles in the region. However, this MERIS product has some discriminatory ability given its high temporal resolution and seasonal assessment methodology.

### 3.1.3 Combination of Both Data Sets

We combined the four MERIS land cover classes for cropland with the two cover classes for grazing land from MODIS to produce one map showing the distribution of these areas in the nine focus countries (Figure 1). As part of the processing of the imagery, the resolution of the two products was standardized to about 500 m pixel size, with an actual area of the pixels of 23.5 ha. All further analysis was done at this resolution.

A change analysis was also performed for the regions of interest from two time periods where these land cover products were available. The NASA produced the MODIS derived land cover product for two periods, 2001 and 2006. The MERIS product is only available for 2006. The change analysis is a comparison of two products at different times. It was therefore decided only to focus on those changes that were most important and also had the highest likelihood of being "real" and not just a product of the differences in mapping methodology. The resulting maps show only those areas that changed from classes in time one (2001) such as closed forest or shrub lands to croplands or grazing lands in time two (2006).

## 3.2 Greenhouse Gas Inventory of the Agriculture Sector

The Intergovernmental Panel on Climate Change (IPCC) has developed internationally agreed guidelines to help countries calculate their national greenhouse gas inventories by using country-specific activity data and default emission factors. The basic methodology used to calculate emissions is to multiply activity data (information on the extent to which human activity takes place) by an emission factor (a coefficient which quantifies the emissions or removals per unit activity). The general equation is therefore:

Emissions = activity data*emission factor

This study uses methods as outlined in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (*2006 Guidelines*), which were produced to update the *Revised 1996 Guidelines*. The *2006 Guidelines* cover new sources and gases as well as updates to previously published methods where technical and scientific knowledge has improved. Concerning agriculture, the main difference is that the *2006 Guidelines* integrate the previously separate Agriculture Chapter with the Land Use, Land-Use Change and Forestry Chapter. However, similar methodologies are used in both.

To provide an estimate of the GHG emission in the agriculture sector for the nine countries in question, this study employed Tier 1 methodologies from the *IPCC 2006 Guidelines*, by using country-specific activity data and default emission factors provided in the *2006 Guidelines*. The GHG sources covered here are[3]:

- Methane from enteric fermentation and manure management
- Carbon dioxide from soils caused by land-use change from native ecosystems to rainfed/irrigated cropland and combined mosaic agriculture
- Direct and indirect nitrous oxide from fertilizer use
- Methane and nitrous oxide from fires in grazing lands ($CO_2$ is not included as described in 3.2.4)

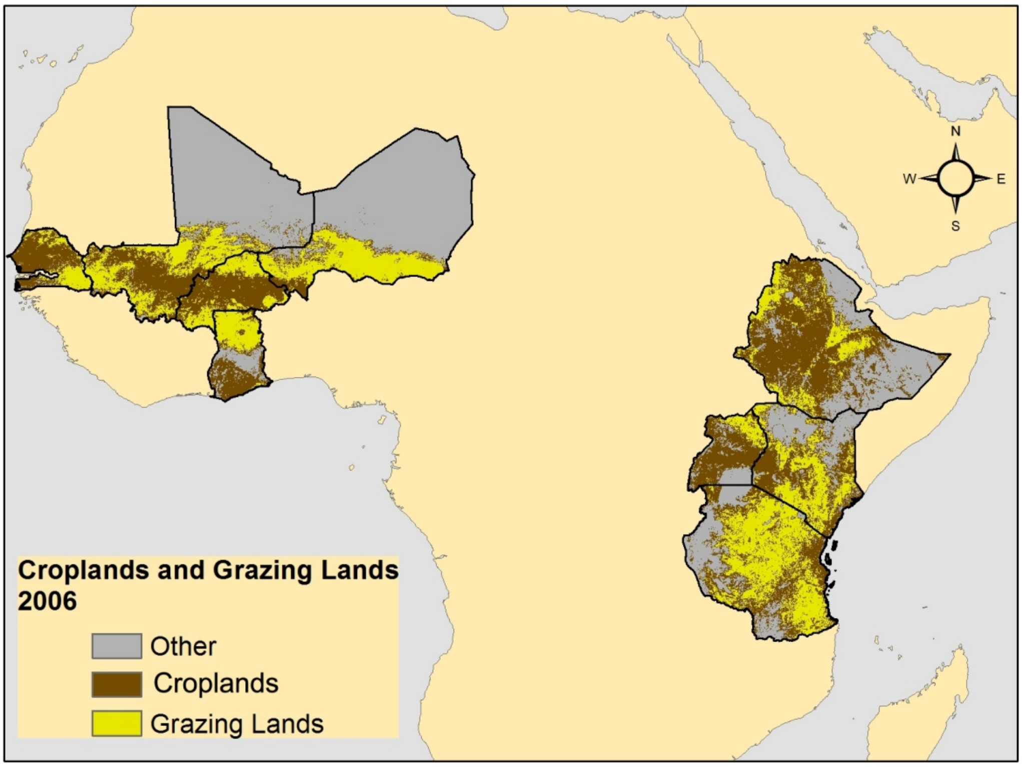

**Figure 1 Distribution of grazing lands from the MODIS landcover map and croplands from MERIS landcover map for 2006**

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[3] This report does not include methane emissions from rice cultivation as insufficient activity data are available.

### 3.2.1. Methane Emissions from Enteric Fermentation and Manure Management

#### *3.2.1.1 Enteric Fermentation*

We estimated methane emissions from enteric fermentation using the equations below (based on equation 10.19 from the *2006 IPCC Guidelines*) for nine different livestock subcategories. The sum of the emissions from the nine livestock categories represents the total methane emission from enteric fermentation for a specific country.

$$\textbf{Emissions} = \textbf{EF}_{(T)} * (\textbf{N}_{(T)}/10^3) \qquad \textbf{(Eq. 1)}$$

Where:

Emissions = methane emissions from enteric fermentation, $tCH_4$/year
$EF_{(T)}$ = emission factor for the defined livestock population, kg $CH_4$/head/yr
$N_{(T)}$ = the number of head of livestock species/category T in the country
(T) = species/category of livestock

The livestock subcategories are: assess, buffaloes, camels, cattle, goats, mules, pigs (swine), sheep and poultry (subdivided into chicken and ducks). Livestock population data for each subcategory are from FAOSTAT (2010a). All but Kenya represent data from 2008. Kenya's population numbers are for 2009. The data collected by FAOSTAT includes FAO estimates, official data and unofficial figures, as categorized by FAO.

The emission factors attributed to each livestock subcategory for enteric fermentation are all IPCC default values ascribed to developing countries (Table 1). The methane emissions resulting from Eq. 1 is then multiplied by 21, the global warming potential for methane at 100 years in the atmosphere, to yield the carbon dioxide equivalent in tons of $CO_2$e (IPCC, 2006).

**Table 1 Default IPCC emission factors (kg $CH_4$/head/yr) for enteric fermentation in Africa for the major livestock categories in the nine countries studied**

| Asses | Camels | Cattle | Goats | Mules | Pigs | Sheep |
|---|---|---|---|---|---|---|
| 10 | 46 | 31 | 5 | 10 | 1 | 5 |

#### *3.2.1.2 Manure Management*

The methodology used to estimate the $CO_2$e emissions from manure management from the nine countries uses the same formula as for enteric fermentation, but uses the emission factors in Table 2[4]. As for enteric fermentation, there is a specific emission factor for each livestock subcategory that also takes into account how the manure is managed. For Africa, the EFs are based on assumptions that most of the manure for most animals, particularly cattle, is deposited on the open grazing lands with a small amount (<4%) burned as fuel. The emission factors also vary depending on temperature. For all livestock other than swine and cattle, the emission factor changes at temperatures above 25°C. For swine and cattle the emission factor increases when temperatures are greater or equal to 28°C. In this study, annual nationwide temperatures from FAO (http://www.fao.org/nr/water/aquastat/countries/ )

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[4] From IPCC 2006 tables in Annex 10A.2 of the report

were used to determine which emission factor is appropriate for a specific livestock and country (thus the different value for Ethiopia which has an average temperature that is different from the other eight countries)

**Table 2 Default IPCC emission factors for manure management in Africa for the major livestock categories in the nine countries studied**

| Region | Asses | Camels | Cattle | Goats | Mules | Pigs | Sheep | Poultry |
|---|---|---|---|---|---|---|---|---|
| East and West Africa | 1.2 | 2.56 | 1.0 | 0.22 | 1.2 | 2.0 | 0.20 | 0.02 |
| Ethiopia | 0.9 | 1.92 | 1.0 | 0.17 | 0.9 | 1.0 | 0.15 | 0.02 |

### 3.2.2 Nitrous Oxide Emissions from Nitrogenous Fertilizer Use

#### *3.2.2.1 Direct Emission from Nitrogenous Fertilizer Use.*

This study uses FAOSTAT nitrogenous fertilizer consumption data for each country averaged over a 3-year period from 2000 to 2002 (2002 is latest year reported; FAOSTAT 2011b). The $N_2O$-N emissions for each country in t $N_2O$-N were estimated as follows (Eq.2):

$$\mathbf{N_2O_{Direct} = EF_{(N2O\text{-}N)} * N_{(NF)} * 44/28} \qquad \textbf{(Eq.2)}$$

Where:
$N_2O_{Direct}$ = Direct nitrous oxide emissions from nitrogenous fertilizer consumption; t $N_2O$/year
$EF_{(N2O\text{-}N)}$ = emission factor for $N_2O$-N (=0.01, dimensionless)
$N_{(NF)}$ = consumption of nitrogenous fertilizer; t N/year, in the country
44/28 = Conversion of $N_2O$–N emissions to $N_2O$

A global warming potential of 298 (for 100 years) was used to convert to t $CO_2$e.

3.2.2.2 Indirect Emission from Nitrogenous Fertilizer Use.

Indirect emissions are those related to the fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs, i.e. the amount of N lost through leaching and runoff. They are estimated as the product of direct emissions and an appropriate emission factor and $Frac_{LEACH}$ (default values from IPCC were used) according to Eq. 3:

$$\mathbf{N_2O_{Indirect} = EF_{(N2O\text{-}N)} * N_{(NF)} * 44/28 * Frac_{LEACH}} \qquad \textbf{(Eq.3)}$$

Where:
$N_2O_{Indirect}$ = Indirect nitrous oxide emissions from nitrogenous fertilizer consumption; t $N_2O$/year
$EF_{(N2O\text{-}N)}$ = emission factor for $N_2O$-N; (=0.01, dimensionless)
$N_{(NF)}$ = consumption of nitrogenous fertilizer; t N/year, in the country
$Frac_{LEACH}$ = Fraction lost by leaching and runoff;
where annual rainfall is less than potential evapotranspiration $FRAC_{LEACH} = 0.05$, and
where rainfall exceeds potential evapotranspiration $FRAC_{LEACH} = 0.3$.
44/28 = Conversion of $N_2O$–N emissions to $N_2O$

A global warming potential of 298 (for 100 years) was used to convert to t $CO_2$e.

Using AQUASTAT data (2011) we determine that the average evapotranspiration exceeds average annual rainfall in Ghana, Niger, Senegal, Ethiopia, Kenya and Uganda. No data were available for Burkina Faso, Mali and Tanzania, however, given the geographic location we assume that average evapotranspiration exceeds average annual rainfall. We find only Uganda with annual rainfall exceeding its evapotranspiration (AQUASTAT 2011).

### 3.2.3 $CO_2$ Emissions from Soil due to Land-use Change

Conversion of native ecosystems to croplands causes emissions from both the soil and from the vegetation. Here **we focus only on the emissions from the soil carbon pool[5].** We identified the areas that changed from "other" to cropland during the 5-year period 2001-2006 so that we could estimate the emissions of $CO_2$ from soil for this conversion using the IPCC methodology (we did not estimate emissions from the vegetation as our focus here is on agricultural related activities). The land cover change analysis used the MODIS derived land cover product for two periods, 2001 and 2006 (the MERIS product is only available for 2006). We mapped only those areas that changed from vegetative classes, such as closed forest or shrub lands, in time one (2001) to croplands or grazing lands in time two (2006). All other change was ignored.

