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NITROUS OXIDE AND METHANE EMISSIONS FROM HEDGEROW SYSTEMS IN CLAVERIA, MISAMIS ORIENTAL, PHILIPPINES: AN INVENTORY

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ABSTRACT

Reports on N_2O emissions from tree-based agricultural systems in the humid tropics is very minimal even though these systems are widely practiced in these areas. This study estimated nitrous oxide emissions through inorganic fertilizer application, tree litterfall and decomposition, maize residue incorporation and livestock manure in *G. arborea* and *E. deglupta* hedgerow agroforestry systems. Methane emissions from livestock holdings in smallholder farms in Claveria, Misamis Oriental, Philippines were likewise estimated following IPCC 2006 guidelines for national GHG inventories. Total emissions from the hedgerow systems studied ranged from 3.56 to 7.46 kg N_2O ha^{-1} yr^{-1}. The major source of N_2O emissions is direct N_2O emissions from soil, ranging from 2.08 to 5.08 kg N_2O ha^{-1} yr^{-1}. Inorganic fertilizer applied, maize crop residue incorporation, and leaf litter fall were the major sources of direct N_2O emissions from the soil. Indirect N_2O emission from leaching is another source of N_2O emissions with values ranging from 0.74 to 1.41 N_2O ha^{-1} yr^{-1}. N_2O emissions from these hedgerow systems can be minimized with the proper design of the hedgerow system, proper component tree species and soil fertility management. Enteric fermentation is the major source of methane emissions from domestic livestock in Claveria. Non-dairy cattle were the main contributor of CH_4 emissions from enteric fermentation. Swine manure contributed largely to CH_4 emissions from manure management. N_2O emissions from the study site is comparable to reported emissions from improved agroforestry systems and mixed fallow system in tropical areas in Kenya and Peruvian Amazon. On the other hand, methane emissions from enteric fermentation of dairy cattle in the study area is low compared to dairy cattle in developed countries.

Key words: GHG emissions, *Eucalyptus deglupta*, *Gmelina arborea*, maize

INTRODUCTION

Nitrous oxide and methane are the important greenhouse gases, contributing 5% and 15% respectively, of the enhanced greenhouse effect. Atmospheric concentration of N_2O emission is increasing at a rate of 0.22 +/- 0.02% per year (Bhatia et al., 2004), from a pre-industrial concentration of ~275 to 320 ppm (Verchot *et al.*, 2004). The rapid increase of N_2O emission is a great concern because of its long atmospheric lifetime of 166 +/- 16 years and higher global warming potential (310 times that of CO_2). Nitrous oxide emissions from agricultural soils are the most important anthropogenic source of this gas. Agriculture contributes 6.2 Tg N yr^{-1}, about 78% of the N emissions from anthropogenic activities (Kroeze *et al.*, 1999). Soil is considered one of the major sources, contributing 65% to the global nitrous oxide emission. Nitrous oxide (N_2O) is a by-product of microbial processes closely associated with anoxic soil conditions and denitrification (Verchot *et al*., 2004). N_2O emission from soil represents a loss of N from the soil system and decreasing N use efficiency. N_2O emissions resulting from anthropogenic N input occurs through the direct pathways of nitrification and denitrification from soil, as well as through a number of indirect pathways, including volatilization losses, leaching and run-off from applied N. The applied N includes synthetic fertilizer and animal manure applied to soils.

Biological generation of methane in anaerobic environments, including enteric fermentation in ruminants, flooded rice fields, and anaerobic animal waste processing, is a principal source of methane in agriculture. Aerobic soils provide 10-20% of annual methane emissions (IPCC, 2006).

Agroforestry is a dynamic, ecologically-based, natural resource management system that, through the integration of trees and livestock in farms, diversifies and sustains smallholder production for increased social, economic and environmental benefits. It is a sustainable alternative agricultural system for degraded lands that can best meet smallholder farm household food needs as well as provide environmental services. It increases income levels and builds assets that improve purchasing power (Garrity 2004). While annual cropping of corn gives immediate income, agroforestry provides a sustainable alternative source to cash. Results of the profitability analysis showed that agroforestry systems were more efficient in utilizing scarce resources and provided higher returns on investment to farmers compared to annual cropping. The crops planted in the agroforestry system include annual cash and food crops, high value fruit trees, and timber trees (Magcale-Macandog et al., 2009).

Agroforestry systems are widely adopted in the uplands of Claveria, Mindanao, Philippines. Among the various agroforestry systems adopted by smallholder farmers in Claveria, hedgerow systems are widely adopted in farms located in sloping areas. In hedgerow intercropping, hedges are grown at certain intervals along the contours to minimize soil erosion, while the strips or alleys between these hedgerows are planted with agricultural crops (annual and/or perennial crops). Hedges can be woody perennials or grasses and plantation crops such as coffee and banana. The suggested cropping pattern is to plant the area with 20% hedgerows, 25% perennials and 55% annuals (Dalmacio and Visco 2000). Agroforestry systems may serve as both a source and sink of nitrogen oxides, depending on the management practices and component trees and crops of the system. Fertilizer applied in agroforestry systems contributes to nitrous oxide emission during the processes of nitrification and denitrification (Bhatia et al., 2004). Aside from the detrimental effects of N_2O emissions to the environment it will also result to loss of N from agricultural soils thereby resulting to reduced N-use efficiency (Millar et al., 2004).

There are very few reports of N_2O emissions from tree-based tropical agricultural systems, despite these systems being the predominant land use in much of the humid tropics (Millar et al., 2004). No study has been conducted in the Philippines to estimate N_2O and CH_4 emissions from agroforestry systems. Efforts to estimate nitrous oxide emission from the decomposition of tree litterfall in agroforestry systems has been lacking and this study will provide insights into the potential of tree litter decomposition in contributing to nitrous oxide emissions. This study sought to estimate nitrous oxide emissions through inorganic fertilizer application, tree litterfall and decomposition, maize residue incorporation and livestock manure in *G. arborea* and *E. deglupta* hedgerow agroforestry systems. It also aimed to estimate methane emissions from livestock holdings in smallholder farms in Claveria, Misamis Oriental. The study also aims to compare nitrous oxide emissions in agroforestry systems with varying hedgerow spacing, tree age, tree species and rate of fertilizer applied. The results of this study will shed important information on nitrous oxide and methane emissions from agroforestry systems with varying hedgerow spacing, tree components, tree age and fertilizer application. Accurate estimates of GHG emissions from these systems are important in the design and composition of agroforestry systems to minimize nitrous oxide and methane emissions.

