Can improved pastures integrated with trees offset GHG emissions? Estimation of Carbon stock, CH_4 and N_20 emissions in silvopastoral systems of Esparza, Costa Rica.

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Abstract

In Central America, silvopastoral and Agro-silvopastoral livestock production is the mainstay of the economy. Improved grass species (*Brachiaria brizantha*) integrated with trees has been introduced to silvopastoral livestock production system in order to contribute to improved productivity and reduce environmental degradation. This silvopastoral land use type were analysed to determine the effects of the newly introduced system in mitigating global climate change by sequestering more carbon and reducing emissions of methane and nitrous oxide.

The new system had influence on emissions of the major greenhouse gases (GHG); CO_2 and CH_4, mainly by increased carbon stocks in pasture farms and reduced rates of enteric methane emission from cattle. However, reductions in nitrous oxide emissions were not observed.

Simulation of CO2Fix V 3.1 model showed higher carbon stocks in improved pasture farms with tree intensification than native pasture farms with low coverage of tree canopy. Total carbon stock in the improved pasture farms showed steady increase over the simulation period while it decreased considerably in the native pasture farms. The amounts of carbon sequestered in the improved pasture farm systems were higher than that of traditionally managed native pasture species.

Daily methane emissions against an average daily milk production per head of dairy cows were lower in improved pasture integrated with trees. Estimates of enteric methane emissions from cattle grazing on improved pasture were considerably lower than in the case of native pasture. Estimates of daily methane emission of a dairy cow, a steer/heifer of 2-3 years old and young cattle of 1-2 years old grazing on improved pasture was 0.495, 0.336, and 0.205 kg/day, while it was 0.535, 0.450 and 0.264 kg/day in native pastures respectively.

Generally, GHG emissions were reduced substantially in silvopastoral farms with improved pastures. Total carbon stocks were higher in improved pastures than in native pasture farms. Similarly, daily enteric methane emissions per unit of milk production were lower in improved pasture integrated with trees than traditionally managed native pasture species.

I. Introduction

Cattle production is the dominant activity in the economy of Tropical America countries where pasture, silvo-pastoral and agro-silvo-pastoral land represent 77% of the total agricultural land (Amezquita 2005). In the tropics and specifically in Central America, farmers have been using tropical grass species (eg *Hyparrenhia rufa*) that is native to the region and of low quality. Poor and lower feed quality intake, among other factors, is directly associated with a relatively higher rate of methane emission (EIIP, 1999; Mangino, 2002; Steinfeld, 2006).

Livestock production is a significant source of greenhouse gas emissions and directly contributes to global warming. It is responsible for 18 percent of the overall global emission in terms of CO_2 equivalent, which is a higher share than the share of transport sector (Steinfeld, 2006). It accounts for 9, 37 and 65 percent of anthropogenic CO_2, CH_4 and N_2O emissions respectively (Ibid, 2006). A large percentage of this methane emission is due to enteric fermentation of the normal digestive systems of ruminants, which accounts for a considerable portion of the global methane budget making up 65-100 million tons annually (IPCC, 1997; EIIP, 1999).

Recently, improved grass species (e.g *Brachiaria brizantha*) integrated with trees has been introduced to contribute to improved cattle farm productivity, generate biodiversity and combat environmental degradation (Pagiola, 2004). This should also contribute to mitigation of global climate change by increasing carbon sequestration and reducing methane emitted per unit kg of milk or beef produced.

Most of the studies on mitigation of greenhouse gases emissions have focused on carbon sequestration in forest ecosystems. Some studies carried out in different ecosystems showed that the amounts of carbon sequestered in silvopastoral systems are higher than that of degraded traditionally managed pastures (CATIE, 2007; Ibrahim, 2006). However, little is known about the impacts of different silvopastoral land use types of Central America in mitigating greenhouse gases emissions. Especially, the potential of improved pasture integrated with trees on reduction of CH_4 emission rate is lacking. Therefore, there is a need to undertake a holistic approach study to assess impacts of improved silvopasoral systems on global climate change while at the same time increasing productivity to reach the growing demand for beef and milk and ensure food security.

The objective of this study was to simulate carbon stocks and estimate methane and nitrous oxide emissions rates in dual purpose cattle production systems of Costa Rica, which employ improved and native pasture integrated with trees of various degrees of canopy covers. Based on these, the study aims at analysing the potentials of silvopastoral land use types in mitigating global climate change by sequestering more carbon and reducing methane and nitrous oxide emissions.

II. Research Methods

1. Study area

The study was conducted in Esparza zone, Puntarenas province of Costa Rica. Geographically, the Esparza zone is located between 09° 59’ 28” north latitude and 84° 40’ 05” west longitude (Municipality of Esparza) and covers an area of 432km^2 (Ibrahim, 2005). The zone is characterized by humid tropical forest life zone (Holdridge 1979) with an average annual temperature of 27^{O} C and an annual precipitation of 2040mm (Ibrahim, 2005). The study area has an altitudinal range of 100-800masl which has a remarkably distinct wet and dry season. The Esparza zone is characterized by seven months of rainy period, from May up to November and five months of dry season from December to April (Ramos, 2003).

The soil types of the study area are mainly dominated by alfisoles, inseptisoles and ultisoles (Ibrahim, 2005), and the general topography of the study area is rugged with slopes ranging between 2-35% while the majority of the sampled areas were less than 23%.

There are 28 (Murgueito, 2004) defined land use types, the most common land use types being pasture lands that accounts up to 65% (Zamora, 2006; Villanueva, 2007). In addition there are different types of forest at various development stages (secondary, riparian, and fragmented) which comprise 28% of the land use (Villanueva, 2007).

Fig 1. Map of cost Rica, and location of the study area.
Source (http://www.lib.utexas.edu/maps/cia05/costa_rica_sm05.gif)

2. Site selection

Long established nine silvopastoral farms were randomly selected from the database of "Integrated Silvopastoral approaches to Ecosystem Management", a project funded by World bank/GEF in Costa Rica. Five improved pasture (*Brachiaria brizantha*, dominant species) farms comprising 12 sample plots (three levels by four replicates) and four replicates of native pasture (*Hyparrhenia rufa*, dominant species) farms were selected. Samples in improved pasture farms had three stratification of tree canopy coverage (low 0-15%, medium 15-30 %and high >30% ground cover) and the native pasture had low percent tree canopy cover.

Plots in each farm were selected depending on the stratified percentage of ground covered by tree canopy. In the majority of improved pasture farms, treatments were randomly allocated to the land with the same soil character and management types, which consists all categories of canopy covers side by side. In the case of native farms randomization was not possible within single farm, thus adjacent farms with similar soil conditions were selected. Ortho photo maps and hand held GPS receiver was used to locate the exact coordinates of each parcels in the farms.

However, it was not possible to consider sample plots of equal size. Thus, the most representative sample plots of various sizes were taken in different farms.

3. Data collection

Interviews

Standard questionnaires were prepared and owners of the sample plots selected were interviewed from 22 august to 29 September 2007. Inventory of cattle population, manure management system, pasture, quantity, quality and types of feeds, and rotation periods of the farm were directly obtained from farmers at the study area. Additional data which was required for the characterization of cattle and pasture was obtained from reports, technical papers and literature at the department of Environment and livestock management of Tropical Agricultural research and Higher Education enter (CATIE).

