ACCOUNTING SYSTEM FOR NON-CO_2 GREENHOUSE GASES

WESTERN KENYA INTEGRATED ECOSYSTEM MANAGEMENT PROJECT

World Agroforestry Centre

TRANSFORMING LIVES AND LANDSCAPES

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1. Introduction

The current emissions of non-CO_2 greenhouse gases from the project blocks will be estimated using the methods described in the IPCC "Revised 2006 Guidelines for National Greenhouse Gas Inventories" and "Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories", also published by the IPCC. Non-CO_2 gases will only be accounted for in the project specific baseline. Although the IPCC methods are designed for national inventories, in the absence of approved methods for project-based estimations, we have adapted these national methods for the project area. However, the level of aggregation implicit in this method is not very applicable to the objectives of the project. We will attempt to develop a better approach to estimating these fluxes at the project level over the life of the project.

This manual presents the general approach to GHG accounting in the WKIEMP project, which is based on a net-net approach to accounting for emissions and removals by sinks associated with land management and land cover change.

Our approach will use the so-called Tier 1 methods in all cases, initially, and we will develop Tier 2 or Tier 3 approached as warranted during the execution of the project. In general, country specific factors have not been developed for Kenya in the agriculture sector, as this sector is not considered a significant[1] source. For our purposes, and given the large degree of variability between the different agroecological zones of the country, region specific factors will be required to improve the accuracy of the estimates based on default factors. Over the course of the project we will develop the emissions factors to allow us to estimate a baseline using Tier 2 methods for all significant sources. Tier 2 accounting will also be used for significant sources in the monitoring and evaluation of the project.

In general, we will present the decisions made at each node of the IPPC decision trees in the Good Practices Guidance. We then present the equation for the Tier 1 estimate, a table that summarizes the calculations, the source of the data to be used for the calculation and a description of the sources of uncertainty in the estimate. The relevant decision trees and tables are appended at the end of this document. The following sections describe methods that will be used to refine these estimates.

[1] A source is considered to be significant if it accounts for between 25-30% of the emissions from the source category.

2. Calculating baselines: plot to region

We will assess regional baselines using mixed-effects models. Mixed models provide a flexible extension of generalized linear models, intended specifically for analyses of grouped data including longitudinal data, repeated measures, blocked designs and multilevel data among others (Pinheiro and Bates, 2000). In this particular case grouped data structures occur as a consequence of sampling at multiple spatial scales across a large project area. Thus, plot-level measurements are grouped within clusters, which are in turn grouped within 10×10 km blocks. Each level is replicated several times, and is associated with specific length or area dimensions. The following linear mixed effects model represents the grouped structure as:

$$y_{ij} = \mathbf{X}_{ij}\beta + \mathbf{Z}_{i,j}b_i + \mathbf{Z}_{ij}b_{ij} + \varepsilon_{ij} \quad (21.)$$

where:

y_{ij} = a two-level grouped response variable (e.g., clusters within FA's), $i = 1 \ldots m$, $j = 1 \ldots m_i$

$\mathbf{X}_{ij}$ = a fixed effects design matrix,

β = unknown fixed effects coefficients,

$\mathbf{Z}_i$ = a $p_i \times r$ design matrix,

b_i = an unknown $r \times 1$ vector of random coefficients, assumed to be independently distributed across plots with distribution $\gamma_i \sim N(0, \sigma^2\mathbf{B})$, for which $\mathbf{B}$ is a *between* subject variance-covariance matrix,

ε_{ij} = within-group error term distributed as $\varepsilon_{ij} \sim N(0, \sigma^2\mathbf{I})$, where $\mathbf{I}$ is a *within* subject covariance matrix.

Generalizations to higher levels of grouping (e.g. plots / clusters / FA's / Elevation zones) are straightforward (see Pinheiro and Bates, 2000). Distributions for all the relevant levels of grouping will initially be assumed to be independently and normally distributed with zero mean, but these assumptions may be modified should they prove to be inappropriate[2]. Models of this type may be fit by different methods including, maximum likelihood (ML), restricted maximum likelihood (REML) and Markov chain Monte Carlo (MCMC) simulation, which under certain circumstances can provide qualitatively different results. Convergence between different methods is generally indicative of stable parameter

[2] There are a variety of diagnostics available for checking this (see Pinheiro and Bates, 2000).

estimates and will be assessed. Once a stable model formulation has been found, best linear unbiased predictions (BLUP's) of variations in response variable (incl. confidence intervals etc.) can be generated at any given level in the multilevel structure. This provides an explicit mechanism for scaling observations from plot-to-region.

3. IPCC Guidelines for non-CO_2 GHG Accounting

Non-CO_2 emissions are derived from a variety of sources, including emissions from soils, livestock and manure and from combustion of living and dead biomass and litter. In contrast to the way that CO_2 emissions are estimated from biomass stock changes, emissions of non-CO_2 GHGs usually involves estimating a rate from an emission source directly to the atmosphere. The rate (Equation 2.6) is generally determined by an emission factor for a specific gas (e.g. CH_4, N_2O) and source category and an area (e.g. for soil or area burned), population (e.g. for livestock) or mass (e.g. for biomass or manure) that defines the emission source.

EQUATION 2.6
NON-CO_2 EMISSION RATES

$$F = A \bullet EF$$

Where:

A = the size of the emission source (can be area, animal numbers or mass unit, depending on the source type)

EF = emission factor for a specific gas and source category

Many of the emissions of non-CO_2 GHGs are either associated with a specific land use (e.g. CH_4 emissions from rice) or are typically estimated from aggregate data (e.g. CH_4 emissions from livestock and N_2O emissions from managed soils). Emissions that are generally based on aggregated data are dealt with separately

3.1 Identification of 'Key Categories'

The IPCC 2006 Guidelines recommend that as far as possible, *key categories* should receive special consideration in terms of three important inventory aspects.

Firstly, identification of *key categories* in GHG inventories enables limited resources available for preparing inventories to be prioritised. It is *good practice* to focus the available resources for the improvement in data and methods onto categories identified as *key*.

Secondly, in general, more detailed higher tier methods should be selected for *key categories*. Inventory compilers should use the category-specific methods presented in sectoral decision trees (see Figure 2.2). For most sources/sinks, higher tier (Tier 2 and 3) methods are suggested for *key categories*, although this is not always the case. For guidance on the specific application of this principle to *key categories*, it is *good practice* to refer to the decision trees and sector-specific guidance for the respective category and additional *good practice guidance* in chapters in sectoral volumes. In some cases, we may be unable to adopt a higher tier method due to lack of resources. This may mean that we are unable to collect the required data for a higher tier or are unable to determine country specific emission factors and other data needed for Tier 2 and 3 methods. In these cases, although this is not accommodated in the category-specific decision trees, a Tier 1 approach can be used, and this possibility is identified in Figure 2.2. It should in these cases be clearly documented why the methodological choice was not in line with the sectoral decision tree. Any *key categories* where the good practice method cannot be used should have priority for future improvements.

Thirdly, it is *good practice* to give additional attention to *key categories* with respect to quality assurance and quality control (QA/QC) as described in Chapter 6 of the Revised Guidelines, Quality Assurance/Quality Control and Verification, and in the sectoral volumes.