METHODOLOGY

Description of the study area

Claveria is a municipality of the province of Misamis Oriental, Mindanao, in the south of the Philippines, about 40 km southeast of Cagayan de Oro City (Fig. 1). It is the biggest municipality in Misamis Oriental, with a total land area of about 82,500 ha (CCLUP, 2000). It is located in a plateau ascending abruptly from the west with elevation of 350 meters above sea level (masl) to 1,200 masl in the east. It has a rugged topography, characterized by rolling hills and mountains. The climate in the area has a pronounced dry season from January to May (<100 mm/mo) and wet season from June to December (>200 mm/mo). Soils in the area are derived from pyroclastic materials and classified as acidic-upland with a depth of more than 1 m. The cultivated land area in Claveria is estimated at 26,055 ha. Maize is grown in 51% of the arable land. In high elevation areas, 1,837 ha are planted to tomato (Magcale-Macandog et al., 2009). Cassava and banana are widely grown and tree-based agricultural systems are widely adopted by the farmers. Most frequent timber tree species planted are *Gmelina arborea*, *Eucalyptus deglupta* and *Paraserianthes falcata*. Other fruit trees found in the area are *Cocos nucifera*, *Durio zibenthinus*, *Mangifera indica*, *Nephelium lappaceum*, and *Lansium domesticum*.

General methodology to calculate nitrous oxide and methane emissions from Agriculture, Forestry and Other Land Use (AFOLU) section of the 2006 IPCC Guidelines

Direct N_2O emissions from soil

Following the 2006 IPPCC Guidelines for National Greenhouse Gas Inventories, the equation for direct N_2O emissions from managed soils in the study site (Tier 1) is:

$$N_2O_{Direct} - N = \left\lfloor N_2O - N_{Ninputs} + N_2O - N_{PRP} \right\rfloor \qquad \text{(Eqn 1)}$$

Where:

$$N_2O - N_{NInputs} = \begin{bmatrix} [(F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \bullet EF_1] + \\ [(F_{SN} + F_{ON} + F_{CR} + F_{SOM})_{FR} \bullet EF_{1FR}] \end{bmatrix} \qquad \text{(Eqn 2)}$$

$$N_2O - N_{PRP} = \left\lfloor (F_{PRP,CPP} \bullet EF_{3PRP,CPP}) + (F_{PRP,SO} \bullet EF_{3PRP,SO}) \right\rfloor \qquad \text{(Eqn 3)}$$

where:

N_2O_{Direct}-N = annual direct N_2O-N emissions produced from managed soils, kg N_2O-N yr-^{1}

N_2O-$N_{N\ inputs}$ = annual direct N_2O-N emissions produced from N inputs to managed soils, kg N_2O-N yr-^{1}

N_2O-N_{OS} = annual direct N_2O-N emissions produced from managed organic soils, kg N_2O-N yr-^{1}. (Note: Since the soil in the study area is not organic soil, this part was not included in the computation for annual direct N_2O-N emissions)

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

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

F_{ON} = annual amount of animal manure, compost sewage sludge 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 mineralized, 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}

F_{OS} = annual area of managed/drained organic soils, ha

F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr-^{1}

EF_1 = emission factor for N_2O emissions from N inputs, kg N_2O-N (kg N input)$^{-1}$

EF_{1FR} = emission factor for N_2O emissions from N inputs to flooded rice, kg N_2O-N (kg N input)$^{-1}$

EF_2 = emission factor for N_2O emissions from drained/managed organic soils, kg N_2O-N ha^{-1} yr^{-1}

EF_{3PRP} = emission factor for N_2O emissions from urine and dung N deposited by grazing animals on pasture, range and paddock, kg N_2O-N (kg N input)$^{-1}$. (Note: the subscripts CPP and SO refer to Cattle, Poultry & Pigs, and Sheep & Other animals, respectively.)

Conversion of N_2O-N emissions to N_2O emissions for reporting purposes is performed by using the following equation:

$$N_2O = N_2O\text{-}N \bullet 44/28 \qquad \text{(Eqn 4)}$$

N in urine and dung deposited by grazing animals on pasture, range and paddock (Tier 1)

$$F_{PRP} = \sum_T \left[(N_{(T)} \bullet Nex_{(T)}) \bullet MS_{(T,PRP)} \right] \qquad \text{(Eqn 5)}$$

Where:

F_{PRP} = annual amount of urine and dung N deposited on pasture, range, paddock and by grazing animals, kg N yr^{-1}

$N_{(T)}$ = number of head of livestock species/category *T* in the country

Nex(T) = annual average excretion per head of species/category *T* in the country, kg N animal^{-1} yr^{-1}

$MS_{(T,PRP)}$ = fraction of total annual N excretion for each livestock species/category *T* that is deposited on pasture, range and paddock

Indirect N_2O emissions

N_2O from atmospheric deposition of N volatilized from managed soils (Tier 1)

$$N_2O_{(ATD)} - N = \left[(F_{SN} \bullet Frac_{GASF}) + (F_{ON} + F_{PRP}) \bullet Frac_{GASM}) \right] \bullet EF_4 \qquad \text{(Eqn 6)}$$

Where:

$N_2O_{(ATD)}$-N = annual amount of N_2O-N produced from atmospheric deposition of N volatilized from managed soils, kg N_2O-N yr^{-1}

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

$Frac_{GASF}$ = fraction of synthetic fertilizer that volatilizes as NH_3 and NO_x, kg N volatilized (kg of N applied)$^{-1}$

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

F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr^{-1}

$Frac_{GASM}$ = fraction of applied organic N fertilizer materials (F_{ON}) and of urine and dung deposited by grazing animals (F_{PRP}) that volatilizes as NH_3 and NO_x, kg N volatilized (kg of N applied or deposited)$^{-1}$

EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, [kg $N\text{-}N_2O$ (kg NH_3-N + NO_x-N volatilized)$^{-1}$]

Leaching/ Runoff, $N_2O(L)$

N_2O from N leaching/runoff from managed soils in regions where leaching/runoff occurs (Tier 1)

$$N_2O_{(L)} - N = (F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) \bullet Frac_{LEACH-(H)} \bullet EF_5 \qquad \text{(Eqn 7)}$$

Where:

$N_2O_{(L)}$-N = annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kg N_2O-N yr^{-1}

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

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

F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr^{-1}

F_{CR} = amount of N in crop residues (above- and below-ground), including N-fixing crops, and form forage/pasture, returned to soils annually in regions where leaching/runoff occurs, kg N yr^{-1}

F_{SOM} = annual amount of N mineralized in mineral soils associated with loss of soil C from soil organic matter as a result of changes to land use or management in regions where leaching/runoff occurs, kg N yr^{-1}

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralized in managed soils in regions where leaching /runoff occurs that is lost through leaching and runoff, kg N (kg of N additions)$^{-1}$

EF_5 = emission factor for N_2O emissions from N leaching and runoff, kg N_2O-N (kg N leached and runoff)$^{-1}$

Methane Emissions from livestock

Methane emissions from enteric fermentation: Enteric fermentation from livestock

$$Emissions = EF_{(T)} \bullet \left(\frac{N_{(T)}}{10^6} \right) \qquad \text{(Eqn 8)}$$

Where:

Emissions = methane emissions from enteric fermentation, kg CH_4 yr^{-1}

$EF_{(T)}$ = emission factor for the defined livestock population, kg CH_4head^{-1}yr^{-1}

$N_{(T)}$ = the number of head of livestock species/category *T* in the country

T = species/category of livestock

Total emissions from livestock enteric fermentation

$$TotalCH_{4Enteric} = \sum_i E_i \qquad \text{(Eqn 9)}$$

Where:

$TotalCH_{4Enteric}$ = total CH_4 emissions for enteric fermentation, Gg CH_4yr^{-1}

E_i = the emissions for the ith livestock categories and subcategories

Methane emissions from manure management

$$CH_{4Manure} = \sum_{(T)} \frac{(EF_{(T)} \bullet N_{(T)})}{10^6} \qquad \text{(Eqn 10)}$$

Where:

$CH_{4Manure}$ = CH_4 emissions from manure management, for a defined population, kg 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

Experimental treatments and management

Established seven-year *E. deglupta* and *G. arborea* hedgerow systems were selected in the study area, while one-year old *E. deglupta* and *G. arborea* hedgerow systems were established in nearby plots in the study area. To establish new hedgerow systems, the plot was manually cleared and cultivated with the use of animal-drawn single blade moldboards. Two hedgerow spacing treatments were established in the study area: 1m x 3 m hedgerow spacing and 1m x 9 m hedgerow spacing. *Eucalyptus deglupta* and *G. arborea* were planted along the hedgerows and maize was planted in the alley areas. Each plot measured 18 m upslope and 10 m across the slope. The study was laid out in a Randomized Complete Block Design (RCBD) with two replications. The treatments used in the study are different combinations of tree species, tree age, and tree spacing (Table 1).

Table 1. The experimental treatments (tree species, tree age, spacing) in the study.

7 year-old trees	1 year-old trees
1x3 m (*G. arborea* + *Z. mays*)	1x3 m (*G. arborea* + *Z. mays*)
1x9 m (*G. arborea* + *Z. mays*)	1x9 m (*G. arborea* + *Z. mays*)
1x3 m (*E. deglupta* + *Z. mays*)	1x3 m (*E. deglupta* + *Z. mays*)
1x9 m (*E. deglupta* + *Z. mays*)	1x9 m (*E. deglupta* + *Z. mays*)
Control, pure maize (*Z. mays*)	Control, pure maize (*Z. mays*)

Maize (Pioneer hybrid 3014) was planted in the alley areas at 1 seed per hill at a planting distance between furrows of 60 cm and 25-30 cm between rows for two cropping seasons in one year. Weeding of the alleys and inter-row cultivation of maize plants were done 30 days after planting (DAP). Nitrogen (N) fertilizer (Urea, 46-0-0) and phosphorus (P) fertilizer (Solophos, 0-18-0) were applied at the rate of 195.65 kg ha^{-1} and 166.67 kg ha^{-1}, respectively. These rates of fertilizer application were based on the results of fertility analysis of soils sampled from the study area and the recommended fertilizer application for maize crop (Table 2). P fertilizer was applied and covered with enough soil to avoid contact with seeds before sowing. On the other hand, N fertilizer was side-dressed at 30 days after planting. After nitrogen application, inter-row cultivation was done to cover the fertilizer with soil and as a weed control measure. A second inter-row cultivation was done 60 days after planting. Hand weeding was also done as needed, 2 to 3 weeks after the second inter-row cultivation.

Field and laboratory measurements

Maize was harvested manually at 105-110 days after planting. Destructive sampling of 16 sample plants per plot was done to determine plant biomass. Roots, stalks, leaves and cobs were segregated, and the fresh weight was taken. One hundred fifty grams (150g) fresh weight of the sub-sample for each component was taken for oven drying at 70° C for 48 hours or until constant weight was attained. Dry weight of each crop component was determined. Plant residue was computed by summing up the dry weights of the different plant parts except the grain portion, which is taken out of the system. The average individual plant residue was computed based on the biomass of the 16 plant samples per plot.

The approximate number of maize plants per plot was computed based on the distance between hills in a row and total number of rows in the treatment plots (Table 2). The rest of the crop remained in the field as crop residue and was incorporated back into the soil during cultivation for the next cropping.