The IPCC methodology (incorporated into the IPCC Tool for "Estimation of Changes in Soil Carbon Stocks associated with Management Changes in Croplands and Grazing Lands based on IPCC Default Data"[6]) has default values for SOC for all countries but we decided to use the Harmonized World Soil Database that provides a spatial distribution of SOC (Figure 2). We focused on those soil $CO_2$ emissions caused by a land-use change from native ecosystems to either rainfed cropland or combined mosaic lands. Using the IPCC Tool, we selected the country, the climate zone (using the IPCC climate zone map[7]) and the soil type (all agricultural soils in the nine countries fell into one of three classes: high activity clay, low activity clay or sandy based on the Harmonized World Soil Database) and our land use change analysis. Then we entered the estimated carbon stock (by climate zone and soil class) and selected the change from native ecosystem to either rainfed cultivation (long-term cultivated land in the IPCC Tool) with reduced tillage and low inputs or to combined mosaic class (shifting cultivation – shortened fallow in the IPCC TOOL). These inputs resulted in the annual carbon stock change for the given land-use change. This was then multiplied by the land area for that specific land cover type in the country (converted to $CO_2e$), for the given practice and geographical location resulting in an estimated total soil emission.

[5] The remote sensing products classify the land cover into a variety of classes but no carbon stock data were associated with these classes with which to estimate emissions—various spatial products exist that provide estimates of the carbon stock of forests and woodlands in the nine countries but generating emission estimates from changes in the vegetation carbon pool were not the focus of this work. Existing literature estimates of emission for deforestation in the nine focal countries will be briefly presented in the results section for comparison.

[6] Available from: http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp4/IPCC_Tool/Instructions_Tool.pdf

[7] These are described as follows: tropical (lowland) moist=mainly wet with 3-5 months dry in winter season; tropical (lowland) dry=mainly dry with 5-8 months dry in winter season; tropical montane dry and moist is for zones above 1000 m and similar precipitation regimes as for lowland moist and dry

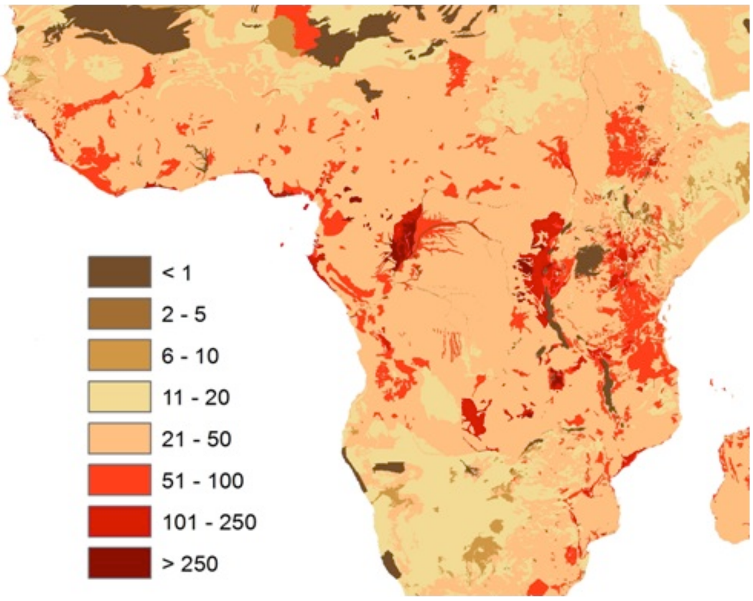

**Figure 2 Soil organic carbon content to 30 cm depth, in t C/ha, from the Harmonized World Soil Database**[8]

### 3.2.4 Non-$CO_2$ Emissions from Fires in Grazing Lands

Fires are widespread and occur frequently in grazing lands of East and West African countries, particularly in the drier grasslands and savannas. Carbon dioxide emissions from biomass burning in grazing lands are not usually accounted for as they are largely balanced by the $CO_2$ that is reincorporated back into biomass via photosynthetic activity within weeks to few years after burning (IPCC 2006). Non-$CO_2$ GHG emissions ($CH_4$ and $N_2O$ ) that result from incomplete combustion of biomass in grazing lands depend on the amount of biomass burned in any one fire and the season in which they burn. The efficiency of combustion and the corresponding fraction of the biomass converted into non-$CO_2$ greenhouse gases may also vary. The emissions of non-$CO_2$ GHGs from a fire are estimated from Eq. 4 (equation and default values for terms in equation from IPCC AFOLU 2006).

$$\mathbf{L_{fire} = A*M_B*C_f*G_{ef}*10^{-3}} \qquad \textbf{(Eq. 4)}$$

Where

$L_{fire}$ = amount of GHG emissions from fire, t of the non-$CO_2$ GHG

A = area burned, ha

$M_B$ = mass of fuel combusted, t dry matter/ha (used average value of aboveground biomass for grassland/savanna for mid to late dry season burn of 5.4 t dry matter/ha)

$C_f$ = combustion factor, dimensionless (=0.89 for mid to late dry season burn)

$G_{ef}$ = emissions factor kg/t dry matter burned (=2.3 for $CH_4$ and 0.21 for $N_2O$)

The emissions from fire for each non-$CO_2$ gas is then multiplied by the corresponding global warming potential (21 for $CH_4$ and 298 for $N_2O$).

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[8] We use SOC values to 30 cm depth; FAO/IIASA/ISRIC/ISSCAS/JRC, 2009. Harmonized World Soil Database (version 1.1). FAO, Rome, Italy and IIASA, Laxenburg, Austria.

The data for area burned were obtained from remote sensing imagery at 1 km resolution (based on the SPOT satellite) for the period 2001-2007 (6 year period)[9]. The satellite collects data daily for a fire year, April 1 to March 31 of the following year, that are used to generate the cumulative area burned during the period of interest; this product was then overlain on the map of grazing lands to obtain estimates of area burned in each country (analysis performed at 500 m resolution).

## 3.3 Mitigation Potential from Land-Use Change

The methodology used to calculate emissions from land-use changed (3.2.3) was used to estimate the mitigation potential from converting a given existing agricultural practice to one that could enhance carbon in the soil using the IPCC Tool. Here, the scenarios produced fall into three major categories: grazing land, rainfed cropland, and combined mosaic vegetation. We report the estimates in units of t $CO_2$eq/ha/yr as an indicator of the mitigation potential. We estimated the sequestration potential for each of the three categories of lands for the following changes in land use practices:

- For grazing land—switching from severely degraded lands to grazing lands with improved management and with medium or high inputs.
- For rainfed cultivation—switching from full tillage to reduced tillage and with different level of nutrient inputs; and from reduced tillage rainfed cultivation to native ecosystems.
- For combined mosaic—converting land from combined mosaic vegetation (assumed to be shifting cultivation cycle) to native ecosystems.

These calculations are made for each land use conversion for each country over the four different climate zones observed in these nine countries (tropical moist; tropical dry, tropical lower montane moist; and tropical lower montane dry) based on the area-weighted average soil type per land use category and area-weighted average soil carbon content (from Fig. 2) per land use category.

Estimates of carbon sequestration in vegetation were also included in those agricultural practices that involved the potential to convert to agroforestry or native vegetation. Growth Habitat (GH), Stand Density (SD) and Site Quality (SQ) are the primary factors influencing the potential carbon benefits for agroforestry.[10,11] Using the USAID AFOLU Carbon Calculator (http://winrock.stage.datarg.net/CarbonReporting/Welcome ) developed by Winrock International, a tool for estimating carbon benefits for a range of activities that account for the GH, SD, SQ, and climate conditions, country wide annual averages were estimated for two scenarios: high (GH, SD, SQ) and low (GH, SD, SQ) using the default values for climate variables. For forestation scenarios, natural forest was the assumed vegetation type and estimates of the average annual carbon sequestration (annualized over a 20 yr period to be consistent with the soil carbon pool) were also obtained from the USAID AFOLU Carbon Calculator.

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[9] Tansey *et al.*2008, (http://bioval.jrc.ec.europa.eu/products/burnt_areas_L3JRC/GlobalBurntAreas2000-2007.php)

[10] Casarim, FM, NL Harris, and S. Brown. 2010. USAID Forest Carbon Calculator: Data and Equations for the Agroforestry Tool. Submitted by Winrock International under USAID.

[11] Carbon accumulation in agroforestry systems under different growth habitat, tree density, and site quality, annual rates are estimated by fitting a Chapman Richards equation to empirical data. See the documentation in the tool.

# 4 Estimates of Greenhouse Gas Emissions

## 4.1 Activity Data—Areas of Agricultural Lands in 2006

Based on the analysis of the remote sensing products for 2006, croplands and grazing lands covered about 52% of the East African countries' lands and 39% of the West African countries' lands in 2006 (Table 3 and Figure 1). For East African countries, about 54% of the total agricultural land was covered by the crop land classes (29% of the country area), whereas in West Africa 47% of the total agricultural land was covered by the four cropland classes (19% of the country area). These data are combined with the emission factors to result in estimates of the total GHG emissions from each source.

Ethiopia and Tanzania in East Africa and Mali in West Africa had the largest area of grazing lands (42-55 million ha), whereas Ethiopia had the largest area of croplands (35 million ha). The mosaic vegetation class, assumed to be various stages of shifting cultivation, had the largest extent in Burkina Faso and Mali (5-6 million ha).

**Table 3 Area of agricultural lands in each of the nine African countries (in million hectares). Total agriculture is the sum of grazing lands, irrigated and rainfed croplands, and mosaic vegetation; and Total cropland is the sum of irrigated and rainfed croplands**

| Region | Country | Total country | Total agriculture | Grazing lands | Total croplands | Irrigated croplands | Rainfed croplands | Mosiac vegetation* |
|---|---|---|---|---|---|---|---|---|
| East Africa | Ethiopia | 114 | 52.62 | 16.89 | 33.41 | 17.29 | 16.12 | 2.32 |
| | Kenya | 58 | 30.06 | 15.55 | 12.85 | 3.31 | 9.54 | 1.65 |
| | Tanzania | 94 | 55.08 | 33.48 | 17.80 | 0.00 | 17.80 | 3.81 |
| | Uganda | 24 | 13.92 | 3.29 | 9.86 | 3.68 | 6.18 | 0.78 |
| | ***Subtotal*** | ***290*** | ***151.69*** | ***69.21*** | ***73.91*** | ***24.28*** | ***49.63*** | ***8.57*** |
| West Africa | Burkina Faso | 28 | 25.82 | 7.96 | 11.89 | 5.66 | 6.23 | 5.97 |
| | Ghana | 24 | 14.57 | 7.84 | 6.63 | 1.21 | 5.42 | 0.10 |
| | Mali | 130 | 42.01 | 21.59 | 15.18 | 7.55 | 7.63 | 5.23 |
| | Niger | 124 | 28.93 | 24.74 | 2.95 | 0.30 | 2.65 | 1.24 |
| | Senegal | 20 | 16.67 | 5.44 | 7.67 | 3.43 | 4.25 | 3.55 |
| | ***Subtotal*** | ***326*** | ***128.00*** | ***67.57*** | ***44.33*** | ***18.15*** | ***26.18*** | ***16.10*** |
| | **Total** | **616** | **279.68** | **136.77** | **118.25** | **42.43** | **75.81** | **24.66** |

** Mosaic vegetation represents the following two classes: Mosaic cropland (50-70%)/ mosaic grassland/shrubland/forest (20-50%), and Mosaic grassland/shrubland/forest (50-70%) / cropland (20-50%)*

Most of the agricultural lands of the nine focal countries were located in the lower montane dry or tropical (lowland) dry climatic zones (Table 4).