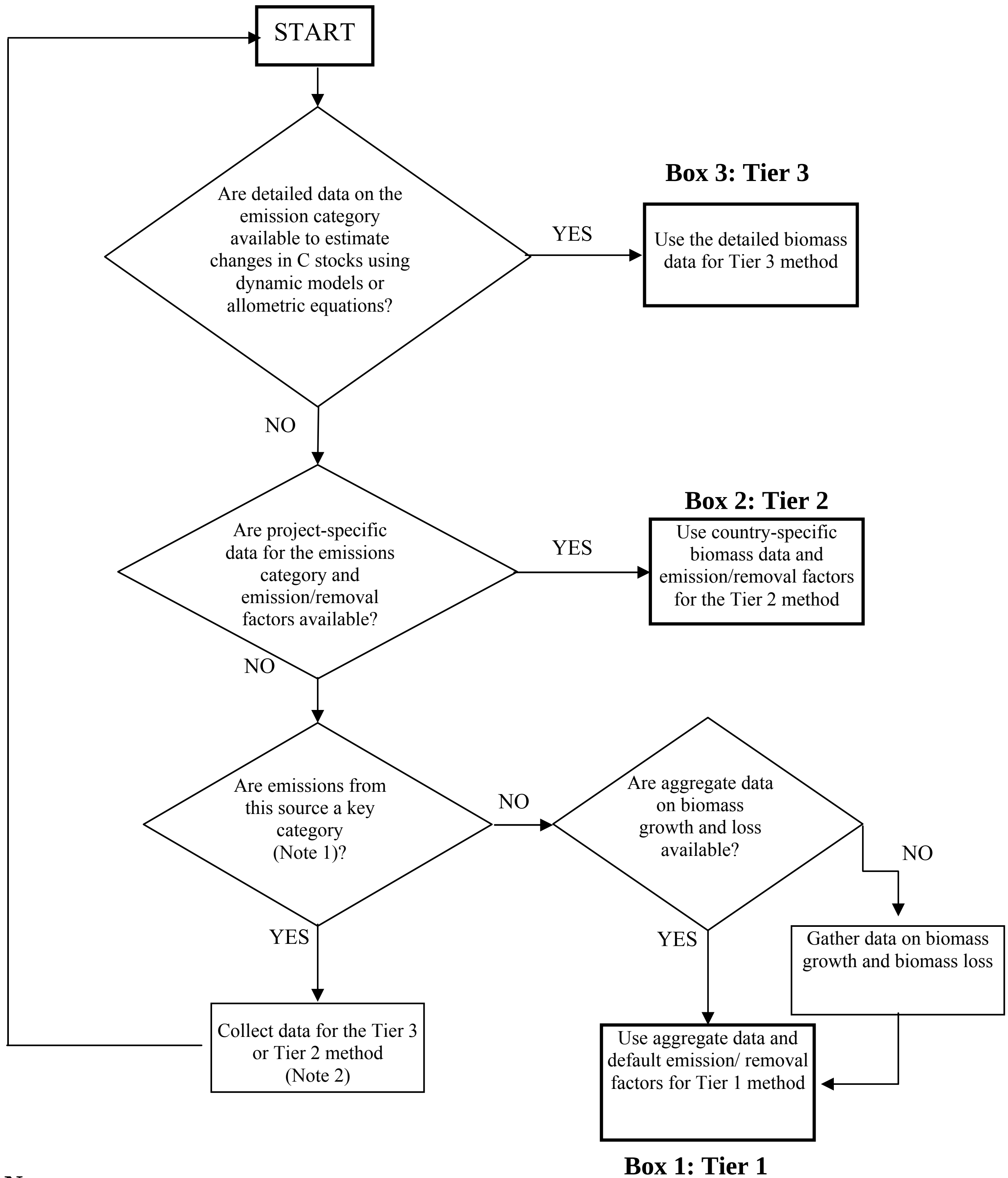
For **all Tiers** it is *good practice* to estimate N_2O emissions from direct application of nitrogen to lands in the conversion to forest land category using the same methods described in Section 3.2.1.4.1 for forest land remaining forest land, remembering to avoid double counting with forest land remaining forest land, or agriculture. If applications data cannot realistically be disaggregated below the forest land remaining forest land or even the agriculture level emissions should be lumped into the parent category, to avoid double counting. In addition the following points apply:

Tier 1: It is assumed that the conversion to forest land does not lead to soil carbon losses. In this case, N_2O emissions from soil carbon mineralisation are also assumed to be zero. Lagged N_2O emissions from nitrogen application during the preceding land use and new land use (managed forest) are implicitly calculated in the inventory and do not need to be reported separately, avoiding double counting.

Tier 2: In the case of WKIEMP, tree planting will very likely lead to soil carbon gains, which will result in increased N_2O emissions, particularly in the wetter sites where the project operates. If soil carbon losses can be documented, e.g. from the afforestation of grassland, then N_2O emissions are reported using the same tiers and methodologies as for the conversion to cropland (Revised Guidelines Section 3.3.2.3, Non-CO_2 emissions from conversion to cropland). Lagged N_2Oemissions from nitrogen application during the preceding land use are implicitly calculated in the inventory and do not need to be reported separately, avoiding double counting. At present, there is no adequate information to estimate the effect of carbon accumulation in soil on N_2O emissions. If within the WKIEMP, we resort to using fertilizers during land rehabilitation, we will need to refer to the accounting methods elaborated in the chapter on agriculture in the Revised Methods.

Tier 3: If, in the unlikely event that we determine that N2O emissions constitute a significant portion of the carbon sequestered, we will need to develop a Tier 3 approach. This approach will consist of reporting N_2O emissions on a spatially explicit basis, where it is *good practice* to apply the same detailed models as for lands remaining forest land, taking account of the interactions identified for Tier 1 and Tier 2 above.

Figure 2.2. Decision tree for identification of appropriate tier to estimate changes in carbon stocks in biomass (Adapted from IPCC 2006).



Notes:

1. The concept of key categories is explained in Volume 1, Chapter 4 (Methodological Choice and Identification of Key Categories).
2. Please see Volume 1, Chapter 2 (Approaches to Data Collection) for guidance on situations in which a country does not have the resources to collect additional data. For key categories, it is good practice to collect data for the most rigorous method that is feasible.

3.2 Emissions sources of non-CO_2 GHGs

The project is likely to impact livestock herd sizes and associated emissions of N_2O and CH_4, and on soil emissions of N_2O. Our first cut at evaluating these emissions will all be through Tier 1 methods. We will refine our accounting approach over the course of the project with the objective to move to at least Tier 2 for soil N_2O emissions.

In the following sections, we will present the results of the considerations from the decision tree (Figure 2.2) for each potential source of non-CO_2 GHG. Based upon the result, we will present the equation for the accounting at the appropriate Tier and an indication of the emissions factors to be used.

3.2.1 Livestock

There are several sources of non-CO_2 GHG emissions from livestock, including enteric fermentation, and N_2O and CH_4 emissions from manure management. Of these, CH4 from enteric fermentation is the emission that is the most likely to be significantly affected by project activities, if the project results in a significant increase in herd size within intervention areas.