The litter input of the hedgerows of 7-yr old *E. deglupta* and *G. arborea*, was estimated by installing four 1m x 1m litter traps (1m x 1m) randomly under the trees inside each plot. Litter fall were collected on a monthly basis. Leaves and other parts composed of branches and twigs were segregated. Fresh weight was taken at the field, and dry weight was determined after oven drying at 70 ºC for 48 hours. Fifty-gram leaf samples (collected inside the plot) were placed in net bags (12 in x 12 in) for the decomposition study in the 7-year old *G. arborea* and *E.deglupta* plots. A total of 8 net bags were randomly placed inside each plot and two bags per plot were collected every 21 days. Samples were weighed for fresh and oven-dried weight. The decomposition rate was computed from the percent loss in weight (Graca et al., 2005).

To have a statistically representative sample of the whole population of farmers in Claveria, a stratified random sampling technique was employed in selecting the respondents for the household interview. Based on the combined elevation and agroforestry system classes, 300 farmers were randomly selected through lots drawn from a list of farmers grouped under each combined elevation and agroforestry system class, as respondents for the household interview. A component of the survey instrument is a set of questions related to livestock holdings and feed requirements (Magcale-Macandog et al., 2009).

Statistical Analysis

Data on maize biomass and litterfall were analyzed using univariate analysis. Treatments with significant differences were further analyzed using the Bonferroni test.

RESULTS AND DISCUSSION

A hedgerow system is effective in addressing soil erosion problems as well as in conserving the topsoil. Further, modeling simulation results showed that maize yields increased and stabilized under the hedgerow system (Magcale-Macandog et al., 2009). *Gmelina arborea* and *Eucalyptus deglupta* are two fast-growing timber species that are planted in hedgerow systems while maize is planted in the alley areas between the hedgerows.

Nitrous Oxide Emissions

N_2O emissions resulting from anthropogenic N input occurs through the direct pathways of nitrification and denitrification from soil and also through a number of indirect pathways including volatilization losses, leaching and runoff from applied N. The applied N includes synthetic fertilizer and animal manure applied to soils. Direct N_2O emissions from the hedgerow systems in Claveria were computed from the amount of inorganic N fertilizer applied in the experimental set-up for two cropping seasons (Table 2), maize crop residues incorporated back into the soil and hedgerow tree leaf litter (Eqn 2).

The IPCC (2006) default value for $Frac_{GASF}$ (the fraction of fertilizer nitrogen applied emitted as NO_x and NH_3) of 0.1 was adopted in the computation for F_{SN} (Eqn 2) . A higher amount of synthetic fertilizer nitrogen (F_{SN}) was applied in the hedgerow system with wider tree spacing treatment (1m x 9 m) (Table 2).

Table 2. Fertilizer nitrogen applied (total of 2 cropping seasons) in the different plots.

Tree Species	Tree Age (yr)	Tree spacing (m x m)	Plot size (ha)	N applied (kg N ha^{-1} yr^{-1})	1-Frac$_{GASF}$	F_{SN} (kg N ha^{-1} yr^{-1})
E. deglupta	1	1 x 3	0.018	221	0.9	199
E. deglupta	1	1 x 9	0.018	345	0.9	311
G. arborea	1	1 x 3	0.018	221	0.9	199
G. arborea	1	1 x 9	0.018	345	0.9	311
Z. mays			0.018	201	0.9	181
E. deglupta	7	1 x 3	0.032	221	0.9	199
E. deglupta	7	1 x 9	0.032	345	0.9	311
G. arborea	7	1 x 3	0.032	221	0.9	199
G. arborea	7	1 x 9	0.032	345	0.9	311
Z. mays			0.018	201	0.9	181

Maize biomass and crop residue

Growth and biomass of maize plants were relatively higher when grown under 1-year-old tree hedgerows compared with 7-year-old tree hedgerows for both hedgerow spacing treatments and tree species. For both tree ages, the growth and biomass of maize crops were relatively higher when grown under *E. deglupta* hedgerows than under *G. arborea* hedgerows at both spacing treatments (Table 3).. Maize plant growth was greater under 1-year-old tree hedgerows, since competition for light between the hedgerow trees and maize crop in the alley areas was minimal.

Table 3. Total maize crop residue per plot.

Tree species	Tree age (year)	Tree spacing (m x m)	Mean individual maize biomass* (g)	Mean individual maize plant residue (g)	Number of maize plants (plants plot^{-1})	Total crop residue (kg ha^{-1} yr^{-1})
E. deglupta	1	1x 3	267.1^{ab}	208.1	1,600	18,494
E. deglupta	1	1x 9	352.4^{ab}	282.4	1,280	20,083
G. arborea	1	1x 3	173.0^{ab}	135.3	1,600	12,028
G. arborea	1	1x 9	266.2^{ab}	211.9	1,280	15,067
Z. mays			432.2^{b}	326.8	1,033	18,756
E. deglupta	7	1x 3	113.6^{a}	78.2	767	1,874
E. deglupta	7	1x 9	165.6^{ab}	122.1	1,000	3,816
G. arborea	7	1x 3	65.6^{a}	40.3	767	966
G. arborea	7	1x 9	138.2^{a}	109.3	1,000	3,416
Z. mays			206.4^{ab}	160.2	1,033	9,194

*Means with the same letter(s) are not statistically significant at α=0.05, Bonferroni test.

As to the effect of hedgerow spacing treatment, results showed that when grown at closer spacing treatment (1x3), maize crop performance was lower than when grown in wider spacing treatment for both ages and species of trees (Table 3). The shape of the tree canopy, root architecture and tree leaf litter composition contributed to the dynamic interaction between trees and crops in agroforestry systems (Magcale-Macandog, et al., 2004; van Noordwijk and Mulia, 2002).

N inputs from maize crop residues

In Claveria, incorporating maize crop residues during land preparation for the subsequent crop is the common practice, Greater crop residues were incorporated back into the soil under 1-year-old hedgerows systems than in the 7-year old hedgerow system for both species of trees. N inputs from maize crop residues (Eqn 2) was higher in wider spacing treatment than in closer spacing treatment (Table 4) at both tree age classes and tree species. Nitrogen input from crop residues was higher under *E. deglupta* hedgerows than *G. arborea* hedgerows.

Table 4. Nitrogen input from crop residues.