Samples for total soil organic carbon and total nitrogen.

Four pits of 40*30*30cm were dug in each sample plots to collect soil samples for the analysis of total soil organic carbon (SOC, hereafter) and total nitrogen. Two pits were marked in an open area at a distance of 50m (A in Fig 3) in such away that a tree lays at its centre where the other two pits (B in Fig 3) were dug in the shaded area, about 2.5m away from tree root.

Fig 2. Soil sampling layout.

In each plot, 8 soil samples, 4 from an open area and 4 from the shaded area with a depth of 0-15cm and 15-30 cm were taken. The two samples taken from 0-15cm in open areas were thoroughly mixed in the field and properly tagged for later laboratory analysis. Samples taken from 0-15cm in shaded areas were mixed in the same manner and tagged separately. Similarly, samples taken from 15-30cm both in open and shaded areas were mixed accordingly and tagged separately for analysis. Therefore, 2 soil samples of 0-15cm, one from open area and one from shaded area, and 2 samples of 15-30 cm one from open and one from shaded area were prepared. Thus, a total of 64 soil samples, four from each of the 16 sample plots, were analyzed at CATIE's soil laboratory for total SOC and total nitrogen.

During soil sampling, soil type, gradient and erosion factors were taken in to consideration. The layout of the sampling was across the gradient. Vegetation cover, grazing types, soil erosion and other factors that might cause differences in soil properties and compaction were considered.

Samples for bulk density

Eight bulk density samples were taken from each of the 16 plots. Samples were taken by a cylinder of predetermined volume (5cm height and 5cm diameter). A cylinder was drilled into the ground at the edge of a pit dug to take soil samples. Another cylinder was put on the former cylinder and was drilled down using wooden block and hammer without causing any compaction. The upper edge of the cylinder with which a bulk density sample was taken was drilled down about 3.75cm below the surface of the soil in order to take the bulk density sample at average depth of the layer considered. A sharp knife was used to cut the surrounding soil profile and detach the cylinder with proper care.

Fig 3. Bulk density sampling technique

Pasture and tree parameters

Pasture biomass.

Pasture samples which were collected during the two dry months of March and April and two rainy months of June and July were analyzed at CATIE animal nutrition laboratory. The average of the dry matter content was converted into hectare, and utilized to estimate biomass of pasture and its carbon content (Annex- 1)

Tree biomass

Major tree parameters like diameter at breast height (DBH), total and commercial height, canopy cover etc which were utilized to estimate above ground biomass was taken from the silvopastural project database at CATIE. The model used in this study for estimating above ground biomass is based on DBH.

It was not necessary to measure tree parameters because of the short time gap between the time of this study and the actual monitoring period of the project. The time gap was shorter than one growing season which was assumed to be negligible in terms of creating considerable changes in DBH, tree height and canopy cover.

In addition, existence of relevant allometry equation in similar condition did not necessitate the development of an allomertic equation specific to the study area by undertaking destructive sampling of trees. For this reason, allometric equation that was developed in a different geographic region with similar climatic factors to the Esparza zone was applied to estimate aboveground biomass.

4. Estimation and analysis.

I. Biomass estimation

Above ground biomass

To estimate the total above ground tree biomass (t ha^{-1}) and calculate carbon storage (Mg C ha^{-1}), an allometric equation developed by Ruiz (2002) was applied.
This equation was developed in Matiguás, Nicaragua, in sub-humid tropical life zone with similar biophysical and agro ecological conditions to Esparza, Costa Rica. This equation explains 94 percent of the variability with in the dataset.

$Log_{10}B= [-2.18062+0.08012(D)-0.0006244(D^2)]$

Where,

B= total dry matter biomass (t $ha^{-}1$)

D=diameter at breast height.

Matiguás and Esparza zone have similar climate; hence the selection of this equation was based on the similarities of climatic conditions between the two areas as a major factor.

Besides, physical conditions like land use types in which the equation was developed and the zone of this study was alike. Average annual temperatures in both areas have 27 degree Celsius, and the rain patterns were similar where more than 80% of the annual precipitation falls between May to December. Both areas have altitudinal range of 200-900 and 100-800masl for Matiguás, Nicaragua and Esparza, Costa Rica, respectively (Ruiz, 2002, Ramos, 2003). Similarly, their precipitation oscillates between 1200-1800mm for Matiguás of Nicaragua and 1500-2000mm for that of Esparza zone.

In this study, estimation of above ground tree biomass considers mainly living trees with greater than 5cm in diameter (dbh) as the main inputs. This is because tree biomass components accounts for the greatest fraction of total aboveground biomass and its estimation does not pose too many logistical problems. (Brown, 1997). Understorey, fine litter and dead wood lying on the ground were not separately sampled in this study. These components make negligible portion of the total biomass in silvopastoral system where large shade trees and pastures are the most common features encountered.

Root biomass

Root biomass was estimated according to the formula formerly developed by IPCC (2003) for tropical areas (Andrade, 2007), and it explains 84 percent of the variability within the dataset,

$$Br=e^{(-1.0587+0.88*\log(Ba))}$$

Where

Br=below ground biomass (Mg ha^{-1})

Ba=above ground biomass (Mg ha^{-1})

Carbon stock estimation

General schematic estimation of carbon stock

Carbon stock in each plots were simulated using CO2Fix model V 3.1(CASFOR-II, 2006). It allows estimating carbon stock and simulating carbon content in above and below ground. In above ground it estimates the carbon stocks (MgC ha^{-1}) in stem, foliage, braches and in below ground it estimates amounts of carbon stocks that exists in roots and soils (Schelhaas, 2004).

Main inputs like biomass expansion factor, current annual increment in volume etc. that are required to parameterize and run this model were collected from the study area and CATIE. Nothing was modified in the model except it was made to start (initialise) simulation from the stand level instead of running from the beginning of the plantation period. Parameterization was done separately for each plot since biomass and soil organic carbon was distinct (Annex-2).

Assumptions

1. Climatic conditions were considered constant.
2. Natural mortality rate of the biomass was considered constant
3. Current annual increment (CAI) was taken as a function of age in all cases.
4. Competition between cohorts was not taken in consideration due to lack of relevant data.
5. Relative growth in foliage, branches and roots were taken as a relative function of growth of stem (proportion).
6. Initial decomposition rate for soluble compounds in the soils were considered constant in all cases.
7. Temperature sensitivity for humus decompositions were considered constant in all cases.

Cohorts

In CO2Fix model vegetations are categorized in to separate cohorts. Cohorts are defined as “a group of individual trees or species, which are assumed to exhibit similar growth, and which may be treated as a single entities with in the model ((Schelhaas, 2004)

In the silvopastoral system studied, various types of indigenous tree species and pastures were encountered. These trees species exhibit different characteristics like growth rate that pose difficulty to treat as a single entity and categorize as one cohort. However, due to the lack of adequate data on the growth rate of all tree species that were encountered in the farm, growth rate of laurel (*Cordia alliodora*) was chosen to model the whole growth rates of the tree cohort. Therefore, for the purpose of running CO2Fix model, only two cohorts were considered in this study; trees and pastures.

