ANIMALCHANGE

SEVENTH FRAMEWORK PROGRAMME

THEME 2: FOOD, AGRICULTURE AND FISHERIES, AND BIOTECHNOLOGIES

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DELIVERABLE D10.5
Deliverable title: Report on adaptation and mitigation options in the showcase farms

Subtitle: Report on non-European studies

Abstract: This deliverable collates the information on simulated effects of mitigation and adaptation options at the farm scale in the non-European study regions from AnimalChange, primarily using the FarmAC model for the mitigation options, and applying semi quantitative modelling for the adaptation options.

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Authors: Marcia Stienezen (DLO), Ib Sillebak Kristensen (AU), Jørgen E. Olesen (AU), Nick Hutchings (AU), Lisbeth Mogensen (AU), Luís Barioni (Embrapa), Rui Veloso (Embrapa), Amaury Burlamaqui (Embrapa), Olivier Bonnet (UFRGS), Paulo de Faccio Carvalho (UFRGS), Eyob Tesfamariam (UP), Abubeker Hassen (UP), Jonathan Vayssières (CIRAD) and Philippe Lecomte (CIRAD).

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Table of Contents

1. Introduction

The EU-project AnimalChange will provide scientific guidance on the integration of adaptation and mitigation objectives and on sustainable development pathways for livestock production in Europe, in Northern and Sub-Saharan Africa and Latin America.

An important part of AnimalChange focuses on the farm level (WP9, WP10 and WP11, together Component 3). Figure 1 provides an overview of information flows within Component 3.

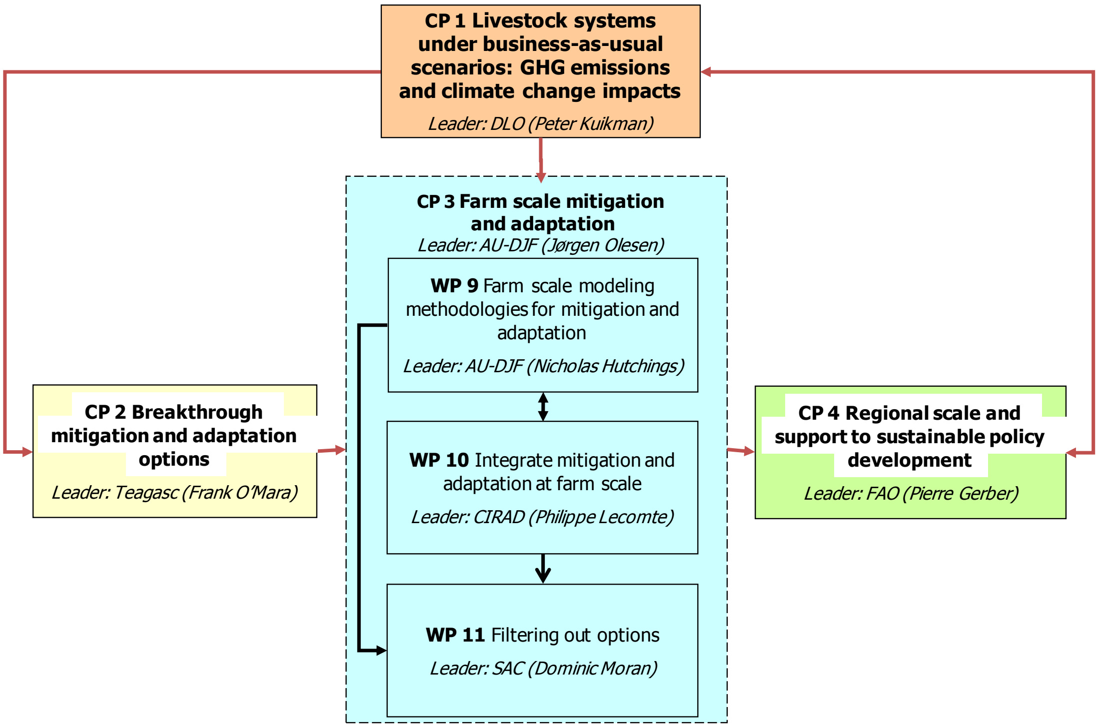

Figure 1. Structure and information flows regarding Component 3 of AnimalChange

The current deliverable (D10.5) is part of WP10. The aim of WP10 of AnimalChange was to investigate, test and demonstrate the effect of single and combined mitigation and adaptation options at farm level using both model farms and real farms (show-case farms). The objective of WP10 was to describe livestock systems, identify and use case study farms, integrate adaptation and mitigation at farm scale and extend the spatial scale to include further issues (*e.g.* animal mobility) that are relevant for the regional scale.

Initially it was the intention to use existing models to calculate on-farm greenhouse gas (GHG) emissions to estimate the effect of mitigation options on the farm scale. However it was not feasible to use the existing farm-scale models since the data required for input in the existing models were very detailed but not available for the farms in the study regions within AnimalChange. To be able to asses on farm GHG emissions from livestock farming a simplified carbon and nitrogen flow-based model was developed (build and tested) within CP3; FarmAC (Hutchings, 2013). From January 2015 onwards testing results with FarmAC were such that FarmAC could be used for on farm calculations of GHG emissions. This meant that from that moment onwards for a limited number of farms, the on farm GHG emissions could be calculated using FarmAC. To be able to compare between farms, despite the limited number of farms, it was decided to focus deliverable D10.3 on the study regions from Europe and deliverable D10.5 on the study regions from Africa and Latin America instead of focussing on model farms and showcase farms, respectively.

On farm GHG emissions were compared between farms. The effect of mitigation options was evaluated across mitigation option (same farm). Off-farm GHG emissions and changes in carbon storage were taken into account for by adding a Life Cycle Analysis (LCA) of pre-chain emissions.

Since FarmAC cannot simulate adaptation, an alternative methodology had to be found. The adaptation options were therefore compared using a semi quantitative assessment.

Chapter 2 provides an overview of the available farms, Chapter 3 provides an overview of on-farm and pre-chain GHG emissions, Chapter 4 provides detailed farm descriptions and information on the effect of mitigation measures upon the on-farm GHG emissions, Chapter 5 provides conclusions regarding mitigation options and Chapter 6 provides insight in the factors determining the choices of adaptation measures.

2. Farms included in study

For modelling GHG emissions with FarmAC, partners within AnimalChange identified 5 African farms, of which 3 model farms and 2 showcase farms, and 13 Latin American farms, of which 5 model and 8 showcase farms (Annex 2).

Model farms are representative, virtual farms for a livestock system in a region type whereas showcase farms are real farms, having typical characteristics of the livestock system.

For use in AnimalChange a farm typology was created by which farms were classified (Stienezen, 2012; Annex 5).

For this report, FarmAC results are available for 2 African farms and 2 farms from Latin America (Table 2.1). The farms originate from Senegal, South Africa and Brazil.

Table 2.1 Farms used for modelling with FarmAC

Region	Agro-Ecological Zone	Farm type	Farm	Code
Senegal-Peanut bassin	Semi-Arid	Semi-arid Mixed Peanut-milet-livestock system	Model farm	**M-AF-001**
South Africa-Kalahari	Semi-Arid	Semi-arid Grass land based beef	Deon Hoon	**S-AF-002**
Brazil-Western (Roraima) Brasilian Amazon	Humid	Humid Grassland based soya bean-trees-beef system	Farm with Agroforestry	**S-LA-005**
Brazil-Campos	Sub-Humid	Sub-humid Dairy cattle on sown pasture relatively intensive integrated systems	Model farm	**M-LA-003**

3. On farm and pre-chain Greenhouse Gas emissions

3.1. LCA study (including GHG emissions in the pre-chain)

For D10.5, the model results of GHG emissions at farm level calculated by the simple farm model (FarmAC, WP9) was extended to take into account the whole life cycle of the agricultural products until farm gate, *i.e.* GHG emission related to pre-chain was included. These emissions will be included by using typical Life Cycle Assessment (LCA) values. Furthermore, the simple farm model, FarmAC estimates GHG emission as a total number per farm. In task 10.2 the GHG emission from on-farm production inclusive pre-chain is expressed per product unit.

3.1.1. Pre-chain GHG emissions

Some GHG emissions are caused by the on-farm activities, for example CH_4 from enteric fermentation, N_2O related to application of manure to fields etc. These on-farm GHG emissions were calculated by the simple farm model, FarmAC. Whereas, other GHG emissions are related to the pre-chain, *e.g.* production and transport of inputs like fertilizer (N), feed, diesel, electricity. To calculate the GHG emissions related to these inputs (pre-chain) we need to know the amount of different inputs and the LCA value for the GHG emission per unit of input.

3.1.2 Functional unit (FU) and allocation

In the simple farm model used in WP9, the functional unit (FU) is 'total GHG emissions per farm from one year of production' *i.e.* the results are given as for example a total GHG emission of 2.3 million kg CO_2-eq. from a North European dairy farm with 192 cows. In contrast this study also uses the GHG emission per products as the functional unit, *e.g.* kg CO_2-eq./kg milk, kg CO_2-eq./kg meat, kg CO_2-eq./kg barley etc. To estimate these carbon footprints, the total GHG emissions (from on-farm production and from the pre-chain) need to be allocated between the different products from the farm.

The animal products, meat and milk are the main products from the types of livestock farms involved in WP10 in the AnimalChange project, whereas crops for sale and manure for sale are seen as by-products. When total GHG emissions per farm per year has been calculated, the emissions related to amount of manure and crops produced are deducted from this total GHG emission by using standard LCA values for GHG emission per kg N in the manure and crops sold. The remaining GHG emission is then divided between the amount of meat produced or allocated between meat and milk, if both products exist. According to

(Kristensen, Mogensen *et al.* 2011), the choice of method used to divide total farm GHG emissions into meat and milk has significant impact on the estimated emission per kg product.

In D10.5 this allocation follow the method suggested by IDF (2010): a Biological allocation based on a standard marginal net energy requirement to produce the actual amount of milk and meat in the shape of kg live weight gain.

Allocation factor for milk = 1 – 5,771 *(kg LW gain/kg ECM) = 1 – 5,771 *((274 + 40)/9486) = 0,808

Manure for sale

Recently, the view on manure has changed from being a waste product to be considered as a co-product from the livestock production (Dalgaard and Halberg, 2007; (EU 2013)). The saved amount of N fertilizer can be calculated as the total N content in the manure after losses multiplied the percentage of N that is supposed to be available for crops (NaturErhvervstyrelsen 2014). Extra emissions related to transport of manure compared to that of fertilizer need to be taken into account.

The amount of manure for sale was defined as amount of collected manure (slurry, deep litter, etc.) not used on own fields.

Table 1. Saved GHG emission from 100 kg N ex-animal for sale/import

Manure system	Deposited at pasture	Slurry	Deep litter
Fertilizer value of manure N, kg [1)]	70	70	45
GHG from avoid fertilizer prod., kg CO_2-eq N [2)]	298	298	191

1) (NaturErhvervstyrelsen 2014)
2) 4,25 kg CO_2/kg N (Elsgaard, Olesen *et al.* 2010) (Elsgaard, 2010)

3.1.3 Feed import

The 'FarmAC model' provides data on amount of feed import per farm per year. In the sheet 'Balance' the total amount of purchased and sold feed ingredients are calculated per feed item as kg dry matter. In the LCA calculations, we need to take into account the GHG contribution from transport of imported feed ingredients, therefore data on place/country of origin needed to be known. These data are not given. This information would also make it possible (at least theoretically) to take into account the actual productivity in the place of production.

Table 2. Factors for CF of feed import, g CO2/kg DM, (Mogensen, Kristensen *et al.* 2014)

	Growing	**Processing**	**Transport (Origin)**	**Total**
Spring barley	484	11	18 (national)	512
Wheat	406	11	18 (national)	434
Rape seed cake	390	28	75 (national/import)	494
Rape seed	963	0	122 (national/import)	1085
Soybean meal	161	29	325 (import)	515

3.1.4. Fertilizer (N, P, K)

The 'FarmAC model' gives in the sheet 'Manure' data on the amount of (kg) N fertilizer used per crop per year as well as types of N fertilizer imported. The 'FarmAC model' does not give any information about amount of P and K fertilizer used and thereby imported. This contribution was not included in the calculation.

In the present calculation all import of N-fertilizer was assumed to be based on calcium ammonium nitrate and the applied CF was 4,25 kg CO_2/kg N (Elsgaard, 2010).

3.1.5. Diesel – including that used by machine pool

In 'FarmAC model' no information is given on the amount of diesel used.

In the LCAs calculations the following standard level of diesel was assumed for different crops:

Table 3. Diesel, l/ha (3,309 kg CO2/l diesel, (Nielsen, Nielsen *et al.* 2003)

	l/ha
Maize whole crop silage	130
Cereal	Wheat 102, Spring barley 83 Cereals 93
Grass silage	80
Grass grazed	6
Rape seed and pea	168

3.1.6. Electricity

Electricity can be used in the livestock housing, for example heating, cooling, housing, milking and in the fields for example for irrigation and drying of cereals at harvest. Neither the 'FarmAC model' nor financial data provide data of on farm use of electricity. Therefore, the

LCA calculations used standard values according to the different farming systems in different regions for the used amount of electricity.

Table 4. Energy use in stable

Kwh	North Europe (Denmark)	Brazil
Per cow per year	700	100
Per young stock per year	18	2

CF for electricity: 0,655 kg CO_2/kwh (based on natural gas)(Nielsen, Nielsen *et al.* 2003)

In order to evaluate the total GHG emissions –direct, indirect and pre-chain- from agricultural systems in relation to management this chapter include systematically characteristics (table 1), N-balances (table 2) and GHG emissions (on farm emissions in table 3 and pre-chain emissions in table 4). Corresponding information is shown in chapter 5, with corresponding mitigation numbers.

3.2. On farm and pre/chain GHG from Humid Equatorial Beef (Amazonia)

Table 1, Table 2, Table 3 and Table 4 respectively present farm characteristics, N balances, on-farm GHG emissions and total GHG emissions (pre-chain GHG emissions included) from a humid equatorial beef farm in Amazonia.

Table 1. Characteristicks of farm: Soil; Management; Herd; Crops and yields

Country	Brasil, Amazonia rain forrest, Roraima					
person data responsible	Amaury/Luis					
Agro Ecological Zone	Brazil Amazone (Sub-humid)					
Farm type	Beef cattle					
System		9iskWork. 1Luis. Soil (baseline =10. potential	7 Agroforestry. Crop_Liv_Rot_Tek	3Crop_Liv_trad (baseline =1)	2Rotation 0N (baseline=1)	6Rotation_7 0N (baseline=1)
		Baseline	Mit_1	Mit2	Mit3	Mit_4
Farm number of baseline		709358-1	7	3	2	6
Crop rotation	All grazing					
Ha plouging possible	[ha]	488	488	488	488	488
Ha, permanent grassland, low productive	[ha]					
Soil type, FAO (2015)		Clay				
Soil organic material in root zone	[tonnes C/ha]	105	90	97	96	119
Change in C stored in the soil	kg C/ha/yr	-984	-940	-747	-795	-57
Clay in root zone	[% clay]	0.26	0.26	0.26	0.26	0.26
Precipitation	[mm/year]	2028	2028	2028	2028	2028
Potential evapotranspiration	[mm/year]	419	421	436	419	419
Manure type	Unit	None				
Breed of animal		**Zebus**				
Milk for sucklers (liter/cow/year)	[liter/cow/year]	2553	2553	2553	2553	2510
Meat	(kg LW/animal/year]	141	141	146	145	148
Herd size (cows)[h]	[cows]	20	20	20	20	25
Herd size (heifers)[h]	[heifers]	70	70	70	70	86
Herd size (bulls)[h]	[bulls]	420	400	798	757	1413
LU/animal		0.63	0.63	0.61	0.61	0.60
LU (ha-1)b	[LU (ha-1)]b	0.66	0.66	0.66	0.66	0.66
Livestock manure(kg excreted N LU-1 /year	[kg N LU-1 /year)]c	57	55	95	91	162
Livestock manure applied (kg deposit-N ha-	[kg N ha-1 /year)]c	37	36	63	59	106
Grazing	[% of herd DM-uptake]	100	100	100	100	100
Grazing area	[% of ha]	100	80	80	100	100
Conserved rouhage	[% of ha]	0	80	80	0	0
Soya	[% of ha]		20	20	0	0
Plant yield. Gross i)	(t DM/year)	8.1	11.9	14.2	13.0	19.0
Total net yield (sold, grazed and conserved)	(t DM/year)	2.7	3.3	5.1	4.3	7.6
Grass net yield	(t DM/year)	2.7	3.4	5.7		6.2
Soya	(t DM/year)		2.8	2.8		
Teak	(t DM/year)		5.2			

a FYM is the separate system with both solid and liquid manure.
b Livestock units is defines as in Eu 500 kg liveweight. In DK one dairy cow is 1.33 LU=142 kg N excretion/anim
c Including manure deposited by cattle on grazed areas.
d DN is day and night time grazing, D is daytime grazing, (–) indicates no grazing.
e Grazing or fresh feed inside.
f Crop area in percent of farm area.
g Grass, clover and grain crops for silage; alfalfa for hay.
h. Year-animals = feedingdays/365
i) Yield to be harwested or grazed in fields