**Table 4 Area of agricultural lands in each of the nine African countries (in million hectares) by climatic zone. A blank cell means no lands of the type exist in that climatic zone**

| Region | Country | Lower montane dry | | | | Tropical dry | | | | Tropical moist | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Grazing land | Irrigated cropland | Rainfed cropland | Mosaic | Grazing land | Irrigated cropland | Rainfed cropland | Mosaic | Grazing land | Irrigated cropland | Rainfed cropland | Mosaic |
| **East Africa** | Ethiopia | 14.23 | 16.27 | 12.69 | 2.00 | 1.99 | 0.88 | 2.55 | 0.32 | 0.67 | 0.14 | 0.88 | |
| | Kenya | 0.24 | 0.86 | 1.31 | 0.19 | 15.31 | 2.45 | 8.23 | 1.46 | 0.00 | | | |
| | Tanzania | 20.48 | | 13.50 | 0.48 | 4.31 | | 2.37 | 1.15 | 8.68 | | 1.93 | 2.18 |
| | Uganda | 3.19 | 3.18 | 5.70 | 0.75 | 0.00 | | | | 0.09 | 0.50 | 0.42 | 0.01 |
| | **Subtotal** | **38.14** | **20.31** | **33.20** | **3.42** | **21.62** | **3.33** | **13.15** | **2.94** | **9.44** | **0.64** | **3.22** | **2.19** |
| **West Africa** | Burkina Faso | | | | | 5.95 | 3.63 | 6.00 | 5.62 | 2.01 | 2.03 | 0.23 | 0.35 |
| | Ghana | | | | | 0.43 | 0.21 | 0.07 | 0.09 | 7.41 | 1.00 | 5.35 | 0.01 |
| | Mali | | | | | 19.56 | 4.75 | 7.17 | 4.41 | 2.03 | 2.80 | 0.46 | 0.82 |
| | Niger | | | | | 24.74 | 0.30 | 2.65 | 1.24 | | | | |
| | Senegal | | | | | 4.99 | 2.78 | 3.52 | 3.54 | 0.45 | 0.65 | 0.73 | 0.01 |
| | **Subtotal** | | | | | **55.67** | **11.67** | **19.41** | **14.91** | **11.90** | **6.48** | **6.77** | **1.19** |
| | **Total** | **38.14** | **20.31** | **33.20** | **3.42** | **77.28** | **15.00** | **32.56** | **17.85** | **21.34** | **7.13** | **10.00** | **3.38** |

## 4.2 Greenhouse Gas Emissions from Agricultural Practices

### 4.2.1. Emissions from Enteric Fermentation and Manure Management

Emissions from enteric fermentation and manure management represent the greatest source of agricultural GHG emissions for all countries, estimated at about 108 million t $CO_2$e/yr (Table 5). Enteric fermentation was more than an order of magnitude greater than manure management. However, the emissions per country vary greatly, with Ghana emitting about 1.9 million t and Ethiopia about 42 million t $CO_2$e/yr (Table 5).

Combining the total emissions from livestock (Table 5) with the area of grazing lands (Table 3), we obtained an average of 1.1 t $CO_2$e/ha/yr for East African countries and 0.50 t $CO_2$e/ha/yr for West African countries. The emissions per ha for Ethiopia were the highest by far at 2.5 t $CO_2$e/ha/yr, which is to be expected given the high number of cattle and other ruminants present in this country.

**Table 5 Emissions (million t $CO_2$e/yr) from enteric fermentation and manure management in the nine East and West African focal countries**

| Region | Country | Total Emissions from Enteric Fermentation | Total Emissions from Manure Management | Total Emissions from Livestock |
|---|---|---|---|---|
| **East Africa** | Ethiopia | 40.55 | 1.41 | 41.97 |
| | Kenya | 11.55 | 0.44 | 11.99 |
| | Tanzania | 13.46 | 0.48 | 13.93 |
| | Uganda | 5.94 | 0.26 | 6.20 |
| | ***Subtotal*** | ***71.50*** | ***2.59*** | ***74.09*** |
| **West Africa** | Burkina Faso | 8.33 | 0.45 | 8.78 |
| | Ghana | 1.77 | 0.09 | 1.87 |
| | Mali | 8.89 | 0.38 | 9.27 |
| | Niger | 9.99 | 0.42 | 10.41 |
| | Senegal | 3.21 | 0.15 | 3.36 |
| | ***Subtotal*** | ***32.19*** | ***1.49*** | ***33.68*** |
| | **Total** | **103.69** | **4.08** | **107.78** |

### 4.2.2 Emissions from Nitrogenous Fertilizer Use

Emissions from nitrogenous fertilizer (Table 6) varied between about 15 thousand $CO_2$e in Niger to a high of 356 thousand t $CO_2$e in Ethiopia followed closely by Kenya at 339 thousand t $CO_2$e, most of which was accounted for by from direct emissions. Indirect emissions were relatively minor in comparison as expected, particularly in the drier countries, accounting for at most 17 thousand t $CO_2$e (Ethiopia) and only 700 - 900 t $CO_2$e in Niger and Burkina Faso. The emissions per ha (total emissions divided by area of croplands) varied from 0.002 (Burkina Faso, Tanzania, and Uganda) to 0.026 t $CO_2$e/yr (Kenya).

**Table 6 Direct and indirect total annual GHG emissions from use of nitrogenous fertilizer, in t $CO_2e$, and rate of application, in the nine East and West African countries based on an average of 2000 to 2002 data (most recent data available)**

| Region | Country | Direct emissions | Indirect emissions | Rate of application kg/ha |
|---|---|---|---|---|
| **East Africa** | Ethiopia | 338,800 | 16,900 | 2.2 |
| | Kenya | 322,900 | 16,200 | 5.4 |
| | Tanzania | 42,100 | 2,100 | 0.5 |
| | Uganda | 18,000 | 5,400 | 0.4 |
| | ***Subtotal*** | **721,900** | **40,600** | |
| **West Africa** | Burkina Faso | 18,200 | 900 | 0.3 |
| | Ghana | 55,200 | 2,800 | 1.8 |
| | Mali | 63,600 | 3,200 | 0.9 |
| | Niger | 14,400 | 700 | 1.0 |
| | Senegal | 83,500 | 4,100 | 2.3 |
| | ***Subtotal*** | **235,000** | **9,200** | **6.4** |
| | ***Total*** | **956,900** | **49,800** | |

The average annual application rates of N fertilizer were estimated by dividing the average annual consumption reported by FAO by the total cropland area obtained from the remote sensing data (Table 3). The rates per ha were very low for these countries suggesting that not all croplands are fertilized. For example, for selected key crops in Kenya and Tanzania, application rates of 10-100 kg/ha were reported[12], but the total area covered by these crops represented only a small fraction of the total area reported in Table 3.

### 4.2.3 Emissions from Land-Use Change

Between 2001 and 2006, native ecosystems underwent a land use change and about 5.5 million ha per year were converted to cropland in the East African countries and about 1.2 million ha per year in the West African countries (Table 7, Figures 3-4). Most of this appeared to be to permanent croplands as only 7% of the total area was converted to the mosaic vegetation classes (assumed to be shifting cultivation). Ethiopia by far converted most native vegetation lands to croplands in this time period—almost 3.6 million ha, and most of this occurred in the lower montane dry zone.

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[12] http://www.fao.org/ag/agl/fertistat/ ;data for 1997

**Table 7 Area change from all native ecosystems to either irrigated cropland, rainfed cropland or mosaic cultivation in each of the nine African countries (in thousand ha/yr) in the four climate zones between 2001 to 2006**

| Region | Country | Lower montane dry | | | Lower montane moist | | | Tropical dry | | | Tropical moist | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Irrigated croplands | Rainfed croplands | Mosaic cultivation vegetation | Irrigated croplands | Rainfed croplands | Mosaic cultivation vegetation | Irrigated croplands | Rainfed croplands | Mosaic cultivation vegetation | Irrigated croplands | Rainfed croplands | Mosaic cultivation vegetation |
| **East Africa** | Ethiopia | 1,211.5 | 1,446.5 | 56.0 | | | | 152.8 | 472.3 | 56.0 | 12.4 | 147.0 | |
| | Kenya | 27.4 | 62.9 | 3.5 | | | | 173.5 | 446.3 | 59.5 | | | |
| | Tanzania | - | 363.9 | 25.7 | | | | | 53.2 | 45.5 | | 101.2 | 95.9 |
| | Uganda | 155.3 | 299.0 | 15.3 | | 4.5 | 1.5 | | | | 31.3 | 25.9 | 0.3 |
| | ***Subtotal*** | ***1,394.2*** | ***2,172.3*** | ***100.5*** | | ***4.5*** | ***1.5*** | ***326.3*** | ***971.8*** | ***160.9*** | ***43.7*** | ***274.1*** | ***96.2*** |
| **West Africa** | Burkina Faso | | | | | | | 22.9 | 41.1 | 33.4 | 25.5 | 0.8 | 0.4 |
| | Ghana | | | | | | | 0.4 | 0.2 | | 20.3 | 539.7 | - |
| | Mali | | | | | | | 56.6 | 58.9 | 21.4 | 63.6 | 1.6 | 1.1 |
| | Niger | | | | | | | 4.6 | 8.2 | 6.5 | | | |
| | Senegal | | | | | | | 29.6 | 51.3 | 28.1 | 39.6 | 115.7 | 0.2 |
| | ***Subtotal*** | | | | | | | ***114.0*** | ***159.7*** | ***89.4*** | ***148.9*** | ***657.7*** | ***1.6*** |
| | **Total** | **1,394.2** | **2,172.3** | **100.5** | **-** | **4.5** | **1.5** | **440.3** | **1,131.5** | **250.4** | **192.7** | **931.8** | **97.8** |

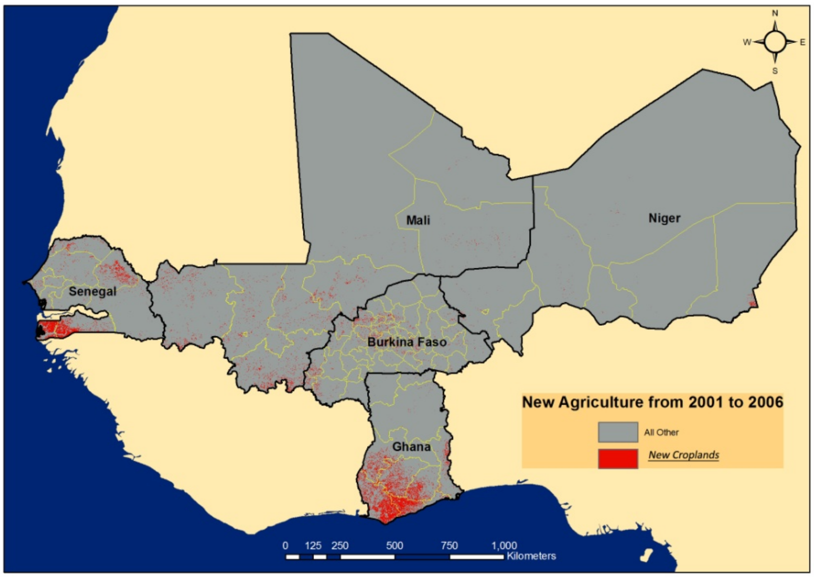

Figure 3 Mapped distribution of total increases in cropland area between 200 2006 for West Africa

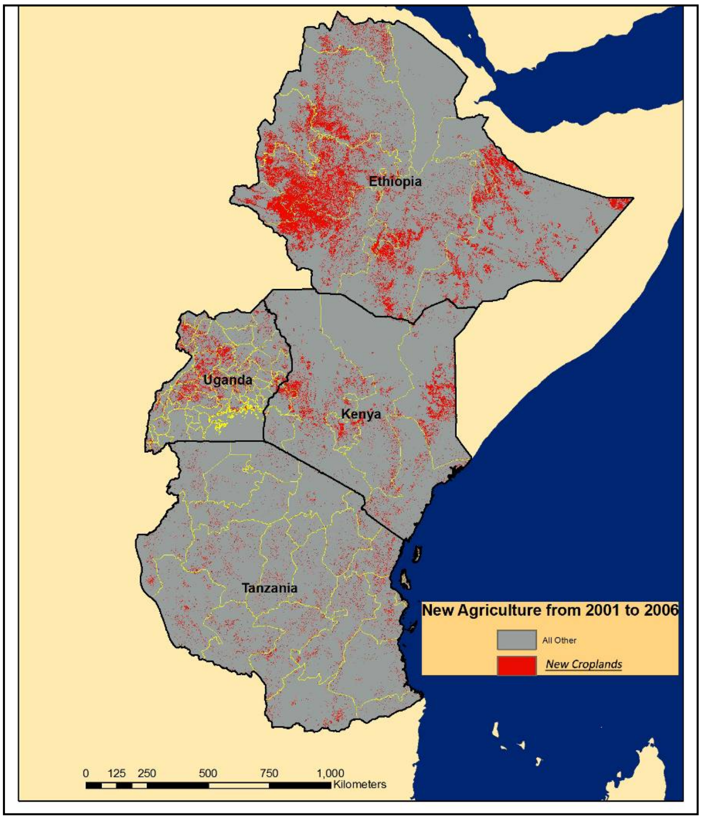

Figure 4 Mapped distribution of total increases in cropland area between 200 2006 for East Africa

The area weighted average SOC contents for cropland soils in East African countri from 37 to 53 t C/ha; for the West African countries it ranged from 19 to 40 t C/ha The area weighted average SOC for grazing lands tended to be somewhat lower th croplands.