Laurel (C. alliodora) was considered as representative growth rate due to the fact that it makes considerable proportion of the whole tree species monitored in the farms. It was reported that out of the 2881 individual trees belonging to 68 species and 35 families studied in Esparza, C. alliodora is one of the six most important tree species in terms of index of value of importance (IVI) (Villanueva et al. 2007).

Thus, simulation of this model was based on the growth rate and current annual increment (CAI) of laurel growing in pasture, which was found to be 0.4-0.7cm/year according to findings from Turrialba research station (Somarriba and Beer, 1987).

Wood density of the pasture was considered to be constant as 1 MgDM/m^3 (as it was parameterized in the sample provided with the model). Wood density of the tree species was considered as 0.45 MgDM/m^3, following the results of laboratory analysis reported by Ruiz (2002).

Carbon content of pasture was considered to be 0.47 MgC/MgDM without respect to its species type (schelhaas, 2004). Carbon contents of stem, foliage, branches and roots of trees were considered to be 0.43, 0.42, 0.43 and 0.43 respectively (Ruiz, 2002).

Climatic parameters

Summation of daily temperature for the year was 9768.1 degree Celsius, while potential evapotranspiration (EVT) and precipitation in the growing season were 1656mm and 2062.1mm respectively (IMN).

Soil parameters

Outputs of total SOC (t C ha$^{-1)}$ form the analysis of samples collected from the fields were utilized as inputs. The total organic carbon stock in the soil depends on two important factors; the concentration of organic carbon in the soil and bulk density of the soil (Andrade and Ibrahim, 2003). Thus, total soil organic carbon per hectare was estimated based on tow factors; organic carbon content of the soil and soil bulk density data analysed at CATIE laboratory, according to the equation utilised by Veldkamp (1994) and Andrade and Ibrahim (2003). Since half of the soil samples were taken from open areas and the rest was taken from shaded areas, content of SOC (%) was multiplied by the corresponding proportion of the area it was taken from.

TSOC=Organic carbon (%)*Bd*d

Where,

TSOC: total soil organic carbon (t Cha^{-1})

Bd: bulk density (gcm^{-3})

d: depth (cm)

However, since it was not possible to quantify the initial carbon contents of non-woody, fine and coarse woody litter, soluble compounds, holocellulose and lignin-like compounds to run the model, automated defaults of the model were used.

Estimation of Methane emission

Methane emission from enteric fermentation was estimated based on the method developed by intergovernmental panel for climate change (IPCC, 2006), Guidelines for national green house gas inventories.

To calculate gross energy intake, the digestibility of an improved and native pasture during rainy and dry season along with an additional supplementary feeds were considered. Based on Tier 2 methodology (IPPC, 2006), regional specific methane emission factor was calculated using gross energy intake, methane conversion factor (Ym) suggested by IPCC and a second factor for the energy content of methane (provided in the same guidelines). Equations and other parameters utilized to characterize cattle and feed in order to develop methane emission factor from enteric fermentation is provided (Annex-3).

Emissions of enteric methane were estimated for dairy cows, steers and heifers (2-3 yr), and young cattle (1-2 yr). Steers and heifers were considered together due to negligible difference in energy requirement and expenditure because of similar cattle management and grazing type. However, calves of less than three months old were not included in this study because they feed mainly on milk.

Methane emission from manure management was found to be insignificant and was not considered in this study. Cattles graze on the field (pasture, range or paddock) and they are not under confined system where manures are decomposed an anaerobically to emit considerable amounts of methane. Thus, methane emissions from manure management were omitted.

Nitrous oxide estimation

Nitrous oxide emission was estimated according to a methodology developed by intergovernmental panel on climate change (IPCC, 2006). There was no nitrous oxide emission from manure management (storage or treatment) since the entire dung and urine from animals was spread over grazing pasture, range or paddock through out the year. Therefore, emissions from managed soils were considered as the only source for nitrous oxide emissions.

No synthetic fertilizers or other forms of organic nitrogen added to pasture except urine and dung nitrogen deposited on pasture lands by grazing animals. Thus, N_20 was estimated by using only nitrogen excretion rate (Kg N/head/day), conversion factor of N_20-N to N_20 and default emission factor provided in guideline.

III. Results

Carbon stock

In the silvopastotral studied, improved pastures with various levels of tree canopy coverage had higher (124.8 ±24.7 MgC ha^{-1}) total carbon stock compared to traditionally managed native pasture species with low tree canopy coverage((P=0.0028). Native pastures farms were the one with the least carbon stock (75.7 ± 18.8 MgC ha^{-1}) both in above and below ground.

The maximum carbon stock in above ground biomass, 34.15% of the total stock per hectare (61.92 t C ha^{-1}) was observed in an improved pasture farm with high coverage of tree canopy. The minimum carbon stock in the above ground biomass, 7.86% of the total stock in hectare (3.86 t C ha^{-1}) was found in the native pasture farm plot.

On an average about 80.12% of the total carbon stock was held in the soil compartment. Totally, 83.19% of carbon stock in improved pasture was found in the soil compartments while in case of native pasture it was 87.74%. Similarly, on an average 19.79% carbon stock was held in the above ground biomass, 17.87% in improved pastures while it was 12.27% in native pastures.

In Fig 4, 5, and 6 the development of carbon stock over the simulation period was shown as an average in both systems. The total carbon stock in improved pastures integrated with trees increased starting around year seven over entire simulation period while it decreased considerably in native pasture farms (Fig 4). Carbon stock in soil compartments decreased in both systems in general, and it showed a significant decrement in native pasture in particular (Fig 5). However, carbon in the aboveground biomass showed a steady build up in both cases after a sharp declining tendency of the first seven years of the simulation period (Fig 6).

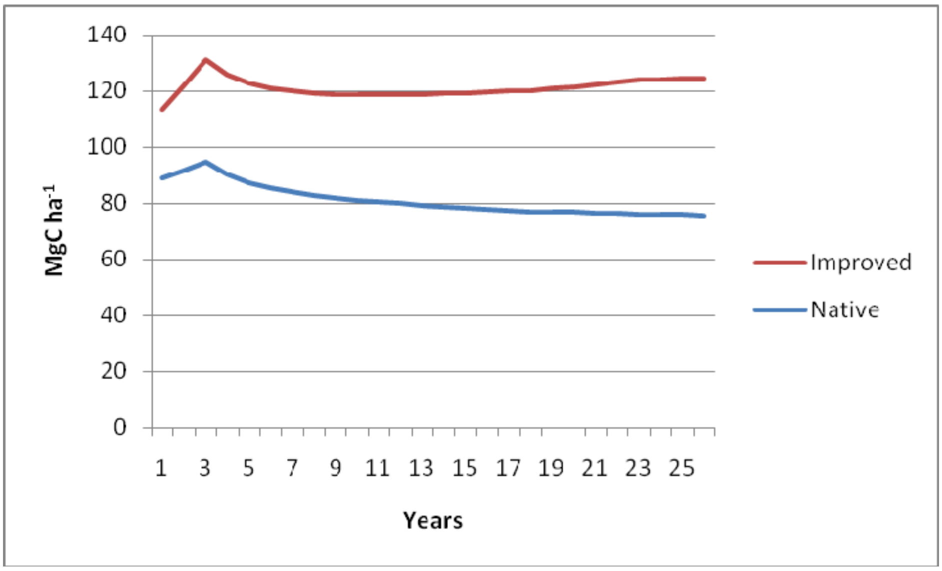

Fig 4. Simulated development of total carbon stock in improved and native pasture farms.