Table 2. N-balances, [kg N/ha/year]

System			9iskWork. 1Luis. Soil (baseline =10. potential	7 Agroforestry. Crop_Liv_Rot_Tek	3Crop_Liv_trad (baseline =1)	2Rotation 0N (baseline=1)	6Rotation_70N (baseline=1)
Farm	Inputs	N in fertiliser	0	0	0	0	70
		N fixation	0	21	19	0	0
		N deposited from atmosphere	15	15	15	15	15
		N in imported crop products	0	0	0	0	0
	Total inputs		15	36	34	15	85
	Outputs	N sold in crop products, incl rouhage	0	38	38	0	0
		N sold in milk	1	1	1	1	1
		N exported in meat	5	4	8	8	14
	Total outputs		5	43	46	9	15
Farm gate balance			**10**	**-7**	**-13**	**7**	**70**
	Losses	Total amm-N loss	2	2	3	3	20
		Total denitrification	17	19	22	21	29
		Nitrate leaching	**76**	**52**	**27**	**50**	**25**
		Change in mineral N in soil	4	3	1	2	2
		Change in organic N in soil	-89	-82	-65	-69	-5
Herd	Inputs	Rouhage storage N-balance after sto	0	0	0	0	0
		Grazed	42	41	71	68	121
	Total inputs		42	41	71	68	121
	Outputs	N sold in milk	1	1	1	1	1
		N exported in meat	5	4	8	8	14
	Total outputs		5	5	9	9	15
Herd balance			37	36	63	60	106
	Efficiency of N use by livestock		**12%**	**12%**	**12%**	**13%**	**13%**
Field balance							
	Inputs	N in fertiliser	0	0	0	0	70
		Manure applied	0	0	0	0	0
		Deposited in field	37	36	63	59	106
		N fixation	0	21	19	0	0
		N deposited from atmosphere	15	15	15	15	15
	Total inputs		52	72	96	74	191
	Outputs	Harvested mechanically	0	38	38	0	0
		Grazed	42	41	71	68	121
		N sold in crop products, incl rouhage	0	38	38	0	0
	Total outputs		42	79	109	68	122
Field balance			**10**	**-7**	**-13**	**6**	**70**
	NEffField		81%	109%	113%	91%	64%
Feed storage		Harvested mechanically	0	38	38	0	0
		N in imported crop products	0	0	0	0	0
		Imported rouhage	0	0	0	0	0
		Imported cash crops (grain, rape)	0	0	0	0	0
		N sold in crop products, incl rouhage	0	38	38	0	0
		N lost from processing/stored crop pı	0	0	0	0	0
		% loss of input	0%	0%	0%	0%	0%

Table 3. The basic-farm: On-farm GHG emission

System		9iskWork. 1Luis. Soil (baseline =10.	7 Agroforestry. Crop_Liv_Rot_Tek	3Crop_Liv_trad (baseline=1)	2Rotation0N (baseline=1)	6Rotation_70N (baseline=1)
GHG results per farm, kg CO2-eq/yr [1)]						
CH4 enteric	[kg CO2-eq/y]	641578	616694	1080140	1028401	1834709
CH4 manure	[kg CO2-eq/y]	0	0	0	0	0
N2O manure	[kg CO2-eq/y]	0	0	0	0	0
N2O field	[kg CO2-eq/y]	551046	634897	709815	696242	931630
Soil C changes	[kg CO2-eq/y]	1760649	1682732	1336566	1423020	102625
Total direct GHG	[kg CO2-eq/y]	2953273	2934323	3126521	3147663	2868964
Indirect from NH3-emission	[kg CO2-eq/y]	0	0	0	0	33594
N2O-indirect leaching	[kg CO2-eq/y]	129900	88922	46544	86036	42852
Total indirect GHG	[kg CO2-eq/y]	129900	88922	46544	86036	76446
GHG, direct + indirect	[kg CO2-eq/y]	3083173	3023245	3173065	3233699	2945410
On farm land, ha	[ha]	488	488	488	488	488
GHG results per ha, kg CO2-eq/yr [1)]						
CH4 enteric	[kg CO2-eq/ha/y]	1315	1264	2213	2107	3760
CH4 manure	[kg CO2-eq/ha/y]	0	0	0	0	0
N2O manure	[kg CO2-eq/ha/y]	0	0	0	0	0
N2O field	[kg CO2-eq/ha/y]	1129	1301	1455	1427	1909
Soil C changes	[kg CO2-eq/ha/y]	3608	3448	2739	2916	210
Total GHG per ha	[kg CO2-eq/ha/y]	6052	6013	6407	6450	5879
Indirect from NH3-emission	[kg CO2-eq/ha/y]	0	0	0	0	69
N2O-indirect leaching	[kg CO2-eq/ha/y]	266	182	95	176	88
Total indirect GHG	[kg CO2-eq/ha/y]	266	182	95	176	157
GHG, direct + indirect	[kg CO2-eq/ha/y]	6318	6195	6502	6626	6036
Adjustment of home-produced feed		2	-12	-32	2	-6
Output of products						
Milk, kg for calves	[kg/y]	51069	51069	51069	51069	62742
Meat, ton LW	[ton LW/y]	72	69	129	123	225
Crop product	[ton DM]	0	390599	306515	0	5705
Input						
Fertlizer, kg N [2)]	[N/ha]	0	0	0	0	70
Fixation	[N/ha]	0	21	19	0	0
Feed [3)]						
- Soya grain export, kg DM	[kg DM/ha]	0	-560	0	0	0
Diesel, l/ha estimate	[l/ha]	6	6	6	6	6
Electricity, stable estimate	[kwh/ha]	2	0	0	3	0

Table 4. The basic-farm: Total GHG emission – including pre-chain.
Presented as total per ha and per kg product

		Amazone_Beef	Agroforestry.	Integration crop-livestock	Rotational grazing	Rotational graz. + N-fertilization
GHG results per farm, kg CO2-eq/yr [1)]						
On-farm total direct GHG	[kg CO2-eq/ha/y]	6052	6013	6407	6450	5879
On-farm total indirect GHG	[kg CO2-eq/ha/y]	266	182	95	176	157
On farm GHG, direct + indirect	[kg CO2-eq/ha/y]	6318	6195	6502	6626	6036
Reduction (%)			-2%	3%	5%	-4%
On farm emissions (kg CO2-eq/kg LW gain)						
Total GHG		42.81	43.88	24.51	26.29	13.08
Reduction (%)			3%	-43%	-39%	-69%
Pre-chain GHG from						
- Net Feed import	[kg CO2-eq/ha/y]	2	-300	-32	2	-6
- Fertilizer (N)	[kg CO2-eq/ha/y]	0	0	0	0	298
- Manure (N)	[kg CO2-eq/ha/y]	0	0	0	0	0
- Diesel	[kg CO2-eq/ha/y]	20	20	20	20	20
- Electricity	[kg CO2-eq/ha/y]	1	0	0	2	0
Total pre-chain GHG emission	[kg CO2-eq/ha/y]	23	-280	-11	24	312
0-check	[kg CO2-eq/ha/y]	0	0	5558	-11602	-151802
Total GHG before allocation	[kg CO2-eq/ha/y]	6341	5916	6491	6650	6347
Output of products						
Meat, ton LW	[ton LW/y]	72	69	129	123	225
Meat, kg LW	[Kg LW/ha/y]	148	141	265	252	461
Reduction (%)			-4%	80%	71%	213%
GHG per kg product						
G CO2/kg meat LW-gain (sold from farm)	[G CO2/kg meat LW-gain	42962	41897	24468	26381	13758
Reduction (%)			-2%	-43%	-39%	-68%
	[Kg meat LW-gain/kg CO2	23	24	41	38	73
Reduction (%)			3%	76%	63%	212%

GHG from Humid Equatorial Beef (Amazonia)

3.3. Sub-humid mixed dairy

Table 1, Table 2, Table 3 and Table 4 respectively present farm characteristics, N balances, on-farm GHG emissions and total GHG emissions (pre-chain GHG emissions included) from a sub-humid mixed dairy farm from the Campos region (Brazil).

Table 1. Characteristicks of farm: Soil; Management; Herd; Crops and yields

Country	Brasil, Campos, Permanent grass before 1970, South Brasil						
Person data responsible	Olivier BONNET						
Agro Ecological Zone	Humid grassland based dairy, Brasil, Campos						
Farm type	Holstein dairy on sub-tropical grassland						
System		Conventional	No-tillage	No-tillage & red. N	No tillage, low N & top grazing	No tillage, low N & 2 years rotation	No tillage, low N, top graz. & 2 years rotation
		Baseline in	Mit1	Mit2	Mit3	Mit4	Mit5
Farm number of baseline		116829-1	3	12	4	16	13
Crop rotation							
Ha plouging possible	[ha]	14	14	14	14	14	14
Soil type, FAO (2015)							
Soil organic material in root zone	[tonnes C/ha]	81	83	83	95	84	52
Change in C stored in the soil	kg C/ha/yr	118	202	198	603	223	591
Clay in root zone	[% clay]	0.30	0.30	0.30	0.30	0.30	0.30
Precipitation	[mm/year]	1911	1911	1911	1911	1906	1906
Potential evapotranspiration	[mm/year]	492	499	499	500	497	498
Manure type	Unit						
Manure storage		None	None	None	None	None	None
Breed of animal	**Holstein dairy cows**						
Milk (liter/cow/year)	[liter/cow/year]	6792	6792	6792	7410	6785	7410
Milk, fat content, %							
Milk, protein content, %							
Milk per kg feed-DM	[liter milk/kg DM]	1.43	1.43	1.43	1.41	1.43	1.41
Meat (kg Year-animal-1/year)	Kg LW meat/LSU/year	10	10	10	10	10	10
Herd size (cows/young stock)[h]	[No cows/young stock]	35	35	35	45	40	45
	[No young stock etc.]	0	0	0	0	0	0
LU/animal		1.05	1.05	1.05	1.05	1.05	1.05
LU/ha b)	[LU/ha)]b	2.63	2.63	2.63	3.38	3.00	3.38
Livestock manure	[kg N /LU /year)]c	64	64	64	76	64	76
Livestock manure applied	[kg N /ha /year)]c	169	169	169	256	192	256
DM feed uptake	[kg DM/cow]	4745	4745	4745	5272	4745	5272
	[kg DM/LU]	4519	4519	4519	5021	4519	5021
N feed uptake	[kg N/cow]	106	106	106	121	105	121
	[kg N/LU]	100	100	100	115	100	115
Feed % protein/DM		14%	14%	14%	14%	14%	14%
Grazingd		365	365	365	365	365	365
Grazing	[% of herd DM-uptake]	31	31	31	58	31	58
Forage crops (%)g,f	[% of herd DM-uptake]	31	31	31	14	31	14
Concentrate feed	[% of herd DM-uptake]	38	38	38	28	38	28
Grazing area	[% of ha]	100	100	100	100	100	100
Conserved rouhage	[% of ha]	100	100	43	100	100	100
Plant yield. Gross i)	(t DM/ha/year)	13.2	14.3	14.2	18.6	14.9	18.4
Total net yield (sold, grazed and conse	(t DM/ha/year)	7.9	8.0	7.9	12.6	9.0	12.6

a FYM is the separate system with both solid and liquid manure.
b Livestock units is defines as in Eu 500 kg liveweight. In DK one dairy cow is 1.33 LU=142 kg N excretion/animal/y and 1 heifer is
c Including manure deposited by cattle on grazed areas.
d DN is day and night time grazing, D is daytime grazing, (–) indicates no grazing.
e Grazing or fresh feed inside.
f Crop area in percent of farm area.
g Grass, clover and grain crops for silage; alfalfa for hay.
h. Year-animals = feedingdays/365
i Yield to be harwested or grazed in fields

Table 2. N-balances, [kg N/ha/year]

System	Conventional	No-tillage	No-tillage & low N	No tillage, low N & top grazing	No tillage, low N & 2 years rotation	No tillage, low N, top graz. & 2 years rotation
Farm						
Inputs						
N in fertiliser	130	130	92	93	94	83
N deposited from atmosphere	22	22	22	22	22	22
N in imported crop products	147	146	147	152	167	152
Total inputs	298	298	261	267	283	257
Outputs						
N sold in crop products, incl rouhage export	0	1	0	1	0	2
N sold in milk	94	94	94	132	108	132
N exported in meat	1	1	1	1	1	1
Total outputs	*95*	*96*	*95*	*135*	*109*	*135*
Farm gate balance	**203**	**202**	**165**	**132**	**174**	**121**
NEffFarm	32%	32%	37%	50%	38%	53%
Losses						
Total amm-N loss	35	36	28	28	29	26
Total denitrification	44	46	44	52	45	51
Nitrate leaching	**113**	**100**	**75**	**16**	**77**	**17**
Change in mineral N in soil	1	2	2	0	2	1
Change in organic N in soil	**10**	**19**	**18**	**55**	**21**	**55**
Herd Inputs						
Rouhage storage N-balance after storage loss	37	37	37	23	42	23
Imported livestock feed, incl rouhage import)	147	146	147	152	167	152
Grazed	80	80	80	215	91	215
Total inputs	264	264	264	390	301	390
Outputs						
N sold in milk	94	94	94	132	108	132
N exported in meat	1	1	1	1	1	1
Total outputs	95	95	95	133	109	133
Herd balance	169	169	169	256	192	256
NEffHerd Efficiency of N use by livestock	36%	36%	36%	34%	36%	34%
Field bala Inputs						
N in fertiliser	130	130	92	93	94	83
Deposited in field	169	169	169	256	192	256
N deposited from atmosphere	22	22	22	22	22	22
Total inputs	320	320	283	371	308	361
Outputs						
Harvested mechanically	44	45	44	28	50	29
Grazed	80	80	80	215	91	215
N sold in crop products, incl rouhage export	0	1	0	1	0	2
Total outputs	124	125	124	243	141	244
Field balance	**196**	**195**	**159**	**128**	**167**	**117**
NEffField	39%	39%	44%	66%	46%	68%
Feed storage						
Harvested mechanically	44	45	44	28	50	29
N in imported crop products	147	146	147	152	167	152
N sold in crop products, incl rouhage export	0	1	0	1	0	2
N lost from processing/stored crop products	7	7	7	4	8	4
% loss of input	15%	15%	15%	15%	15%	14%

Comment: The N-efficiency in dairy herd is too high. This is due to low crude protein (CP) in grazed sorghum (12 % CP/DM) and ryegrass (15% CP/DM). Grazing animals will select high quality leafy material during grazing, and if CP is fixed to 20 % CP then the NEffHerd will decrease by 17%. If also heifer is included in the dairy herd then NEffHerd will decrease further by 8%. With assumed 20 % CP and heifers the NEffHerd will be as expected 27 %. Which is still a bit high for grazing herds?

Table 3. The basic-farm: On-farm GHG emission

	Conventional	No-tillage	No-tillage & low N	No tillage, low N & top grazing	No tillage, low N & 2 years rotation	No tillage, low N, top graz. & 2 years rotation
GHG results per farm, kg CO_2-eq/yr [1)]						
CH_4 enteric	74953	74953	74953	107076	85661	107076
CH_4 manure	0	0	0	0	0	0
N_2O manure	0	0	0	0	0	0
N_2O field	72398	75718	71632	84985	74531	83319
Soil C changes	-6062	-10394	-10163	-30968	-11474	-30364
Total direct GHG	141290	140277	136421	161092	148718	160031
Indirect from NH_3-emission	1538	1538	1021	1024	1025	886
N_2O-indirect leaching	5554	4906	3674	788	3792	829
Total indirect GHG	7091	6444	4696	1812	4817	1715
GHG, direct + indirect	148381	146721	141117	162904	153535	161746
On farm land, ha	14	14	14	14	14	14
GHG results per ha, kg CO_2-eq/yr [1)]						
CH_4 enteric	5354	5354	5354	7648	6119	7648
CH_4 manure	0	0	0	0	0	0
N_2O manure	0	0	0	0	0	0
N_2O field	5171	5408	5117	6070	5324	5951
Soil C changes	-433	-742	-726	-2212	-820	-2169
Total GHG per ha	10092	10020	9744	11507	10623	11431
Indirect from NH_3-emission	110	110	73	73	73	63
N_2O-indirect leaching	397	350	262	56	271	59
Total indirect GHG	507	460	335	129	344	123
GHG, direct + indirect	10599	10480	10080	11636	10967	11553
Adjustment of home-produced feed	27	-38	12	27	25	-3
Output of products						
Milk, kg delivered	237707	237707	237707	333432	271386	333432
Meat, ton LW	0	0	0	0	0	0
Crop product	193	1280	193	771	77	1157
Input						
Fertlizer, kg N [2)]	130	130	92	93	94	83
Fixation	0	0	0	0	0	0
Manure, kg N and type	0	0	0	0	0	0
Feed [3)]						
- Cereals, kg DM	0	0	0	0	0	0
- Rape seed cake, kg DM	0	0	0	0	0	0
- Rapeseed, kg DM	0	0	0	0	0	0
- Soy bean meal, kg DM	0	0	0	0	0	0
- Other	4563	4563	4563	4693	5214	4693
Diesel, l/ha estimate	0	0	0	0	0	0
Electricity, stable estimate	250	250	250	321	286	321

Table 4. The basic-farm: Total GHG emission – including pre-chain. Presented as total per ha and per product.