Tree species	Tree age (year)	Tree spacing (m x m)	Total crop residue (kg ha^{-1} yr^{-1})	N fraction of maize residues	N input from residues (F_{CR}) (kg N ha^{-1} yr^{-1})
E. deglupta	1	1x 3	18,494	0.0040	73.98
E. deglupta	1	1x 9	20,083	0.0045	90.37
G. arborea	1	1x 3	12,028	0.0040	48.11
G. arborea	1	1x 9	15,067	0.0056	84.37
Z. mays			18,756	0.0048	90.03
E. deglupta	7	1x 3	1,874	0.0051	9.56
E. deglupta	7	1x 9	3,816	0.0045	14.34
G. arborea	7	1x 3	966	0.0056	5.41
G. arborea	7	1x 9	3,416	0.0040	13.66
Z. mays			9,194	0.0045	41.37

N inputs from litter fall (F_{LI}) of 7-year old hedgerow trees

With regard to 7-year old hedgerow tree species, the mean monthly and total litterfall of *E. deglupta* was relatively higher than the litterfall of *G. arborea* . The mean monthly litterfall of *E. deglupta* with wider spacing treatment (1 x 9) was significantly higher than the litterfall of *G. arborea* trees in narrow spacing treatment (Table 5). Liitter fall is relatively higher under wider spacing treatment for both tree species. Intraspecific competition among hedgerow trees is relatively lower when trees are spaced farther apart, allowing full tree canopy development.

Table 5. Litterfall from 7 year old *E. deglupta* and *G. arborea* trees.

Tree Species	Spacing (m x m)	Mean monthly litterfall* (g m^{-2} mo^{-1})	Total Leaf litter fall (kg ha^{-1} yr^{-1})	N fraction	N input from litterfall (F_{LI}, kg N ha-1 yr^{-1})
G. arborea	1x 3	54.85^{a}	6,033	0.0147	88.69
G. arborea	1x 9	65.73^{ab}	7,231	0.0147	106.29
E. deglupta	1x 3	70.11^{ab}	7,712	0.0102	78.66
E. deglupta	1x 9	82.79^{b}	9,107	0.0107	97.45

* Means with the same letter(s) are not statistically significant at α=0.05, Bonferroni test.

The proportion of leaf litter in the total litter fall under *E. deglupta* hedgerows ranged from 76 to 82%, while leaf litter of *G. arborea* range from 77 to 86% of the total litter, under both tree spacing treatments (Fig. 3). *Gmelina arborea* leaf litter had higher N content (1.47%) than *E. deglupta* leaf litter (1.02 – 1.07%), so that the N inputs from leaf litter were higher under *G. arborea* hedgerows than under *E. deglupta* hedgerows at each spacing treatment (Table 5).

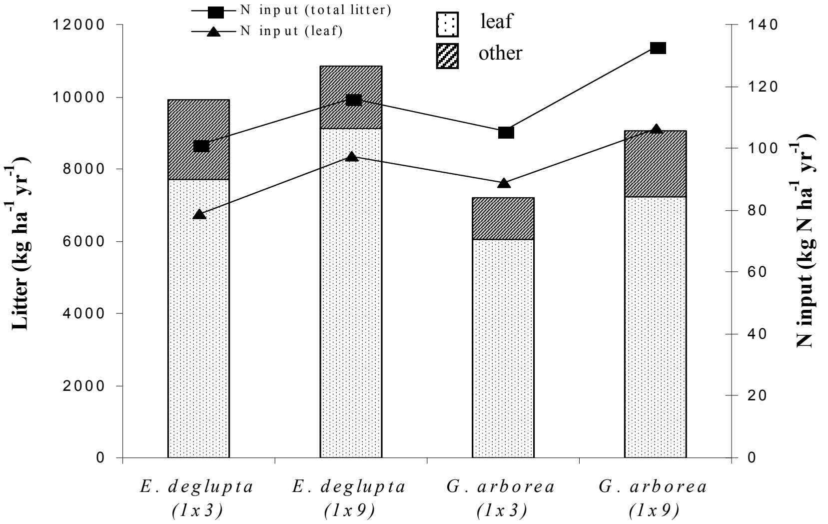

Fig 3. Leaf and total (leaf, twigs, branches) litter from 7-yr old *E.deglupta* and *G. arborea* trees.

Leaf litter decomposition

During the first two samplings (21 and 42 days) of the leaf litter decomposition experiment, *G. arborea* leaf litter had greater weight loss, as indicated by the reduction in oven dry weight (ODW), implying faster rates of decomposition (Fig. 4). Nutrient turnover was relatively faster underthe *Gmelina* hedgerow system having a faster rate of decomposition. Magcale-Macandog and Rocamora (1997) reported that complete decomposition of *G. arborea* leaf litter takes place within four months. Examination of the leaves of the two tree species reveals that *G. arborea* leaves are thinner and wider, while *E. deglupta* leaves are thicker and narrower. The N content of *G. arborea* leaves was 2.25%, while bark contained 1.56% (Mamicpic, 1997). Leaves of *E. deglupta* had 2.3% N (http://weather.nmsu.edu/hydrology/wastewater/plant-nitrogen-content.htm). Baggs et al. (2001) reported that the average N content of the improved-fallow residues (2.3-3.2%) was above the typical threshold (1.7-1.8%) for immediate net N mineralization (Melillo et al., 1982; Constantinides and Fownes, 1994; Senevitrane, 2000).

Between 65% and 90% of total N_2O emitted was lost in the first 28 days after residue incorporation (Baggs et al., 2001). Total N_2O per ton biomass emitted over 84 days after incorporation of improved- and natural-fallow residues was positively correlated with residue N concentration and acid detergent lignin content, and negatively correlated with residue C:N ratio, but not significantly correlated with total extractable polyphenol content. Further, daily fluxes of N_2O from improved-fallow and maize treatments were positively correlated with rainfall, water-filled pore space (WFPS), and air temperature.