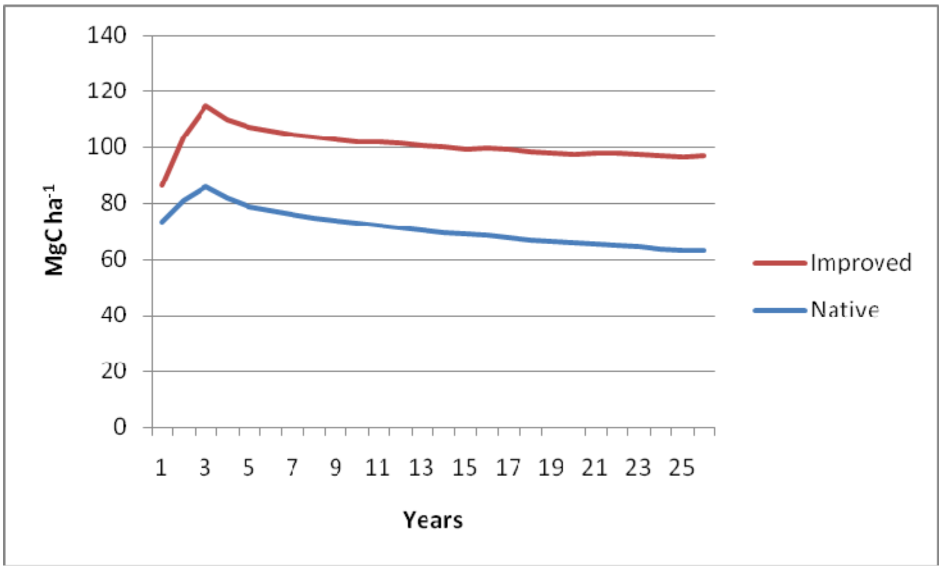

Fig 5. Simulated development of carbon stock in soil compartments in improved and native pasture farms.

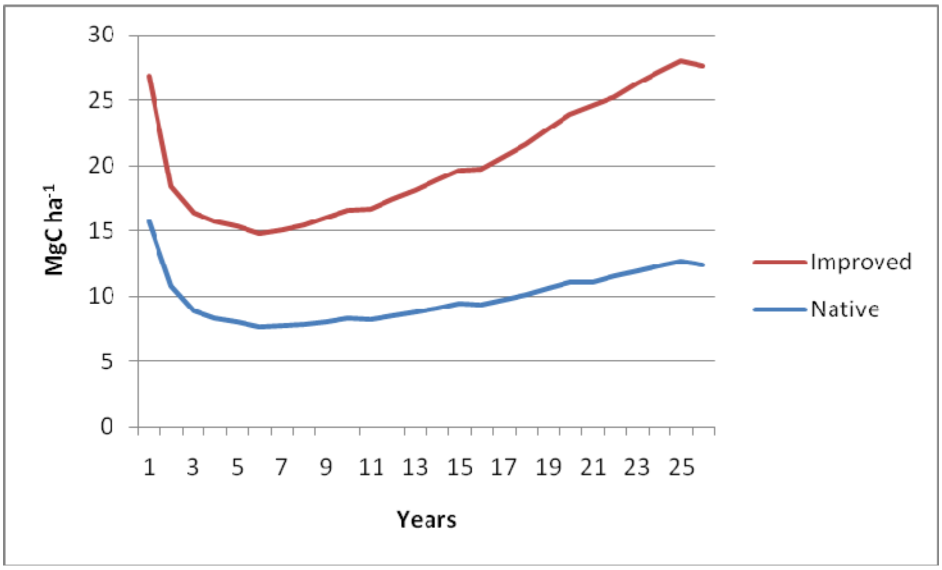

Fig 6. Simulated development of carbon stock in the aboveground biomass in improved and native pasture farms.

Carbon flow

On an average, improved pasture with various tree intensification levels sequestered 8.84 and 9.66 t C $ha^{-1}yr^{-1}$ during the first and second year of simulation period, respectively, while native pasture sequestered 2.73 and 3.05 t C $ha^{-1}yr^{-1}$. At the third year both systems started to release carbon to atmosphere. However, improved pasture farms integrated with trees began to remove carbon from the atmosphere from year nine to the last year of the simulation period while farms with native pasture and low coverage of tree canopy were sources of carbon starting from the third year onwards to the end of the simulation period.

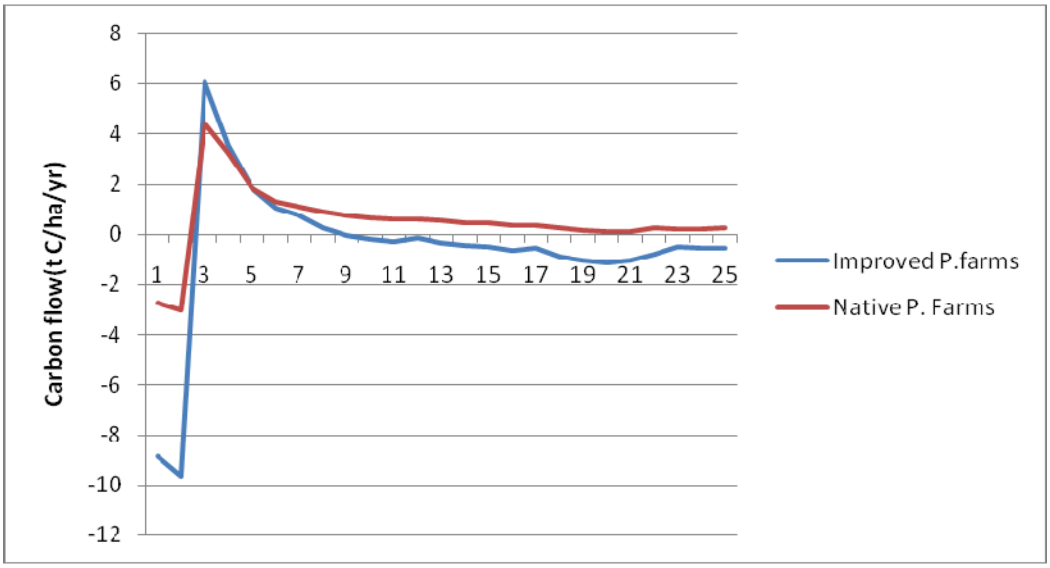

Fig 7. Carbon flow chart.

Total soil organic carbon

There were no significant differences between the contents of total SOC between improved pasture with various tree intensification levels and native pasture with low coverage of tree canopy ($p=0.2115$). However, there were significant differences found between spatial conditions (shaded and open, $P=0.0496$) and depth (0-15 and 15-30cm, $P<0.0001$). The average total SOC (%) in improved pasture farms was greater by 0.92 than in the case of native pasture farms.