		Conventional	No-tillage	No-tillage & low N	No tillage, low N & top grazing	No tillage, low N & 2 years rotation	No tillage, low N, top graz. & 2 years rotation
GHG results per farm, kg CO2-eq/ha/yr [1]							
On-farm total direct GHG	[kg CO2-eq/ha/y]	10092	10020	9744	11507	10623	11431
On-farm total indirect GHG	[kg CO2-eq/ha/y]	507	460	335	129	344	123
On farm GHG, direct + indirect	[kg CO2-eq/ha/y]	10599	10480	10080	11636	10967	11553
Reduction (%)			-1%	-5%	10%	3%	9%
On farm emissions (g/liter)							
Total GHG		624	617	594	489	566	485
Reduction (%)			-1%	-5%	-22%	-9%	-22%
Pre-chain GHG from							
- Net Feed import	[kg CO2-eq/ha/y]	2367	2302	2353	2434	2700	2404
- Fertilizer (N)	[kg CO2-eq/ha/y]	550	550	391	395	397	352
- Electricity	[kg CO2-eq/ha/y]	164	164	164	211	187	211
Total pre-chain GHG emission	[kg CO2-eq/ha/y]	3081	3016	2908	3040	3285	2967
Total GHG before allocation	[kg CO2-eq/ha/y]	13680	13496	12987	14676	14251	14520
Output of products							
Milk, ton delivered	[Ton/y]	238	238	238	333	271	333
Reduction (%)			0%	0%	40%	14%	40%
Meat, ton LW	[ton LW/y]	0	0	0	0	0	0
Reduction (%)			0%	-100%	-100%	-100%	-100%
Allocation of GHG, %		99.2%	99.2%	99.2%	99.2%	99.1%	99.2%
GHG per kg product							
G CO2/liter milk	[G CO2/liter milk]	0.799	0.788	0.758	0.611	0.729	0.604
Reduction (%)			-1%	-5%	-24%	-9%	-24%
G CO2/kg meat LW-gain (sold from farm)	[G CO2/kg meat LW-gain]	4.650	4.587	4.414	3.556	4.243	3.518
Reduction (%)			-1%	-5%	-24%	-9%	-24%

Farm from Sub-humid mixed dairy, Brasilien, Campos

The total GHG-emission per litre milk is on a low level. If Crude Protein of grazed grass is assumed to 20 % CP/DM, and heifers is included in the herd the emission will be around 1.0 kg CO_2 per litre of milk. Same level is found in New Zealand 100 % grazing systems, see (Flysjö, Henriksson *et al.* 2011). However differences between systems can still be evaluated:

The pre-chain GHG emissions comes from imported concentrate (4-5 kg DM/cow/day), plus N-fertilizer (130-80 kg N/ha, see table 2.). Electricity for milking etc. is assumed to 100 kWh/year/cow.

Mitigation 1: The mitigations with no-tillage have minor influence, due to no changes in productivity. The conventional extra leaching in the relatively short period (two weeks) is 12 % higher than plant covered soils in no-tillage, see table 2. However in the 20 year simulations the extra N is built into soil-N. Running the model to new soil-fertility equilibrium (100 years) would increase yields or losses. So the total GHG is nearby equal (10550 kg CO_2-eq/ha, see table 3. The FarmAC model has to be initialized for low mineralization when no-tillage, running for more than 20 years simulation to re-stabilize at higher soil-C & -N level.

Mitigation 2: 38 kg N/ha (30 %) lower fertilization reduces kg CO_2-eq by 13 kg per kg fertilizer-N (4%)

Mitigation 3: Top grazing increasing the stocking rate from 2.63 LU/ha to 3 (14%, table 1) and thereby the direct enteric CH_4 production, so GHG-emission per ha was increased by 10%.

3.4 Conclusions LCA calculations

In Table 3.4.1, the effect of different mitigation options on whole chain GHG emissions, pre-chain included, was analyzed on a Brazilian dairy and beef farm, and this total GHG emission was allocated between milk and meat following the allocation method from IDF (2010).

In milk production the most efficient mitigation option was top grazing in combination with No-tillage, low N (and +/- 2 year rotation) resulting in a 24% reduction per kg milk. This reduction was also promoted by a 40% increased milk production. No-tillage gave only a 1% reduction, 5% reduction if combined with low N and 9% reduction if no-tillage, low N and 2 year rotation all were combined.

In beef production, agroforestry only cause a 2% reduction. Whereas, 'integration of crop and livestock' and 'rotational grazing' cause 43% and 39% reduction, respectively. This was also promoted by a 21 and 29% increase in amount of beef produced on the farm. Finally, the most efficient mitigation option was 'rotational grazing in combination with N fertilization', which cause 68% reduction on total GHG per kg beef and 3,13 times higher production.

Table 3.4.1. Effect of different mitigation options on GHG emissions (relative to basic farm without any mitigation option) – only including *on-farm* emission

Farm		Brazil Mixed Dairy Campos	Brazil Beef Amazone
	***On farm* GHG emission from milk & meat**	Rel. kg CO2/ha	
Mitigation option			
Basic	Basic	100	100
M1	No-tillage	99	
M2	No-tillage-low N	95	
M3	No-tillage-low N-top grazing	110	
M4	No-tillage-low N-2 year rotation	103	
M5	No-tillage-low N-top grazing-2 year rotation	109	
M6	Agroforestry		98
M7	Integration crop-livestock		103
M8	Rotational grazing		105
M9	Rotation grazing + N fertilization		96

In Table 3.4.2, the effect of the different mitigation options was analyzed when only on-farm emissions were included and the total on-farm emission was not allocated to the different products.

In milk production, the small mitigation effect of no-tillage and no-tillage + low N was the same at farm gate. With these mitigation effects no changes was seen on amount of milk produced. Whereas, the most efficient mitigation per kg milk produced; 'Top grazing in combination with No-tillage, low N and +/- 2 year rotation' was not a mitigation option looking at total farm emissions as the 40% increased milk production was not taken into account.

Similar picture was seen for beef production, the small mitigation effect of agroforestry was the same at farm gate. Whereas, the most efficient mitigation per kg beef produced; 'integration of crop and livestock', 'rotational grazing' and 'rotational grazing in combination with N fertilization' was not a mitigation option looking at total farm emissions as the huge increase in beef production caused by these mitigation options was not taken into account.

Table 3.4.2. Effect of different mitigation options on GHG emissions per kg product of milk and beef from Brazil (relative to basic farm without any mitigation option) – including GHG from *pre-chain*

Farm		Brazil Mixed Dairy Campos	Brazil Beef Amazone
Total GHG-emission, including *pre-chain*			
	Total GHG emission per kg milk & meat, incl. *pre-chain*	Rel. CO2, g/kg milk	Rel. CO2, g/kg meat LW
Mitigation option			
Basic	Basic	100	100
M1	No-tillage	99	
M2	No-tillage-low N	95	
M3	No-tillage-low N-top grazing	76	
M4	No-tillage-low N-2 year rotation	91	
M5	No-tillage-low N-top grazing-2 year rotation	76	
M6	Agroforestry		98
M7	Integration crop-livestock		57
M8	Rotational grazing		61
M9	Rotation grazing + N fertilization		32
Production			
	Rel. production from milk & meat	Milk production, rel. ton per farm	Meat production, rel. ton per farm
Basic	Basic	100	100
M1	No-tillage	100	
M2	No-tillage-low N	100	
M3	No-tillage-low N-top grazing	140	
M4	No-tillage-low N-2 year rotation	114	
M5	No-tillage-low N-top grazing-2 year rotation	140	
M6	Agroforestry		96
M7	Integration crop-livestock		179
M8	Rotational grazing		171
M9	Rotation grazing + N fertilization		313

Table 3.4.3. Effect of different mitigation options on total GHG emissions per kg product of milk and beef from Brazil – including GHG from pre-chain. And the production per ha.

Farm		Brazil Mixed Dairy Campos	Brazil Beef Amazone
Total GHG-emission, including *pre-chain*			
	Total GHG emission per kg milk & meat, incl. *pre-chain*	CO2, g/kg milk	CO2, g/kg meat LW
Mitigation option			
Basic	Basic	799	42962
M1	No-tillage	788	
M2	No-tillage-low N	758	
M3	No-tillage-low N-top grazing	611	
M4	No-tillage-low N-2 year rotation	729	
M5	No-tillage-low N-top grazing-2 year rotation	604	
M6	Agroforestry		41897
M7	Integration crop-livestock		24468
M8	Rotational grazing		26381
M9	Rotation grazing + N fertilization		13758
Production			
	Production per ha from milk & meat	Milk production, liter per ha	Meat production, kg LW/ha
Basic	Basic	16979	148
M1	No-tillage	16979	
M2	No-tillage-low N	16979	
M3	No-tillage-low N-top grazing	23817	
M4	No-tillage-low N-2 year rotation	19385	
M5	No-tillage-low N-top grazing-2 year rotation	23817	
M6	Agroforestry		141
M7	Integration crop-livestock		265
M8	Rotational grazing		252
M9	Rotation grazing + N fertilization		461

4. Mitigation options evaluated across farms, only on farm emission

A gross list of mitigation and adaptation options was created within AnimalChange (Van den Pol – van Dasselaar, 2012). From the options on this list the local expert of each farm selected the five best mitigation options for his farm (Annex 3).

Some of these mitigation options turned out to be so complex that it was not feasible to calculate the effect of these options on farm GHG emissions with FarmAC. Therefore the mitigation options chosen and the mitigation options modelled with FarmAC might not match.

The implementation of the mitigation options on the farms depends on the local situation (site specific). This means that a specific mitigation option can be implemented differently on the various farms. The mitigation option "fertilisation rate" for example can be implemented as an increase of N-fertilisation on farm A and as a decrease of N-fertilisation on farm B, or it can be implemented as a change of N application strategy during the growing season.

By using a generic approach (*e.g.* reducing N fertilisation by 50 kg) the effect of the mitigation option "fertilisation rate" could be compared over farms; however, the generic approach would not have been effective in reducing on farm GHG emissions on all farms. Therefore we chose to implement the mitigation options for each farm individually.

From four farms a general farm description, an overview of the selected mitigation measures and the results of the modelling with FarmAC is given in this chapter. These farms are respectively Humid Equatorial Beef, Sub-humid mixed dairy, Semi-arid mixed livestock farming and Semi-arid land based livestock farming.

4.1. Humid Equatorial Beef (Amazonia)

4.1.1. General introduction

The showcase Humid Equatorial grass-based Amazonian farm (Fazenda São Paulo; S-LA-005-Amazon_beef_pasture_after_deforestation) is a representative commercial beef production farm in the Brazilian Amazon region. The farm is located at coordinates 2°17'40.16" N, 61°14'52.95" W, in areas of colonization of State of Roraima, in northerly part of the Brazilian Amazon. The São Paulo farm has an area of 488 ha of non-fertilized *Brachiaria brizantha* cv Marandu permanent pastures, established after deforestation occurred around 20 year ago.

Pasture utilization rate was considered to be 1/3 of the forage produced for all the simulations. This figure is within the range expected for commercial grazing only systems on tropical pastures in Brazil (Barioni *et al.*, 2005). Forage not grazed was regarded as incorporated to the soil. No synthetic N fertilizer is applied in the baseline.

The soil is classified as an Argisol with 30% clay and poor natural fertility with pH = 4.2 (water) and P = 1.48 mg/dm3 (Mehlich). Climate is hot and humid. Rainfall is well distributed along the year, totaling slightly above 2000 mm. Annual maximum, minimum and mean temperatures are, respectively, 32.5, 22.2 and 27.4 °C.

The animals are Zebu (*Bos indicus*) Nellore breed. Cows produce part of the animals to be raised. Weaned and 1 yr old males are purchased in the market. Males are castrated at about 350 kg LW. The steers are slaughtered at about 30 months of age with an average of 500 kg of liveweight. Average male liveweight daily gain is 0.44 kg/day. Average cow milk production was considered to be 850 kg/lactation (Albertini, 2010) and the average intercalving interval was 14 months, so average daily milk production was calculated as 2 kg/day. Parameter files were altered accordingly to the lower maintenance requirement of the zebu animals, according to the Australian Standards (CSIRO, 2007). For the simulation on FarmAC, the herd was divided into 6 categories with parameters presented in Table 1.

All livestock categories graze along the whole year. Stocking rates were adjusted following locally observed data. The diet of the animals is composed exclusively by grazed grass and mineral supplement for all the categories. Feed intake was calibrated so that animal performance matches observed data. Average year-round composition of feed and incorporated material is given in Table 2.

Table 1. Number of animals (baseline scenario) and model parameters (for all scenarios).

Category[1]	# of animals	DM Intake (kg/day)	Avg LW (kg)	Avg LWG (kg/day)	Growth ME Req (MJ/kg)
Weaned calves (1)	142	4.2	160	361	12
1-2 yr old steers (2)	155	6.4	282.5	442	15.5
2-3 yr old steers (3)	139	8.7	440	447	21
1-2 yr old heifers (4)	20	5.6	260	340	15.5
2-3 yr old heifers (5)	20	7.4	390	335	21
3+ yr mature cows (6)	70	7.0	450	27	23

1 The actual FarmAC categories are described in portuguese. The original category names are: (1) Zebus Bezerro desmamado; (2) Zebu macho 1-2 anos; (3) Zebu macho 2-3 anos; (4) Zebu novilha 1-2 anos; (5) Zebu novilha 2-3 anos; (6) Zebu fêmea adulta +3 anos

Table 2. Feed and incorporated material composition for all scenarios

Category (portuguese)	Diet	Incorporated
DM Digestibility	57	-
Digestible Energy	10.5	-
Crude Protein	10	4.7
Fibre (kg/kg DM)	33	41.9
NFE	51	51
Fat	1.5	1.4
Ash	7.5	7.2

4.1.2. Mitigation options

Following a review of mitigation options for Brazil (Neves *et al.*, 2004; Carvalho *et al.*, 2010; Muniz *et al.*, 2011; Salton *et al.*, 2011; Mora-Calvo, 2012; Torres *et al.*, 2014) and local knowledge, four mitigation options were tested on the showcase grass-based using FarmAC at the farm level as specified below. Table 3 summarises key data used to run each of the scenarios in FarmAC.

M1. Agroforestry
M2. Integration crop-livestock
M3. Improved grazing management – rotational grazing
M4. N Fertilisation.

Mitigation 1 (M1): Agroforestry

Well managed agroforestry can be an efficient carbon sink (Neves *et al.*, 2004; Vergutz *et al.*, 2010; Ramos, 2013; Figueroa, 2014; Loss *et al.*, 2014) and improve animal performance due to shading (Ainsworth *et al.*, 2012).

This mitigation scenario was built in FarmAC by including 20 ha of Teak (*Tectona grandis*) trees besides 97.6 ha a crop-livestock sequence of soybean and Brachiaria. The remaining 370.7 were kept as in the baseline scenario.

Table 3. Selected Inputs for the Baseline and Mitigation Scenarios

Item	Baseline	M1	M2	M3	M4
Scenario in FarmAC=709357	1	7	3	2	6
Farm size	488	488	488	488	488
Number of animals (excluding suckling calves)	546	526	546	883	1569
Steer slaughter weight, kg/animal	500	500	500	500	500
Steer age at slaughter, months	30	30	30	30	30
Potential grass yield, kg DM/ha	9000	13200	13500	14430	21100
Grass yield, kg DM/ha	8110	11870	12130	12960	18900
N fertiliser, kg N/ha	0	0	0	0	100
Brachiaria area, ha	488	370.4	370.4	488	488
Soybean area, ha		97.6	97.6		
Teak area, ha		20			
Soybean production kg/ha	0	2800	2800	0	0
Teak production kg/ha	0	5600	0	0	0

M1 = Agroforestry M2 = Integration crop-livestock M3 = Changing the grazing management – grazing rotated M4 = Fertilisation rate

Mitigation 2 (M2): Integration crop-livestock

Studies have shown that well managed integrated crop-livestock systems can increase soil carbon stocks (Carvalho *et al.*, 2010; Muniz *et al.*, 2011; Salton *et al.*, 2011; Tirloni *et al.*, 2012; Assad *et al.*, 2013).

This scenario was simulated in FarmAC by including 97.6 ha sequence soybean and Brachiaria. The remaining 390.7 ha of pastures had the same treatment as the baseline scenario. Productivity data were collected on the farm in experimental plots.

Mitigation 3 (M3): Improved grazing management – Rotational Grazing

Improving grazing management can result in higher pasture productivity and quality and consequently increase animal performance (Gomide and Gomide, 2001; Andrade, 2003; Crosson *et al.*, 2006; Barbosa *et al.*, 2007) and higher soil C stocks (Maia *et al.*, 2009; Carvalho *et al.*, 2010).

In this scenario, the alternate grazing management was replaced by a rotational system. So higher herbage production and higher stocking rates were input in FarmAC.

Mitigation 4 (M4): Applying N fertiliser

As FarmAC simulations indicated exhaustion of available nitrogen to sustain long-term productivity of Brachiaria pasture, we have tested the addition of urea fertilization at a rate of 70 kg N/ha in two applications, in the scenario Mitigation 3, as described above.