**Table 8 Area weighted average soil organic carbon to 30 cm depth for crop and grazing lands of the nine focal African countries**

| Region | Country | Cropland (t C/ha) | Grazing land (t C/ha) |
|---|---|---|---|
| **East Africa** | Ethiopia | 46.5 | 37.7 |
| | Kenya | 45.4 | 33.9 |
| | Tanzania | 52.5 | 54.0 |
| | Uganda | 37.3 | 32.9 |
| **West Africa** | Burkina Faso | 35.3 | 33.7 |
| | Ghana | 40.1 | 37.6 |
| | Mali | 36.3 | 35.4 |
| | Niger | 27.0 | 22.4 |
| | Senegal | 18.5 | 27.5 |

The total $CO_2$ emissions from soil due to land-use change were about 14.9 million t $CO_2$e/yr (Table 9). Ethiopia alone accounts for the largest emissions at about 7.3 million t $CO_2$e/year. Emissions from land-use change in Kenya, Tanzania and Ghana were similar to each other at about 1.7-1.8 million t $CO_2$e/yr. Emissions from land use change in Niger were the lowest of all at about 0.03 million t $CO_2$e/yr.

Recent estimates of total emissions caused by gross deforestation, including the vegetation only, for the same time period are about 32.2 million t $CO_2$e/yr for the East African countries and 9.6 t $CO_2$e/yr in the West African counties (Harris et al. 2010). These estimates are almost three times those from soil alone.

**Table 9 Annual emissions, in thousand t $CO_2$/year, from soil (to a depth of 30 cm) caused by land-use change in each of the nine countries. The change is from native ecosystems to cropland* and to combined mosaic agriculture and does not include any emissions caused by clearing vegetation. A blank cell means that conversion did not occur in that country**

| **Region** | **Country** | **Tropical Dry** | | **Tropical Moist** | | **Lower Montane Dry** | **Low Montane Moist** | **Total Emissions** |
|---|---|---|---|---|---|---|---|---|
| | | **Cropland** | **Combined Mosaic** | **Cropland** | **Combined Mosaic** | **Cropland** | **Cropland** | |
| **East Africa** | Ethiopia | 711 | 64 | 619 | | 5,945 | | **7,342** |
| | Kenya | 1,341 | 190 | | | 282 | | **1,816** |
| | Tanzania | 170 | 158 | 390 | 355 | 761 | | **1,837** |
| | Uganda | | | 145 | 1 | 949 | 17 | **1,115** |
| | ***Subtotal*** | ***2,221*** | ***412*** | ***1,154*** | ***356*** | ***7,937*** | ***17*** | ***12,111*** |
| **West Africa** | Burkina Faso | 120 | 77 | 75 | 1 | | | **277** |
| | Ghana | 1 | | 1,663 | | | | **1,668** |
| | Mali | 212 | 51 | 174 | 3 | | | **444** |
| | Niger | 19 | 12 | | | | | **34** |
| | Senegal | 83 | 30 | 256 | | | | **373** |
| | ***Subtotal*** | ***434*** | ***170*** | ***2,169*** | ***4*** | | | ***2,795*** |
| | **Total** | **2,655** | **582** | **3,323** | **360** | **7,937** | **17** | **14,906** |

**We combined change in irrigated and rainfed cropland classes into one class as the IPCC Soil carbon tool did not distinguish between these two for estimating the carbon emissions; we assumed that the croplands were subject to reduced tillage with low inputs*

The focus on emissions due to land use change was emissions from soil, however to put soil emissions in perspective we made a first order approximation of the emissions due to clearing the vegetation too. In the analysis of the remote sensing imagery, we did not track the class of land cover that the change occurred in. If we assume that this was from lands that had carbon stocks at the low end of the range of default values for woody vegetation/shrublands typical of the climatic zone and region[13], **we estimate the emissions from the vegetation to be 250 million t $CO_2$e/yr. The emissions from soil at about 14.9 million t $CO_2$e/yr represented about 6% of those from vegetation**.

### 4.2.4 Emissions of Non-$CO_2$ GHGs from Fires in Grazing Lands

Fires occured in each of the nine countries and were particularly widespread in the East African countries (Figure 5 and Table 10). Total average annual area burned for the nine countries was about 9.5 million ha, with 74% occurring in the East African countries.

Although fires often tend to vary from year to year, the fires in this region were relatively constant from year to year for the East African countries, with the exception of Uganda, which had a spike in burned area in 2005-06 from an average of about 24-28% of the grazing land area to 42% of the area (Annex A). Area burned in West Africa was more variable from year to year (Annex A), particularly in Ghana. Fires in Niger burned very small areas, of the order of 20,000 ha or less a year of grazing land out of more than 24 million ha.

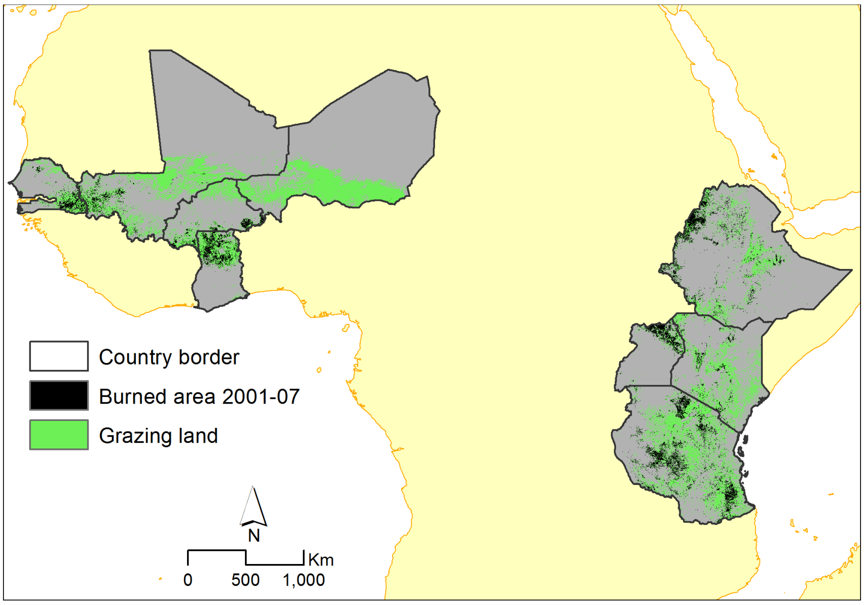

**Figure 5 Area of grazing lands burned during the period 2001-2007 (burned area data from (http://bioval.jrc.ec.europa.eu/products/burnt_areas_L3JRC/GlobalBurntAreas2000-2007.php)**

Average annual emissions of methane and nitrous oxide resulting from the fires varied from 0.2 to 1.7 million t $CO_2$e/yr in East African countries to about 0.2-0.5 million t $CO_2$e/yr in the West African countries (except for Niger which is about 9,000 t) (Table 10). Emission of $N_2O$, in $CO_2$e, were higher than those for $CH_4$, mostly due to the higher global warming potential of $N_20$ (298) compared to $CH_4$ (21). The amount of biomass burned was assumed to

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[13] Based on the default values in the IPCC 2006 AFOLU, the range in above ground carbon stocks that we used was 20-80 t C/ha

be the same for all nine countries in this analysis (from IPCC 2006 AFOLU default values) given lack of more country specific data for grazing lands at this time.

**Table 10 Average annual area burned in thousand ha and resulting emissions of $CH_4$ and $N_2O$[14], in thousand t $CO_2e$/year for the nine East and West African countries**

| Region | Country | Average annual burned | Average annual percent burned (% ) | CH4 emissions | N2O emissions | Total non-CO2 emissions |
|---|---|---|---|---|---|---|
| **East Africa** | Ethiopia | 2,353 | 13.8 | 546 | 708 | 1,254 |
| | Kenya | 436 | 2.7 | 101 | 131 | 232 |
| | Tanzania | 3,257 | 9.6 | 756 | 980 | 1,736 |
| | Uganda | 983 | 29.2 | 228 | 296 | 524 |
| | ***Subtotals*** | ***7,028*** | ***55.2*** | ***1631*** | ***2114*** | ***3,745*** |
| **West Africa** | Burkina Faso | 575 | 7.2 | 133 | 173 | 306 |
| | Ghana | 922 | 11.6 | 214 | 277 | 491 |
| | Mali | 453 | 2.1 | 105 | 136 | 241 |
| | Niger | 17 | 0.1 | 4 | 5 | 9 |
| | Senegal | 468 | 8.6 | 109 | 141 | 249 |
| | ***Subtotals*** | ***2,435*** | ***29.6*** | ***565*** | ***732*** | ***1,297*** |
| | **Totals** | **9,463** | **85** | **2,197** | **2,846** | **5,043** |

### 4.2.5 Total Emissions

The total annual amount of GHG emissions from the nine African countries was almost 129 million t $CO_2e$/yr during the period 2001-2006 (Table 11), excluding irrigated rice cultivation. In comparison, emissions from the energy and industrial processes sectors were about 45 million t $CO_2e$/yr based on data for the 1990s (summarized from the nine countries' national communications).

It is clear that the largest quantity of GHG emissions was from the livestock sector, mostly methane from enteric fermentation as expected (83% of the total), followed by emissions from soil only from land use change (11% of the total). Emissions from use of fertilizer were

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[14] $CO_2$ emissions from biomass burning in grassland are not included became they are largely balanced by the $CO_2$ that is reincorporated back into biomass via photosynthetic activity within weeks to few years after burning.

lower than all other sources and represent just 0.7% of the total emissions. Despite the large area of grazing lands burned each year (about 9 million ha), the emissions of $CH_4$ and $N_2O$, as $CO_2e$, represented about 4% of total emissions. This is mostly due to the low quantities of aboveground biomass available on grazing lands for burning (about 5 t/ha).

The four East African countries accounted for 70% of the total emission from the nine countries, dominated by the emissions from soils after land use change and livestock in Ethiopia. The five West African countries emitted fewer GHGs than East African countries because they had fewer ruminants, converted smaller area of native ecosystems to cropland, had fewer fires, and applied low quantities of N fertilizer.

The total emissions that we report here are comparable to those reported by each country in their National Communications, though as expected our estimates are higher reflecting likely increases in agricultural production since the time of their reports (Table 11). However, the estimates for different gases vary, for example the nitrous oxide emissions reported in the National Communications for the focal countries and year (< 11,000 t $CO_2e$/yr for Kenya to about 6 million t $CO_2e$/yr for Ethiopia) bear no resemblance to the estimates we obtained in Table 11. Reported estimated emissions from the National Communications for other sources were incomplete or unclear.

**Table 11 Total annual GHG emissions, in 1,000 t $CO_2e$, from land-use change, livestock, nitrogen fertilizer consumption and fires in grazing lands in the nine East and West African Countries during the period 2001-2006. The estimated total emissions from the National Communications (NC) is also given covering years 1994 to 2000 (specific years for each country are given in Annex B)**

| Region | Country | Land-Use Change | Livestock | Nitrogen Fertilizer | Grazing Area Burned | Total | Total from NC* |
|---|---|---|---|---|---|---|---|
| East Africa | Ethiopia | 7,339 | 41,966 | 356 | 1,254 | 50,915 | 32,728 |
| | Kenya | 1,812 | 11,988 | 339 | 232 | 14,372 | 12,088 |
| | Tanzania | 1,833 | 13,935 | 44 | 1,736 | 17,548 | 28,017 |
| | Uganda | 1,112 | 6,204 | 23 | 524 | 7,863 | 5,797 |
| | ***Subtotal*** | ***12,097*** | ***74,093*** | ***762*** | ***3,745*** | ***90,697*** | ***78,629*** |
| West Africa | Burkina Faso | 273 | 8,779 | 19 | 306 | 9,377 | 4,501 |
| | Ghana | 1,664 | 1,865 | 58 | 491 | 4,079 | 4,637 |
| | Mali | 440 | 9,270 | 65 | 241 | 10,016 | 7,036 |
| | Niger | 31 | 10,405 | 15 | 9 | 10,461 | 6,231 |
| | Senegal | 369 | 3,364 | 88 | 249 | 4,070 | 4,514 |
| | ***Subtotal*** | ***2,778*** | ***33,683*** | ***245*** | ***1,297*** | ***38,003*** | ***26,919*** |
| | **Total** | **14,874** | **107,776** | **1,009** | **5,043** | **128,699** | **105,548** |

### 4.2.6 Uncertainties and Next Steps

In sum, we have estimated the baseline GHG emissions for the approximate period of 2001 to 2006, in t $CO_2e$/yr, for the main sources in the agricultural sector using consistent data sets and methods for all countries. Where data exist, we show that for livestock our estimates are comparable to those reported in the National Communications; for other sources no comparable data exist. The total emissions are on the order of about 129 million t $CO_2$e/yr, with emissions from activities related to livestock dominating (84% of the total).