The contents of total SOC (up to 30cm depth) observed in an improved pasture farms varied from 51.39 to 115.59 t C ha^{-1}, while in case of the native pasture farms it ranged from 50.31 to 82.5 t C ha^{-1}. On average, improved pasture farms had 89.53 t C ha^{-1} SOC while native pasture farms contained 73.27 t C ha^{-1} SOC.

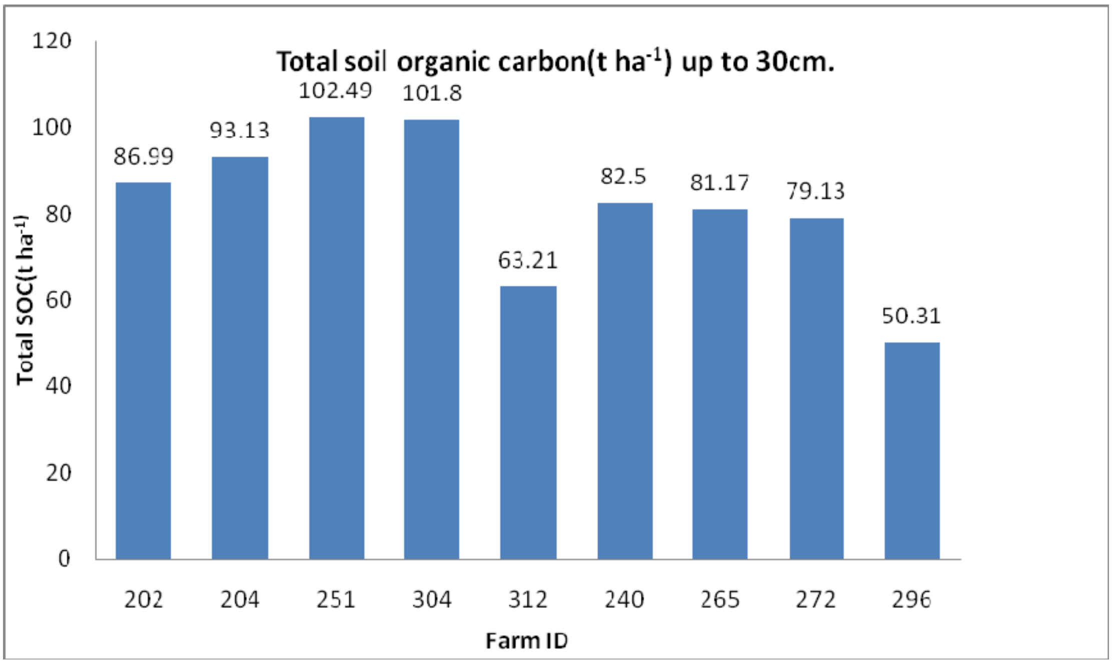

Fig 8. Total soil organic carbon (t C ha^{-1}).

Total nitrogen

There were no differences observed in total nitrogen between improved pasture with various levels of tree canopy covers and native pasture with low coverage of tree canopy (p=0.2877). However, there were significant differences between depths (0-15 and 15-30cm) at P= 0.0357 and different spatial conditions (shade and open) at P<0.0001. Improved pasture with high coverage of tree canopy had higher mean values and native pasture with low coverage of tree cover had the smallest mean values.

Soil bulk density

There were significant differences between improved pastures with various tree intensification levels and native pasture with low coverage of tree canopy for the depth of 0-15cm (p=0.0004, Red in Fig 9). Similarly, there were differences for the depth of 15-30cm (p=0.0150, Blue in Fig 9). However, there were no statistical differences observed between different conditions (open and shade) and depth (0-15 and 15-30cm). In addition there were no differences found for the interaction effects of condition-treatments between 0-15 and 15-30cm.

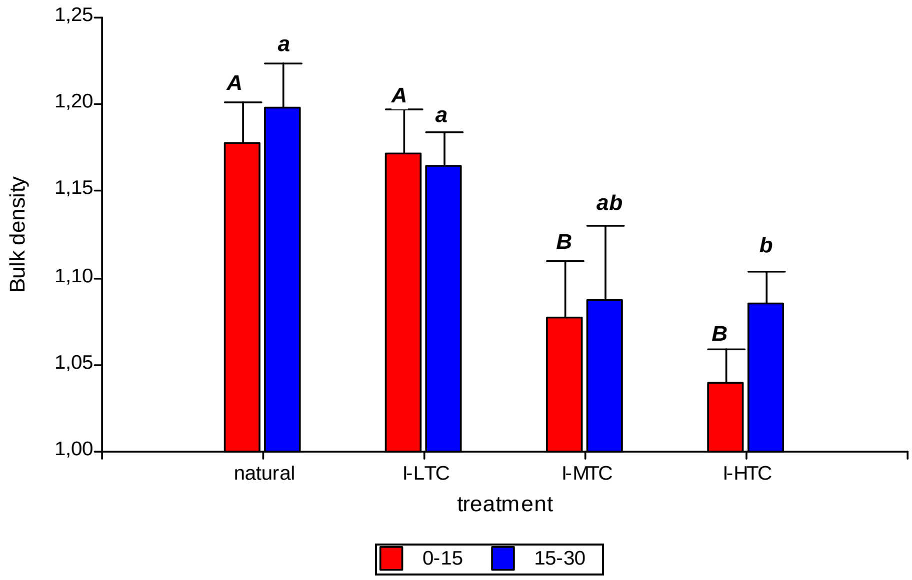

Fig 9. Results of bulk density in the farm. Different letters indicates significant differences. I-HTC=improved pasture with >30% coverage of tree canopy, I-MTC=improved pasture with 15-30% coverage of tree canopy, I-LTC=improved pasture with <15% coverage of tree canopy and Natural=naïve pasture with low coverage of tree canopy.

Methane emission from enteric fermentation

Dairy cows in grazing on improved pasture emitted lower (237.80 ±0.84 g Ch_4 cow^{-1}day^{-1}) enteric methane per milk produced compared to dairy cows grazing on native pasture (P=0.0079). Dairy cows grazing on native pasture emitted higher methane (260 ±2.08 g CH4 cow^{-1}day^{-1}cow^{-1}) per units of milk produced per day.

During rainy season dairy cows grazing in improved pasture farms emitted lower (194.8 ±4.15 g CH4 cow-1day-1) enteric methane than dairy cows grazing in native pastures, whcich emitted (237±6.99 g CH4 cow^{-1}day^{-1}) at (p<0.0001). During dry season, (151days) methane emission showed no statistical significance difference between dairy cows grazing on improved and native pasture. However, the overall summations of emissions of the two seasons showed that dairy cows grazing on improved pasture emitted lower (495.20 ± 10.8 g CH4 cow^{-1}day^{-1}) than dairy cows grazing on native pasture (0.0021). Dairy cows grazing in native pasture emitted higher (536 ±15.25 g CH4 cow^{-1}day^{-1}).