4.1.3 Results

Tables 4 to 6 show the estimated baseline N fluxes, C fluxes and GHG emissions of the Amazonian farms for the baseline and mitigation options tested.

Soil carbon is an important source of GHG flows for all the scenarios, representing about 40 to 60 % of the CO_2-e emissions for all scenarios except for the fertilized pasture (14 % of the emissions). It is important to note that the system is not at steady-state for most of the scenarios. In order to make enough nitrogen available for the informed grass production enough mineralization of soil organic matter (SOM) is necessary, as N concentration in SOM is fairly constant as documented in many countries, Taghizadeh-Toosi *et al.* (2014). Therefore, grass only pastures without N fertilizer deplete soil N and C after deforestation. Although soil C loss has been observed in some studies, rates are usually much lower and several other studies report increase rather than depletion of soil C stocks when native vegetation is converted to pasture (Guo &Gifford, 2002; Cerri *et al.*, 2003).

Further studies are necessary to elucidate of the mismatch of the FarmAC results in relation to the literature. Such studies may test one of the following hypothesis: (1) The difference in soil depth considered for the FarmAC simulations in relation to the literature studies (usually top 20 or 30 cm; (2) Time span and changes in the soil organic matter degradation rates along the pasture lifespan; (3) Presence of non-symbiotic N fixation. Except if hypothesis (3) is true and N fixation is substantial, the unfertilized pastures will degrade in long-term. This is in accordance to the reports that pasture degradation has been reported as one of the major problems in livestock production in the Brazilian Amazon and nitrogen fertilization has been pointed out as one of the main options to recover pasture productivity (Cerri *et al.* 2005; Gouvello *et al.*, 2010; Souza Braz *et al.* 2013). Interestingly, ca. 20 yrs of continuous pasture management of *Brachiaria*, legumes are reported to increase in abundance in the vegetation cover and this coincides with a rapid build-up of soil carbon (Blanfort *et al.*, see AnimalChange D3.3).

As the diet remained the same, enteric methane was proportional to production for all the scenarios. Beef productivity was higher in the improved pasture management scenarios, but particularly for the fertilized pastures due to higher stocking rates. Also, N fertilization (70 kg/ha/yr) was effective to reduce rates of soil carbon loss (from 3608 to 210 kg CO_2-e/ha/yr) as it increased pasture primary productivity and, consequently, the soil carbon input. The use of N fertilizer was also the most effective mitigation when evaluated as emission intensities (reduced from 43.0 to 13.8 kg liveweight/kg CO_2-e). The literature indicates that pasture recovery with the use of fertilizers is one of the most effective ways to reduce GHG emissions in ruminant production systems, particularly in developing countries (Neely *et al.*, 2009; Soussana *et al.*, 2010) and it is the core of the Brazilian NAMAs for the Agricultural Sector (Mozzer, 2011). In the simulations carried out in this study, the crop-livestock systems in part of the area were less effective than direct fertilization in the whole area. Anyways they produce a reduction in soil carbon losses (from 1036 to 754 kg/ha/yr). Improved pasture management alone and Teak introduction (Agroforestry system) also allowed reduction in soil C losses. However agroforestry and Crop-livestock systems slightly increased total emissions, particularly due to higher animal number and production (Table 5). However, the lowest emission intensities were achieved through improved fertilized pastures followed by improved pasture management without fertilization. One of the reasons for this result is that Crop Rotations and Teak covered a small proportion of the area and therefore had less impact.

Table 4. FarmAC C flux results for the baseline São Paulo beef farm and the various mitigation options simulated

Item	Baseline	M1	M2	M3	M4
C fixed from atmosphere	5601	8009	9676	8979	13183
C in imported manure	0	0	0	0	0
C in imported feed	1	0	0	1	0
C in imported bedding	0	0	0	0	0
C in exported milk	5	5	5	5	6
C in exported meat	34	33	61	58	106
C in mortalities	0	0	0	0	1
C in crop products sold	0	344	270	0	5
C in CO_2 emitted by the soil	6028	8074	9226	8880	11637
C in organic matter leached from the soil	0	0	0	0	0
CO-C from burning crop residues	0	0	0	0	0
CO_2-C in gases from burning crop residues	0	0	0	0	0
Black carbon in gases from burning crop residues	0	0	0	0	0
Change in C stored in the soil	-984	-940	-747	-795	-57

M1 = Agroforestry M2 = Integration crop-livestock M3 = Changing the grazing management – grazing rotated M4 = Fertilisation rate

Table 5. FarmAC greenhouse gas (GHG) results in CO_2 equivalents for the baseline São Paulo beef farm and the various mitigation options simulated

	Item	Unit	Baseline	M1	M2	M3	M4
Direct	Enteric CH_4	kg CO_2-e/ha	1315	1264	2213	2107	3760
	Manure CH_4	kg CO_2-e/ha	0	0	0	0	0
	Manure N_2O emissions	kg CO_2-e/ha	0	0	0	0	0
	Field N_2O emissions	kg CO_2-e/ha	1129	1301	1455	1427	1909
	Change in C stored in soil	kg CO_2-e/ha	3608	3448	2739	2916	210
		kg CO_2-e/ha					

Indirect	Housing NH_3 emissions	kg CO_2-e/ha	0	0	0	0	0
	Manure storage NH_3 emissions	kg CO_2-e/ha	0	0	0	0	0
	NH_3 emissions from field-applied manure	kg CO_2-e/ha	0	0	0	0	0
	NH_3 emissions from fertilisers	kg CO_2-e/ha	0	0	0	0	69
	N_2O emissions resulting from leaching of N	kg CO_2-e/ha	266	182	95	176	88
	Total indirect emissions	kg CO_2-e/ha	266	182	95	176	157
Total	Total GHG emissions	kg CO_2-e/ha	6318	6195	6502	6626	6036

M1 = Agroforestry M2 = Integration crop-livestock M3 = Changing the grazing management – grazing rotated M4 = Fertilisation rate

Table 6. FarmAC N flux results (kg N/ha) for the baseline São Paulo beef farm and the various mitigation options simulated

Scale	Item	Baseline	M1	M2	M3	M4
Farm	Imported livestock feed	27	0	0	26	0
	Imported bedding	0	0	0	0	0
	N fixation	0	10840	10843	0	0
	N deposited from atmosphere	7320	7320	7320	7320	7320
	N in fertiliser	0	0	0	0	34160
	Imported manure	0	0	0	0	0
	N sold in crop products	0	18448	18329	0	92
	N sold in milk	305	305	305	305	374
	N exported in meat	2251	2155	4047	3849	7037
	N in mortalities	16	15	29	28	50
	Exported manure	0	0	0	0	0
	Gaseous loss housing	0	0	0	0	0
	N lost from processing/stored crop products	0	0	0	0	0
	Gaseous loss storage	0	0	0	0	0
	Runoff	0	0	0	0	0
	Gaseous loss field	9104	10324	12066	11795	23569
	Nitrate leaching	36985	25318	13252	24496	12201
	Change in mineral N in soil	2146	1503	570	1076	1111
	Change in organic N in soil	-43263	-40162	-31573	-33886	-2367
Herd						
	Livestock feed consumed in housing	0	0	0	0	0
	Grazed	20719	19915	34881	33210	59249
	Deposited in housing	0	0	0	0	0
	Deposited in field	18147	17440	30500	29029	51787
	N sold in milk[1]	305	305	305	305	374
	N exported in meat	2251	2155	4047	3849	7037
	N in mortalities	16	15	29	28	50
	Efficiency of N use by livestock	12.3%	12.4%	12.5%	12.5%	12.5%

M1 = Agroforestry M2 = Integration crop-livestock M3 = Changing the grazing management – grazing rotated M4 = Fertilisation rate

4.1.4 Conclusion

Simulations of the Amazonian farms after deforestation with FarmAC indicate that all the mitigation options tested were effective in reducing emission intensities. Intensities rank Baseline > Agroforestry > Improved pasture management > Crop-Livestock > Improved pasture management and N application. The rank reflects the area covered by agroforestry as only 20 and 98 out of 488 ha were covered by trees and soybean, respectively.

Emissions per unit of area were similar to baseline within a ± 10% range, indicating sustainable intensification will reduce emission intensities but may not reduce emissions per unit of area. Soil carbon was a major component of the mitigation for the mitigation options tested, usually accounting for over 50% of the emissions, except for the mitigation option where nitrogen was added.

We conclude that recovering or improving pasture productivity in the whole area would be more effective than using crop rotation or agroforestry in a small proportion of the area and that nitrogen input would be essential for long-term sustainability of those systems, allowing for higher soil carbon stocks than baseline levels.

4.2. Sub-humid mixed dairy

4.2.1. General description

This model farm simulate a typical mixed dairy farm from the South part of Brazil, in the state of Rio Grande do Sul, on the Campos biome (M-LA-003 SubHumid Mixed Dairy – Dairy farm from South Brazil, Campos). The farm is a typical small family farm (14 ha) as the ones attended by the Universidade Federal do Rrio Grande do Sul for technical help where native vegetation have been replaced by cultivated crop and forages around 30 years ago for milk production. Cows are Holstein type. Position is assumed to be 28°09'00'' S, 55°10'33'' O. Soil has a clay fraction around 0.3 and a sand fraction around 0.3, and no more than 1 m of root depth. Soil organic C is estimated between 60 and 80 t/ha. Original vegetation was native permanent grassland with domination of grass and no or very few trees. We simulated these conditions over 500 years to stabilise soil parameters of the model. We consider grassland with a maximum potential aboveground production of 20 t/ha/year of DM with a proportion of belowground production equal to 1.1 of the aboveground total production, no irrigation and no fertilisation. Atmospheric N deposition is considered around 22 kg N/ha/year.

Baseline scenario for the farm represents typical farm management in the area. The total area is divided in two areas of 7 ha each. The subtropical region allows growing two cultures in rotation per year, one based on C4 species during spring and summer (summer crop or forage) and one based on C3 species during autumn and winter (winter forages). In the first 7 ha area, the farm grow forage sorghum (*Sorgo bicolor*, variety for forage: sudangrass) during summer, a C4 summer grass and a mixed pasture of cultivated Italian ryegrass (*Lolium multiflorum*, 50% soil cover) and forage Black oat (*Avena strigosa*, 50% soil cover) during winter. Both forages are managed under rotational stocking, with 5-6 grazing rotations per ½ year for both sorghum and ryegrass/oat. In the second 7 ha area, the farm grow sorghum for silage (*Sorgo bicolor*, variety for silage: grain sorghum) during summer with one cut per year, and the same mixed pasture of ryegrass/oat as in the first area during winter. N mineral fertilizer is applied at the beginning of spring (october-november, 57 kg N/ha on forage sorghum and 92 kg N/ha on silage sorghum) and beginning of autumn (march-april, 55 kg N/ha on mixed pasture of ryegrass/oat). Over the one year period, produced yield is 3.1 T/ha for forage sorghum, 7.3 T/ha for sorghum silage and 2.1 T/ha for mixed pasture ryegrass/oat. Real production for both pastures is higher, but aboveground residual material is integrated to the soil. There is neither housing nor real manure management.

This system produce 237 707 kg of milk per year with 35 Holstein cows, (*i.e.* around 6791 kg/cow/year). Cows are highly suplemented with 5 kg DM/animal/day concentrates (bought externaly) and 4 kg DM/animal/day silage, 100% produced on the farm. Daily intake of forage was estimated as 4 kg DM/animal/day. See table 1 for nutritional information of the different feed items. There is no reproduction activity on the farm so heifers are bought externaly. Mean live weight is 525 kg and mean age 4 years old. This represent a quite simple situation that was chose as baseline to explore better the mitigation effect of changes in the crop an grazing management.

Table 1: Nutitional information of the feeds used in the model Farm M-LA-003. Scenarios : B=baseline, M=mitigation.

Feeds	Sorghum forage		Mix oats	Ryegrass-	Sorghum silage	Concen-trate
Scenarios	B, M1, M2	M3	B, M1, M2	M3	All	All
Fibre_concentration	0.45	0.40	0.34	0.27	0.31	0.10
NFE_concentration	0.49	0.49	0.35	0.35	0.51	0.10
CP_concentration	0.12	0.14	0.15	0.17	0.06	0.14
Fat_concentration	0.03	0.03	0.03	0.03	0.03	0.04
Energy_concentration	11.71	12.70	12.73	13.25	11.63	17.80
Ash_concentration	0.06	0.06	0.10	0.10	0.05	0.03
Nitrate_concentration	0.00	0.00	0.00	0.00	0.00	0.00
DMDigestibility	0.60	0.65	0.65	0.68	0.60	0.92
processStorageLoss	0.00	0.00	0.00	0.00	0.15	0.00

4.2.2 Mitigation options

Four mitigation options have been considered here: M1: better management of soil regarding regional situation (no-till with use of cover crop all year long), M2: reduced fertilization rate that can be implemented thanks to no-till management, M3: a better grazing management (resulting in higher grass production and quality as well as higher intake rate of DM per animal) and M4: Crop rotation. We implemented these mitigation options in an additive way as they represent a progressive improvement of management practices as they are observed in the region.

M1 – Cover crops (no-tillage system)

In tropical and sub-tropical area, it is possible to grow crop or cultivated pasture all year long. However, tillage represent a real problem as soil microbial activity remains intense all year long, leading to high organic matter degradation, soil CO_2 emission and a rapid decrease in soil C stocks in case of conventional tillage management. No-tillage systems are therefore highly recommended (C sequestration rates 0.6 to 1.3 ton C/ha/yr higher than with conventional tillage) even if not globally applied yet. The southern part of Brazil in characterized by the presence of four seasons, with large difference in mean temperature between summer (26ºC) and winter (15ºC). Different crops or pastures are consequently grown in summer (generally C4 species, with high production capacities) and winter (generally C3 imported cultivates). Conventional tillage system was the norm in the area until 10 or 15 years ago; resulting in decrease of soil organic C relatively to native vegetation (temperatures are high in the transition periods of autumn and spring when tillage was applied) as well as chemical, physical and biological soil degradation (Bayer *et al.* 2000). But as no-tillage management involves investment in new machinery, it is still not generalised in small properties.

First mitigation option was therefore simulating a no-tillage system, involving that soil was cover by plants all year long. At the end of winter, generalist herbicide (Glyphosate) is sprayed-down to kill residual forage. Then summer crops seeds are directly stubble sowed on the straw. At the end of summer, after collect of the summer crop or end of the grazing cycle, winter forage (mixed pasture of ryegrass/oat) seeds are directly stubble sowed. The change in microbial activity and consequently soil CO_2 emission was however not well simulated in the present version of the model and would need further work. Primary production of the different cultivates was maintained equal to the baseline scenario, as well as the constitution of the animal daily diet.

M2 – Reduced fertilization rate

Fertilizer application rates implemented in baseline scenario correspond to rates of fertilizer application currently observed in farms still using tillage system (around 110 kg N/ha/year for rotation with forage sorghum and 150 kg N/ha/year for rotation with sorghum silage). Adoption of the no-tillage management allows reducing fertilizer application rates (62 kg N/ha/year for rotation with forage sorghum and 122 kg N/ha/year for rotation with sorghum silage). Primary production of the different cultivates remain equal to the baseline scenario, as well as the constitution of the animal daily diet.

M3 – Improving grazing management

In the southern part of Brazil, traditional grazing management for cultivated pasture consist in rotational stocking method with relatively high sward height when animals enter the plot and animals leaving the plot when the sward was nearly grazed down to the flour (entering – leaving height of sward for forage sorghum: 80-10 cm, for mixed pasture ryegrass/oat: 35-5 cm). A new management practice consists in decreasing the intensity of the grazing while increasing the frequency of the rotation (entering – leaving height of sward for forage sorghum: 50-30 cm, for mixed pasture ryegrass/oat: 25-15 cm). The number of grazing rotations typically changes from 4-5 under baseline scenario to 12-15 under improved grazing management. This new management allows: 1- to offer only the best part of the cultivate to the animals (top part of the plant with a higher leaves/stems ratio), increasing its intake rate and nutritional value of consumed parts and 2- a higher primary production of the cultivate as more residual leaves remain after the animals leaved the pasture.

This mitigation option was simulated by improving feed nutritional value (grazed as well as residual part that will be incorporated to the ground, see table 1) and increasing cultivates forages production as follow: Produced yield is 6.5 T/ha for forage sorghum, 8.2 T/ha for sorghum silage and 5.3 T/ha for mixed pasture ryegrass/oat. Another import change was the diet composition of the animal. It is composed of more forage (9 kg DM/animal/day for forage sorghum and 8 kg DM/animal/day for mixed pasture ryegrass/oat), less silage (2 kg DM/animal/day) and less concentrates (4 kg DM/animal/day). As a consequence, the relative area used to grow sorghum silage was decreased: only 4 ha were used to grow sorghum silage whereas 10 ha were used to grow forage sorghum. This new diet composition also strongly reduces production costs.