Although we have used a consistent set of data and methodology, the uncertainty around these estimates is likely to be large. First, given the resolution of the remote sensing data sets (about 500 m resolution) it is likely that the uncertainty in the area estimates used in the soil emissions from land use change and in the fire emissions could be high. Also, the data used for the livestock and nitrogen emissions, although from reputable sources (e.g. FAO), they ultimately originate from country reports, the quality of which varies by country. The consumption of nitrogen fertilizer is particularly uncertain given the low rates of application per unit area of land it translates to.

We used the IPCC methodologies for estimating emissions for each source using a Tier 1 approach and use of default values for emission factors. The IPCC recommends that higher tier levels be used for key categories (i.e. significant emission sources), where the approach and emission factors need to be more country specific. A more complex method for estimating $CH_4$ emissions from livestock practices (enteric fermentation and manure management) should be used, particularly where a particular livestock species/category represents a significant share of a country's emissions as is the case for cattle in most countries. An improved method would require detailed information on animal characteristics and management practices that can then be used to develop emission factors specific to the conditions of the country.

Although it appears the GHG emissions from use of N fertilizer are not a significant source and thus not a key category for this time period, although expected to increase, this could be due to the lack of quality data and use of the simple IPCC Tier 1 approach. There is room for improvements in the simple IPCC method that could take into account other factors that affect $N_2O$ emissions such as soil carbon content, climate, soil texture, crop type, and fertilizer type (Pearson and Brown 2010). Although potentially a low source of GHGs at present, attempts to maintain or enhance crop production so as to reduce conversion of native vegetation (forests in particular) in the future will certainly require higher inputs of N fertilizer, thus a higher tier approach with the use of country specific emission factors and the use of a more complex model (Pearson and Brown 2010) will be needed to improve the accounting of $N_2O$ emissions.

Emissions caused by burning grazing lands are potentially a significant source. According to the validation analysis performed by Tansey et al. (2011), the application of the method to Africa tended to underestimate the actual area burned, particularly in lands covered by shrubs and grasses and small burned areas (50 ha or less); this of course would underestimate the emissions. We used the fire product to estimate the area of grazing lands that burned, which also of course assumes we have identified their area correctly. Given these issues it is clear that uncertainties in the area burned per year exist. Furthermore, we used a very conservative estimate for the mass of vegetation that burned and applied the same value for all countries. To improve estimates of emissions from fire would need both improved analysis of remote sensing fire products with improvements in the estimates of the carbon stocks of the vegetation being burned.

Clearly there are many ways that this analysis could be improved. It would be beneficial to reduce the scale of analysis to key agricultural areas of each country, using higher resolution remote sensing products to obtain more accurate data on land cover/land use and area burned. As mentioned above, improved monitoring of the number of ruminant animals, quantity of N fertilizer used, and the carbon stocks of burned areas of grazing lands would reduce the uncertainty and lead to improved methods and emission factors for these sources of GHG emissions. These will be key steps needed to develop improved baselines for GHG emissions from agricultural practices against which improvements in practices could be monitored.

# 5 Mitigation Potential from Changes in Agricultural practices

Emissions of GHGs from agriculture are substantial and beg the question—what opportunities exist to reduce these emissions or even to increase sequestration? Given the common practices and magnitude of GHG emissions from livestock (and fire which is often set to improve the forage for grazing animals) in all of these countries, it is unlikely that very much can be done in the near future to reduce these emissions. There is a possibility that improved fire management could reduce the incidence of fire and thus emissions but the extent to which this can be implemented is unclear.

Given the past low emissions from use of N fertilizers and the low intensity of use (kg/ha), there appears to be no opportunity to reduce nitrous oxide emissions either. However, given the low rate of N application per ha, **there is an opportunity to increase the rate of application to improve crop production and at the same time reduce the need to clear native ecosystems for new croplands** (the second largest source of $CO_2$ emissions). Even a doubling of N fertilizer use would still only make this source of GHGs responsible for about 1% of the total. **What is needed is more research on the relationship between increases in crop production for the variety of crops grown in these countries versus increases in N fertilizer application and the related $N_2O$ emissions**. Our analysis showed that one ton of N fertilizer application is equivalent 4.9 t $CO_2$e of emissions, and given that the carbon stock in forests of many of the study countries is about 180 t $CO_2$e, clearing 1 ha of forest would be equivalent to the emissions from applying about 38 additional tons of N fertilizer. At say an average application rate of 100kg/ha, this would be equivalent to fertilizing about 38 ha for 10 years. If increasing fertilizer can double productivity (as has been seen in the US for example) then each improved hectare of agriculture will reduce the need to clear forest with the associated emissions. However, to maintain enhance crop production will mean fertilizer will need to be added continually through time and there will likely be a point where cumulative $N_2O$ emissions will outweigh advantages from stopping clearing of native ecosystems. **Clearly to meet the goals of reducing emissions from forest conversion while at the same time increasing crop production will require this additional fertilization, thus acquiring more knowledge about the relationships between crop production, nitrogen fertilizer, and GHG emissions is vital.**

Due to the limitations in terms of activities that can immediately affect emissions from livestock and from fire use, and the limited use of fertilizers in the focal countries, we here focus on activities that could lead to an emission reduction in the near term and then discuss additional work that is needed to determine other near-term mitigation approaches. In particular, the type of cropping practices that exist in many of the focal countries favors activities that change cropping practices to enhance soil carbon.

However, changing practices to increase soil C sequestration should be approached with caution. Although changing practices can enhance soil carbon sequestration, the amount sequestered only remains this way if the practice is continued—any reversion to the previous practice will cause the carbon to be re-emitted. In addition, if the change in practice is implemented to generate carbon credits, then the amount sequestered will need to be quantified and monitored through time, which for soils can be relatively expensive compared to the likely revenue generated from the carbon credits.

Given the challenges associated with carbon crediting projects based on soil carbon sequestration, an alternative approach could be to develop national policies that encourage changes in agricultural practices with appropriate incentives for landowner adoption. Under a national policy, the monitoring could be based on activity data only (monitor area of land that is implementing a given changed practice) and then combine the activity data with national carbon sequestration factors (national tables) developed for key agricultural areas and practices using local data and models (akin to the approach used in many areas of the USA).

In this section we provide a first order approximation of such carbon sequestration factors that could be used with monitored activity data. These potential carbon sequestration factors are based on use of the IPCC soil carbon tool with the estimated soil carbon stocks for each country and climatic zone for the following changes in agricultural practices:

- For rainfed cultivation—switching from full tillage to reduced tillage and with different level of nutrient inputs;
- For rainfed cultivation--switching from reduced tillage to native ecosystems.
- For grazing land—switching from severely degraded lands to grazing lands with improved management and with medium or high inputs.
- For combined mosaic—converting land from combined mosaic vegetation (assumed to be shifting cultivation cycle) to native ecosystems

## 5.1 Changing Tillage and Input Practices in Rainfed Cropland

Each of the nine countries shows mitigation potential when converting rainfed cropland from full tillage to reduced tillage depending on the each of their respective climatic zones (Table 12). However, it is not clear at this time what actual practices are used in a given country and it is possible that few lands are actually currently under full tillage. The change in soil carbon varies between 0.4 t $CO_2$e/ha/yr in Senegal's tropical dry climate with a shift from low to medium inputs[15] up to 5.3 t $CO_2$e/ha/yr in Uganda's lower montane moist climate with a shift

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[15] Cropland Input Factors; from *the IPCC Soil Carbon Tool*: The input factors represent the effect of changing carbon input to the soil, as a function of crop residue yield, bare-fallow frequency, cropping intensity, or applying amendments. Input factors are categorized as low, medium, high, and high w/manure amendments.

- ***Low*** residue return is due to removal of residues (via collection or burning), frequent bare-fallowing or production of crops yielding low residues (e.g. vegetables, tobacco, cotton).
- ***Medium*** input cropping systems represent annual cropping with cereals where all crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g. manure) is added.

from low to high inputs with manure. Across the climatic zones and countries, we observe that the mitigation potential directly correlates with the level of inputs with shifts from low to high inputs with manure providing the greatest mitigation potential. Although soil carbon is enhanced with reductions in tillage and increases in inputs, new knowledge and capacity will be needed by landowners to put the change into practice.

## 5.2 Changing from Reduced Tillage Practices to Native Ecosystems or Agroforests in Rainfed Cropland

The range of mitigation potential in soil alone from converting rainfed cropland with reduced tillage and low inputs to native ecosystems (i.e. abandon cultivation and allow for system to return to native systems) is from 1.0 t $CO_2$e/ha/yr in Senegal's tropical dry climate to 4.1 t $CO_2$e/ha/yr in Uganda's tropical dry climate (Table 13). These rates are expected to last about 20 years only after which time the soil carbon stocks are expected to reach a new steady state where inputs equal losses from decomposition. In general as expected, the soil carbon enhancement is greater in moist then dry climatic zones.

**Table 13 Potential change in annual carbon stock (t $CO_2$e/ha/yr) in soil at 30 cm depth when converting rainfed cropland with reduced tillage practices and low inputs to native ecosystems**

| Region | Country | Tropical, Dry | Tropical, Moist | Lower Montane, Dry | Lower Montane, Moist |
|---|---|---|---|---|---|
| **East Africa** | Ethiopia | 1.1 | 3.9 | 2.2 | |
| | Kenya | 2.2 | | 3.1 | |
| | Tanzania | 3.2 | 3.9 | 2.1 | |
| | Uganda | 4.1 | 2.5 | | 3.7 |
| **West Africa** | Burkina Faso | 1.9 | 2.9 | | |
| | Ghana | 1.9 | 3.0 | | |
| | Mali | 1.8 | 2.7 | | |
| | Niger | 1.5 | | | |
| | Senegal | 1.0 | 1.7 | | |

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- ***High input (without manure)*** rotations have significantly greater crop residue inputs due to production of high residue yielding crops, use of green manures, cover crops, improved vegetated fallows, frequent use of perennial grasses in annual crop rotations, but without manure applied.
- ***High input (with manure)*** rotations have high input of crop residues as in "high input without manure" (above), together with regular additions of animal manure.

**Table 12 Potential change in annual carbon stock (t $CO_2$e/ha/yr) in soil at 30 cm depth from converting rainfed cropland with full tillage to reduced tillage with: a. low inputs to medium inputs; b. low to high inputs with manure; c. low to high inputs without manure. A blank cell means that conversion is not possible**

| Region | Country | Tropical, Dry | | | Tropical, Moist | | | Lower Montane, Dry | | | Lower Montane, Moist | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Low to Medium Inputs | Low to High Inputs with manure | Low to High Inputs without manure | Low to Medium Inputs | Low to High Inputs with manure | Low to High Inputs without Manure | Low to Medium Inputs | Low to High Inputs with Manure | Low to High Inputs without Manure | Low to Medium Inputs | Low to High Inputs with Manure | Low to High Inputs without Manure |
| **East Africa** | Ethiopia | 0.5 | 1.4 | 0.7 | 1.5 | 4.0 | 2.2 | 0.9 | 3.7 | 1.5 | | | |
| | Kenya | 0.9 | 2.8 | 1.3 | | | | 1.3 | 5.3 | 2.1 | | | |
| | Tanzania | 1.3 | 4.0 | 1.9 | 1.5 | 4.0 | 2.2 | 0.8 | 3.5 | 1.4 | | | |
| | Uganda | 1.7 | 5.2 | 2.4 | 1.0 | 2.6 | 1.5 | | | | 1.6 | 5.3 | 2.7 |
| | **Average** | **1.1** | **3.4** | **1.6** | **1.3** | **3.5** | **1.5** | **1.0** | **4.2** | **1.7** | **1.6** | **5.3** | **2.7** |
| **West Africa** | Burkina Faso | 0.8 | 2.4 | 1.1 | 1.1 | 3.0 | 1.6 | | | | | | |
| | Ghana | 0.8 | 2.4 | 1.1 | 1.1 | 3.0 | 1.7 | | | | | | |
| | Mali | 0.8 | 2.3 | 1.1 | 1.0 | 2.8 | 1.5 | | | | | | |
| | Niger | 0.6 | 1.8 | 0.8 | | | | | | | | | |
| | Senegal | 0.4 | 1.3 | 0.6 | 0.6 | 1.7 | 1.0 | | | | | | |
| | **Average** | **0.7** | **2.0** | **1.0** | **1.0** | **2.6** | **1.4** | | | | | | |

The sequestration estimates in Table 13 include soil only so will represent a significant underestimate of carbon sequestration for the return to native ecosystems. Estimates of carbon sequestration in native vegetation for the first 20 yr of regrowth were estimated to be: 4.4 t $CO_2$e/ha/yr for tropical dry zone, 9.2 t $CO_2$e/ha/yr for tropical moist, 6.4 t $CO_2$e/ha/yr for montane systems, and about 1 t $CO_2$e/ha/yr for shrublands. Except for shrublands, the amount sequestered in vegetation is higher than in soil. However it is clear that accounting for carbon sequestration in both key pools substantially increased the total mitigation potential to as high as 7-8 t $CO_2$e/ha/yr and 12-13 t $CO_2$e/ha/yr in dry zones and moist zones, respectively, for East African countries and 5-6 t $CO_2$e/ha/yr and 11-12 t $CO_2$e/ha/yr in dry zones and moist zones, respectively, for West African countries. As previously mentioned, soil carbon could reach a new stable level after about 20 yours, while native vegetation will continue to sequester carbon for many decades more depending upon the plant form and species composition.