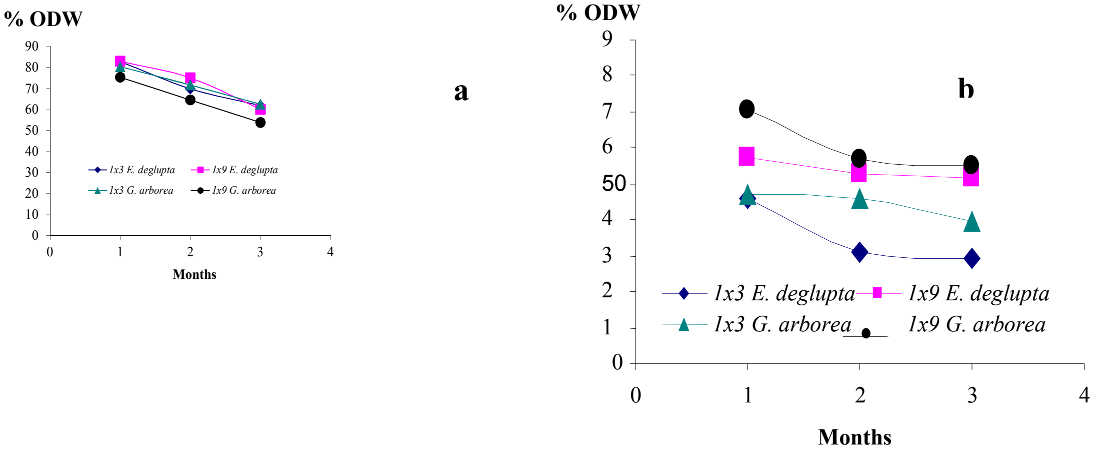

Fig. 4 Decomposition of *E. deglupta* and *G. arborea* leaf litter: (a) first cropping and (b) second cropping.

Synthetic fertilizer applied and decomposition of leaf litter are the major sources of direct nitrous oxide emissions (Eqn 2) (Table 6). Decomposition of maize crop residues is another source of direct nitrous oxide emissions in the agroforestry systems studied. Results have shown that the wider hedgerow spacing treatment (1m x 9m) had higher emissions of nitrous oxide for both age classes of trees. This is due to the higher amount of inorganic fertilizer applied, higher maize crop residues and higher leaf litter at wider spacing treatment.

Table 6. Annual direct nitrous oxide emissions from N inputs to hedgerows systems.

Tree species	**Tree spacing (m x m)**	**F_{SN} (kg N ha-^{1} yr^{-1})**	**F_{CR} (kg N ha-^{1} yr^{-1})**	**F_{LI} (kg N ha-^{1} yr^{-1})**	**EF_1 (kg N_2O-N (kg N input)$^{-1}$**	**N_2O-$N_{N\ inputs}$ (kg N_2O ha^{-1} yr^{-1})**
1 year old						
E. deglupta	1x3	199	9.5		0.01	2.08
E. deglupta	1x9	311	14.3		0.01	3.25
G. arborea	1x3	199	5.4		0.01	2.04
G. arborea	1x9	311	13.7		0.01	3.25
Z. mays		181	41.4		0.01	2.22
7 years old						
E. deglupta	1x3	199	74.0	88.7	0.01	3.62
E. deglupta	1x9	311	90.4	106.3	0.01	5.08
G. arborea	1x3	199	48.1	78.7	0.01	3.26
G. arborea	1x9	311	84.4	97.4	0.01	4.93
Z. mays		181	90.0		0.01	2.71

Note: Leaf litter data was not taken from 1-yr old trees, which were too young to shed leaves.

Annual direct N_2O emissions from the hedgerow systems ranged from 2.08 to 5.08 kg N_2O ha^{-1} yr^{-1} (Table 6). These values were comparable with the measured N_2O emissions from improved agroforestry systems in Western Kenya (Millar et al., 2004).

In a mixed fallow system where *Sesbania sesban* and *Macroptilium atropurpureum* residues (composed of leaves, twigs and pods) were incorporated into the soil prior to the planting of maize, 4.1 kg N_2O-N ha^{-1} was emitted over 84 days. Emissions also increased after incorporation of fallow residues. Moreover, N_2O emissions were higher after incorporation of improved-fallow legume residues (*Sesbania sesban*, *Crotalaria grahamiana*, *Macroptilium atropurpureum*) than natural-fallow residues (mainly consisting of *Digitaria abyssibica*, *Hibiscus cannabinus*, *Bidens pilosa*, *Guizotia scabra*, *Leonotis nepetifolia*, and *Commelina benghalensis*). Generally, larger emissions are measured after incorporation of material with a high N content, or low C:N ratio, than material with a low N content due to promotion of mineralization and subsequent availability of substrate for nitrification and denitrification (Baggs et al., 2000).

N_2O emissions from soil have previously been shown to increase after incorporation of crop residues in tropical conditions (Millar et al, 2004). Organic material is often readily decomposed, and N_2O is released during nitrification and/or denitrification depending upon aeration of the soil. The magnitude of emissions varies depending on residue composition or quality and quantity of biomass incorporated (Aulakh et al., 1991; Baggs et al., 2000, 2001), and with temperature, water content, aeration, soil type, and cultivation (Aulakh et al., 1984). Generally, greater N_2O emissions are measured after incorporation of material with a high rather than low N content (Kaiser et al., 1998; Baggs et al., 2000), but for tropical agroforestry residues, lignin and polyphenol contents have a strong influence in determining the availability of N for release (Palm and Sanchez, 1991; Handayanto et al., 1994), with lower N_2O emissions measured from residues with high polyphenol protein binding capacity (Baggs et al., 2001).

Emissions from the improved-fallow systems estimated from the maize cropping season after residue incorporation ranged from 1.7 to 4.2 kg N_2O-N ha^{-1} over 122 days at Dindi farm (Western Kenya), and was 0.8 kg N_2O-N ha^{-1} over 184 days at Oloo farm (Western Kenya), with 0.3 kg N_2O-N ha^{-1} emitted from the natural fallow system. The cropping season estimates for Dindi farm were higher than the annual emissions of N_2O measured by Palm et al. (2002) from Amazonian multistrata, forest fallow, and shifting cultivation fallow agroforestry systems (0.6, 0.8, and 0.8 kg N_2O-N ha^{-1} yr^{-1}, respectively) (Baggs et al., 2000).