M4 – Crop rotation

In the model farm we only simulated two crop rotations. The first one with 7 ha (4 ha in mitigation option 3) of sorghum silage during summer and a mixed pasture of ryegrass/oat during winter. The second one with 7 ha (10 ha in mitigation option 3) of cultivate pasture (sorghum forage) during summer and a mixed pasture of ryegrass/oat during winter. Common practice in the study area is to maintain the same crop rotation in the same area year after year, leading to potential nutrient deficit in some areas. Mitigation 4 consists simply in inter-year rotation between the two crop rotations (mixed pasture of ryegrass/oat remains during winter, but the two areas grow alternatively sorghum forage and sorghum silage). This mitigation option was not implemented in isolation but additionally two either mitigation options 2 or 3, or both.

4.2.3 Results

We simulated one baseline scenario and 5 mitigation scenarios for this model Farm using FarmAC (see results in Table 2):
Baseline scenario: scenario simulating common situation before applying mitigation options.
Mitigation 1 scenario (M1): simulation of cover crop mitigation option.
Mitigation 2 scenario (M2): simulation of cover crop and reduced fertilization rate mitigation options simultaneously.
Mitigation 3 scenario (M3): simulation of cover crop, reduced fertilization rate and rotation in the crop mitigation options simultaneously.
Mitigation 4 scenario (M4): simulation of cover crop, reduced fertilization rate and improved grazing management mitigation options simultaneously.
Mitigation 5 scenario (M5): simulation of cover crop, reduced fertilization rate, improved grazing management and rotation in the crop mitigation options simultaneously.

Considering the baseline scenario, the farm has a negative balance of GHG emissions with 10092 kg CO_2 eq/ha/year for direct emissions (enteric CH_4, field N_2O and change in C stored in soil) and 506 kg CO_2 eq/ha/year for indirect emissions (NH_3 from fertilizer application and N_2O from N leaching, Table 2). "On farm" GHG emissions per kg of milk produced remains unexpected low with 0.624 kg CO_2 eq/kg milk. The main reason for low emission per litre milk is partly that heifers are produced outside the farm. If heifers were included the allocated emission per litre milk would increase by nearby 20%. And partly that the protein content of grazed is assumed very low (12 % crude protein of DM in sorghum and 15 % in ryegrass). If instead selection of high quality leaves is assumed, and uptake of 20 % crude protein is assumed, the emission will increase further nearby 10 %. In total of heifers and protein the increase in emission per litre of milk would be 25 % higher than shown figures, and the total emission would be around 0.78 kg CO_2 eq/kg milk, which remains relatively low values.

Change in C stored in soil differs between the two crop rotations, with very low C losses in the sorghum silage rotation and net C fixation in the forage sorghum rotation, due to assumed high amount of plant residues after grazing of sorghum compared to silage where total material is removed from field. Resulting average C balance in soil is -433 kg CO_2 eq/ha/year (Table 2), which is unexpected for a conventional tillage system in sub-tropical conditions that is considered to lose C and not fixing it. The model parameters must be revised in that respect. Nevertheless, total direct emissions (CH_4 + N_2O) reach a value of 10525 kg CO_2 eq/ha/year, relativizing the potential error in C soil sequestration (which has an absolute value 20 times lower) as predicted here. Predicted N_2O emissions from N leaching are relatively height (397 kg CO_2 eq/ha/year).

In Mitigation 1 scenario a no-tillage system is applied. Changes in direct (10020 kg CO_2 eq/ha/year, Table 2) and indirect (460 kg CO_2 eq/ha/year) GHG emissions relatively to baseline scenario are low mostly because the model, in its current version, does not consider effect of tillage or no-tillage on soil microbial activity, only extra plant residues whole year is taken into account. If more trustful analysis is needed the FarmAC initialisation need to include extra residues, and residue figures have to be corrected, if consequence of no tillage shall be analysed by the FarmAC model. As total farm milk production is unchanged, "on farm" (direct & indirect) GHG emissions per kg of milk produced (0.617 kg CO_2 eq/kg milk) remains very close to the value observed in baseline scenario. However, some variables change significantly relatively to the baseline scenarios, mostly because of the longer time with cover crop in Mitigation 1 scenario. Soil C sequestration increases from -433 to -742 kg CO_2 eq/ha/year, due to extra input of plant residues (Table 2, "change in C stored in soil") as does field N_2O emissions (from 5171 to 5408 kg CO_2 eq/ha/year), whereas N_2O emissions from leaching of N decrease decreases a little (from 397 to 350 kg CO_2 eq/ha/year).

In Mitigation 2 scenario we reduced fertilization rate as well as applying a no-till system, without affecting production yield used for animal feeding (small changes in primary production reflected in changes in incorporated residual material). For the present FarmAC initialisation, this situation is close to critical N-deficiencies (mineralization is too low for the assumed yields). Total farm milk production was not affected (23707.5 kg milk/year), nor was total enteric CH_4 emissions (5353.8 kg CO_2 eq/ha/year, Table 2) relatively to baseline and mitigation 1 scenarios. On the other hand, field N_2O emissions came back close to their value of baseline scenario (5116 kg CO_2 eq/ha/year), average soil C sequestration remains around its value from mitigation 1 scenario (-726 kg CO_2 eq/ha/year, mostly due to forage sorghum crop rotation as soil C remained nearly constant in the sorghum silage rotation) and NH_3 emissions from fertilizers (73 kg CO_2 eq/ha/year) and N_2O emissions from leaching of N (262 kg CO_2 eq/ha/year) decreased relatively to baseline and mitigation 1 scenarios, due to reduced N-fertilization. The result was a reduction of both direct (9744 kg CO_2 eq/ha/year, Table 2) and indirect (335 kg CO_2 eq/ha/year) GHG emissions relatively to baseline scenario (a reduction of 5% in total GHG emissions), as well as in "on farm" (direct & indirect) GHG emissions per kg of milk produced (0.593 kg CO_2 eq/kg milk).

Mitigation 3 scenario repeated the parameters of mitigation 2 scenario adding an inter-year rotation between the two crop rotations (the two areas grow alternatively sorghum forage and sorghum silage during summer). This resulted in better efficiency in the use of nutrients (from fertilizer and from plant residuals integrated to the soil) allowing higher assumed yield in forages (3.7 T/ha for forage sorghum and 2.3 T/ha for mixed pasture ryegrass/oat) and silage (8.2 T/ha) and so the capacity for the farm to increase the number of dairy cows (from 35 to 40 animals). First consequence was an increase in enteric methane emission (6118 kg CO_2 eq/ha/year, Table 2) and total milk production (271386 kg/year, a 14% increase), both in direct proportion to the number of animals. This time, changes in C stored in soil were equal between the two crop rotations (as expected) with total soil C stored values higher than in baseline and mitigation 2 scenarios (-820 kg CO_2 eq/ha/year). Field N_2O emissions increased (5324 kg CO_2 eq/ha/year) relatively to baseline scenario because of higher quantities of plant residues, whereas NH_3 emissions from fertilizers and N_2O emissions from leaching of N remained very similar to the value predicted in mitigation 2 scenario (lower than in baseline scenario). Resulting balance for total GHG emissions (direct and indirect) was 10967 kg CO_2 eq/ha/year, an increase of 3.5% relatively to baseline scenario. But as milk production increased at the same time, "on farm" GHG emissions per kg of milk produced decreased from 0.624 to 0.566 kg CO_2 eq/kg milk.

Mitigation 4 scenario involved a strong change in grazing management resulting in significant increases of primary production and nutritional value of the forages consumed by the animals. As a result, it was possible to increase the number of dairy cows (from 35 to 45 animals) as well as milk production per head (from 6791 to 7409 kg/cow/year, Table 2). Other results were an increase in enteric methane emission (7648 kg CO_2 eq/ha/year) and field N_2O emissions (6558 kg CO_2 eq/ha/year) relatively to baseline scenario because of, respectively, a higher number of animals and higher quantities of plant residues. On the other hand, NH_3 emissions from fertilizers (73 kg CO_2 eq/ha/year) and N_2O emissions from leaching of N (53 kg CO_2 eq/ha/year) where strongly reduced, when the higher plant protein yield was used by animals, and not incorporated in soil and then leached. Resulting balance for total GHG emissions (direct and indirect) was 12159 kg CO_2 eq/ha/year, an increase of 15% relatively to baseline scenario, mostly due to higher enteric methane and field N_2O emissions. But "on farm" GHG emissions per kg of milk produced were reduced to 0.510 kg CO_2 eq/kg milk (18% reduction), primarily due to 10 % higher milk production and higher protein in feed uptake.

Mitigation 5 scenario was very similar to mitigation 4 scenario. Inter-year rotation between the two crop rotations did not result in large changes in GHG emissions, mostly because the system in mitigation 4 scenario was already well efficient. Changes in C stored in soil (fixation) were equal between the two crop rotations, which can be view as a positive result. Total methane emission and total farm milk production were equal to mitigation 4 scenario. Field N_2O emissions and NH_3 emissions from fertilizers were only marginally reduced (Table 2). "On farm" GHG emissions per kg of milk produced were 0.506 kg CO_2 eq/kg milk.

4.3.2 Conclusion

Simulation of South Brazilian (Campos) small family farms with FarmAC gave good results regarding GHG balance even if different processes as soil emissions in sub-tropical area, incorporation of residual material or no-tillage systems will have to be better estimated. Two different families of mitigation options were simulated: first, mitigation options that consist in improving soil conservation and nutrient use in the system (cover crop, reduced fertilization rate and rotation of the crop). Such mitigation options result in direct reduction of GHG emissions (however not higher than 5% reduction) in the farm system, mostly through reducing N leaching and increasing soil C sequestration. Secondly, mitigation options that consist in improving pasture and grazing management and so milk production per ha (increase of 40%). Such mitigation option increased direct emissions such as enteric CH_4 emissions and soil N_2O emissions (increase of nearly 35%), but these increases are partially balanced by higher soil C sequestration (up to 5 times more C sequestration, due to higher plant residues) and reduced N emissions from fertilizers application and leaching (up to 75% reduction). At the end, combining the different mitigation options resulted in an increase of 14% of total "on farm" GHG emission but a reduction of 19% in production efficiency (kg CO_2 eq emission per kg milk produced).

Table 2: Results per ha of the main output variables of the model.

Item	Unit	Baseline	Mitigation 1	Mitigation 2	Mitigation 3	Mitigation 4	Mitigation 5
Farm							
Imported livestock feed	kgN/ha/yr	146.82	146.27	146.52	167.45	151.39	151.54
Imported bedding	kgN/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N fixation	kgN/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N deposited from atmosphe	kgN/ha/yr	22.06	22.06	22.06	22.03	22.06	22.03
N in fertiliser	kgN/ha/yr	129.50	129.50	92.00	93.50	92.86	82.86
Imported manure	kgN/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N sold in crop products	kgN/ha/yr	0.34	1.13	0.34	0.14	1.55	2.33
N sold in milk	kgN/ha/yr	94.40	94.40	94.40	107.78	132.42	132.42
N exported in meat	kgN/ha/yr	0.66	0.66	0.66	0.75	0.85	0.85
N in mortalities	kgN/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
Exported manure	kgN/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
Gaseous loss housing	kgN/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N lost from processing/store	kgN/ha/yr	6.55	6.79	6.60	7.58	4.26	4.23
Gaseous loss storage	kgN/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
Runoff	kgN/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
Gaseous loss field	kgN/ha/yr	73.04	75.07	64.70	67.29	81.86	78.77
Nitrate leaching	kgN/ha/yr	112.94	99.77	74.72	77.12	15.10	16.21
Change in mineral N in soil	kgN/ha/yr	1.09	1.99	1.65	1.81	0.30	0.67
Change in organic N in soil	kgN/ha/yr	10.14	18.79	18.35	20.96	54.76	54.40
Herd							
Livestock feed consumed in	kgN/ha/yr	183.67	183.67	183.67	209.91	174.39	174.39
Grazed	kgN/ha/yr	80.09	80.09	80.09	91.10	246.95	246.95
Deposited in housing	kgN/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
Deposited in field	kgN/ha/yr	168.70	168.70	168.70	192.48	288.07	288.07
N sold in milk	kgN/ha/yr	94.40	94.40	94.40	107.78	132.42	132.42
N exported in meat	kgN/ha/yr	0.66	0.66	0.66	0.75	0.85	0.85
N in mortalities	kgN/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
Efficiency of N use by livest	-	0.36	0.36	0.36	0.36	0.32	0.32
Fields							
N fixation	kgN/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N deposited from atmosphe	kgN/ha/yr	22.06	22.06	22.06	22.03	22.06	22.03
N in fertiliser	kgN/ha/yr	129.50	129.50	92.00	93.50	92.86	82.86
Manure applied	kgN/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
Gaseous loss fields	kgN/ha/yr	73.04	75.07	64.70	67.29	81.86	78.77
Nitrate leaching	kgN/ha/yr	112.94	99.77	74.72	77.12	15.10	16.21
Harvested mechanically	kgN/ha/yr	43.74	45.31	44.09	50.17	28.81	29.41
Harvested by grazing	kgN/ha/yr	80.09	80.09	80.09	91.10	246.95	246.95
Change in mineral N in soil	kgN/ha/yr	1.09	1.99	1.65	1.81	0.30	0.67
Change in organic N in soil	kgN/ha/yr	10.14	18.79	18.35	20.96	54.76	54.40

Table 2 continued.

Item	Unit	Baseline	Mitigation 1	Mitigation 2	Mitigation 3	Mitigation 4	Mitigation 5
C Balance							
C fixed from atmosphere	kg C/ha/yr	10782.78	11670.68	11577.09	12083.83	15359.54	15181.97
C in imported manure	kg C/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
C in imported feed	kg C/ha/yr	2065.06	2041.96	2052.57	2341.57	2119.70	2125.90
C in bedding	kg C/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
C in exported milk	kg C/ha/yr	848.96	848.96	848.96	969.24	1190.83	1190.83
C in exported meat	kg C/ha/yr	5.80	5.80	5.80	6.63	7.46	7.46
C in mortalities	kg C/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
C in crop products sold	kg C/ha/yr	5.92	39.31	5.92	2.37	23.68	35.52
C in CO2 emitted by the soil	kg C/ha/yr	8944.84	9681.92	9644.57	9877.11	12389.50	12393.67
C in organic matter leached	kg C/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
CO-C from burning crop res	kg C/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
CO2-C in gases from burnin	kg C/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
Black carbon in gases from	kg C/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
Change in C stored in the sc	kg C/ha/yr	118.07	202.46	197.97	223.49	592.86	584.95
Net C balance (should be al	kg C/ha/yr	0.00	0.00	0.00	0.00	-415.23	-593.60
N Balance							
N in imported manure	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N fixation	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N deposited from atmosphe	kg N/ha/yr	22.06	22.06	22.06	22.03	22.06	22.03
N in fertiliser	kg N/ha/yr	129.50	129.50	92.00	93.50	92.86	82.86
N in bedding	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N in imported crop products	kg N/ha/yr	146.82	146.27	146.52	167.45	151.39	151.54
N lost from processing/store	kg N/ha/yr	6.55	6.79	6.60	7.58	4.26	4.23
N sold in crop products	kg N/ha/yr	0.34	1.13	0.34	0.14	1.55	2.33
N sold in milk	kg N/ha/yr	94.40	94.40	94.40	107.78	132.42	132.42
N exported in meat	kg N/ha/yr	0.66	0.66	0.66	0.75	0.85	0.85
N in mortalities	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N in exported manure	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
Total amount of N exported	kg N/ha/yr	95.41	96.20	95.41	108.67	134.82	135.60
N lost in NH3 emission from	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N lost in N2 emission from n	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N lost in N2O emission from	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N lost in NH3 emission from	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N lost in runoff from manure	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
Emission of N2 from the fiel	kg N/ha/yr	33.13	34.65	32.78	34.10	42.01	41.27
Emission of N2O from the fi	kg N/ha/yr	11.04	11.55	10.93	11.37	14.00	13.76
N lost via NH3 emission fror	kg N/ha/yr	23.46	23.46	15.58	15.64	15.61	13.51
N lost as NH3 from field-app	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N lost in NH3 emission from	kg N/ha/yr	5.42	5.42	5.42	6.18	10.22	10.22
N lost via NO3 leaching fron	kg N/ha/yr	112.94	99.77	74.72	77.12	15.10	16.21
N lost via leaching of organi	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N2O in gases from burning (	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
NH3 in gases from burning (	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
NOx in gases from burning (	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N in other gases from burnir	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 continued.