Estimates of annual average carbon sequestration in agroforests over a 20 yr period ranges from about 5 t $CO_2$e/ha/yr with low growth habit, low tree density and poor site quality to 18 t $CO_2$e/ha/yr with high growth habit, high tree density and good site quality. The lower end of the range for agroforests is comparable to the estimates for revegetation with native species in dry and montane systems, whereas the upper end of the range for agroforests exceeds that for native revegetation, reflecting the better management. The rates of C sequestration in vegetation are up to order of magnitude more than sequestration in the soil carbon pool. As with native vegetation, carbon sequestration in agroforests will likely continue for more than 20 years, but this will depend on the species planted and their intended use (e.g. fruits or fuel).

## 5.3 Improving Management of Degraded Grazing Lands

Annual carbon stock change from the conversion of severely degraded grazing land to improved grazing land positively correlated with the level of inputs[16] over the three climatic zones in which grazing land was observed to occur in the nine focal countries (Table 14). The range of annual carbon stock change varies from 2.1 t $CO_2$e/ha/yr in Senegal's tropical moist climate, with low to medium inputs, to 5.9 t $CO_2$e/ha/yr in Tanzania's tropical moist climate with low to high inputs. The rates for C sequestration in degraded grazing lands are higher than the estimated rates from changing tillage practices in rainfed croplands. The general practices needed to achieve these increased rates would likely be fertilization and/or improved manure management along with improved management of grazing stock.

[16] Grassland Input Factors; from the *IPCC Soil Carbon Tool* (input factor represents level of improvement that affects primary productivity and hence carbon inputs to soil)

- ***Medium*** applies to grasslands classified as improved, but where no additional management inputs have been used.
- ***High*** applies to grasslands classified as improved, and where one or more additional management inputs/improvements have been used (beyond that required to be classified as improved grassland).

**Table 14 Potential change in annual carbon stock (t $CO_2$/ha/yr) in soil at 30 cm depth from converting severely degraded grazing land to improve with: a. low inputs to medium inputs and b. low to high inputs**

| Region | Country | Tropical, Moist | | Lower Montane, Dry | | Lower Montane, Moist | |
|---|---|---|---|---|---|---|---|
| | | Low to Medium Inputs | Low to High Inputs | Low to Medium Inputs | Low to High Inputs | Low to Medium Inputs | Low to High Inputs |
| East Africa | Ethiopia | 3.4 | 4.4 | 3.2 | 4.1 | | |
| | Kenya | | | 4.0 | 5.2 | | |
| | Tanzania | 4.6 | 5.9 | 4.3 | 5.6 | | |
| | Uganda | 2.2 | 2.8 | 2.7 | 3.5 | 4.4 | 5.7 |
| West Africa | Burkina Faso | 3.4 | 4.4 | | | | |
| | Ghana | 3.3 | 4.2 | | | | |
| | Mali | 3.4 | 4.3 | | | | |
| | Niger | | | | | | |
| | Senegal | 2.1 | 2.6 | | | | |

## 5.4 Converting Mosaic Vegetation to Native Ecosystems

Of the four changes in land use analysed here, converting combined mosaic cultivation to native ecosystem shows the highest potential in annual soil carbon stock change reaching 8.4 t $CO_2$ hayr in Ghana's tropical dry climate (Table 15). However, this varied greatly across the countries and zones with an annual carbon stock change of as little as 1.1 t $CO_2$/ha/yr in Senegal's tropical moist climate (of limited area). The West African countries have higher rates of C sequestration in soil in the dry zone than in the moist zone. As above, for converting rainfed cropland to native vegetation, inclusion of the carbon sequestration in vegetation (assumed that the initial stock in vegetation is equivalent to that in shrubland in the region) would result in sequestration rates between 10-13 t $CO_2$/ha/yr in the moist zone and about 5-12 t $CO_2$/ha/yr in the dry zone of East and West African countries.

**Table 15 Annual carbon stock change potential (t $CO_2$/ha/yr) in soil at 30 cm depth and in vegetation for converting combined mosaic cultivation to native ecosystems**

| Region | Country | Tropical, Moist | Tropical, Dry | Tropical Moist-soil & Vegetation | Tropical Dry-Soil & Vegetation |
|---|---|---|---|---|---|
| East Africa | Ethiopia | 5.0 | 2.0 | 13.2 | 5.5 |
| | Kenya | 1.6 | | 9.8 | |
| | Tanzania | 4.3 | 3.7 | 12.6 | 7.2 |
| | Uganda | | 6.0 | | 9.5 |
| West Africa | Burkina Faso | 2.6 | 1.5 | 10.9 | 5 |
| | Ghana | 2.1 | 8.4 | 10.4 | 11.8 |
| | Mali | 1.7 | 7.4 | 10 | 10.9 |
| | Niger | 1.9 | | 10.1 | |
| | Senegal | 1.1 | 1.4 | 9.3 | 4.9 |

## 5.5 Comparison of Potential Mitigation Factors by Practice

It is clear that to have a larger mitigation effect, agricultural practices that include use of vegetation will result in higher quantities of carbon sequestration (Table 16), though converting croplands to native ecosystems will have an opportunity cost in lost crop production. However, converting croplands to agroforests has some of the highest total mitigation potential with the added benefit of little to no opportunity cost, and depending on the multipurpose trees planted could produce a financial benefit. Improving management of degraded grazing lands through increasing inputs can increase soil carbon stocks similar in magnitude to changing tillage and inputs on croplands, but in the case of grazing lands there would be minimal opportunity cost.

**Table 16 Comparison of carbon sequestration factors, in in t $CO_2$e/ha/yr, for changes in agricultural practices for East and West African focal countries**

| Agricultural activity | East Africa | West Africa |
|---|---|---|
| Rainfed croplands | | |
| Change tillage and inputs | 0.5-5 | 0.4-3 |
| Convert to native ecosystems | 7-13 | 5-12 |
| Convert to agroforests | 6-22 | 7-21 |
| Improve management of degraded grazing lands | 2-6 | 2-4 |
| Convert mosaic lands to native ecosystems | 6-12 | 5-11 |

## 5.6 Next Steps in Mitigation Potential Assessment

Further analyses are needed to improve the estimates of the mitigation potential through additional activities. For these activities, scientific research is required plus country-specific information on current practices.

### 5.6.1 Improvements in quantification of soil C sequestration from changes in soil management

The estimates given above in section 5.1 indicate that the mitigation potential from changing tillage practices directly correlates with the level of inputs with shifts from low to high inputs with manure providing the greatest mitigation potential. However, it is unclear what actual tillage/input combinations are currently practiced in the focal countries and what the potential is for change, including how to overcome economic and cultural barriers. Further specific studies are needed to better quantify the initial soil carbon stocks under present practices and how changed tillage practices with different levels of input change the soil carbon stocks and the level of crop production.

### 5.6.2 Increasing fertilization to decrease deforestation

As discussed at the start of section 5, the potential exists to increase fertilizer use thereby increasing yields and by result decreasing demand for more agricultural areas from conversion of native ecosystems. It is also likely that increased use of fertilizer in combination with changes in tillage practices will enhance soil carbon stocks (see also section 5.1 and above). As stated above the emissions from a hectare of forest in many of the focal countries is equivalent to 38 tons of N fertilizer application while the highest annual country-wide average application detailed in this report was just 6 kg per hectare per year (although rates of up to 10-100 kg/ha have been reported for several key crops in several of the focal countries[17]). To further detail the mitigation potential of fertilizer application, more data are needed on the relationship between fertilizer application and crop yields and a better spatial understanding of which areas in each country should be considered as "bread basket" agricultural lands and which should be viewed as low productivity lands.

### 5.6.3 Evaluation of alternatives for fires management / methods for fire control

As shown in section 4.2, fire use during grazing land management represents a significant source of emissions. With currently available data it is not possible to know the degree to which emissions can be reduced. Are there alternatives to the use of fire for land management? Where fire use is necessary, where are fires getting out of control and causing emissions outside the specific management area? And associated to this, what new activities could be put in place to better manage livestock production while at the same time reduce the use of fire?

It not clear to what extent grazing lands are degraded in the focal countries, but opportunities exist to increase the C stocks in soil with nutrient inputs (fertilization and/or improved manure management) along with improved management of grazing stock. To fully realize the mitigation potential more knowledge is needed on identifying which lands can be managed and what practices are best suited to restore the degraded lands (reduce fire, increase nutrient inputs, and/or change grazing practices).

### 5.6.4 Evaluation of rice cultivation practices and emission reduction potential

In this report we were unable to detail emissions associated with rice cultivation due to the inability to define area of rice cultivation and rice cultivation practices. Worldwide it is estimated that rice production is responsible for about 25% of anthropogenic $CH_4$ emissions (Denman et al. 2007). Rice emissions may be decreased through a range of practices including:

- Draining wetland rice once or several times each growing season;
- Using rice cultivars with low exudation rates;
- Drying soils during off-growing season;
- Adusting timing of residue incorporation and/or composting prior to incorporation.

To evaluate the potential for mitigation in the focal countries would require country specific information on rice cultivation areas and rice cultivation practices.

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[17] http://www.fao.org/ag/agl/fertistat/; data for 1997

## Conclusion/recommendations

Croplands and grazing lands covered more than half of the East African countries' lands and about 40% of the West African countries' lands in 2006. Grazing lands exceeded the area of cropland in West African countries, whereas cropland exceeded the area of grazing lands in East African countries. Most croplands were rainfed (about 65% of all croplands).

The total amount of GHG emissions from the nine African countries was almost 129 million t $CO_2$e/yr in the mid-2000s. The largest amount of GHG emissions was from the livestock sector, mostly methane from enteric fermentation as expected (83% of the total), followed by emissions from soil only from due to the conversion of native ecosystems to cropland (11% of the total). Emissions from use of fertilizer are lower than all other sources and represent just 0.7% of the total emissions. Despite the large area of grazing lands burned each year (about 9 million ha), the emissions of $CH_4$ and $N_2O$, as $CO_2$e, represent about 4% of total emissions.

The uncertainty in the baselines estimates of GHG emissions is high but there are many other ways by which this analysis could be improved. Some of the key steps **recommended** for improving baselines for GHG emissions from agricultural practices against which any future improvements in practices could be monitored include:

- Reduce the scale of analysis to **key** agricultural areas of each country,
- Use higher resolution remote sensing data to obtain more accurate data on land cover/land use and area burned;
- Improvements in monitoring and reporting the number of ruminant animals,
- Improvements in quantifying use of N fertilizer in agriculture;
- Improved estimates of carbon stocks of burned areas of grazing lands that could lead to improved methods and emission factors for these sources of GHG emissions.

Emissions of GHGs from agriculture are substantial and beg the question—what opportunities exist to reduce these emissions or even to increase sequestration? Given the common practices and magnitude of GHG emissions from livestock and fire in all of these countries, it is unlikely that very much can be done in the near future to reduce these emissions. And, given the low emissions from use of N fertilizers and the low intensity of use **there is an opportunity to increase the rate of application to improve crop production and at the same time reduce the need to clear native ecosystems for new croplands** (the second largest source of $CO_2$ emissions). Instead, we focused on those potential mitigation activities that enhance carbon in soil and vegetation. We found that the change in practices that included soil only resulted in carbon sequestration rates of about 0.4 to 5 t $CO_2$e/ha/yr and for changes that included in soil and vegetation (agroforests and conversion of marginal lands to native ecosystems) of about 6 to 22 t $CO_2$e/ha/yr.