3.2.1.1 CH_4 emissions from enteric fermentation in domestic livestock

In the national accounting system, this category is not a significant source, but it may be significant in the project area. Furthermore, we do not have adequate data at this time to permit a Tier 2 estimate. The estimate that we are presenting at this point is a Tier 1 estimate.

$$Emissions = EF_T \bullet N_T \bullet \frac{10^3\,kg}{Mg}$$

Where:

Emissions = methane emissions from Enteric Fermentation, Mg CH_4 yr^{-1}

EF_T = emission factor for the defined livestock population, kg CH_4 $head^{-1}$ yr^{-1}

N_T = the number of head of livestock species / category T in the country

T = species/category of livestock

Table 10.10 (From 2006 Revised Guidelines) shows the enteric fermentation emission factors for each of the animal species except cattle. As shown in the table, emission factors for sheep and swine vary for developed and developing countries. The differences in the emission factors are driven by differences in feed intake and feed characteristic assumptions (see Annex 10A.1). Table 10.11 presents the enteric fermentation emission factors for cattle. A range of emission factors is shown for typical regional conditions. As shown in the table, the emission factors vary by over a factor of four on a per head basis. While the default emission factors shown in Table 10.11 are broadly representative of the emission rates within each of the regions described, emission factors vary within each region. Animal size and milk production are important determinants of emission rates for dairy cows. Relatively smaller dairy cows with low levels of production are found in Asia, Africa, and the Indian subcontinent. Relatively larger dairy cows with high levels of production are found in North America and Western Europe.

TABLE 10.10
ENTERIC FERMENTATION EMISSION FACTORS FOR TIER 1 METHOD[1]
(KG CH_4 HEAD^{-1} YR^{-1})

Livestock	Developed countries	Developing countries	Liveweight
Buffalo	55	55	300 kg
Sheep	8	5	65 kg - developed countries; 45 kg - developing countries
Goats	5	5	40 kg
Camels	46	46	570 kg
Horses	18	18	550 kg
Mules and Asses	10	10	245 kg
Deer	20	20	120 kg
Alpacas	8	8	65 kg
Swine	1.5	1.0	
Poultry	Insufficient data for calculation	Insufficient data for calculation	
Other (e.g., Llamas)	To be determined[1]	To be determined[1]	

All estimates have an uncertainty of ±30-50%.

Sources: Emission factors for buffalo and camels from Gibbs and Johnson (1993). Emission factors for other livestock from Crutzen *et al.*, (1986), Alpacas from Pinares-Patino *et al.*, 2003; Deer from Clark *et al.*, 2003 .

[1] One approach for developing the approximate emission factors is to use the Tier 1 emissions factor for an animal with a similar digestive system and to scale the emissions factor using the ratio of the weights of the animals raised to the 0.75 power. Liveweight values have been included for this purpose. Emission factors should be derived on the basis of characteristics of the livestock and feed of interest and should not be restricted solely to within regional characteristics.

TABLE 10.11 TIER 1 ENTERIC FERMENTATION EMISSION FACTORS FOR CATTLE[1]			
Regional characteristics	**Cattle category**	**Emission factor [2] (kg CH_4 $head^{-1}$ yr^{-1})**	**Comments**
North America: Highly productive commercialized dairy sector feeding high quality forage and grain. Separate beef cow herd, primarily grazing with feed supplements seasonally. Fast-growing beef steers/heifers finished in feedlots on grain. Dairy cows are a small part of the population.	Dairy Other Cattle	121 53	Average milk production of 8,400 kg $head^{-1}$ yr^{-1}. Includes beef cows, bulls, calves, growing steers/heifers, and feedlot cattle.
Western Europe: Highly productive commercialised dairy sector feeding high quality forage and grain. Dairy cows also used for beef calf production. Very small dedicated beef cow herd. Minor amount of feedlot feeding with grains.	Dairy Other Cattle	109 57	Average milk production of 6,000 kg $head^{-1}$ yr^{-1}. Includes bulls, calves, and growing steers/heifers.
Eastern Europe: Commercialised dairy sector feeding mostly forages. Separate beef cow herd, primarily grazing. Minor amount of feedlot feeding with grains.	Dairy Other Cattle	89 58	Average milk production of 2,550 kg $head^{-1}$ yr^{-1}. Includes beef cows, bulls, and young.
Oceania: Commercialised dairy sector based on grazing. Separate beef cow herd, primarily grazing rangelands of widely varying quality. Growing amount of feedlot feeding with grains. Dairy cows are a small part of the population.	Dairy Other Cattle	81 60	Average milk production of 2,200 kg $head^{-1}$ yr^{-1}. Includes beef cows, bulls, and young.
Latin America: Commercialised dairy sector based on grazing. Separate beef cow herd grazing pastures and rangelands. Minor amount of feedlot feeding with grains. Growing non-dairy cattle comprise a large portion of the population.	Dairy Other Cattle	63 56	Average milk production of 800 kg $head^{-1}$ yr^{-1} Includes beef cows, bulls, and young.
Asia: Small commercialised dairy sector. Most cattle are multi-purpose, providing draft power and some milk within farming regions. Small grazing population. Cattle of all types are smaller than those found in most other regions.	Dairy Other Cattle	61 47	Average milk production of 1,650 kg $head^{-1}$ yr^{-1} Includes multi-purpose cows, bulls, and young
Africa and Middle East: Commercialised dairy sector based on grazing with low production per cow. Most cattle are multi-purpose, providing draft power and some milk within farming regions. Some cattle graze over very large areas. Cattle are smaller than those found in most other regions.	Dairy Other Cattle	40 31	Average milk production of 475 kg $head^{-1}$ yr^{-1} Includes multi-purpose cows, bulls, and young
Indian Subcontinent: Commercialised dairy sector based on crop by-product feeding with low production per cow. Most bullocks provide draft power and cows provide some milk in farming regions. Small grazing population. Cattle in this region are the smallest compared to cattle found in all other regions.	Dairy Other Cattle	51 27	Average milk production of 900 kg $head^{-1}$ yr^{-1} Includes cows, bulls, and young. Young comprise a large portion of the population
[1] Emission factors should be derived on the basis of the characteristics of the cattle and feed of interest and need not be restricted solely to within regional characteristics. [2] IPCC Expert Group, values represent averages within region, where applicable the use of more specific regional milk production data is encouraged. Existing values were derived using Tier 2 method and the data in Tables 10 A.1 and 10A. 2.			

3.2.1.2 CH_4 emissions from manure management

The data are not available to do an 'enhanced' Livestock Population Characterization. This category is not considered a *key source category* in the national inventory, so no country or region specific emission factors exist. Thus, we will use Tier 1 and IPCC default emission factors. The estimate that we will present at this point is a Tier 1 estimate. We do not anticipate developing the factors for a Tier 2 estimate.

$$CH_{4manure} = EF_T \bullet N_T \bullet \frac{10^3 kg}{Mg}$$

Where:

$CH_{4manure}$ = methane emissions from manure management, Mg CH_4 yr^{-1}

EF_T = emission factor for the defined livestock population, kg CH_4 $head^{-1}$ yr^{-1}

N_T = the number of head of livestock species / category T in the country

T = species/category of livestock

Table 10.14 shows the default emission factors for cattle, swine, and buffalo for each region and temperature classification. Emission factors are listed by the annual average temperature for the climate zone where the livestock manure is managed. The temperature data should be based on national meteorological statistics where available.

Tables 10.15 and 10.16 present the default manure management emission factors for other animal species. Separate emission factors are shown for developed and developing countries in Table 10.15, reflecting the general differences in feed intake and feed characteristics of the animals in the two regions. Except for poultry "layers (wet)," these emission factors reflect the fact that virtually all the manure from these animals is managed in 'dry' manure management systems, including pastures and ranges, drylots, and daily spreading on fields (Woodbury and Hashimoto, 1993).