Item	Unit	Baseline	Mitigation 1	Mitigation 2	Mitigation 3	Mitigation 4	Mitigation 5
Change in N stored in soil	kg N/ha/yr	10.14	18.79	18.35	20.96	54.76	54.40
Change in N stored in miner	kg N/ha/yr	1.09	1.99	1.65	1.81	0.30	0.67
N surplus	kg N/ha/yr	202.97	201.64	165.18	174.31	131.48	120.82
N excreted in housing	kg N/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
N excreted in field	kg N/ha/yr	168.70	168.70	168.70	192.48	288.07	288.07
N in grazed feed	kg N/ha/yr	80.09	80.09	80.09	91.10	246.95	246.95
DM in grazed feed	kg N/ha/yr	3650.00	3650.00	3650.00	4171.43	9907.14	9907.14
N fed in housing	kg N/ha/yr	183.67	183.67	183.67	209.91	174.39	174.39
Total N losses from product	kg N/ha/yr	6.55	6.79	6.60	7.58	4.26	4.23
Total N losses from fields	kg N/ha/yr	192.54	181.62	146.03	151.99	101.21	99.21
Change in N stored in orgar	kg N/ha/yr	11.23	20.78	19.99	22.77	55.06	55.07
N balance (should be about	kg N/ha/yr	-0.79	-0.76	-0.84	-0.45	-24.78	-33.46
FarmDirectGHG							
Enteric methane emissions	kg CO2 eq/ha/yr	5353.79	5353.79	5353.79	6118.62	7648.27	7648.27
Manure methane emissions	kg CO2 eq/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
Manure N2O emissions	kg CO2 eq/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
Field N2O emissions	kg CO2 eq/ha/yr	5171.31	5408.40	5116.56	5323.61	6558.29	6442.92
Change in C stored in soil	kg CO2 eq/ha/yr	-432.98	-742.40	-725.96	-819.54	-2174.03	-2145.00
Total GHG emissions	kg CO2 eq/ha/yr	10092.12	10019.79	9744.39	10622.70	12032.53	11946.20
FarmIndirectGHG							
Housing NH3 emissions	kg CO2 eq/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
Manure storage NH3 emissi	kg CO2 eq/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
NH3 emissions from field-ap	kg CO2 eq/ha/yr	0.00	0.00	0.00	0.00	0.00	0.00
NH3 emissions from fertilise	kg CO2 eq/ha/yr	109.84	109.84	72.96	73.24	73.12	63.29
N2O emissions resulting fro	kg CO2 eq/ha/yr	396.68	350.41	262.44	270.85	53.02	56.94
Total indirect emissions	kg CO2 eq/ha/yr	506.52	460.25	335.40	344.10	126.14	120.22
Indicators							
Total farm milk production	kg/yr	237707.5	237707.5	237707.5	271386.2	333432.0	333432.0
Total farm meat production	T liveweight/yr	0.35	0.35	0.35	0.40	0.45	0.45
Farm milk production per he	kg/yr	6791.64	6791.64	6791.64	6784.65	7409.60	7409.60
Milk production per unit area	kg/ha/yr	16979.10	16979.10	16979.10	19384.73	23816.57	23816.57
Meat production per unit are	kg/yr	0.03	0.03	0.03	0.03	0.03	0.03
LivestockDMintake	kg DM/yr	166.08	166.08	166.08	189.80	237.25	237.25
farmConcentrateDM	tonnes DM/yr	0.00	0.00	0.00	0.00	0.00	0.00
farmGrazedDM	tonnes/yr	51.10	51.10	51.10	58.40	138.70	138.70
farmUnutilisedGrazableDM	tonnes DM/yr	17.94	25.33	25.30	18.56	0.49	0.18
farmUnutilisedGrazableDMF	Percent	25.99	33.14	33.11	24.11	0.36	0.13
farmDMproduction	tonnes DM/yr	184.78	200.34	198.62	207.96	258.66	256.53
farmUtilisedDM	tonnes/yr	110.35	112.48	110.82	126.68	177.29	177.46
FarmHarvestedDM	tonnes/yr	110347.3	112476.0	110818.0	126684.7	177291.5	177457.8
roughageDMimported	tonnes/yr	0.00	0.00	0.00	0.00	0.00	0.00
roughageDMExported	tonnes/yr	0.00	0.00	0.00	0.00	0.00	0.00

4.3 Semi-arid mixed livestock farming

4.3.1 General description

This model is a typical **mixed millet-groundnut-beef cattle system** of the groundnut Bassin of Senegal. Its position is assumed to be 14°35'28,20"N -16°30'25.27"O. The Groundnut Basin is located in the Sudano-Sahelian zone of Senegal with an average precipitation of 600 mm per year which falls exclusively during the months of June through October (ANSD, 2011). The area is densely populated (*i.e.* 200 people.km-2) and has doubled in the past 40 years (Delaunay *et al.*, 2013). Due to population pressure soil fertility problems appeared and intensification stays a major stake. Dior (local name) is the dominant soil type of the area (Khouma, 2000) and is classified as part of the oxic subgroups of Alfisols (USDA system) or also known to be part of the tropical ferruginous soils, weakly leached according to the French soil classification system (Jalloh *et al.*, 2011). They are inherently low in OM content. The main staple crop is millet and groundnut as a cash crop. Cattle (Zebu Gobra breed) is traditionally the main livestock activity. Although cropping practices are similar throughout the farms, the main animal husbandry practices for cattle differ depending farming systems. The traditional agro-pastoral system of the region is based on a bundle of practices that ensured access to various fodder ressources throughout the year. Livestock are given access to crop residues and to grass (fallow fields) that are essential to the functioning of this system (Lericollais and Faye, 1994). Demographic and climatic pressures among others have driven farmers to adopt livestock fattening (Pélissier, 1966; Lericollais and Milleville, 1993; Lericollais and Faye, 1994). Animals are kept in stall and fed rations made up agro-industrial residues, concentrates and on-farm crop residues and by consequence the fallow is no longer in practice (Lericollais and Faye, 1994; Sow *et al.*, 2004).

4.3.3 The two systems compared

With the objective **to evaluate if intensification in a mitigation option**, two typical farms were compared on the basis of FarmAc simulations. The farms simulated are simplified systems that correspond to observed systems encountered in the Groundnut Basin (Audouin, 2013; Odru, 2013): a Traditional farm (farm1) and an Intensive farm (Farm 2). Farm 2 can be considered as the farm with mitigation options: i) Increasing housing (grass constant) and ii) Improving roughage quality (more groundnut hay and feed concentrate in the feed ration).

As indicated in table 2, to faciliate comparison, herd composition was the same on all farms: ten tropical livestock units (TLU) of Zebu Gobra. The field area was five hectares which corresponds to a livestock stocking rate of 2 TLU/ha (1 TLU = 250 kg live weight). We considered two types of fields in all farms. The hut field was under continuous cultivation of millet is located in the immediate vicinity of the habitations/compound. The more distant bush fields were under different rotation patterns depending on the farm (Table 1).

Table 1. The main characteristics of the two farms simulated

	Traditional (Farm 1)	Intensive (Farm 2)
Livestock housing	Wandering	Stable (bare soil)
Feed ration	Grazing fallow/crop residues on crop fields (no concentrate feed)	Trough/stall feeding Forage/roughage Concentrate feed
Manure management	(no manure collection and storage)	Manure Heap
Soil-Crop fertilization	Direct deposition during grazing and, Night park/penning	Broadcast (burnt residues)
Crop rotation	Millet-groundnut-fallow (3 years)	Millet-groundnut (2 years)

Table 2. Structure and main inputs of the two simulated farms

		Units	Farm 1	Farm 2
Farm structure	Millet hut field	ha	1	1
	Millet bush field	ha	1.33	2
	Groundnut	ha	1.33	2
	Fallow	ha	1.33	0
	Calves	heads	2	2
	Young bulls	heads	2	2
	Heifers	heads	2	2
	Suckler cows	heads	3	3
	Bull	heads	1	1
	Stocking rate	$TLU.ha^{-1}$	2	2
Farm inputs	Crop residues	$kgN.year^{-1}$	0	1.4
	Concentrate feeds	$kgN.year^{-1}$	16.8	190.1
	Mineral fertilizer [b]	$kgDN.year^{-1}$	0	0

On **Farm 1**, there was no animal housing. The animals were kept on the fallow field during the rainy season and on the crop fields after the harvest to graze on residues. Faeces and urine are deposited directly onto the fields. It was a three years rotation of millet, groundnut and fallow grass.

On **Farm 2**, animals were kept in rudimentary housing structures on bare soil and were fed by trough a mixture of imported by-products, concentrate feeds and farm crop residues. Manure was collected and pilled up a heap until it was broadcasted in the fields prior to millet cultivation. A typical millet-groundnut rotation was conducted on the bush fields that had been previously been cleared of residues by fire.

4.3.3 Results

Table 3 presents the GHG balance resulting from the simulations of the two farms. Methane from enteric fermentation is the largest source of GHG emissions in all two farms ranging accounting for 50 to 85 % of total GHG emissions (kg eq. CO_2.year-1). On Farm 1, nitrous oxide emissions from fileds were the second highest source of emissions (16% of total GHG emissions). There are no emissions from housing and manure management on Farm 1 because manure is directly deposited on fields. However nitrous oxide emissions from manure management were the second highest source of emissions on Farm 2 (27% of total GHG emissions). Indirect emissions is significantly increased for the intensive system (8% of total GHG emissions). It mainly corresponds to NH3 volatilization.

Table 3. GHG balance of the two simulated farms

		Unit	Farm 1	Farm 2
Direct GHG emissions	Enteric methane emissions	kg eq. CO_2.year^{-1}	14103	13007
	Manure methane emissions	kg eq. CO_2.year^{-1}	0	1791
	Manure N_2O emissions	kg eq. CO_2.year^{-1}	0	7000
	Field N_2O emissions	kg eq. CO_2.year^{-1}	2661	1863
	Change in C stored in soil	kg eq. CO_2.year^{-1}	-318	99
Indirect GHG emissions	Housing NH_3 emissions	kg eq. CO_2.year^{-1}	0	493
	Manure storage NH_3 emissions	kg eq. CO_2.year^{-1}	0	1701
	NH_3 emissions from field-applied manure	kg eq. CO_2.year^{-1}	0	4
	NH_3 emissions from fertilizers	kg eq. CO_2.year^{-1}	0	0
	N_2O emissions resulting from leaching of N	kg eq. CO_2.year^{-1}	99	3
Production	Meat	Tons LW.year^{-1}	0.99	4.89
GHG balance	Total GHG/ha	kg eq. CO_2.ha^{-1}	3309	5192
	Total GHG/kg meat	kg eq. CO_2.kg LW^{-1}	16.64	5.31

In table 3, the GHG emission balances are presented according to two different functional units: per unit of production area (ha) and per unit of live weight animal product (kg LW). The farm area is the same on all two farms. Considering emissions on the basis of unit area, emissions are increased by 57% in the intensive system (Farm 2) with reference to the traditional system (Farm 1). However considering emissions on the basis of animal production, total GHG emissions are decreased by 68% in the intensive farms; *i.e.* emissions per animal product are cut by 3, where animal productivity is increased by 5.

4.4. Semi-arid grass land based livestock farming

4.4.1 General description

The farm selected for this study is located in the arid region of South Africa with very low rainfall (Semi-arid grass land based livestock farming, Kalahari region, South Africa). Therefore neither agronomic crops nor planted pasture are grown. The animals feed on natural grasses, forbs, and shrubs. The farmer has adopted a four paddock grazing system and the model simulation (C and N balance) was conducted only for a third of the total farm, which is available for grazing by the animals during a specific period. The selected mitigation measure was the addition of leaks with ammonium or nitrate as sources of N (additives) (650 g per head).

The model grassland based livestock farming is typical commercial farm representing farms around the dry Kalahari region of South Africa. The farm was a 9147 ha rangeland beef system located in a sandy soil, which is typical soil in the Kalahari region. Long-term annual mean precipitation of the area is 250 – 300 mm and the mean annual temperature is about 24 ^{o}C. The area is dry and consequently it has low carrying capacity of 13 LU per hectare.

The herd used for this study consisted of 345 beef bred cows, 210 calves, 10 weaner, 24 heifers (1-3 heifers), and 12 bulls of Bonsmara breed. The mean daily weight gain by bulls and beef heifers was 0.9 kg. Overall the quantity of live weight produced per ha was 142 kg.

The livestock farming system was free grazing and no synthetic fertilizer was applied. The field had multispecies grasses, forbs, shrubs, and trees. Some of the shrubs and trees were legumes. Leaves from trees located below 1.5 m were considered available for consumption by livestock. Organic nitrogen was mainly excreted by cattle on grass in situ throughout the year.

The simulation of the herd in FarmAC was firstly divided into five animal herds: calves (<12 months old), heifers (1-2 years old), weaner, heifers (> 2 years), and bulls (>2 years). The baseline scenario of Table 4.2.4.1 summarizes the key input data used to run FarmAC model.

4.4.2 Mitigation options

As described, the mitigation options tested in this study were including additives to the food ration of the animals under baseline The additive were a) a mixture of 10% molasses + 40% salt + 24% Bran + 5% cotton oilcake + 6% NH_4PO_4 + 1% $CaPO_4$+ 6.5% lime (650 g per head) only during winter **(M1)**, b) . a mixture of 10% molasses + 40% salt + 24% Bran + 6% $CaNO_3$ + 5% cotton oilcake + 1% $CaPO_4$+ 6.5% lime (650 g per head) only during winter **(M2)**, c) similar additive as “b” but given to the animals throughout the year **(M3)**, d) similar additive as “c” but given to the animals throughout the year **(M4)**.

4.4.3 Results

Table 4.4.3.1 shows the results from FarmAC. Baseline Carbon and N balance are shown in Annex 1.

Table 4.4.3.1. Key farm data used to model the extensive livestock production system in Kalahari South Africa and two mitigation options using FarmAc.

Item		**Baseline**	**M1**	**M2**	**M3**	**M4**
Farm size (ha)		3800	3800	3800	3800	3800
Number of animals	Bulls (> 2 years	12	12	12	12	12
	Heifers (>2 years)	355	355	355	355	355
	Heifers (1-2 years)	14	14	14	14	14
	Weaner	10	10	10	10	10
	Calves (<12 months)	210	210	210	210	210
Livestock units (LU)	Bulls (> 2 years	10	10	10	10	10
	Heifers (>2 years)	291	291	291	291	291
	Heifers (1-2 years)	12	12	12	12	12
	Weaner	8	8	8	8	8
	Calves (<12 months)	172	172	172	172	172
Total farm meat production (tonnes live weight per year)		142.9	143.9	143.9	144.3	144.3
GHG (ton CO_2 equivalents/yr)		3983	4026	4009	4099	4049
GHG emission per unit meat produced (kg/kg)		27.9	28.0	27.9	28.4	28.1
Net C sequestration (ton C/yr)		64.5	66.0	66.0	67.4	67.5
Net N sequestration (ton C/yr)		8.34	8.99	9.04	10.39	10.63

It was apparent that annual meat production increased with the introduction of feed additives. The replacement of ammonium based by nitrate based N source feed additives did not result in annual meat production differences both when additive was introduced only during winter and throughout the year. Annual live weight gain by animals fed with additives throughout the year was higher than those fed only during winter. Nonetheless, the provision of both ammonium and nitrate based additives resulted in an increase in farm scale greenhouse gas emission. Greenhouse gas emission from nitrate based additives was lower than ammonium based despite the similarity in the total amount of N applied. Farm scale greenhouse gas emission per unit meat produced was slightly higher for animals fed with ammonium based N additives throughout the year. Nonetheless, farm scale greenhouse gas emission per unit meat produced remained more or less similar between baseline and mitigation measures. Greenhouse gas emission values from this study were slightly higher than reported values from organic beef production in Sweden (22.3 kg of CO_2 equivalent GHG emission per kg beef) (Koneswaran and Nierenberg, 2008) but lower than the resource intensive Kobe beef production in Japan (36.4 kg of CO_2 equivalent GHG emission per kg beef) (Cederberg and Stadig, 2003; Ogino *et al.*, 2007).

Model simulations using FarmAC also showed that the inclusion of nitrogen based additives increased net carbon and nitrogen storage in the soil. Computer model simulations also showed that inclusion of additives in the diet of the animals throughout the year resulted in relatively higher carbon and nitrogen storage in the soil. The positive net carbon and nitrogen sequestration observed was expected considering the presence of inedible trees and shrubs contributing to the soil carbon. In addition, the mass balance used in this simulation represents only a third of the farm while the other third was left to rest (no grazing) and the other third used for goats and sheep. Therefore this farm system, which represents most of the extensive commercial farm systems in the area have a net positive carbon sequestration.

4.4.4 Conclusions mitigation options

Extensive beef production system in the Kalahari region of South Africa is characterised by low carrying capacity due to low rainfall and net positive soil carbon sequestration due to the presence of shrubs and trees, which contribute to the soil carbon. Model simulation results using FarmAC model showed that the addition of additives can improve beef production as well as carbon sequestration. The addition of ammonium and nitrate based additives resulted in a slight increase of greenhouse gas emission. The amount of greenhouse gas emitted per unit weight of meat produced, however, remained similar.

5. Conclusions mitigation options

The results of the FarmAC simulations are in accordance with results reported in literature, and the simulated results for both Africa and Brazil may therefore be considered to reflect the best estimates of mitigation at farm scale.

Values FarmAC parameters were not always available. Therefore the simulated results presented in this study should be interpreted with some caution, and further studies would be needed to validate the results.

Implementation of mitigation measures is site specific. In this study it was not possible to evaluate if the used implementation was the best option.

Simulations of the Amazonian farms after deforestation with FarmAC indicate that all the mitigation options tested were effective in reducing emission intensities. Intensities rank Baseline > Agroforestry > Improved pasture management > Crop-Livestock > Improved pasture management and N application. The rank reflects the area covered by agroforestry as only 20 ha and 98 ha out of 488 ha were covered by trees and soybean, respectively.
Emissions per unit of area were similar to baseline within a ± 10% range, indicating sustainable intensification will reduce emission intensities, but may not reduce emissions per unit of area. Soil carbon was a major component of the mitigation for the mitigation options tested, usually accounting for over 50% of the emissions, except for the mitigation option where nitrogen was added. Recovering or improving pasture productivity in the whole area would be more effective than using crop rotation or agroforestry in a small proportion of the area and that nitrogen input would be essential for long-term sustainability of those systems, allowing for higher soil carbon stocks than baseline levels.