Further analyses are needed to improve the estimates of the mitigation potential through additional activities. For these activities, scientific research is required plus country-specific information on current practices. Some key areas of further investigation are:

- Improvements in quantification of soil C sequestration from changes in soil management, including better understanding of present practices and how these can be realistically changed;

- Increasing fertilization of croplands to increase productivity and thus decrease the need to deforest new lands;
- Evaluation of alternatives for fire management and methods for fire control;
- Develop new techniques for improving management of grazing stock, and more knowledge is needed on identifying which lands can be managed.

# Annex A  Area burned between 2001-2007

The following table summarizes the annual area of grazing lands that were burned each year (burned area data from (http://www-tem.jrc.it/Disturbance_by_fire/products/burnt_areas/index.htm)

| Country | Total grazing (ha) | Burned 2001-02 (ha) | Burned 2001-02 (%) | Burned 2002-03 (ha) | Burned 2002-03 (%) | Burned 2003-04 (ha) | Burned 2003-04 (%) | Burned 2004-05 (ha) | Burned 2004-05 (%) | Burned 2005-06 (ha) | Burned 2005-06 (%) | Burned 2006-07 (ha) | Burned 2006-07 (%) | Total burned 2000-2007 (ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ethiopia** | 17,087,154 | 2,081,353 | 12% | 2,207,691 | 13% | 2,755,515 | 16% | 2,419,583 | 14% | 2,204,431 | 13% | 2,447,304 | 14% | **14,115,877** |
| **Kenya** | 15,947,157 | 399,042 | 3% | 416,984 | 3% | 463,255 | 3% | 459,456 | 3% | 423,480 | 3% | 450,802 | 3% | **2,613,019** |
| **Tanzania** | 34,074,096 | 4,207,124 | 12% | 3,230,966 | 9% | 4,149,291 | 12% | 2,899,654 | 9% | 3,064,524 | 9% | 1,991,601 | 6% | **19,543,159** |
| **Uganda** | 3,368,303 | 888,658 | 26% | 798,788 | 24% | 947,781 | 28% | 988,237 | 29% | 1,419,808 | 42% | 853,690 | 25% | **5,896,963** |
| **Burkina Faso** | 7,970,835 | 593,721 | 7% | 463,794 | 6% | 817,949 | 10% | 490,812 | 6% | 493,626 | 6% | 588,561 | 7% | **3,448,463** |
| **Ghana** | 7,926,040 | 820,294 | 10% | 780,144 | 10% | 1,698,469 | 21% | 530,001 | 7% | 802,517 | 10% | 899,001 | 11% | **5,530,426** |
| **Mali** | 21,469,398 | 366,021 | 2% | 113,416 | 1% | 737,976 | 3% | 189,613 | 1% | 512,060 | 2% | 799,164 | 4% | **2,718,249** |
| **Niger** | 24,594,781 | 6,965 | 0% | 23,593 | 0% | 32,927 | 0% | 2,111 | 0% | 19,700 | 0% | 19,653 | 0% | **104,949** |
| **Senegal** | 5,422,169 | 445,947 | 8% | 207,389 | 4% | 571,300 | 11% | 314,285 | 6% | 673,506 | 12% | 593,369 | 11% | **2,805,797** |

# Annex B GHG Inventories

The majority of the focal countries in this study, with the exception of Uganda, (which used the 1995 version) use the methodologies in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (*Revised 1996 Guidelines*) to estimate anthropogenic GHGs in their agricultural sector.

The first iteration of the *IPCC Guidelines for National Greenhouse Gas Inventories* were accepted in 1994 and published in 1995. The *1996 Revised Guidelines* consist of three volumes that cover topics such as reporting instructions, the GHG inventory workbook, and GHG inventory reference manual. The GHG workbook provides instructions on how to calculate emissions of carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) from major agriculture emission sources (as well as all other sectors).

The agriculture module demonstrates how to calculate greenhouse gas emissions from five agricultural sources, with each sector having specific activity data and emission factors.

- Domestic Livestock: Enteric Fermentation and Manure Management
- Rice Cultivation
- Prescribed Burning of Savannas
- Field Burning of Agricultural Residue
- Agricultural Soils

Sources of data used in the emission estimates' vary from country specific to IPCC default factors. Most of the activity data are for the early 1990s. The following tables describe the emission estimates from agriculture sector for the nine focal countries and the data sources used.

### Table B-1 GHG Sources in the Agriculture Sector for the Focal West Africa Countries (1 Gg = 1000 tons)

| Country | GHG Sources and Sinks | $CH_4$ (Gg) | $N_2O$ (Gg) | Nox (Gg) | CO (Gg) | $CO_2e$ (Gg) |
|---|---|---|---|---|---|---|
| **Burkina Faso** | Agriculture - for 1994 | 214.32 | 0.67 | 4.11 | 192.98 | 4708.4 |
| | A. Enteric Fermentation | 196.8 | | | | 4132.8 |
| | B. Manure Management | 9.2 | | | | 193.2 |
| | C. Rice Cultivation | 0.72 | | | | 15.12 |
| | D. Prescribed Burning of Savannas | 6.38 | 0.08 | 2.85 | 167.38 | 158.78 |
| | E. Field Burning of Agricultural Residue | 1.22 | 0.03 | 1.26 | 25.6 | 34.92 |
| | F. Agricultural Soils | | 0.56 | | | 173.6 |
| **Ghana** | Agriculture - for 1994 | 220.60 | 2.01 | | | 6179.143 |
| | A. Enteric Fermentation | 61.60 | | | | 1587.857 |
| | B. Manure Management | | | | | |
| | C. Rice Cultivation | 3.88 | | | | 107.4571 |
| | D. Prescribed Burning of Savannas | 154.00 | 1.91 | | | 4384 |
| | E. Field Burning of Agricultural Residue | 1.03 | 0.04 | | | 31.84571 |
| | F. Agricultural Soils | | 0.06 | | | 24.1 |
| **Mali** | Agriculture - 1995 | 334.92 | 1.78 | | | |
| | A. Enteric Fermentation | 277.88 | | | | |
| | B. Manure Management | | 1.65 | | | |
| | C. Rice Cultivation | 48 | | | | |
| | D. Prescribed Burning of Savannas | 6.696 | 0.09 | 3.55 | 209.39 | |
| | E. Field Burning of Agricultural Residue | 1.7484 | 0.0402 | 1.681 | 69.1917 | |
| | F. Agricultural Soils | | | | | |
| **Niger** | Agriculture for - 2000 | 286 | 15 | 0 | 10 | |
| | A. Enteric Fermentation | 271 | | | | |
| | B. Manure Management | 12 | 0 | | | |
| | C. Rice Cultivation | 2 | | | | |
| | D. Prescribed Burning of Savannas | 0 | 0 | 0 | 6 | |
| | E. Field Burning of Agricultural Residue | 0 | 0 | 0 | 4 | |
| | F. Agricultural Soils | | 15 | | | |
| **Senegal** | Agriculture - for 2000 | 213.38 | 5.74 | 0.79 | 14.72 | 627589 |
| | A. Enteric Fermentation | 197.87 | | | | |
| | B. Manure Management | | | | | |
| | C. Rice Cultivation | 14.81 | | | | |
| | D. Prescribed Burning of Savannas | | | | | |
| | E. Field Burning of Agricultural Residue | 0.7 | 0.02 | 0.79 | 14.72 | |
| | F. Agricultural Soils | | 5.72 | | | |

### Table B-2 Methods and data sources used by Burkina Faso in estimating their GHG emissions from the agriculture sector

| Country and Methodology | GHG Source | Activity Data | Data Source |
|---|---|---|---|
| **Burkina Faso- 1996 IPCC Methodology** | A. Enteric fermentation | Major sources of GHG emissions: cattle, sheep, goats and poultry average from 1993-1995. Estimations were based on a 2% growth rate for cattle, 3% for sheep, poultry and goats. The country used default emission factors provided by the IPCC. They applied a 20% reduction in emissions to sheep, goats, camels, horses, donkeys and pigs because of poor raising conditions, in accordance with volume 2 of the IPCC. | Enquête Nationale sue les Effets du Cheptel (ENEC, 1990); IPCC |
| | B.Manure Management | Data used are based on those available from biogas installations | Enquête Nationale sue les Effets du Cheptel (ENEC, 1990); IPCC. Manuel de Zootechnie en Region chaudes and by LHOSTE (1993) |
| | C. Rice Cultivation: Flooded Rice Fields | Rice is mostly produced from irrigation. Family farms were not taken into consideration | L'INERA |
| | D. Prescribed Burning of Savannahs | Do not have access to spatial analysis. Information was extrapolated from the IPCC. | IPCC |
| | E. Field Burning of Agricultural Residue | In the centre of the country a local study was conducted from 1990 to 1991, and found that 45-49% of residues are collected as fuel (90%), feed (7%), building (3%). 55-51% of residues remain on site as feed and to be incinerated. Although there is national data for residue/grain ratios for sorghum, maize, and mil the fractions and other information was drawn from IPCC. Biomass emission factor used: 29.9 | IPCC and SP/CONAGESE (1999) for emission factor |
| | F. Agricultural Soils | The emission factors and the ratio of nitrogen burned or excreted are provided by the IPCC. The rest of the data on nitrogen fixing flora and fertilizers used is provided by field studies conducted in Burkina Faso. Data on non-nitrogen fixing data (sorghum, mil, maize, and rice) are averaged over 1993-1995 and multiplied by 0.85 to get the dry weight. Emissions from histosols were estimated to be 0. Emissions come from cultivated soils. | IPCC,BUNASOLS |

## Table B-3 Methods and data sources used by Ghana in estimating their GHG emissions from the agricultural sector

| Country and Methodology | GHG Source | Activity Data | Data Source |
|---|---|---|---|
| **Ghana - 1996 IPCC revised methodology** | Country activity data was collected to the extent possible with IPCC default factors employed where country data were not available. However, we were not able to locate more specific information. | | |

## Table B-4 Methods and data sources used by Mali in estimating their GHG emissions from the agricultural sector

| Country and Methodology | Emitting Activity | Activity Data | Data Source |
|---|---|---|---|
| **Mali - 1996 IPCC Methodology. All emission factors are default IPCC emission factors** | A. Enteric Fermentation | Animals used: cows, goats, sheep, camels, horses, pigs, donkeys | Document des inventaires de GES de 1995 au Mali CNRST/Mali |
| | B. Manure Management | Emission from manure management are low because cattle are not enclosed and there are low levels of it. However there is a need to use more manure in agriculture, but in this case there is frequent rotation of cattle from enclosed areas to the field and so emissions remain low | IPCC 1993 : Guide d'Inventaire des émissions de GES |
| | C. Rice Cultivation | Rice cultivation is the main source of methane in Mali, with naturally flooded, low lying, flood controlled, gravity irrigated, and rain fed rice cultures. Used IPCC methodology to calculate emissions | Centre National de la Recherche Scientifique et Technologique (CNRST)/Mali; IPCC |
| | D. Prescribed Burning Savannah | The national data provided is incomplete only covering 3% of the 9191.42 ha burned yearly, so estimates were based on SPOT infra-red imagery at a 1 : 200,000 scale | Direction Nationale des Ressources Forestières Faunique et Halieutique (DNRFFH); SPOT |
| | E. Field Burning of Agricultural Residue | Burning occurs at the end of the dry season before which some of the residue is used by farmers for various purposes. Used IPCC emission factors and coefficients IPCC default data | Rapport annuels de la Direction national de l'Agriculture (DNA, 1995); DNSI/DNA, DIAPER, CILSS, PNUD, PANEM, 1995, : Rapport de campagne; IPCC |
| | F. Agricultural Soils | Cultivated land represents 12% of the country's total area and 37% of suitable agricultural land. Losses in organic matter: 542 kg/ha; nitrogen 31kg/ha | PNAE-CID, MDRE 1996; Project UNDP/RAF/93/G31 et MIL/97/G32 CNRST (Bamako) |