TABLE 10.14
MANURE MANAGEMENT METHANE EMISSION FACTORS BY TEMPERATURE FOR CATTLE, SWINE, AND BUFFALO[a]
(KG CH_4 HEAD^{-1} YR^{-1})

Regional characteristics	Livestock species	CH_4 emission factors by average annual temperature (°C)[b]																		
		Cool					Temperate											Warm		
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28
North America: Liquid-based systems are commonly used for dairy cows and swine manure. Other cattle manure is usually managed as a solid and deposited on pastures or ranges.	Dairy Cows	48	50	53	55	58	63	65	68	71	74	78	81	85	89	93	98	105	110	112
	Other Cattle	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Market Swine	10	11	11	12	12	13	13	14	15	15	16	17	18	18	19	20	22	23	23
	Breeding Swine	19	20	21	22	23	24	26	27	28	29	31	32	34	35	37	39	41	44	45
Western Europe: Liquid/slurry and pit storage systems are commonly used for cattle and swine manure. Limited cropland is available for spreading manure.	Dairy Cows	21	23	25	27	29	34	37	40	43	47	51	55	59	64	70	75	83	90	92
	Other Cattle	6	7	7	8	8	10	11	12	13	14	15	16	17	18	20	21	24	25	26
	Market Swine	6	6	7	7	8	9	9	10	11	11	12	13	14	15	16	18	19	21	21
	Breeding Swine	9	10	10	11	12	13	14	15	16	17	19	20	22	23	25	27	29	32	33
	Buffalo	4	4	5	5	5	6	7	7	8	9	9	10	11	12	13	14	15	16	17
Eastern Europe: Solid based systems are used for the majority of manure. About one-third of livestock manure is managed in liquid-based systems.	Dairy Cows	11	12	13	14	15	20	21	22	23	25	27	28	30	33	35	37	42	45	46
	Other Cattle	6	6	7	7	8	9	10	11	11	12	13	14	15	16	18	19	21	23	23
	Market Swine	3	3	3	3	3	4	4	4	4	5	5	5	6	6	6	7	10	10	10
	Breeding Swine	4	5	5	5	5	6	7	7	7	8	8	9	9	10	11	12	16	17	17
	Buffalo	5	5	5	6	6	7	8	8	9	10	11	11	12	13	15	16	17	19	19
Oceania: Most cattle manure is managed as a solid on pastures and ranges, except dairy cows where there is some usage of lagoons. About half of the swine manure is managed in anaerobic lagoons.	Dairy Cows	23	24	25	26	26	27	28	28	28	29	29	29	29	29	30	30	31	31	31
	Other Cattle	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Market Swine	11	11	12	12	12	13	13	13	13	13	13	13	13	13	13	13	13	13	13
	Breeding Swine	20	20	21	21	22	22	23	23	23	23	23	24	24	24	24	24	24	24	24
Latin America: Almost all livestock manure is managed as a solid on pastures and ranges. Buffalo manure is deposited on pastures and ranges.	Dairy Cows	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
	Other Cattle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Swine	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
	Buffalo	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2

Table 10.14
Manure management methane emission factors by temperature for Cattle, Swine, and Buffalo[a]
(kg CH_4 head^{-1} yr^{-1})

Regional characteristics	Livestock species	CH_4 emission factors by average annual temperature (°C)[b]																		
		Cool					Temperate											Warm		
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28
Africa: Most livestock manure is managed as a solid on pastures and ranges. A smaller, but significant fraction is burned as fuel.	Dairy Cows	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Other Cattle	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Swine	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Middle East: Over two-thirds of cattle manure is deposited on pastures and ranges. About one-third of swine manure is managed in liquid-based systems. Buffalo manure is burned for fuel or managed as a solid.	Dairy Cows	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3
	Other Cattle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Swine	1	1	1	2	2	2	2	2	3	3	3	3	4	4	4	5	5	5	6
	Buffalo	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Asia: About half of cattle manure is used for fuel with the remainder managed in dry systems. Almost 40% of swine manure is managed as a liquid. Buffalo manure is managed in drylots and deposited in pastures and ranges.	Dairy Cows	9	10	10	11	12	13	14	15	16	17	18	20	21	23	24	26	28	31	31
	Other Cattle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Swine	2	2	2	2	2	3	3	3	3	4	4	4	5	5	5	6	6	7	7
	Buffalo	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Indian Subcontinent: About half of cattle and buffalo manure is used for fuel with the remainder managed in dry systems. About one-third of swine manure is managed as a liquid.	Dairy Cows	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6	6
	Other Cattle	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Swine	2	2	3	3	3	3	3	3	4	4	4	4	4	5	5	5	6	6	6
	Buffalo	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Source: See Annex 10A.2 , Tables 10A-4 to 10A-8 for derivation of these emission factors,

The uncertainty in these emission factors is ±30 %.

[a] When selecting a default emission factor, be sure to consult the supporting tables in Annex 10A.2 for the distribution of manure management systems and animal waste characteristics used to estimate emissions. Select an emission factor for a region that most closely matches your own in these characteristics.

[b] All temperatures are not necessarily represented within every region. For example, there are no significant warm areas in Eastern or Western Europe. Similarly, there are no significant cool areas in Africa and the Middle East.

Note: Significant buffalo populations do not exist in North America, Oceania, or Africa.

TABLE 10.15

MANURE MANAGEMENT METHANE EMISSION FACTORS BY TEMPERATURE FOR SHEEP, GOATS, CAMELS, HORSES, MULES AND ASSES, AND POULTRY[a] (KG CH_4 HEAD^{-1} YR^{-1})

Livestock	CH_4 emission factor by average annual temperature (°C)		
	Cool (<15°C)	Temperate (15 to 25°C)	Warm (>25°C)
Sheep			
Developed countries	0.19	0.28	0.37
Developing countries	0.10	0.15	0.20
Goats			
Developed countries	0.13	0.20	0.26
Developing countries	0.11	0.17	0.22
Camels			
Developed countries	1.58	2.37	3.17
Developing countries	1.28	1.92	2.56
Horses			
Developed countries	1.56	2.34	3.13
Developing countries	1.09	1.64	2.19
Mules and Asses			
Developed countries	0.76	1.10	1.52
Developing countries	0.60	0.90	1.20
Poultry			
Developed countries			
Layers (dry)[b]	0.03	0.03	0.03
Layers (wet)[c]	1.2	1.4	1.4
Broilers	0.02	0.02	0.02
Turkeys	0.09	0.09	0.09
Ducks	0.02	0.03	0.03
Developing countries	0.01	0.02	0.02

The uncertainty in these emission factors is ±30 %.

Sources: Emission factors developed from: feed intake values and feed digestibilities used to develop the enteric fermentation emission factors (see Annex 10A.1); Except for poultry in developed countries, methane conversion factor (MCF), and maximum methane producing capacity (B_o) values reported in Woodbury and Hashimoto (1993). Poultry for developed countries was subdivided into five categories. Layers (dry) represent layers in a "without bedding" waste management system; layers (wet) represent layers in an anaerobic lagoon waste management system. For layers, volatile solids (VS) are values reported in USDA (1996); typical animal mass values are from ASAE (1999); and B_o values for Layers are values reported by Hill (1982). For broilers and turkeys, B_o values are from Hill (1984); typical animal mass values are from ASAE (1999); and VS values are those reported in USDA (1996). B_o values for ducks were transferred from broilers and turkeys; typical animal mass values are from MWPS-18; and VS values are from USDA, AWMFH. Typical mass of sheep, goats and horses, and VS and B_o values of goats and horses for developed countries updated according to the analysis of GHG inventories of Annex I countries. All manure, with the exception of Layers (wet), is assumed to be managed in dry systems, which is consistent with the manure management system usage reported in Woodbury and Hashimoto (1993).