Simulation of South Brazilian (Campos) small family farms with FarmAC gave good results regarding GHG balance even if different processes as soil emissions in sub-tropical area, incorporation of residual material or no-tillage systems will have to be better estimated.
Mitigation options that consist in improving soil conservation and nutrient use in the system (cover crop, reduced fertilization rate and rotation of the crop) result in direct reduction of GHG emissions (however not higher than 5% reduction) in the farm system, mostly through reducing N leaching and increasing soil C sequestration. Mitigation options that consist in improving pasture and grazing management and so milk production per ha (increase of 40%) increased direct emissions such as enteric CH_4 emissions and soil N_2O emissions (increase of nearly 35%), but these increases are partially balanced by higher soil C sequestration (up to 5 times more C sequestration, due to higher plant residues) and reduced N emissions from fertilizers application and leaching (up to 75% reduction). At the end, combining the different mitigation options resulted in an increase of 14% of total “on farm” GHG emission but a reduction of 19% in emission intensity (kg CO_2 eq emission per kg milk produced).

For the semi-arid beef cattle farm in Senegal measures were included to improve livestock productivity by using feed additives. Considering emissions on the basis of unit area, emissions are increased by 57% in the intensive system with reference to the traditional system. However, considering emissions on the basis of animal production, total GHG emissions are decreased by 68% in the intensive farms.

Regarding the cattle farm in the Kalahari region of South Africa model simulation results using FarmAC showed that the addition of additives can improve beef production as well as carbon sequestration.

Regarding the Kalahari region of South Africa model simulation results using FarmAC showed that the addition of ammonium and nitrate based additives resulted in a slight increase of greenhouse gas emission. The amount of greenhouse gas emitted per unit weight of meat produced, however, remained similar.

In general can be concluded that intensification of African farming systems increases GHG emission per unit of area but on the other hand GHG emission per unit of animal product is reduced and animal productivity is increased.

Levels of changes in GHG emissions are site specific and depending on mitigation measure or combination of mitigation measures.

Results indicate that there is high potential for reducing GHG emissions in Africa through improving livestock productivity, whereas the potential for reducing GHG emissions in Latin America is less, although there seems to be scope for enhancing soil carbon storage in grasslands.

6. Adaptation

6.1 Introduction

AnimalChange intended to use existing models to analyse adaptation measures. The existing models, however, didn't fit this purpose and therefore FarmAC was developed within the project. FarmAC has been producing good results from January 2015 onwards. Since this was only two months before the end of the project, it was not possible to analyse the adaptation measures with FarmAC and another methodology was used: semi quantitative modelling. This report describes the results for the non-European study regions of AnimalChange.

In the previous chapters of this report mitigation was discussed. Whereas mitigation is focussing on reducing GHG emissions to reduce further climate change, adaptation on the other hand is focussing on dealing with the already occurring or expected climate change. Measures focussing on mitigation are in most cases not related to measures focussing on adaptation except when they link to the production of feed for the cattle (Topp *et al.*, 2015).

Topp *et al.* (2015) described that the best adaptation measures of farming systems are different for each farming system. The best adaptation measures depend on the weather conditions at the farm, the perceived and actual risk of extreme events, the precise nature of the farming system and the attitude of the farmer (Topp *et al.*, 2015).

For the European farms available for this research (Annex 2), local experts were asked to list the four best adaptation options for their farm. Furthermore the reason for choosing these options was monitored just as the implementation method of the measure on the farm and the expected impact of climate change on the farm. The factors affecting productivity of both the crop and the dairy cow were considered according to Topp *et al.* (2015) (Table 6.1). From this information, a matrix was set up that provides insight into the relations between the different factors that affect the selection of the best adaptation option.

Table 6.1. Impact categories assessed for dairy production systems

Category	Impacts
Crop	Thermal growing season
	Drought
	Heat stress
	Water logging
Livestock	Heat stress
	Diseases
	Land accessibility

From Topp *et al.* (2015).

The local experts were researchers and advisors. Since no farmers were included as local expert, we were not able to include farmers' attitude in this study. The selection of best measures is based solely upon technical information from *e.g.* research.

In task 10.4 of AnimalChange a questionnaire was conducted among farmers from the study regions of AnimalChange. In the questionnaire livestock farmers' perception was taken into account. It would be interesting to combine the results of this questionnaire with the results of the current study. Furthermore, additional information is needed on the barriers to implement adaptation options (*e.g.* farming systems, farmers' profiles, and market, funding and information access). This would provide a further insight in adoption potentials of the different adaptation measures.

6.2 Analysis

Figure 6.1 shows the available farms from the non-European study regions within the project. These are both showcase farms and model farms. Annex 2 gives agro ecological zone, region, farm type and farm name from these farms. Farm typology (Annex 5) is used as defined in the AnimalChange project (Stienezen *et al*., 2012).

For 15 farms, there was a selection of the four best adaptation measures available (Annex 4). For 4 out of the 15 farms, additional information on expected impact from climate change (Annex 7) was available and for 8 out of the 15 farms additional information on implementation of the measures (Annex 6) was available. This information was combined in a matrix to get insight into the relations between the different factors that affect the selection of the best adaptation option. This matrix is too large to present in this report but will be available as part of the AnimalChange database.

In total fifteen different adaptation measures were identified by the local experts from the non-European study regions as best adaptation measures for their farms. These measures are listed in Table 6.2. The definition of the measures has been described in Deliverable 8.1 (van den Pol–van Dasselaar, 2012).

Figure 6.1. Farms, model farms and showcase farms, available in AnimalChange in Africa and Latin America. Source: http://www.animalchange.eu/model_showcase_farms.php

Table 6.2. Adaptation measures chosen as best option for selection of farms in AnimalChange for Africa and Latin America

1	Fertilisation rate
2	Water management (irrigation and drainage)
3	Use of mixtures of plant species
4	Feed storage
5	Animal breeding (local breeds)
6	Animal breeding (change breeds)
7	Supplemental feeding
8	Shifts in livestock systems
9	Livestock mobility
10	Use of plants more resistant to drought, flooding, pests and diseases
11	Rotational grazing
12	Improve livestock management
13	Change the grazing management
14	Clean the pasture from unwanted species
15	Restoring degraded lands

The adaptation measures selected by local experts were selected because the measures were expected to increase animal and plant production or to be the best measures available for their specific farm situation to maintain plant and livestock productivity under the expected impact of climate change (Annex 6).

As for farm types in this study are very divers, farm types were clustered to be able to find trends (Annex 2). These new farm types are used in Table 6.3.

The adaptation measures

- “Fertilisation rate”,
- the two measures on “Animal breeding”,
- “Use of mixtures of plant species”,
- “Supplemental feeding” and
- “Shifts in livestock system”

were appointed for respectively 7, 6 (3 plus 3), 4, 4 and 4 farm types out of the 8, to be one of the four best adaptation measures (Table 6.3).

The farm types “Small holder farming”, “Beef grassland based extensive”, “Dairy integrated cropping and livestock farming” and “Beef integrated cropping and livestock farming” are represented by respectively 4, 2, 2 and 3 farms in the database. The remaining farm types are represented by one farm in the database. In “Small holder farming” and “Beef grassland based extensive” the local experts, from the respectively 4 and 2 farms, selected different adaptation measures to be the best option for their farm. Therefore more than four adaptation measures are listed (Table 6.3.).

“Livestock mobility” is chosen by all local experts from “Small holder farming”. These farms are all located in Africa.

The local experts from the three farms from “Beef integrated cropping and livestock farming” all chose the same four adaptation measures to be the best. The farms originated from the *Cerrado* region.

The local experts from the two farms from “Dairy integrated cropping and livestock farming” both chose the same four adaptation measures to be the best. The farms originated from the Campos region.

Table 6.3 confirms the conclusion of Top *et al.* (2015) that the best adaptation measures are dependent on the farming system. However, it is shown that not only the selection of best adaptation measures can differ between farm types (Table 6.3). The farm implementation can also differ. An example is shown in Table 6.4. The on farm implementation of “Fertilisation rate” is for example different for farm type “Small holder farming” and “Beef integrated cropping and livestock farming” (Table 6.4).

And even within a farm type, the implementation can be different. There may even be implementation differences between farms of the same farm type within one region as a result of site differences. The on farm implementation of “Use of plants more resistant to drought, flooding, pests and diseases” and “Rotational grazing” is for example different for farm type “Beef integrated cropping and livestock farming” (Table 6.5).

Due to the limited number of farms in the database and available data on the impact from climate change it was not possible to show impact from climate change upon adaptation measures.

Taking into account the fact that the implementation of adaptation is site specific we can conclude that the sets of adaptation measures and ways of implementing are a good advice for the specific farms represented by the farms in this report.

6.3 Conclusions

The adaptation measures selected by local experts were selected because the measures were expected to increase animal and plant production or to be the best measures available for their specific farm situation to maintain plant and livestock productivity under the expected impact of climate change. Adaptation measures are often presented as generic measures. On farm implementation is, however, site specific. This should be taken into account when suggesting a specific adaptation measure.

The adaptation measures

- “Fertilisation rate” and
- “Animal breeding (change of breeds and local breeds)”,

were found to be suitable adaptation measures for most farm types.

Table 6.3. Adaptation measures selected as best options for different farm types*

Adaptation measure	Nr of farm types: Number of farm types adaptation measure is selected as being one of the four best options	Farm type: Small holder farming	Beef grassland based extensive	Beef integrated cropping and livestock farming	Dairy integrated cropping and livestock farming	Beef integrated cropping, agroforestry and livestock farming	Dairy grassland based	Beef grassland based	Industrial beef
1. Fertilisation rate	7	x	x	x	x	x		x	x
2. Water management (irrigation and drainage)	1				x				
3. Use of mixtures of plant species	4	x				x	x	x	
4. Feed storage	1								x
5. Animal breeding (local breeds)	3	x	x	x					x
6. Animal breeding (change breeds)	3	x					x	x	
7. Supplemental feeding	4		x		x		x		x
8. Shifts in livestock systems	4	x			x		x	x	
9. Livestock mobility	1	x							
10. Use of plants more resistant to drought, flooding, pests and diseases	3	x	x	x					
11. Rotational grazing	3		x	x		x			
12. Improve livestock management	1					x			
13. Change the grazing management	1		x						
14. Clean the pasture from unwanted species	1		x						
15. Restoring degraded lands	1		x						

*Farm types used in this table are from combining farm types from Annex 5.

Table 6.4. Reason for selection and implementation method of the adaptation measures “Fertilisation rate” for farm type “Beef grassland based extensive” and “Small holder farming”

Farm type	**Why chosen?**	**How implemented on farm?**
Beef grassland based extensive	A pasture fertilization strategy could use 2 MT of lime, 1 MT of simple superphosfate and 120 kg of urea per hectare/year.	25 hectares of pasture per year should be renovated.
Small holder farming	Fertilizer it is utilized in crops besides manure to increase crop productivity in a mixed crop-livestock systems where animals are also fed in crop residues.	Mineral fertilization: Contribution only on maize (30 kg N / ha) and manure management (night park Rotation on corn cropping land every 4 months)

Table 6.5. Reason for selection and implementation method of the adaptation measures “Use of plants more resistant to drought, flooding, pests and diseases” and “Rotational grazing” for farm type “Beef integrated cropping and livestock farming” from two sites from the Cerrado region.

Site	Adaptation ID	Why measure chosen	How measure implemented
Sertaneja farm (S-LA-003) Temporary grass-sugarcane-maize-eucalyptus-beef system	10	Most of the planted pasture areas in the Sertanejo farm presented low yields in 2013 and once that beef price is higher than two years ago the farmer should invest in soil fertilization and new available species of pasture.	By using the cropping practice with maize and pasture planted in one planting operation. After the harvest of maize for the dry feed the farmer will have a new pasture.
	11	Sertanejo farm has incorporated many paddocks and by monitoring and evaluations of their yields, the establishment of animal stocks can be improved.	New pasture species such as Minerão Stilozants, with better drought tolerance, should be introduced to supply forage in the dry season.
Calcare Farm (S-LA-004) Grain-grassland based beef system	10	Double crop systems should adopt rotations using plants more drought tolerant in the second rainy season crop. Moreover, Brachiaria seeds should be planted with a second cereal crop to optimize the farm income and the carbon sequestration.	The Brachiaria harvest, in the dry season, should be carried by grazing of crossbred (bos Indicus and bos taurus) animals.
	11	The rotational grazing should be optimized.	Electric fences should be used.

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Annex 1. Additional information farm S-AF-002

Baseline greenhouse gas emissions farm S-AF-002

Parameter	C (kg yr^{-1})
Enteric methane emissions	947686.5
Field N2O emissions	3271333
Change in C stored in soil	-236467
Total GHG emissions	3982553

Baseline carbon balance farm S-AF-002

Parameter	C (kg yr^{-1})
C fixed from atmosphere	8247846
C in exported meat	33159.58
C in crop products sold	352315.2
C in enteric methane emissions	28459.05
C in CO2 emitted by livestock	365938.4
C in CO2 emitted by the soil	7403489
Change in C stored in the soil	64485
C lost to the environment	7797886

Baseline N balance farm S-AF-002

Parameter	N (kg/yr)
N fixation	4280
N deposited from atmosphere	37989
N exported in meat	3716
N sold in crop products	1006
Total amount of N exported	4722
N lost in NH3 emission from urine deposited in field	1221.288
Emission of N2 from the field	20956.65
Emission of N2O from the field	6985.55
Change in N stored in soil	5449.078
Change in N stored in mineral form in soil	2953.745
Total N losses from fields	29163.49
Change in N stored in organic and mineral form in soil	8402.823
N surplus	37547.81

Annex 2. Farms initially identified for use in FarmAC

Agro-Ecological Zone	Region	Farm type	Farm	Farm ID
Semi-Arid	Senegal-Peanut bassin	Semi-arid Mixed Peanut-milet-livestock system	Model farm	**M-AF-001**
Semi-Arid	Senegal-Peanut bassin	Semi-arid Mixed Peanut-milet-livestock system	Modou DIOUF	**S-AF-001**
Semi-Arid	Burkina Faso	Semi-arid Cotton/Maize crop livestock	Model farm	**M-AF-002**
Semi-Arid	South Africa-Kalahari	Semi-arid land based beef	Deon Hoon	**S-AF-002**
Sub-Humid	Burkina Faso	Sub-humid Crop-livestock and pastoral subhumid activities	Model farm	**M-AF-003**
Sub-Humid	Brazil-Cerrado	Sub-humid Extensive grassland based beef system	Cavalcante-GO Rui Farm	**S-LA-001**
Sub-Humid	Brazil-Cerrado	Sub-humid Grassland-sugarcane-beef system	Portal dos Bandeirantes Farm	**S-LA-002**
Sub-Humid	Brazil-Cerrado	Sub-humid Mixed temporary grass-sugarcane-maize-eucalyptus-beef system	Sertaneja Farm	**S-LA-003**
Sub-Humid	Brazil-Cerrado	Sub-humid Grain-grassland based beef system	Calcare Farm	**S-LA-004**
Sub-Humid	Brazil-Campos	Sub-humid Dairy cattle on sown pasture relatively intensive integrated systems	Granja Ortiz	**S-LA-008**
Sub-Humid	Brazil-Campos	Sub-humid Dairy cattle on sown pasture relatively intensive integrated systems	Model farm	**M-LA-003**
Sub-Humid / Humid	Kenya	Sub-humid / Humid Rainfed crop-livestock farming systems	Smallholder farming Lower Nyando, Kisumu	**S-AF-004**
Sub-Humid / Humid	Kenya	Sub-humid / Humid Rainfed crop-livestock farming systems	Smallholder farming Lower Nyando, Kisumu	**S-AF-005**
Humid	Brazil-Western (Roraima) Brasilian Amazon	Humid grassland based soya bean-trees-beef system	Farm with Agroforestry	**S-LA-005**
Sub-Humid / Humid	French Guiana	Sub-humid / Humid Grassland based beef semi intensive system	Hugues Bergères Farm	**S-LA-006**
Sub-Humid / Humid	French Guiana	Sub-humid / Humid Extensive grassland based beef system	Marjolaine Bergère Farm	**S-LA-007**
Sub-Humid / Humid	Brazil-Eastern (Belem) Brasilian Amazon	Sub-humid / Humid Dairy cattle on pasture	Model farm	**M-LA-006**
Sub-Humid / Humid	Brazil-Eastern (Belem) Brasilian Amazon	Sub-humid / Humid Beef cattle on pasture	Model farm	**M-LA-007**
Sub-Humid	Brazil-Cerrado	Industrial dairy	Model farm	**M-LA-001**
Sub-Humid	Brazil-Cerrado	Industrial beef (beef feedlots)	Fazenda Farroupilha - Monte Alegre-GO	**M-LA-002**

M = Model farm, S = Showcase farm (real farm), LA = Latin America, AF = Africa

Farms initially identified for use in FarmAC with new farm type description (only from farms with choice for best adaptation measures available)