## Table B-5 Methods and data sources used by Niger in estimating their GHG emissions from the agricultural sector

| Country and Methodology | GHG Source | Activity Data | Data Source |
|---|---|---|---|
| **Niger - 1996 IPCC revised methodology** | A. Enteric fermentation | There are three types of livestock production. 1) Pastoral; 2) agro-pastoral; 3) Intensive. Level 1 method was used in the absence of disaggregated data on animal population and on specific emission factors. To estimate emissions, a distinction was made between dairy and meat cows since the former represent 15% of the total number of cattle head, according to the Ministry in charge of Animal Resources. | National Institute of Statistics (INS) for pigs and poultry, and Direction of Livelihood Statistics and Animal Products Direction (DSE/PA). |
| | B. Manure Management | Manure management represents the most important source of methane emissions in the agricultural sector. The evolution of emission values of time series correlates with the evolution of the cattle population. Therefore, uncertainties still linger as in the case of CH4 emissions from enteric fermentation. Manure from N2O is almost inexistent. | |
| | C. Rice Cultivation: Flooded Rice Fields | Only data on land areas under irrigated rice production has been considered. This area amounted to 12,118 hectares in 2000. Water management regime considered for the two types of rice production are the permanent flooding for large-scale irrigation scheme and the rain flood for rain-fed rice respectively. | ONAHA 2005 Report |
| | D. Prescribed Burning of Savannahs | National Communication did not go into detail | |
| | E. Field Burning of Agricultural Residue | Crop residues are increasingly used by producers for other purposes (cattle feeding, fuels, etc.) and are therefore collected after harvesting. Hence, burning of crop residues is not very common in Niger. This activity is a source of N2O, NOx and CO emissions even if the quantities burnt on-site are not very significant. | |
| | F. Agricultural Soils | The total quantity of fertilizers used in the country (kg of N/year) is equal to the total nitrogen content in the total quantity of the various types of fertilizers used each year. These include: urea with 46% of nitrogen for 100 kg of urea, 15-15-15 with 15% of nitrogen, DAP with 18% of nitrogen;<br>· the quantity of grain legumes produced in the country (kg/year) refers to the total production of the following crops: cowpea, groundnut, sesame, onion, pepper, garlic;<br>· Rain-fed crops (kg/year) include: millet, sorghum, rice, maize and bambara groundnut. | 2005 Report, DCV/MDA; fertilizer production: 2004/2005 annual reports of DCV and Direction des Cultures de Rentes (DCR) and Centrale d'Approvisionnement 2006 of MDA. |

### Table B-6 Methods and data sources used by Senegal in estimating their GHG emissions from the agricultural sector

| Country and Methodology | GHG Source | Activity Data | Data Source |
|---|---|---|---|
| **Senegal - 1996 IPCC revised methodology** | A. Enteric fermentation | Average of population from 1999-2001; herd age; weight; milk production; feed; growth; workload etc. Estimations for cattle were done with level two methodologies because of the availability of local emission factors. Default IPCC factors were used for other categories | (Direction de L'Elevage)DIREL |
| | Manure Management | Little data is available for manure management. Therefore default data was used. | (Direction de L'Elevage)DIREL |
| | C. Rice Cultivation: Flooded Rice Fields | Used national date from 1999-2001. Default emission factors were used. | Association pour le Développement de la riziculture en Afrique de l'Ouest (ADRAO) |
| | D. Prescribed Burning of Savannahs | They included this in the forestry sector | |
| | E. Field Burning of Agricultural Residue | SODEFITEX provided data for cotton, CSS for sugar cane and DAPS for cereal over and average from 1999-2001; National data was not available for the cultivated/residue ratios and the dry matter data were not available on the national scale for mil, sorgho, maiz, rice and cotton so default values were used. Biogas is taken into account in the energy sector. A default value was also used for the combustion of cane sugar stems before cultivation (6.5 t of dry matter/ha). | Société de Développement de Fibres et Textiles (SODEFITEX); Compagnie Sucrière Sénégalaise (CSS); Direction de l'Analyse, de la Prévision et des Statistiques (DAPS). |
| | F. Agricultural Soils | National data on fertilizer was provided by SENCHIM; Direction de l'horticulture for march vegetation, SODEFITEX for cotton, CSS for sugar cane and DAPS for cotton and other vegetables (peanut, niebe and green beans) N2 emissions were not accounted for because they are of cultivated organic soils is not known. Manure was part of the calculation but it data is not well known on the national scale. Poultry manure was considered for peppers and onions with an N2 concentration of 35 kg/ton | SODEFITEX; CSS; DAPS; SENCHIM; Thiam (2007) |

## Table B-7 GHG Sources in the Agriculture Sector for the Focal East Africa Countries (1 Gg = 1000 tons)

| Country | GHG Sources and Sinks | $CH_4$ (Gg) | $N_2O$ (Gg) | Nox (Gg) | CO (Gg) |
|---|---|---|---|---|---|
| **Ethiopia** | Agriculture - for 1994 | 1,540 | 20 | 74 | 4,004 |
| | A. Enteric Fermentation | 1,337 | | | |
| | B. Manure Management | 50 | | | |
| | C. Rice Cultivation | | | | |
| | D. Prescribed Burning of Savannas | | 18 | | |
| | E. Field Burning of Agricultural Residue | 148 | 2 | 66 | 3,895 |
| | F. Agricultural Soils | 5 | 0 | 7 | 109 |
| **Kenya** | Agriculture - for 1994 | 576 | 0 | 0 | 0 |
| | A. Enteric Fermentation | 549 | | | |
| | B. Manure Management | 23 | 0 | | |
| | C. Rice Cultivation | 3 | | | |
| | D. Prescribed Burning of Savannas | | | | |
| | E. Field Burning of Agricultural Residue | 0 | 0 | 0 | |
| | F. Agricultural Soils (synthetic fertilizer) | | 0 | | |
| **Tanzania** | Agriculture - for 1989 | 1,336 | 2 | 42 | 2,309 |
| | A. Enteric Fermentation | 872 | | | |
| | B. Manure Management | 8 | | | |
| | C. Rice Cultivation | 85 | | | |
| | D. Prescribed Burning of Savannas | 48 | 1 | 21 | 1,255 |
| | E. Field Burning of Agricultural Residue | 323 | 1 | 21 | 1,053 |
| | F. Agricultural Soils (nirtogen fertilizer) | | 1 | | |
| **Uganda** | Agriculture - for 1994 | 198,392 | 40 | 1,174 | 16,867 |
| | A. Enteric Fermentation | 197,400 | | | |
| | B. Manure Management | 7 | | | |
| | C. Rice Cultivation | 24 | | | |
| | D. Prescribed Burning of Savannas | 960 | 40 | 1,165 | 16,830 |
| | E. Field Burning of Agricultural Residue | 2 | 0 | 9 | 37 |
| | F. Agricultural Soils | | 0 | | |

## Table B-8 Methods and data sources used by Ethiopia in estimating their GHG emissions from the agricultural sector

| Country and Methodology | GHG Source | Activity Data | Data Source |
|---|---|---|---|
| **Ethiopia - Revised 1996 IPCC Methodology** | A. Enteric Fermentation | Enteric fermentation accounts for 87% of methane from Ethiopia's Agriculture sector stemming from the quality and quantity of feed consumed by ruminant animals. | (Wondwosen et al. 2000), Central Statistical Authority (CSA), FAO, Ministry of Agriculture (MoA) |
| | B. Manure Management | Manure management systems that promote anaerobic conditions such us liquid/slurry storage facilities and anaerobic lagoons produce the most methane | Central Statistical Athority (CSA), FAO, Ministry of Agriculture (MoA) |
| | C. Rice Cultivation: | Not practiced in Ethiopia | Central Statistical Authority (CSA), FAO, Ministry of Agriculture (MoA) |
| | D. Prescribed Burning of Savannas | Main source of CO and NOx in Ethiopia | Central Statistical Authority (CSA), FAO, Ministry of Agriculture (MoA) |
| | E. Field Burning of Agricultural Residue | Heating value (mj/kg): 15.5 | Ethiopian Energy Authority Data Base; Central Statistical Athority (CSA), FAO, Ministry of Agriculture (MoA) |
| | F. Agricultural Soils | Fertiliser use mainly responsible for $N_2O$ emissions in agriculture sector which is responsible for 81% if $N_2O$ emissions | Central Statistical Authority (CSA), FAO, Ministry of Agriculture (MoA) |

**Table B-9 Methods and data sources used by Kenya in estimating their GHG emissions from the agricultural sector**

| Country and Methodology | GHG Source | Activity Data | Data Source |
|---|---|---|---|
| **Kenya - Revised 1996 IPCC Methodology** | A.Enteric fermentation | livestock reared on range and paddocks mostly | Central Bureau of Statistics, Ministry of Agriculture with IPCC default value to fill in the gaps. IPCC |
| | B.Manure Management | Confinement in stalls is practiced in pig farming from which manure is often stored in solid form around stalls. | Central Bureau of Statistics, Ministry of Agriculture with IPCC default value to fill in the gaps. IPCC |
| | C. Rice Cultivation | 90% of rice is paddy rice that is grown under conditions of conitnuous flooding. There are 15,000 ha of rice in Kenya | Central Bureau of Statistics, Ministry of Agriculture with IPCC default value to fill in the gaps. IPCC |
| | D. Prescribed Burning of Savannas | Not included in in National Communication | Central Bureau of Statistics, Ministry of Agriculture with IPCC default value to fill in the gaps. IPCC |
| | E. Field Burning of Agricultural Residue | 25% is the fraction taken of ag residue that is burned in the field for crops like rice, millet and sorghum, while 75% and 100% is the corresponding ratio for maize and sugarcan respectively. According to IPCC guidelines an amount equal to the emissions is taken up by crops that grow during each year | Central Bureau of Statistics, Ministry of Agriculture with IPCC default value to fill in the gaps. IPCC |
| | F. Agricultural Soils | Only direct emissions have been computed. Fertilizer use: 25 kg/ha | Central Bureau of Statistics, Ministry of Agriculture with IPCC default value to fill in the gaps. IPCC |

**Table B-10 Methods and data sources used by Tanzania in estimating their GHG emissions from the agricultural sector**

| Country and Methodology | GHG Source | Activity Data | Data Source |
|---|---|---|---|
| **Tanzania - Revised 1996 IPCC Methodology** | A.Enteric fermentation | Dairy cattle were limited to pregnant and milked exotic species, the rest were considered to be non-dairy cattle. Activity data in 1990 surveys [14,15,16] and emission factors generated using Tier 1 approach[3] were used to estimate methane from enteric fermentation. FAO data were high for non-dairy cattle and low for dairy cattle. | MoA (1994), Kishimba (1995); Sechambo et al (1995); Makwetta (1995) |
| | B.Manure Management | $N_2O$ emissions were estimated from animal waste management systems such as liquid systems and storage of animal waste in heaps of drylots for more than one month | |
| | C. Rice Cultivation | Not clear about method/data used | |
| | D. Prescribed Burning of Savannas | Carbon not included. Part of closed carbon cycle. For non-$CO_2$ emissions the emission factors are based on experience gained in West Africa and Latin America | IPCC |
| | E. Field Burning of Agricultural Residue | Field burning of agricultural residues in this inventory focuses cotton stalks, rice husks and sugarcane leaves. The activity data were estimated from crop production[1,12], while the emission factors were developed by the local experts and reported in 1994[1] | IPCC, MoA (1993) |
| | F. Agricultural Soils | This inventory covers $N_2O$ emissions related to the use of both organic and inorganic fertilisers, biological Nitrogen fixation, and $N_2O$ emissions from human sewage, and leaching. Although the literature provided bits and pieces, the major ones of controversy include the records of nitrogenous fertiliser imports, type and coverage of histosol[15] and estimation of production of pulses and non-nitrogen fixing crop. | Kishimba (1995) |

*Note: Agricultural activity data is crude and is based on the interpretation of cash crop yields, fertilizer imports and annual exports.*

**Table B-11 Methods and data sources used by Uganda in estimating their GHG emissions from the agricultural sector**

| Country and Methodology | GHG Source | Activity Data | Data Source |
|---|---|---|---|
| **Uganda - 1995 IPCC Guidelines** | A.Enteric fermentation | Country activity data was collected to the extent possible with IPCC default factors employed for all data. However, we were not able to locate more specific information | National Census of Agriculture and Livestock (1990 - 1991) |
| | B.Manure Management | | National Census of Agriculture and Livestock (1990 - 1991) |
| | C. Rice Cultivation | | |
| | D. Prescribed Burning of Savannas | | Department of Agriculture |
| | E. Field Burning of Agricultural Residue | | Department of Agriculture |
| | F. Agricultural Soils | | Department of Agriculture |

*Note: Default factors were used for all*

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