[a] When selecting a default emission factor, be sure to consult the supporting tables in Annex 10A.2 for the distribution of manure management systems and animal waste characteristics used to estimate emissions. Select an emission factor for a region that most closely matches your own in these characteristics.

[b] Layer operations that manage dry manure.

[c] Layer operations that manage manure as a liquid, such as stored in an anaerobic lagoon.

3.2.1.3 N_2O emissions from manure management

Calculation of N_2O emissions from manure management is fairly complex because there are both direct emissions associated manure management, and indirect emissions and indirect emissions associated with volatilization of NO_x and NH_4, which is in turn redeposited onto soil surfaces, where it is subject to nitrification and denitrification. Indirect emissions are also associated with leaching of NO_3^- from manure and losses in runoff.

Whereas there are two principal types of livestock management in the Project area – extensive grazing and paddock raised – we will need to work with baseline data as it becomes available to better quantify the direct and indirect emissions and establish the best way to calculate emissions.

3.2.1 Direct N_2O Emissions from Soils

This category is likely to be a *key source category* if significant numbers of N-fixing trees are planted. No country or region specific activity data on the fertilizer use or organic inputs exist. Dry pulse production is important in the project area, but no data exist to allow us to quantify production. Organic soils exist in the region, however mapping of these soils is only completed at a coarse scale and the types of crops grown on these soils are poorly quantified. Emissions factors do not exist for this region. Thus, we will use a Tier 1 and IPCC default emission factors initially and refine our estimates over the course of the project through a targeted research effort.

If more detailed emission factors and activity data are available for the application of synthetic fertilisers and organic N (FSN and FON) under different conditions *i*, Equation 11.1 would be expanded to become:

EQUATION 11.2
DIRECT N2O EMISSIONS FROM MANAGED SOILS (TIER 2)

$$N_2O_{direct} - N = \sum_i (F_{SN} + F_{ON})EF_{1i} + (F_{CR} + F_{SOM})EF_1 + N_2O - N_{OS} + N_2O - N_{PRP}$$

Where:

EF_{1i} = emission factors developed for N_2O emissions from synthetic fertiliser and organic N application under conditions *i* (kg N_2O–N (kg N input)-1); *i* = 1, …n.

F_{SN} = annual amount of synthetic fertiliser N applied to soils, kg N yr^{-1}

F_{ON} = annual amount of animal manure, compost, and other organic N additions applied to soils, kg N yr^{-1}

F_{CR} = annual amount of N in crop residues (above-ground and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils, kg N yr^{-1}

F_{SOM} = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N yr^{-1}

$N_2O–N_{OS}$ = annual direct $N_2O–N$ emissions from managed organic soils, kg $N_2O–N$ yr^{-1}

$N_2O–N_{PRP}$ = annual direct $N_2O–N$ emissions from urine and dung inputs to grazed soils, kg $N_2O–N$ yr^{-1}

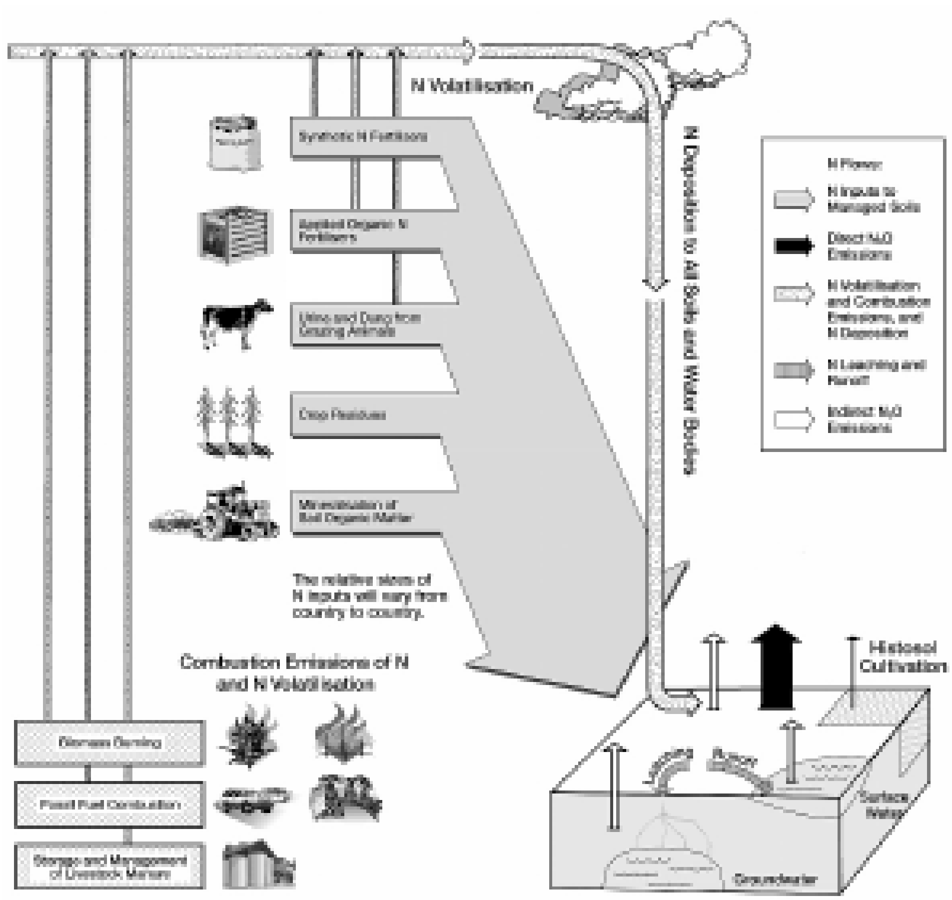
Equation 11.2 may be modified in a variety of ways to accommodate any combination of N source-, crop type-,management-, land use-, climate-, soil- or other condition-specific emission factors that a country may be able to obtain for each of the individual N input variables (FSN, FON, FCR, FSOM, FOS, FPRP). Conversion of $N_2O–N$ emissions to N_2O emissions for reporting purposes is performed by using the following

equation:

$$N_2O = N_2O–N \bullet 44/28$$

Figure 11.1 Schematic diagram illustrating the sources and pathways of N that result in direct and indirect N_2O emissions from soils and waters

Note: Sources of N applied to, or deposited on, soils are represented with arrows on the left-hand side of the graphic. Emission pathways are also shown with arrows including the various pathways of volatilisation of NH_3 and NO_x from agricultural and non-agricultural sources, deposition of these gases and their products NH_4^+ and NO_3^-, and consequent indirect emissions of N_2O are also illustrated. "Applied Organic N Fertilisers" include animal manure, all compost, sewage sludge, tankage, etc. "Crop Residues" include above- and below-ground residues for all crops (non-N and N fixing) and from perennial forage crops and pastures following renewal. On the lower right-hand side is a cut-away view of a representative sections of managed land; Histosol cultivation is represented here.



3.2.1.4 *Source Data*

Data will be collected on area of different crops, crop productivity, livestock population, manure management, and agroforestry system by project block at the outset of the project. This data will be crosschecked using remote sensing data. Emission factors will be developed for the project area and compared with results obtained in other similar environments in Latin America.

3.2.1.5 Uncertainty assessment

The largest source of uncertainty in this submodule will be the estimation of the area under different crops, and annual crop productivity. We will conduct annual field surveys minimize this uncertainty. Methods to limit uncertainties regarding animal populations and manure management have been dealt with earlier. Using the Tier 1 method, there will also be uncertainty introduced by the generic emissions factors. Emission factors are unlikely to be known more accurately than ± 30%, and may be uncertain to ± 50%. Developing the emissions factors for a Tier 2 approach will minimize this uncertainty.