Farm type	**Region**	**Farm description**	**Farm type new**	**Site**	**Code**
Semi-Arid	Senegal-Peanut bassin	Peanut-milet-livestock system	Small holder farming	Model farm	**M-AF-001**
Semi-Arid	Senegal-Peanut bassin	Peanut-milet-livestock system	Small holder farming	Modou DIOUF	**S-AF-001**
Semi-Arid	South Africa-Kalahari	Semi-arid Grassland based beef	Beef grassland based extensive	Deon Hoon	**S-AF-002**
Sub-Humid	Brazil-Cerrado	Extensive grassland based beef system	Beef grassland based extensive	Cavalcante-GO Rui Farm	**S-LA-001**
Sub-Humid	Brazil-Cerrado	Grassland-sugarcane-beef system	Beef integrated cropping and livestock farming	Portal dos Bandeirantes Farm	**S-LA-002**
Sub-Humid	Brazil-Cerrado	Temporary grass-sugarcane-maize-eucalyptus-beef system	Beef integrated cropping and livestock farming	Sertaneja Farm	**S-LA-003**
Sub-Humid	Brazil-Cerrado	Grain-grassland based beef system	Beef integrated cropping and livestock farming	Calcare Farm	**S-LA-004**
Sub-Humid	Brazil-Campos	Dairy cattle on sown pasture relatively intensive integrated system	Dairy integrated cropping and livestock farming	Granja Ortiz	**S-LA-008**
Sub-Humid	Brazil-Campos	Dairy cattle on sown pasture relatively intensive integrated system	Dairy integrated cropping and livestock farming	Model farm	**M-LA-003**
Sub-Humid / Humid	Kenya	Rainfed crop-livestock farming system	Small holder farming	Smallholder farming Lower Nyando, Kisumu	**S-AF-004**
Sub-Humid / Humid	Kenya	Rainfed crop-livestock farming system	Small holder farming	Smallholder farming Lower Nyando, Kisumu	**S-AF-005**
Humid	Brazil-Western (Roraima) Brasilian Amazon	Soya bean-trees-livestock system	Beef integrated cropping, agroforestry and livestock farming	Farm with Agroforestry	**S-LA-005**
Sub-Humid / Humid	Brazil-Eastern (Belem) Brasilian Amazon	Dairy cattle on pasture	Dairy grassland based	Model farm	**M-LA-006**
Sub-Humid / Humid	Brazil-Eastern (Belem) Brasilian Amazon	Beef cattle on pasture	Beef grassland based	Model farm	**M-LA-007**
Sub-Humid	Brazil-Cerrado	Industrial beef (beef feedlots)	Industrial beef	Fazenda Farroupilha - Monte	**M-LA-002**

M = Model farm, S = Showcase farm (real farm), LA = Latin America, AF = Africa

Annex 3. Five best mitigation options initially identified farms

Farm ID	Fertilisation rate	Legumes in the rotation	Cover crops	Irrigation	Restoring degraded lands	Improving pastures	Improving roughage quality	Feeding maize and less grass	Additive nitrate	Increasing housing (grass constant)	Replacemnt rate cattle	Cover slury stores & manure heaps	Anaerobic digestion	Agroforestry	Genetic improvement in dairy cattle	Change the grazing management	Clean the pasture from unwanted species	Integrate livestock and crop production	Fire Control
M-AF-001	-	3	-	-	-	-	4	-	-	1	-	5	-	-	-	-	-	-	**2**
S-AF-001[a]	-	3	-	-	-	-	4	-	-	1	-	5	-	-	-	-	-	-	2
M-AF-002	-	2	-	-	-	6	3	-	-	4	-	1	5	-	-	-	-	-	-
M-AF-003	-	3	-	-	-	5	1	-	-	2	-	4	6	-	-	-	-	-	-
S-AF-002	-	-	-	-	3	5	-	-	-	-	4	-	-	-	-	1	2	-	-
S-AF-004	3	-	-	-	-	-	-	-	-	-	-	2	-	4	5	-	-	1	-
S-AF-005	2	4	-	-	-	-	-	-	-	-	-	3	-	-	5	-	-	1	-
M-LA-001																			
M-LA-002	-	-	-	-	-	3	-	1	2	-	-	-	-	-	-	-	5	4	-
S-LA-001[b]	3	-	-	5	1	2	4	-	-	-	-	-	-	-	-	-	-	-	-
S-LA-002[c]	3	-	-	5	1	2	4	-	-	-	-	-	-	-	-	-	-	-	-
S-LA-003[d]	3	-	-	5	1	2	4	-	-	-	-	-	-	-	-	-	-	-	-
S-LA-004[e]	3	-	-	2	1	4	5	6	-	-	-	-	-	-	-	-	-	-	-
S-LA-005[f]	-	-	-	-	4	-	-	-	-	-	-	-	-	2	-	1	5	3	-
S-LA-006[g]	4	5	-	-	-	-	-	-	-	-	1	-	-	3	-	2	-	-	-
S-LA-007	5	2	-	-	-	4	-	-	-	-	1	-	-	3	-	2	-	-	-
S-LA-008[h]	3	5	4	-	-	-	-	-	-	-	-	-	-	6	-	2	-	1	-
M-LA-003	3	5	4	-	-	-	-	-	-	-	-	-	-	6	-	2	-	1	-
M-LA-006	5	-	-	-	3	2	-	-	-	-	-	-	-	-	3	1	4	-	-
M-LA-007	6	-	7	-	1	2	5	8	-	-	-	-	-	-	-	3	-	4	-

M = Model farm, S = Showcase farm (real farm), LA = Latin America, AF = Africa

[a] Modou DIOUF is already working on Increasing housing (grass constant) and Improving roughage quality

[b] Cavalcante-GO Rui Farm is already working on Improving pasture by using a minimum of fertilization rate each three years

[c] Portal dos Bandeirantes Farm is already working on Improving pasture by using a minimum of fertilization rate each three years, Sugarcane crop to feed some animals in the dry season.

[d] Sertaneja Farm is already working on Eucalyptus tree crops deployed in degraded pastures, Corn crops to produce dry feed supplement, Sugarcane crop to feed some animals in the dry season and Production of Brachiaria hay to feed the cows calved during the dry season.

[e] Calcare Farm is already working on Corn silage for feedlot , Use of grain residuals as suplementary animal feed and Use of sugarcane in a mixed (with elephant grass) forage.

[f] Farm with Agroforestry is already working onAgroforestery with Tectona grandis tree crops deployed in degraded pastures, rice crops, soja crops and rotational grazing.

[g] Hugues Bergères Farm is already working on soil carbon sequestration through grazing management.

[h] Granja Ortiz is already working on Integrated crop-livestock systems and change in grazing management.

Annex 4. Four best adaptation options initially identified farms

Farm ID		Fertilisation rate	Water management (irrigation and drainage)	Use of mixtures of plant species	Feed storage	Animal breeding (local breeds)	Animal breeding (change breeds)	Supplemental feeding	Shifts in livestock systems	Livestock mobility	Use of plants more resistant to drought, flooding, pests and diseases	Rotational grazing	Improve livestock management	Change the grazing management	Clean the pasture from unwanted species	Restoring degraded lands
M-LA-001																
M-LA-002		1	-	-	4	2	-	3	-	-	-	-	-	-	-	-
M-LA-003		4	**3**	-	-	-	-	**2**	**1**	-	-	-	-	-	-	-
M-LA-006		-	-	**3**	-	-	**2**	**4**	**1**	-	-	-	-	-	-	-
M-LA-007		2	-	**3**	-	-	4	-	**1**	-	-	-	-	-	-	-
M-AF-001		-	-	-	-	3	-	-	4	1	2	-	-	-	-	-
M-AF-002																
M-AF-003																
S-LA-001		1	-	-	-	3	-	-	-	-	2	4	-	-	-	-
S-LA-002		1	-	-	-	3	-	-	-	-	2	4	-	-	-	-
S-LA-003		1	-	-	-	3	-	-	-	-	2	4	-	-	-	-
S-LA-004		1	-	-	-	3	-	-	-	-	2	4	-	-	-	-
S-LA-005		3	-	4	-	-	-	-	-	-	-	1	2	-	-	-
S-LA-006																
S-LA-007																
S-LA-008		4	3	-	-	-	-	2	1	-	-	-	-	-	-	-
S-AF-001		-	-	-	-	3	-	-	4	1	2	-	-	-	-	-
S-AF-002		-	-	-	-	-	-	1	-	-	-	-	-	2	3	4
S-AF-004		1	-	-	-	2	3	-	-	4	-	-	-	-	-	-
S-AF-005		4	-	2	-	1	-	-	-	3	-	-	-	-	-	-

M = Model farm, S = Showcase farm (real farm), LA = Latin America, AF = Africa

Annex 5. Farm type definitions

In this report also farm typology “Sub-humid” and “Sub-humid/Humid” is used for the non-European land based systems.

Table 1. Livestock classification or farm typology as used in component 3 of AnimalChange from Deliverable 10.1

European land-based systems	European landless systems	Non-European land-based systems	Non-European landless systems
Maritime - mixed dairy	Northern European pig	Arid irrigated grassland	Industrial pig
Maritime - mixed beef	Southern European pig	Arid rainfed grassland	Industrial poultry
Maritime - grassland beef	Northern European poultry	Semi-arid grassland	Industrial dairy
Maritime - grassland dairy	Southern European poultry	Humid	Industrial beef
Continental - mixed dairy	Beef feedlots	Tropical highland	Backyard pig
Continental - mixed beef			Backyard cattle
Continental - grassland beef			Urban dairy
Mountain - grassland beef			
Mountain - grassland sheep			
Mediterranean - mixed dairy			
Mediterranean - grassland sheep			
Boreal - grassland sheep			

Annex 6. Reason why adaptation measure is chosen and how it is implemented

Farm ID	Adaptation ID	Why chosen?	How implemented on farm?
M-LA-002	**1**	The local maize crop for silage production presented yield below the regional average.	Adequate technical assistance is necessary as well as the farmer's training to use available appropriate technologies.
	4	Store for dry feed was not adequate.	The dry feed mix when prepared and stored locally can, possibly, be cheaper.
	5	Bos Indicus and bos taurus crossbreeding should be used to produce the indicated animals for the local feedlot because this technology, economically feasible, has been already implemented in the cerrado region.	The local market should pay a higher price for a softer beef.
	7	Alternatives supplementary feeding must be locally evaluated and cotton, maize and soybean residues considered.	The farmer should analyse the prices of alternative raw materials of the regional seed industry and large commercial crop farms that generate such residues.
S-LA-001	**1**	A pasture fertilization strategy could use 2 MT of lime, 1 MT of simple superphosfate and 120 kg of urea per hectare/year.	25 hectares of pasture per year should be renovated.
	5	Bos Indicus and bos taurus crossbreeding should be used to produce the indicated animals for the local feedlot because this technology, economically feasible, has been already implemented in the cerrado region.	The local market should pay a higher price for a softer beef.
	10	Stylosanthes guianiensis specie should be planted with Brachiaria at the same time.	The padocks with stylosanthes should be used during the dry season.
	11	The number of pasture areas are 16 but and 30% of the total area should be reserved to the dry season.	The assumption is that stock pile of dry pasture is enough to maintain the herd.

M = Model farm, S = Showcase farm (real farm), LA = Latin America, AF = Africa

Farm ID	Adaptation ID	Why chosen?	How implemented on farm?
S-LA-003	**1**	The local maize crop for dry feed presented yield below the regional average.	Adequate technical assistance is necessary as well as the farmer's interest to use available appropriate technologies. For instance, before the planting days the farmer should apply gypsum in the soil and after the planting date the use (in two fertilizations) of at least 90 kg of N and 30 kg of k2O per hectare.
	5	Bos Indicus and bos taurus crossbreeding should be used to produce the indicated animals for the local feedlot because this technology, economically feasible, has been already implemented in the cerrado region.	The local market should pay a higher price for a softer beef.
	10	Most of the planted pasture areas in the Sertanejo farm presented low yields in 2013 and once that beef price is higher than two years ago the farmer should invest in soil fertilization and new available species of pasture.	By using the cropping practice with maize and pasture planted in one planting operation. After the harvest of maize for the dry feed the farmer will have a new pasture.
	11	Sertanejo farm has incorporated many paddocks and by monitoring and evaluations of their yields, the establishment of animal stocks can be improved.	New pasture species such as Minerão Stilozants, with better drought tolerance, should be introduced to supply forage in the dry season.
S-LA-004	**1**	Given that the farm is implanted in a very expensive land area, the farmer should maximize their crop yields.	The use of gypsum, adequate fertilization rates and other new agro-technologies should be considered to improve the crop yields.
	5	Bos Indicus and bos taurus crossbreeding should be used to produce the indicated animals for the local feedlot because this technology, economically feasible, has been already implemented in the cerrado region.	The local market should pay a higher price for a softer beef.
	10	Double crop systems should adopt rotations using plants more drought tolerant in the second rainy season crop. Moreover, Brachiaria seeds should be planted with a second cereal crop to optimize the farm income and the carbon sequestration.	The Brachiaria harvest, in the dry season, should be carried by grazing of crossbred (bos Indicus and bos taurus) animals.
	11	The rotational grazing should be optimized.	Electric fences should be used.

M = Model farm, S = Showcase farm (real farm), LA = Latin America, AF = Africa

Farm ID	Adaptation ID	Why chosen?	How implemented on farm?
S-LA-005	**1**	increase meat production per hectare	Residual fertilization of crops
	3	produce more biomass per hectare and improving ambience for animals	Trees are planted in combination with other plants. In the first
	11	optimize the use of forage production	There was a pasture of 33ha. We divided into eight parts. We started to respect the forage lifecycle. Goal is to put the animals to graze, when the quality and production curves touching.
	12	remove less productive animals	Selection within the herd
	15	incorporate unproductive areas to the production system, with good productivity	Trees are planted in combination with other plants. In the first
S-AF-002	**7**	Prolonged dry season and drought is part of the system and climate change will decrease rainfall amount and also incresae the frequency of drought cycle.	Provision of mineral licks/supplementation during the growing season and nitrogen based supplements during winter will improve feed utilisation and growth performance.
	13	Due to reduced rainfall, the annual primary productivity is expected to decline which demands an adjustment in grazing management to match th requirment of livetock with the availbale forage resources	Adjustment of stocking rate to match the availbale forage in a paddock
	14	Due to change in rainfall and frequent drought the veldt will be dominated by unpalatable drought tolerant shrubs and some other alien species.	Mechanical, chemical as well as biological control of unwanted species and use of mixed livetock species are used to control bush encrochment.
	15	Due to reduced rainfall annual primary productivity is expected to decline which can easily lead of over grazing and degradation of grazing lands.	Resting of selected paddocks for the whole season will benefit in terms of restoring the degraded lands.

M = Model farm, S = Showcase farm (real farm), LA = Latin America, AF = Africa

Farm ID	Adaptation ID	Why chosen?	How implemented on farm?
S-AF-004	**1**	Fertilizer it is utilized in crops besides manure to increase crop productivity in a mixed crop-livestock systems where animals are also fed in crop residues.	DAP 25kg/1.5 acres and manure 8 bags of 70kg
	5	Traditional agropastoral system to mainstream agriculture	1 local bull, 2 cows, 1 young bull, 3 female calves, 2 rambs, 2 female sheep, 1 young female sheep
	6	Change of animal breed to crossbreed which are more productive and adaptable to the condition of the area	1 crossbreed cow
	9	To search for new grazing areas	Use of different communal grazing areas
S-AF-005	**1**	Fertilizer it is utilized in crops besides manure to increase crop productivity in a mixed crop-livestock systems where animals are also fed in crop residues.	Mineral fertilization: Contribution only on maize (30 kg N / ha) and manure management (night park Rotation on corn cropping land every 4 months)
	3	Use of crop residues to feed animals	Rotation(1 acre), maize, potatoes, groundnuts & cassava
	5	Traditional agropastoral system to mainstream agriculture	Local cows, local sheep, local poultry, donkey, ducks
	9	To search for new grazing areas	Use of different communal grazing areas

M = Model farm, S = Showcase farm (real farm), LA = Latin America, AF = Africa

Annex 7. Estimated impact from climate change upon farm

Estimated impact from the factors determining the on farm expected impact of climate change on crop and livestock (++ strong positive effect, + positive effect, 0 no effect, - negative effect, -- strong negative effect, a. Depends on the Amazon area. In Water logging area is positive, if not, is negative)

			Crop impacts				Livestock impacts		
Farm ID	**Farm type**	**Farm**	**Thermal growing season**	**Drought**	**Heat stress**	**Water logging**	**Heat stress**	**Diseases**	**Land accessibility**
S-LA-005	Humid grass land based soya bean-trees-beef system	Farm with Agroforestry	0	--	-	--	-	0	a
S-AF-002	Semi-arid Grassland based beef	Deon Hoon	0	--	0	0	+	0	0
S-AF-004	Sub-humid / Humid Rainfed crop-livestock farming systems	Smallholder farming Lower Nyando, Kisumu	-	--	-	-	--	--	-
S-AF-005	Sub-humid / Humid Rainfed crop-livestock farming systems	Smallholder farming Lower Nyando, Kisumu	-	--	-	-	--	--	-

M = Model farm, S = Showcase farm (real farm), LA = Latin America, AF = Africa