Table 1. Methane emissions by dual purpose cows grazing on improved (*B. brizantha*) and native pasture (*H.ruffa*) in rainy season. (Lt/c/d=liter/cow/day, Mj/c/d=Mega joule/cow/day, g/c/d=gram/cow/day).

Pasture type.	Farm ID	Average Milk prod (Lt/c/d)	Gross energy (Mj/c/day)	CH4 emission (kg/c/d)	CH4 emission (g/c/d)
Improved	202	5.25	165.55	0.193	193
	204	4.97	163.23	0.191	191
	251	5.63	168.69	0.197	197
	304	6.06	172.25	0.201	201
	312	5.10	164.31	0.192	192
Native	240	1.75	196.42	0.229	229
	265	2.1	200.58	0.234	234
	272	2.8	208.90	0.244	244
	296	2.625	206.82	0.242	242

Table 2. Methane emission from enteric fermentation of cows grazing on improved (*B. brizantha)* and native pasture, dry period.

Pasture type.	Farm ID	Average Milk prod (Lt/c/d)	Gross energy (Mj/a/day)	CH4 emission (kg/a/day)	CH4 emission (g/a/day)
Improved	202	5.25	254.68	0.297	297
	204	4.97	251.12	0.293	293
	251	5.63	259.51	0.303	303
	304	6.06	264.98	0.310	310
	312	5.10	252.77	0.295	295
Native	240	1.75	246.15	0.288	289
	265	2.1	251.37	0.294	295
	272	2.8	261.80	0.306	307
	296	2.625	259.44	0.303	304

Similarly, rainy and dry season methane emissions from steers and heifers of 2-3 years old and young cattle of 1-2 years old were lower in an improved pasture than in case of native ones. During rainy season, emissions in an improved pasture were 127 and 81 g/a/day while it was 192 and 116 g/a/d in native pasture. In dry season, emissions were 208 and 125 g/a/d in improved pastures and 257 and 147 g/a/d in native pastures for steers and heifers (2-3 yr) and young cattle (1-2 yr) respectively.

Daily methane emission for a dairy cow, steer and heifer of 2-3 years old and young cattle of 1-2 years old grazing on improved pasture (*B. brizantha*) was estimated to be 0.495, 0.336 and 0.205 kg/day, respectively. In the case of native pastures (*h. ruffa)*, emission was estimated 0.535, 0.450 and 0.264kg/day for a dairy cow, steer and heifer of 2-3 years old and young cattle of 1-2 years age old respectively.

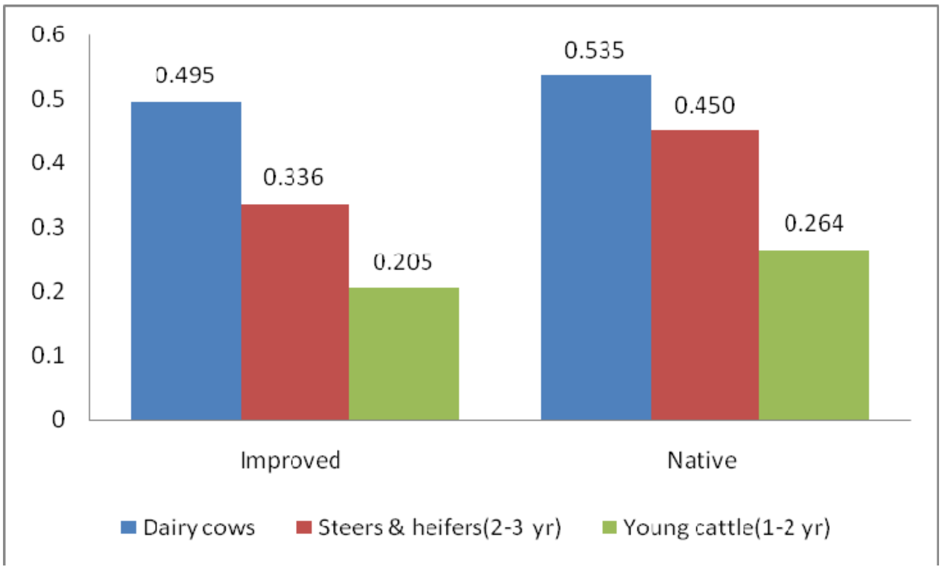

Fig 10. Emissions of methane from enteric fermentation.

Nitrous oxide emission from managed soil

There was no significance differences observed in nitrous oxide emission from managed soils ($p=0.4073$). Dairy cows grazing on improved pasture emitted (3.07 ±1.72 g N_2O $cow^{-1}day^{-1}$) nitrous oxide and cows grazed on native pasture emitted (3.43±1.5 g N_2O cow^{-1} day^{-1}).

However, looking at daily emission figures, N_20 emission from a dairy cows, steers and heifers (2-3 yr) and young (1-2 yr) grazing on improved pasture were 5, 2.5, and 1.7g/a/day respectively, while in case of native pasture it was 4.3, 4.3 and 1.7g/a/day. In case of a dairy cows, nitrous oxide emissions were greater in improved pasture than native ones. However, in the case of steers and heifers of 2-3 years old, emissions were greater in native pasture while it was equal in young cattle of 1-2 years old.

IV. Discussion

Native pasture farms with less than 15% tree canopy cover were the system that stored the least carbon stocks at the end of the simulation period. In general, improved pasture farms integrated with multipurpose tree having greater than 15% canopy coverage sequestered considerably more carbon. Total carbon stocks in the system were increasing over the simulation period in improved pastures. Improved farms with the highest tree density (>30% canopy cover) had the highest (141.06 t C ha^{-1}) carbon stock in the system. The result of this study was similar to the previous finding reported, 140.5 t C ha^{-1} (Zamora, 2005) and 119.6 t C ha^{-1} (Ibrahim, 2007) in improved pasture with low tree density.

However, it has to be noted that some degree of uncertainty may be involved with the outputs of this model. Inaccuracy of the CO2Fix model might occur due to two causes; the stochastic character of estimated model coefficients and measurement errors in the data or lack of data used for model construction (Schelhaas, and Nabuurs, 2001). Although it is difficult to avoid occurrences of natural variation in growth rate, mortality, climatic conditions e.t.c that might affect the simulated outputs of this model, input data utilized were based on previous studies in order to minimize the risk of uncertainty to an acceptable level.

Considerable amount of carbon stock in the native pasture was stored in the soil compartment compared to the above ground biomass compartment of improved pasture integrated with trees. Less tree density coupled with native pasture could not able to offset the release of GHG in the former case, thus, native pasture farms were sources GHG than being sinks. As trees become mature enough and are not distributed over age classes, the system starts to release carbon to atmosphere, and removing carbon from atmosphere is subjected to pasture management regime.

Total soil organic carbon and total nitrogen

The results showed no differences in the contents of total SOC and total nitrogen between improved pasture with various tree canopy covers and native pasture with low coverage of tree canopy. SOC result was not statistically different between six land use types, according to the previous study carried out in the pacific zone of Costa Rica except it was much lower in the case of degraded pastures (Ibrahim, 2007).