3.2.2 Indirect N_2O emissions from soils

Calculation of indirect N_2O emissions from managed is fairly complex because there are indirect emissions associated with volatilization of NO_x and NH_4, which is in turn redeposited onto soil surfaces, where it is subject to nitrification and denitrification. Indirect emissions are also associated with leaching of NO_3^- to deep soil layers from and losses in runoff. We will need to work with baseline data as it becomes available to better quantify the indirect emissions and establish the best way to calculate emissions.

4. Targeted Research to Refine IPCC Coefficients.

The following sections describe methods which will be used to refine the IPCC estimates.

4.1 Soil Emission Factor Determination

To account for seasonal and interannual variability, we will use the hole-in-the-pipe model (Firestone and Davidson 1989), which provides a conceptual framework to explain the variability of nitrogen oxide emissions, including the effects of deforestation and land-use change (Davidson, 1991). This model can easily be incorporated in ecosystem models such as CENTURY or NASA-CASA. This conceptual, mechanistic model is applicable to studies at various scales. The metaphor of fluid flowing through a leaky pipe (Figure 1) is used to describe two levels of regulation of N-oxide emissions from soils: (i) the amount of fluid flowing through the pipe is analogous to the rate of N cycling in general, or specifically to rates of NH_4^+ oxidation by nitrifying bacteria and NO_3^- reduction by denitrifying bacteria; and (ii) the amount of N that "leaks" out of the pipe as gaseous N-oxides, through one "hole" for NO and another "hole" for N_2O, is determined by several soil properties, but most commonly and most strongly by soil water content. This effect of soil water content, and in some cases acidity or other soil factors, determines the relative rates of nitrification and denitrification and, hence, the relative proportions of gaseous end products of these processes. The first level of regulation determines the total amount of N-oxides produced (NO + N_2O) while the second level of regulation determines the relative importance of NO and N_2O as the gaseous end products of these processes.

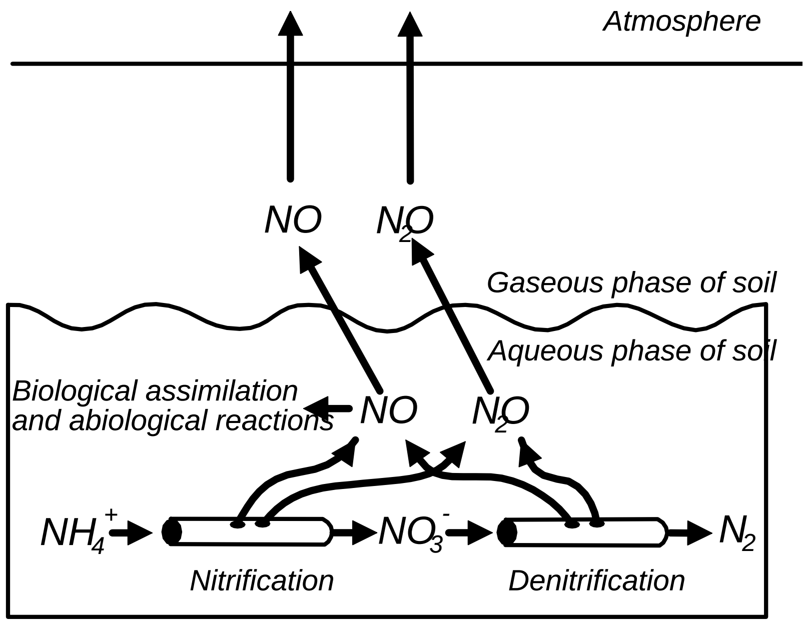


Figure 8. Hole-in-the-Pipe Conceptual Model

This mechanistic model is based, first, on the idea that emissions of N-oxides increase with increasing N fertility. The second level of regulation addresses the relative importance of NO and N_2O production. Both nitrification and denitrification produce both gases, but nitrification often produces greater quantities of NO relative to N_2O, and denitrification usually produces greater quantities of N_2O relative to NO (Davidson, 1993). Several factors have been shown to affect the ratio of N_2O to NO (Firestone and Davidson, 1989), but Davidson (1993) suggested that soil water content could be a useful predictor of the ratio at regional and global scales. At water content below field capacity (field capacity is often operationally defined as water content at 0.010 MPa tension), nitrification is often the predominant gas producing processes, so NO predominates. In wet soils, denitrification increases as O2 diffusion decreases and, as soils become more anaerobic, N_2O from denitrification becomes the predominant N-oxide. The water content effect is a continuum, although the response of the N_2O:NO ratio to soil water content may not be linear. Experimental evidence and field studies exist that support this hypothesized relationship (Davidson, 1993; Davidson et al., 1993; Keller and Reiners 1994; Riley and Vitousek, 1995).

4.2 Measurement of N_2O and NO Fluxes

Surface fluxes of N_2O and NO will be analyzed using chamber techniques in a subset of reference plots, stratified by spectral soil condition (erosion phase and hydraulic conductivity), that are representative of the variation encountered in the project landscape. Chambers will be made of a polyvinyl chloride (PVC) ring (20-cm diameter x 10-cm height) and a vented PVC cover made from an end-cap of a 20 cm diameter PVC pipe. PVC rings will be pushed into the soil to a depth of 2-3 cm to make the base of the chamber. An intensive sampling scheme involving monthly measurements will be made in plots representing project interventions and appropriate controls. A less intensive scheme will be used to capture variability associated with landscape variability.

NO fluxes will be measured using a dynamic chamber technique similar to Davidson et al. (1991). At the time of measurement, a vented cover will be placed over the base, making a chamber with approximately a 4 L head-space volume. Air will be circulated in a closed loop between a Scintrex LMA-3 NO_2 analyzer (Scintrex, Inc., Ontario, Canada) and the chamber through Teflon tubing using a battery operated pump, at a rate of 0.5 L min^{-1}. Inside the instrument, NO will be oxidized to NO_2 by reaction with CrO_3 and the NO_2 will be then mixed with Luminol solution to produce a luminescent reaction directly proportional to the mixing ratio of NO_2. Because of problems with humidity wetting the CrO_3 catalyst, we will dry the air stream entering the analyzer using a Nafion gas sample dryer (Perma Pure Inc., Toms River, NJ). NO concentrations will be recorded at 5 second intervals over a period of 3 to 4 minutes using a data logger. Fluxes will be calculated from the rate of increase of NO concentration using the steepest linear portion of the accumulation curve. The average length of time used for the calculation of fluxes is 1.9 min. The instrument will be calibrated 2-3 times daily in the field, by mixing varying amounts of a 1 ppm NO standard with NO- and NO_2-free air.

N_2O fluxes will be measured with a static chamber technique (Matson et al., 1990), using the same chamber bases as those used for the NO measurement. At the time of measurement, a PVC cover (20-cm PVC end-cap) will be placed over the base making a chamber with a head-space volume of approximately 5.5 L. Four 20mL headspace samples will be withdrawn at 10-minute intervals and returned to the laboratory for analysis with a gas chromatograph fitted with an electron capture detector.

N_2O fluxes will subsequently be calculated from the rate of concentration increase, determined by linear regression, based on the four samples. Occasionally, and particularly for very high fluxes, the accumulation curve may appear nonlinear, probably due to the reduction in the concentration gradient between the soil atmosphere and the head-space (Hutchinson and Livingston, 1993). In these cases, only points representing the linear portion of the accumulation curve will be used. In almost all cases, NO and N_2O flux measurements for a particular site will be made on the same day and within 90 minutes of each other.