A long-term experiment on nitrous oxide and methane fluxes in six different land use systems was established in 1985 in the Peruvian Amazon (Palm *et al*., 2002). The high and low input agriculture systems were greater N_2O sources than the agroforestry systems, and the fallow control was an even lower source. Tsuruta *et al.* (2000) reported a transient increase in N_2O emissions associated with increased N availability in tree-based agricultural systems in Indonesia. Fertilizer application increases the N-oxide flux from soils because it stimulates the microbial processes of nitrification and denitrification, which results in increased gas fluxes. In addition, heavy rainfall soon after the application of fertilizer to wet soils stimulates N_2O emissions (Verchot *et al*., 2004). In agroforestry systems designed to restore or maintain soil fertility, trees are often grown in the fields, or nearby, and tree litter is used as a green manure. N_2O flux is very much dependent on the quality of the plant litter that is produced and incorporated into the soil (Millar et al., 2004).

Direct nitrous oxide emissions from animal urine and dung

Livestock holding, mostly cattle and carabaos, is widespread in Claveria, with 74% of the households raising one head. Livestock serve various purposes and are utilized in cultivating and preparing the land prior to crop planting, local means of transportation to and from the farm, as well as for transporting domestic water and farm produce.

Animal manure is another source of nitrogen emissions from these agroforestry systems. Calculations show that in Claveria, cattle are a great contributor of annual direct nitrous oxide emissions from urine and dung inputs to grazed soils (63.46 kg N_2O yr^{-1}) and swine (46. 16 kg N_2O yr^{-1}) (Eqn 5) Another contributor of annual direct nitrous oxide emissions from urine and dung inputs to grazed soils is swine (46. 16 kg N_2O yr^{-1}) (Eqn 5) . On the average, each household raises at least 1 head of swine. (Table 7).

Indirect nitrous oxide emissions from volatilization

Following the IPCC guidelines, the amount of N_2O emissions from volatilization from synthetic fertilizer applied and animal manure (Eqn 6) is minimal for all the experimental plots (Table 8). The total N excretion by livestock was obtained by dividing the total N excretion using local values (6515kg N/yr) by the number of households surveyed (300) to yield an average of 21.71 kg N excreted by livestock for each of the plots. Indirect nitrous oxide emissions from volatilization ranged from 0.34 to 0.54 kg N_2O-N yr^{-1}, with the wider spacing treatment having higher emissions.

Table 7. Annual direct nitrous oxide emissions from urine and dung inputs to grazed soils (F_{PRP}).

Livestock Type	**Number of animals**	**Nex(T) (kg N animal^{-1} yr^{-1})**	**Total Nex(T) (kg N yr^{-1})**	**EF_3 kg N_2O-N (kg N input)$^{-1}$**	**$MS_{(T,PRP)}$**	**N_2O-N_{PRP} (kg N_2O yr^{-1})**
Non-dairy cattle	258	12.3	3173.4	0.02	1	63.46
Carabao	62	14.2	880.4	0.02	1	17.60
Goat	46	0.6	27.6	0.01	1	0.27
Swine	398	5.8	2308.4	0.02	1	46.16
Poultry	1252	0.1	125.2	0.02	1	2.50
Total			6515			129.99

Table 8. Indirect nitrous oxide emissions from volatilization.

Tree Species	**Tree spacing (m x m)**	**F_{SN} (kg N ha^{-1} yr^{-1})**	**Frac $_{GASF}$**	**F_{PRP} (kg N ha^{-1} yr^{-1})**	**Frac $_{GASM}$**	**EF_4 (kg N_2O-N kg N^{-1})**	**$N_2O_{(ADT)}$ – N (kg N_2O-N yr^{-1})**	**$N_2O_{(ADT)}$ (kg N_2O-N yr^{-1})**
1 year old								
E. deglupta	1x3	199	0.1	21.71	0.2	0.01	0.24	0.37
E. deglupta	1x9	311	0.1	21.71	0.2	0.01	0..35	0.54
G. arborea	1x3	199	0.1	21.71	0.2	0.01	0.24	0.37
G. arborea	1x9	311	0.1	21.71	0.2	0.01	0.35	0.54
Z. mays		181	0.1	21.71	0.2	0.01	0.22	0.34
7 years old								
E. deglupta	1x3	199	0.1	21.71	0.2	0.01	0.24	0.37
E. deglupta	1x9	311	0.1	21.71	0.2	0.01	0.35	0.54
G. arborea	1x3	199	0.1	21.71	0.2	0.01	0.24	0.37
G. arborea	1x9	311	0.1	21.71	0.2	0.01	0.35	0.54
Z. mays		181	0.1	21.71	0.2	0.01	0.22	0.34

Indirect nitrous oxide emission from leaching

The indirect nitrous oxide emissions from leaching (Eqn 7) ranged from 0.7 to 1.4 (Table 9). Higher emissions from leaching were associated with higher inorganic nitrogen fertilizer and crop residue application.

Table 9 . Indirect nitrous oxide emission from leaching.

Tree Species	**Tree spacing (m x m)**	**F_{SN} (kg N ha^{-1} yr^{-1})**	**F_{CR}**	**$FRAC_{LEACH-(H)}$ (kg N (kg N additions)$^{-1}$)**	**EF_5 (kg N_2O-N (kg N leached and runoff)$^{-1}$**	**$N_2O_{(L)}$-N emissions from leaching (kg N_2O-N yr^{-1})**	**$N_2O_{(L)}$ emissions from leaching (kg N_2O-N yr^{-1})**
1 year old							
E. deglupta	1x3	199	9.5	0.3	0.0075	0.469	0.74
E. deglupta	1x9	311	14.3	0.3	0.0075	0.732	1.15
G. arborea	1x3	199	5.4	0.3	0.0075	0.460	0.72
G. arborea	1x9	311	13.7	0.3	0.0075	0.731	1.15
Z. mays		181	41.4	0.3	0.0075	0.500	0.79
7 yrs old							
E. deglupta	1x9	199	74.0	0.3	0.0075	0.614	0.96
E. deglupta	1x3	311	90.4	0.3	0.0075	0.903	1.41
G. arborea	1x9	199	48.1	0.3	0.0075	0.556	0.87
G. arborea	1x3	311	84.4	0.3	0.0075	0.890	1.40
Z. mays		181	90.0	0.3	0.0075	0.609	0.96

Total N_2O emissions

Total emissions from the hedgerow systems studied ranged from 3.56 to 7.46 kg N_2O ha^{-1} yr^{-1} (Eqn 1 and Eqn 4). The major source of N_2O emissions was direct N_2O emissions from soil, ranging from 2.08 to 5.08 kg N_2O ha^{-1} yr^{-1}. Indirect N_2O emission from leaching was another source of N_2O emissions, next to direct N_2O emissions from the soil, with values ranging from 0.72 to 1.41 N_2O ha^{-1} yr^{-1} (Table 10).