In this study, the maximum SOC (up to 30 cm) found in an improved pasture was 115.59 t C ha^{-1}, while the minimum was 50.30 t C ha^{-1} in a native pasture. The result of this study is in between the previous research findings of SOC (up to 1m depth) reported from improved pasture of Costa Rica and Nicaragua, which was 117.53 and 106.3 t C ha^{-1}(Ibrahim, 2007).

It is obvious that soil carbon pool responds much more rapidly to environmental changes (e.g land use changes) in the tropics (Veldkamp, 1994). In this study, however, expected rapid change in soil organic content could not be statistically observed in the short period of project lifespan. This indicates that land use changes in terms of pasture species might not bring significant difference in SOC and total nitrogen within very short periods. If it does make a difference in organic carbon and nitrogen contents, it may change only the most upper parts of the soil profile.

However, total SOC and total nitrogen contents showed significance differences between depths of 0.15cm and 15-30cm soil profiles both in improved and native pasture. This clearly indicates that the upper layer of the soil had much SOC than the next profile considered in this study, due to the constant pulverisation of decomposed pasture and litter to the upper surface of the soil.

Similarly, there were differences observed between shaded and open areas in both cases. This might be linked to the function and age of trees in pasture lands. Trees serve as shade against rain, sun and protection from wind, and animals spend considerable times of the year around tree roots. The probability that animals deposit dung and urine under trees is likely much higher than open areas. The constant decomposition of tree litter, dung and urine assisted accumulation of organic carbon under tree roots compared with open areas. Moreover, since trees has been in the pastures long before the introduction of improved pasture, shaded areas might have received considerable amounts of tree litter compared to open areas.

Soil bulk density

Although there was relatively higher grazing rate and stocking density in improved pasture, soil bulk density was higher in the native pastures with low coverage tree canopy than in the case of improved pasture with various tree intensification levels. This indicates that compaction and trampling effects by cattle was not a determinant factor for the results of bulk density.

However, difference in bulk density reflects the impact of production of fine roots of improved pasture in soil structuring that gave soils increased porosity. Similarly, it can be related to slightly increased fertility of the soil in terms of SOC and nitrogen in improved pasture, though it was not confirmed by independent analysis mentioned above. Increased fertility could be due to continuous inputs from high production of improved pasture and tree foliage to some extent. However, it is difficult to correlate differences in bulk density to only foliage from trees since there were no differences observed between samples taken from shaded and open areas.

Methane emission from enteric fermentation

Methane emissions from improved pasture farms integrated with multipurpose trees were lower than native pasture with trees of lower canopy coverage. CH_4 emissions from dual purpose cows grazing on improved pasture were lower than cows grazing on native pasture during rainy season. This result is similar to previous emission finding reported from dairy cows grazing on improved and native pasture during rainy season, which was 422 and 434 g/a/day, respectively (Mora, 2005).

Cows grazing on improved pasture emitted lower methane per an average daily milk production than those grazing in native one. Cattle (cows, steer and heifers of 2-3 age, and young cattle of 1-2 age) grazing on improved pasture emitted less methane than corresponding cattle grazing on native pasture mainly due to improvement in feed quality.

There were no reductions observed in N_20 emissions from dairy cows grazing on improved pasture in comparison with dairy cows grazing native pasture. Similarly, in dry season, since the quality of the feed declines significantly, there were no differences observed in methane emission rates between the two motioned above. This could be due to the IPCC formulas that do not apply during dry period when the digestibility of the pasture goes well below 40%.

There is uncertainty involved in the guidelines for national greenhouse gas inventories of the IPCC in the estimation of livestock population, activity data and emission factors. The uncertainty of estimating emission factors using Tier 2 method is in the order $\pm$ 20% (Dong, 2006). In this study however, besides using Tier 2 methodology, the complete inventory of cattle population employed, detailed characterization of cattle categories, and parameterization of pasture and feeds for both rainy and dry season probably increased the robustness of the model far below 20%.

V. Conclusion and recommendation

The findings of this study clearly supported that improved pasture integrated with trees contribute to mitigation of global climate change. The hypothesis that total carbon stocks are higher in the cattle farms with improved pastures and high percent of tree canopy cover than native pastures with low percent of tree canopy cover was statically confirmed. Similarly, the second hypothesis that methane emissions per unit milk production are lower in improved pasture compared to traditionally managed pastures was also statistically supported. Therefore, the overall carbon budget (inventory of C in carbon pools) of improved pasture farms integrated with trees of high percent canopy cover was higher than in the case of native pasture with low percent tree canopy cover.

Similarly, improved pasture has significantly contributed in terms of improved productivity. Cuts in enteric emissions rates of methane, which otherwise would have been given off as carbon was converted to increased milk and beef in case of improved pasture. Thus, the introduction of improved pasture integrated with trees benefited farmers to intensify cattle farm productivity and gain additional income in terms of beef, milk and other wood products.

However, future studies have to focus on optimal tree canopy cover to offset greenhouse gases emissions without jeopardizing pasture growth, cattle management and farmers livelihoods. Similarly, there is a need to undertake detailed studies to identify farm level carbon budget taking in to account the density of trees required per farm to compensate for the GHG emissions from cattle production in the farm.

Carbon sequestration depends not only on the density of trees in the farm but also on age and species type. Logging of trees has to focus only on matured trees while giving room for the growth of natural regenerations that can better remove Carbon dioxide from the atmosphere.

Last but not the least is the question of biodiversity and coexistence of local species with the dominant improved species being introduced to pastures. Improved pasture species seem to be deep rooted which makes it drought resistant and more competitive than the native grass species in the area. Detailed assessment of the compatibility of improved pastures with existing local species has to be carried out before the local species are wiped out.

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Appendix-1. Data on improved and native pasture dry matter content