4.3 CH_4 consumption by soils

Surface fluxes of CH_4 will be measured using chambers techniques similar to NO and N_2O. A conceptual model will be used to estimate consumption by soils under improved and traditional land use practices. The model is based upon the linkage between CO_2 in the soil atmosphere and CH_4 fluxes. Microbial and root respiration affects the availability of O_2 to microbial populations in the soil. Hence, the availability of O_2 is affected by both physical restraints on diffusion, which are determined by soil water content and soil texture, and by biological processes of O_2 consumption. Thus, the effect of high rates of soil respiration reinforces the effect of restricted diffusivity during the wet season by increasing the probability of occurrence of anaerobic microsites where methanogenesis can occur and by reducing the probability of well aerated microsites of CH_4 consumption. The combined effect either reduces the sink strength of CH_4 or results in the soil becoming a net source.

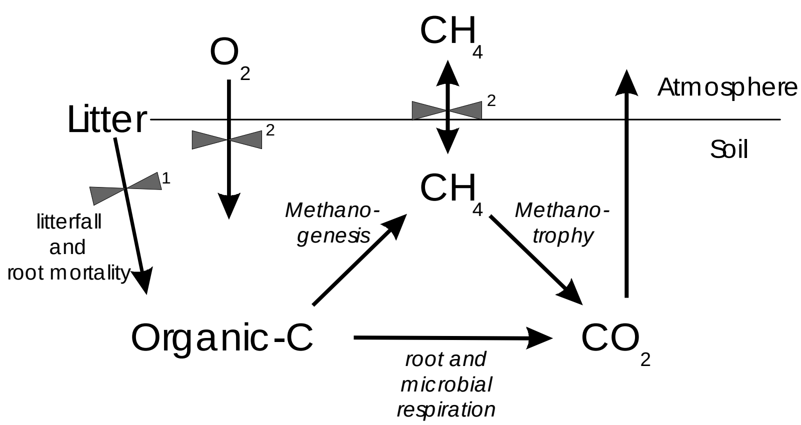


Figure 9. Conceptual model of CH_4 exchange between the atmosphere and the soil.

The significance of this is that seasonality of precipitation must be interpreted in terms of its effects both on diffusivity and on plant phenology and microbial activity. Furthermore, responses of plant communities to seasonal patterns of precipitation vary depending upon the land use and ecosystem type within the same climatic regime. Where agricultural ecosystems are very productive during the wet season and senescent during the dry season, CH_4 fluxes can vary from net emission to relatively high rates of uptake (Figure 9). Deeper rooted woody ecosystems, in contrast, maintain modest rates of soil respiration during the dry season, which results in lower rates of net CH_4 uptake. Parameterizing this conceptual model for the systems that will be part of this project will be straight forward and the model is easy to link with other ecosystem models such as CENTURY or NASA-CASA.

5. Laboratory Procedures

To be written after equipment arrives

6. Worksheets

MODULE	**AGRICULTURE**					
SUBMODULE	**METHANE AND NITROUS OXIDE EMISSIONS FROM DOMESTIC LIVESTOCK ENTERIC FERMENTATION AND MANURE MANAGEMENT**					
WORKSHEET	**4-1**					
SHEET	**1 OF 2 METHANE EMISSIONS FROM DOMESTIC LIVESTOCK ENTERIC FERMENTATION AND MANURE MANAGEMENT**					
	STEP 1			**STEP 2**		**STEP 3**
	A	B	C	D	E	F
Livestock Type	Number of Animals (1000s)	Emissions Factor for Enteric Fermentation (kg/head/yr)	Emissions from Enteric Fermentation (t/yr)	Emissions Factor for Manure Management (kg/head/yr)	Emissions from Manure Management (t/yr)	Total Annual Emissions from Domestic Livestock (Gg)
			C = (A x B)		**E = (A x D)**	**F = (C + E)/1000**
Dairy Cattle		**36**		**1.00**		
Non-dairy Cattle		**32**		**1.00**		
Buffalo		**55**				
Sheep		**5**		**0.21**		
Goats		**5**		**0.22**		
Camels		**46**		**2.56**		
Horses		**18**		**2.18**		
Mules & Asses		**10**		**1.19**		
Swine		**1**		**2.00**		
Poultry		**--**		**0.023**		
Totals						

MODULE	**AGRICULTURE**
SUBMODULE	**METHANE AND NITROUS OXIDE EMISSIONS FROM DOMESTIC LIVESTOCK ENTERIC FERMENTATION AND MANURE MANAGEMENT**
WORKSHEET	**4-1 (SUPPLEMENTAL)**
SPECIFY AWMS	**PASTURE, RANGE, AND PADDOCK**
SHEET	**1 OF 2 METHANE EMISSIONS FROM DOMESTIC LIVESTOCK ENTERIC FERMENTATION AND MANURE MANAGEMENT**

Livestock Type	A Number of Animals (1000s)	B Nitrogen Excretion Nex (kg/head/yr)	C Fraction of Manure Nitrogen per AWMS (%/100) (fraction)	D Nitrogen Excretion per AWMS, Nex (kg/head/yr)
				D = (A x B x C)
Dairy Cattle		**60**	**83**	
Non-dairy Cattle		**40**	**96**	
Sheep		**12**	**99**	
Swine		**16**	**0**	
Poultry		**0.6**	**81**	
Others		**40**	**99**	
Total				

MODULE	AGRICULTURE		
SUBMODULE	METHANE AND NITROUS OXIDE EMISSIONS FROM DOMESTIC LIVESTOCK ENTERIC FERMENTATION AND MANURE MANAGEMENT		
WORKSHEET	4-1		
SHEET	2 OF 2 METHANE EMISSIONS FROM DOMESTIC LIVESTOCK ENTERIC FERMENTATION AND MANURE MANAGEMENT		
STEP 4			
Animal Waste Management System (AWMS)	A Nitrogen Excretion Nex $_{(AWMS)}$ (kg N/yr)	B Emission Factor For AWMS EF_3 (kg N_2O-N/kg N)	C Total Annual Emissions of N2O (Gg)
			C = (A x B)[44/28] x 10^{-6}
Anaerobic lagoons		**0.001**	
Liquid systems		**0.001**	
Daily spread		**0.0**	
Solid storage and drylot		**0.02**	
Pasture range and paddock		**0.02**	
Others		**0.005**	
Total			

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MODULE	**AGRICULTURE**							
SUBMODULE	**BURNING OF AGRICULTURAL RESIDUES**							
WORKSHEET	**4-4**							
SHEET	**1 OF 3**							
	STEP 1			**STEP 2**		**STEP 3**		
Crops (specify locally important crops)	A Annual Production (Gg crop)	B Residue to Crop Ratio	C Quantity of Residue (Gg biomass)	D Dry Matter Fraction	E Quantity of Dry Residue (Gg dm)	F Fraction Burned in Fields	G Fraction Oxidized	H Total Biomass Burned (Gg dm)
			C = (A X B)		E = (C x D)			H = (E x F xG)
Maize		1.0		0.4				
Millet		1.4						
Sorghum		1.4						
Bean		2.1						

MODULE	AGRICULTURE
SUBMODULE	BURNING OF AGRICULTURAL RESIDUES
WORKSHEET	4-4
SHEET	2 OF 3

STEP 4

	I Carbon Fraction of Residue	J Total Carbon Released (Gg c)	K Nitrogen – Carbon Ratio	L Total Nitrogen Released (Gg N)
		J = (H x I)		L = (J x K)
Maize	.4709		0.02	
Millet			0.016	
Sorghum			0.02	
Bean				