Methane Emissions

Methane emissions from the agroforestry systems in Claveria mainly come from livestock enteric fermentation and manure management. Non-dairy cattle are the major source of methane from enteric fermentation (Eqn 8) in Claveria while swine are the major source of methane from manure management (Eqn 10) (Table 11).

Total methane emissions

Enteric fermentation is the major source of methane emissions from domestic livestock in Claveria (Table 12). Non-dairy cattle and carabaos are the major contributors of methane emissions (12,126 kg CH_4 yr^{-1}) from enteric fermentation (Eqn 8). Swine are the major contributor of methane emissions from manure management, 2,786 kg CH_4 yr^{-1} (Table 12).

Table 10. Direct and indirect soil soil N_2O emissions in *E. deglupta* and *G. arborea*

Tree species	Tree spacing (m x m)	$N_2O\text{-}N_{N\ inputs}$ (kg N_2O ha^{-1} yr^{-1})	$N_2O\text{-}N_{PRP}$ (kg N_2O yr^{-1})	$N_2O_{(ADT)}$ (kg N_2O-N yr^{-1})	$N_2O_{(L)}$ (kg N_2O-N yr^{-1})	Total N_2O emissions (kg N_2O-N yr^{-1})
1 year old						
E. deglupta	1 x 3	2.08	0.43	0.37	0.74	3.62
E. deglupta	1x 9	3.25	0.43	0.54	1.15	5.37
G. arborea	1x 3	2.04	0.43	0.37	0.72	3.56
G. arborea	1x 9	3.25	0.43	0.54	1.15	5.37
Z. mays		2.22	0.43	0.34	0.79	3.78
7 years old						
E. deglupta	1x 3	3.62	0.43	0.37	0.96	5.38
E. deglupta	1x 9	5.08	0.43	0.54	1.41	7.46
G. arborea	1x 3	3.26	0.43	0.37	0.87	4.93
G. arborea	1x 9	4.93	0.43	0.54	1.40	7.30
Z. mays		2.71	0.43	0.34	0.96	4.44

Table 11 . Population of various animal types in Claveria and the corresponding emission factors for enteric fermentation and manure management

Animal type	Enteric fermentation		Manure management	
	Population	$EF_{(T)}$ (kg CH_4 $head^{-1}$ yr^{-1})	Population	Emission factor (kg CH_4 $head^{-1}$ yr^{-1})
Non-dairy cattle	258	47	258	1
Carabao	62	55	62	2
Goat	46	5	46	0.22
Swine	398	1	398	7
Poultry	1252	-	1252	0.02

Table 12. Total methane emissions from domestic livestock in Claveria.

Animal type	Enteric fermentation (kg CH_4 yr^{-1})	Manure management (kg CH_4 yr^{-1})	Total methane emissions (kg CH_4 yr^{-1})
Non-dairy cattle	12,126	516	12,642
Carabao	3,410	186	3,596
Goat	230	10	240
Swine	398	2,786	3,184
Poultry	-	25	25
Total	16,164	3,523	19,687

CONCLUSION

N_2O emissions from tree-based hedgerow systems vary with tree species, spacing between hedgerows and fertilizer management. In the tree-based hedgerow systems studied, inorganic fertilizer applied, maize crop residue incorporation, and leaf litter fall were the major sources of direct N_2O emissions from the soil. The higher amount of inorganic fertilizer applied in the alley crops in the wider spacing treatment is a major source of direct N_2O emissions from these systems. Maize crop residues is another source of direct N_2O emissions and results showed that maize crop biomass and crop residues were greater under wider spacing treatment for both *E. deglupta* and *G. arborea* hedgerows. Under 7-year-old hedgerow systems, maize crop growth and biomass were greater under *E. deglupta* hedgerows than under *G. arborea* hedgerows. This implies that there is greater competition for above-ground and below-ground resources between *G. arborea* trees and maize crops. The quantity and quality of tree leaf litter fall from the hedgerow species is also a major factor affecting N_2O emissions. *E. deglupta* had higher leaf litter fall and higher leaf N content. Higher N_2O emissions occurred in *E. deglupta* hedgerow system at both tree age classes and hedgerow spacing treatments. However, the rate of decomposition in *E. deglupta* leaf litter is slower compared with the leaf litter of *G. arborea*, resulting to lower influx of N_2O emissions attributed to leaf litter decomposition.

N_2O emissions from these hedgerow systems can be minimized with the proper design of the hedgerow system, proper component tree species and soil fertility management. Direct N_2O emissions from fertilizer application can be minimized by applying organic fertilizer instead of inorganic fertilizer since organic fertilizers bind nitrogen and release them slowly. Planting hedgerow tree species with high leaf litter fall and high leaf N content, such as leguminous tree species will also contribute directly to organic N fertilizer for the crops growing in the alley areas, thus the need for inorganic fertilizer would be minimal. Aboveground and below ground canopy architecture of the tree component is also a very important consideration in the choice of hedgerow tree species to minimize competition between the tree species and the alley crops. Enteric fermentation is the major source of methane emissions from domestic livestock in Claveria. Non-dairy cattle were the main contributor of CH_4 emissions from enteric fermentation. Manure management is another source of CH_4 emissions, and swine manure contributed largely to CH_4 emissions in Claveria. Methane from swine manure can be harnessed and utilized as biofuel.

N_2O emissions from the study site is comparable to reported emissions from improved agroforestry systems and mixed fallow system in tropical areas in Kenya and Peruvian Amazon. On the other hand, methane emissions from enteric fermentation of dairy cattle in the study area is low compared to dairy cattle in developed countries.

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