Month	Farm ID	Improved (B.brizantha)			Native(H.rufa)		
		%DM	KgDM/ha	Age	%DM	KgDM/ha	age
March	1	52.7	2427.98	3	44.0	389.09	35
	2	52.5	2155.30	2	45.1	412.08	35
	3	56.9	1886.55	4	54.4	874.32	35
	4	54.1	1535.21	4	54.6	507.50	35
	5	52.0	1587.39	4	43.3	180.89	35
	6	48.7	1905.25	2	56.4	482.49	35
	7	50.7	172.16	5	46.7	362.72	10
	8	46.4	238.22	7	46.7	224.90	20
	9	52.7	1983.79	3	56.6	686.41	35
	10	51.9	1690.49	2	46.2	256.67	40
	11	45.3	1250.99	4	48.4	481.00	35
	12	51.6	2708.88	8	49.0	461.63	16
April	1	43.5	1204.24	3	43.0	387.16	35
	2	41.6	1288.48	2	42.6	462.49	35
	3	41.7	929.37	4	37.0	270.87	35
	4	40.0	1091.83	4	40.0	219.65	35
	5	38.7	1427.52	4	45.1	364.14	35
	6	43.2	1157.07	2	40.6	391.3	35
	7	43.0	1120.04	5	37.4	349.36	10
	8	36.6	266.13	7	32.2	809.32	20
	9	40.9	1332.3	3	36.0	763.83	35
	10	38.4	1166.79	2	32.7	242.91	40
	11	36.3	1542.78	4	36.2	562.56	35
	12	38.9	2329.53	8	35.3	676.09	16
June	1	28.8	2960.71	3	22.6	1319.86	35
	2	25.9	3872.38	2	22.5	1332.31	35
	3	27.7	2686.64	4	24.6	967.80	35
	4	26.2	2557.37	4	24.9	1777.19	35
	5	20.8	3205.33	4	21.1	949.58	35
	6	29.6	3188.90	2	25.2	1745.99	35
	7	28.6	3579.93	5	22.9	1339.38	10
	8	25.3	772.56	7	22.1	1268.91	20
	9	23.5	3833.47	3	20.3	1653.18	35
	10	23.6	2272.42	2	26.1	1499.75	40
	11	25.9	3554.18	4	27.3	1925.07	35
	12	26.7	4302.31	8	28.1	2314.13	16
July	1	26.0	3206.42	3	26.9	3342.89	35
	2	26.4	3427.75	2	26.9	3388.80	35
	3	27.2	3228.39	4	26.2	2105.57	35
	4	25.2	3071.17	4	22.4	4297.63	35
	5	26.0	4397.31	4	25.1	4161.03	35
	6	26.2	4080.51	2	22.8	3445.70	35
	7	27.4	3126.94	5	25.5	2693.08	10
	8	27.0	828.15	7	25.6	2392.98	20
	9	27.4	3878.06	3	28.3	2306.20	35
	10	25.6	2944.23	2	26.5	1710.63	40
	11	28.4	4209.86	4	27.3	2845.27	35
	12	28.2	4641.05	8	27.5	3214.33	16

Appendix-2. Inputs utilised for CO2Fix parameterization.

General parameter	Stem biomass	Foliage biomass	Branch biomass	Root biomass	Maximum biomass	Soil component
Scenario: Native pasture Simulation period: 25 years Max biomass in the system:200 Mg/ha Growth as a function of age Competition relative to total biomass in the stand. Management Mortality: depends only on the volume harvested Relative growth in % -CAI(current annual increment)-m3/ha/yr	2 cohorts 1) Trees Carbon conten:0.43 MgC/MgDM Wood density:0.45 Mg/Dm/m3 2) Pasture Carbon content 0.5 MgC/MgDM Wood density: 1 Mg/Dm/m3 Carbon initial: 0 MgC/ha Age CAI(m3/ha/yr) 0 0.01	2 cohorts 1) Trees Carbon content:0.42 MgC/MgDm Growth correction factor:1 Turnover (1/yr): 0.5 Age relative growth 5 0.1 5 0.5 10 0.32 15 0.2 20 0.2 25 0.2 2) Pasture Carbon content: 0.5 MgC/MgDm Initial carbon:11.077 MgC/ha Growth correction factor:1 Turnover rate(1/yr):0.8 Age relative growth 0 1200	2 cohorts 1)Trees Carbon content:0.43 MgC/MgDm Growth correction factor:1 Turnover (1/yr):0.3 Age relative growth 0 1 5 0.8 10 0.6 15 0.5 20 0.4 25 0.4 2)Pasture Carbon content:0.5 MgC/MgDm Initial carbon:0 MgC/ha Growth correction factor:1 Turnover rate (1/yr):0	2 cohorts 1) Trees Carbon content:0.43 MgC/MgDm Growth correction factor:1 Turnover rate(1/yr):0.4 Age relative growth 0 1 5 0.8 10 0.7 15 0.5 20 0.3 25 0.3 2) Pasture Carbon content:0.5 MgC/MgDm Initial carbon:0 MgC/ha Growth correction factor:1 Turnover rate(1/yr):0.9	-Mortality: In both cohorts mortality was considered constant as 1% each year -Extraction/harvest. Trees: it was considered 5% every 5 year Age % 5 0.05 10 0.05 15 0.05 20 0.05 25 0.05 Pasture: harvest of 0.5 each year.	General parameters _degree days(above zero) :9768.1^{O}c -PET in the growing season: 1656.73mm Ppt in the growing season: 2062.1mm Yasso model parameters Temp sensitivity for humus decomposition rate:0.6 Initial decomposition rate of soluble materials:0.5

Appendix-3. Parameters and equations utilised for enhanced characterisation of cattle and feeds.

Parameter	**Symbol**	**Cows**	**Steer/heifer (2-3yr)**	**Young (1-2 yr)**	**Sources of equations**
Net Energy for lactation (MJ/day)	NE_l	16.408[1] 6.658[2]	-	-	Calculated using equation 10.8,2006 IPCC GNGGI [1]for cows feeding on improved pasture [2]for cows with native pasture
Weight (kg)	W	400	300	250	Data from Esparza, and literature.
Weight Gain (kg/day)	WG	0	0.25	0.20	Mora, Vesalio (2005)
Net Energy for pregnancy (MJ/day)	NE_p	2.006	0	0	Calculated using equation 10.13,2006 IPCC GNGGI
Mature Weight (kg)	MW	400	450	400	Data from literature
Pregnancy coefficient	C_p	0.1	-	-	Table 10.7, 2006 IPCC GNGGI
Feeding Situation	C_a	0.36	0.36	0.36	Table 10.5, 2006 IPCC GNGGI
Females giving birth (%)	-	58.17			Own data/survey
Feed Digestibility (%)	DE	Depend on season and species	Depend on season and species	Depend on season and species	CATIE animal nutrition laboratory
Ratio of gross energy that is available for maintenance (%)	REM	0.520* 0.444** 0.457*** 0.413***	0.520 0.444 0.457 0.413	0.520 0.444 0.457 0.413	Calculated using equation 10.14,2006 IPCC GNGGI *Improved pasture and rainy season **Improved pasture and dry season ***Native pasture and rainy season ****Native pasture and dry season
Maintenance coefficient	Cf_i	0.386	0.370	0.322	Table 10.4, 2006 IPCC GNGGI
Net Energy for Maintenance (MJ/day)	NE_m	34.525	26.671	20.245	Calculated using equation 10.3,2006 IPCC GNGGI
Net Energy for Activity (MJ/day)	NE_a	5.869	4.534	3.442	Calculated using equation 10.4, 2006 IPCC GNGGI
Portion of gross energy that is available for growth (%)	REG	0.318* 0.199* 0.220*** 0.152****	0.318 0.199 0.220 0.152	0.318 0.199 0.220 0.152	Calculated using equation 10.15,2006 IPCC GNGGI
Growth coefficient	C	-	1.2	0.8	Page 17, 2000 IPCC GNGGI
Net Energy for Growth (MJ/day)	NE_g	0.000	4.071	0.179	Calculated using equation 10.6, 2006 IPCC GNGGI
Gross Energy intake (MJ/day)	**GE**	166.79*	109.07	69.08	Calculated using equation 10.16,2006 IPCC GNGGI

		256.59** 203.19*** 254.64****	178.48 164.34 219.44	106.74 99.65 125.48	
Energy intensity of feed (MJ/kg)	-	18.45	18.45	18.45	IPCC default value
Feed intake (kg dm/day)	-	9.78	7.72	6.26	Calculated using equation 10.17,18a &18b, 2006 IPCC GNGGI