MODULE	**AGRICULTURE**
SUBMODULE	**BURNING OF AGRICULTURAL RESIDUES**
WORKSHEET	**4-4**
SHEET	**3 OF 3**

STEP 6

	M Emission Ratio	N Emissions (Gg N)	O Conversion Ratio	P Emissions From Field burning of Agricultural Residues (Gg)
		N = (J x M)		P = (N x O)
CH_4	0.005		16/12	
CO	0.060		28/12	
		N = (L x M)		P = (N x O)
N_2O	0.007		44/28	
NO_x	0.121		46/14	

MODULE	**AGRICULTURE**
SUBMODULE	**AGRICULTURAL SOILS**
WORKSHEET	**4-5**
SHEET	**1 OF 5 DIRECT NITROUS OXIDE EMISSIONS FROM AGRICULTURAL FIELDS, EXCLUDING CULTIVATION OF HISTOSOLS**

	STEP 1	STEP 2	
Type of N input to Soil	A Amount of N Input (Kg N/yr)	B Emission Factor for Direct Emissions EF_1 (kg N_2O-N/kg N)	C Direct Soil Emissions (Gg N_2O-N/yr)
			C = (A x B) x 10^{-6}
Synthetic fertilizer (F_{SN})		0.0125	
Animal Waste (F_{AW})		0.0125	
N-Fixing crops (F_{BN})		0.0125	
Crop Residue (F_{CR})		0.0125	
		Total	

MODULE	**AGRICULTURE**
SUBMODULE	**AGRICULTURAL SOILS**
WORKSHEET	**4-5A (SUPPLEMEMNTAL)**
SHEET	**1 OF 1 MANURE NITROGEN USED**

A Total Nitrogen Excretion (kg N/yr)	B Fraction of Nitrogen burned for Fuel (fraction)	C Fraction of Nitrogen Excreted During Grazing $Frac_{GRAZ}$* (fraction)	D Fraction of Nitrogen Excreted Emitted as NO_x and NH_3 (fraction)	E Sum (fraction)	F Manure Nitrogen Used (corrected for NOx and NH3 emissions) F_{AW} (kg N/yr)
				E = 1-(B + C + D)	F = (A x E)
	0.25		0.2		
			0.2		
			0.2		

*$Frac_{GRAZ}$ will be calculated according to Annex 1 of the IPCC Guidelines

MODULE	**AGRICULTURE**					
SUBMODULE	**AGRICULTURAL SOILS**					
WORKSHEET	**4-5B (SUPPLEMEMNTAL)**					
SHEET	**1 OF 1 NITROGEN INPUT FROM CROP RESIDUES**					
A Production of non – N – Fixing Crops (kg dm/yr)	B Fraction of Nitrogen of non – N – Fixing Crops (kg N/kg dm)	C Production of Pulses and Soybeans (kg dm/yr)	D Fraction of Nitrogen in N – Fixing Crops (fraction)	E One minus the Fraction of Crop Residue Removed from Field (fraction)	F One minus the Fraction of Crop Residue Burned (fraction)	G Nitrogen Input from Crop Residues (kg N/yr)
						G = 2 x (A x B + C x D) x E X F
	0.015		0.03			

MODULE	**AGRICULTURE**			
SUBMODULE	**AGRICULTURAL SOILS**			
WORKSHEET	**4-5**			
SHEET	**2 OF 5 DIRECT NITROUS OXIDE EMISSIONS FROM CULTIVATION OF HISTOSOLS**			
	STEP 3			**STEP 4**
	D Area of Cultivated Organic Soils F_{OS} (ha)	E Emissions Factor for Direct Emissions EF_2 (kg N_2O-N/ha/yr)	F Direct Emissions from Histosols (Gg N_2O-N//yr)	G Total Direct Emissions of N_2O (Gg)
			F = (D x E) X 10^{-6}	G = (C + F)(44/28)
		10		
		10		
		10		
		10		
		Total		

MODULE	**AGRICULTURE**		
SUBMODULE	**AGRICULTURAL SOILS**		
WORKSHEET	**4-5**		
SHEET	**3 OF 5 DIRECT NITROUS OXIDE EMISSIONS FROM GRAZING ANIMALS, PASTURE RANGD AND PADDOCK**		
	STEP 5		
Animal Waste Management System (AWMS)	A Nitrogen Excretion $Nex_{(AWMS)}$	B Emission Factor for AWMS EF_3 (kg N_2O-N/ha/yr)	C Emission of N2O from Grazing Animals
			$C = (A \times B)(44/28) \times 10^{-6}$
Pasture range and paddock		0.02	

Indirect N_2O Emissions

MODULE	AGRICULTURE							
SUBMODULE	AGRICULTURAL SOILS							
WORKSHEET	4-5							
SHEET	5 OF 5 INDIRECT NITROUS OXIDE EMISSIONS FROM ATMOSPHERIC DEPOSITION OF NH_3 AND NO_x							
	STEP 6							
Type of Deposition	A Synthetic Fertilizer N applied to soil, N_{FERT} (Kg N/yr)	B Fraction of Synthetic Fertilizer N Applied that volatilizes $Frac_{GASFS}$ (kg N/kg N)	C Amount of synthetic N applied to soil that volatilizes (kg N/kg N)	D Total N Excreted by Livestock N_{ex} (kgN/yr)	E Fraction of Total Manure N Excreted that Volatilizes $Frac_{GASM}$ (kg N/kg N)	F Total N Excretion by Livestock that Volatilizes (kg N/kg N)	G Emission Factor EF_4 (kg N_2O-N/kg N)	H Nitrous Oxide Emissions (Gg N_2O-N/kg N)
			C = (A x B)			F = D x E)		H = (C + F) x G x 10^{-6}
Total		0.1			0.2		0.01	

<table>
<tr><td>MODULE</td><td colspan="7">AGRICULTURE</td></tr>
<tr><td>SUBMODULE</td><td colspan="7">AGRICULTURAL SOILS</td></tr>
<tr><td>WORKSHEET</td><td colspan="7">4-5</td></tr>
<tr><td>SHEET</td><td colspan="7">5 OF 5 INDIRECT NITROUS OXIDE EMISSIONS FROM LEACHING</td></tr>
<tr><td></td><td colspan="7">STEP 7</td></tr>
<tr><td rowspan="2">Type of Deposition</td><td>I
Synthetic Fertilizer N applied to soil, N_{FERT}
(Kg N/yr)</td><td>J
Total N Excreted by Livestock N_{ex}
(kgN/yr)</td><td>K
Fraction of N that Leaches $Frac_{LEACH}$
(kg N/kg N)</td><td>L
Emission Factor EF_5
(kg N_2O-N/kg N)</td><td>M
Nitrous Oxide Emissions from Leaching
(Gg N_2O-N/kg N)</td><td>N
Total Nitrous Oxide Emissions
(Gg N_2O/kg N)</td><td>O
Total Nitrous Oxide Emissions
(Gg)</td></tr>
<tr><td></td><td></td><td></td><td></td><td>$M = (I + J) \times K \times L \times 10^{-6}$</td><td>$N = (H + M)(44/28)$</td><td>O = G + C+ N (G from worksheet 4-5, sheet 2, step 4; C from worksheed 4-5 sheet 3, step 5; N from worksheet 4-5 sheet 5, step 8).</td></tr>
<tr><td>Total</td><td></td><td></td><td>0.3</td><td>0.025</td><td></td><td></td><td></td></tr>
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