Report on farm scale eco-efficiency of mitigation and adaption options

Ib Silleback Kristensen, Jörgen E. Olesen, Nicholas John Hutchings, Lisbeth Mogensen, Philippe Faverdin, Kairsty Topp, Ana Barradas, Bruno Godinho, Donal O'Brien, Laurence Shalloo, et al.

ANIMALCHANGE

SEVENTH FRAMEWORK PROGRAMME
THEME 2: FOOD, AGRICULTURE AND FISHERIES, AND BIOTECHNOLOGIES

Grant agreement number: FP7- 266018

DELIVERABLE 10.3
Deliverable title:
Report on farm scale eco-efficiency of mitigation and adaption options. Report on European studies.

Abstract:
This deliverable collates the information on simulated effects of mitigation and adaptation options at the farm scale in Europe, primarily using the FarmAC model for the mitigation options, and applying semi quantitative modelling for the adaptation options.

Due date of deliverable: M*40* Actual submission date: M*48*

Start date of the project: March 1st, 2011 Duration: 48 months

Organisation name of lead contractor: AU

Authors: Ib Sillebak Kristensen (AU), Jørgen E. Olesen (AU), Nick Hutchings (AU), Lisbeth Mogensen (AU), Philippe Faverdin (INRA), Kairsty Topp (SRUC), Ana Barradas (Fertiprado), Bruno Godinho (Fertiprado), Donal O' Brien (Teagasc), Laurence Shalloo (Teagasc), Gertjan Holshof (DLO), Hink Perdok (Provimi-Cargill) and Marcia Stienezen (DLO).

Revision: V *1*

Dissemination level: PU

Release	Date	Reason of change	Status	Distribution

Table of Contents

1.1.1.1 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.

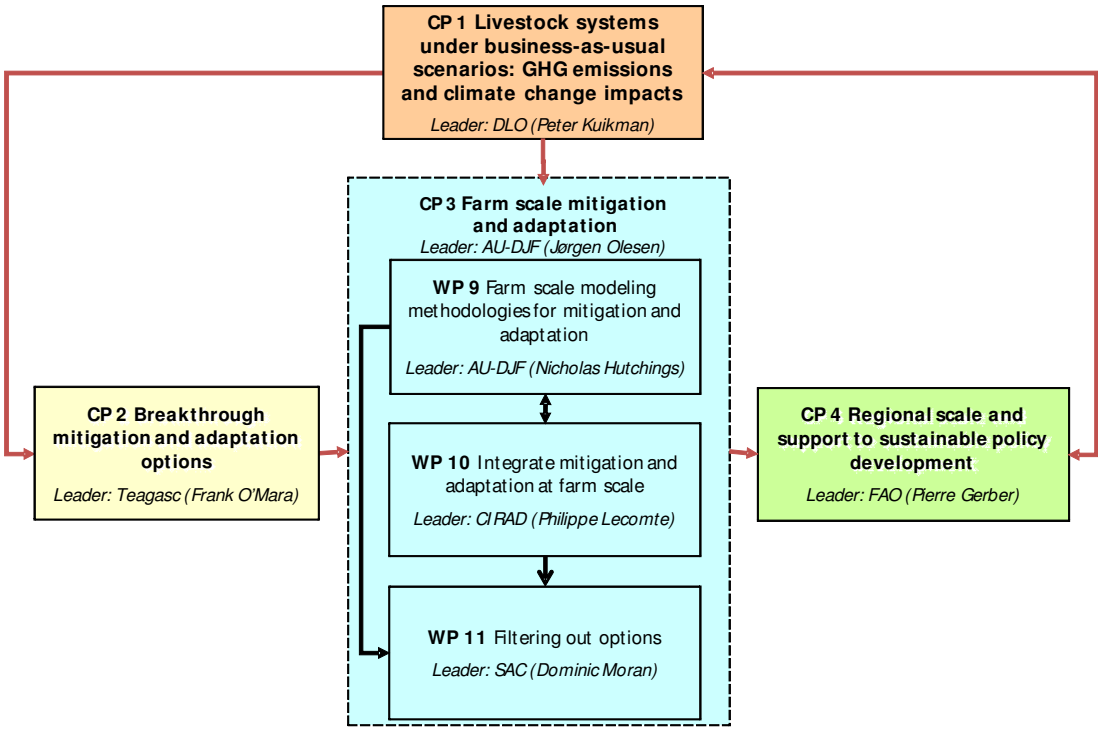

Figure 1. Structure and information flows regarding Component 3 of AnimalChange

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.

2.1.1.1 Farms included in study

For modelling GHG emissions with FarmAC, partners within AnimalChange identified 25 European farms, of which 15 model farms and 10 showcase farms (Annex 2). Two of the 25 farms were pig farms. Furthermore 4 sheep farms, 8 beef farms and 11 dairy farms were initially available.

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 1).

For this report, FarmAC results are available for 9 European farms of which 6 model farms and 3 showcase farms (Table 2.1). The farms originate from Ireland, Italy, the Netherlands and France.

Table 2.1. Farms included in modelling mitigation options with FarmAC

Country	**Farmtype**	**Farm**	**Farm ID**
Ireland	Maritime grassland beef	Average National Beef	M-EU-002
Ireland	Maritime grassland dairy	Greenfield	M-EU-003
Ireland	Maritime grassland dairy	Average National Dairy	M-EU-004
Ireland	Maritime grassland beef	Derry Patrick	S-EU-003
Ireland	Maritime grassland dairy	Curtins	S-EU-004
Italy	Mediterranean mixed dairy	Italian mediterranean mixed dairy	M-EU-013
Netherlands	Maritime mixed dairy	Dutch common dairy	M-EU-001
Netherlands	Maritime mixed dairy	De Marke	S-EU-005
France	Continental mixed dairy	Dairy farm Lorraine	M-EU-006

3.1.1.1 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/mport)	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 CO2/kwh (based on natural gas)(Nielsen, Nielsen et al. 2003)

In order to evaluate the total GHG emissions – “on-farm” 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. Mitigation options evaluated across mitigation option – per farm, including pre-chain.

From the farms included in modelling mitigation options with FarmAC (Table 2.1.) this chapter presents farm characteristics (soil; management; herd; crops and yields) (Table 1), N balances (Table 2), on-farm GHG emissions (Table 3) and total GHG emissions (pre-chain GHG emissions included; Table 4).

3.2.1. Maritime Mixed Dairy

3.2.1.1. Maritime Mixed Dairy – Dutch average sandy soil, M-EU-001.

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

Country		Netherland			
person data responsible		Gertjan			
Agro Ecological Zone		Maritime, Europe			
Farm type		Dairy			
System		Dutch sandy soil	Nitrate feeding	20% replacement	Reduced grazing
		Baseline	M1	M2	M3
Farm number of baseline		325076-5	15	16	17
Crop rotation	permanent grass & maize				
Ha plouging possible	[ha]	49	49	49	49
Soil type, FAO (2015)		Coarce sand			
Soil organic material in root zone	[tonnes C/ha]	235	235	233	235
Change in C stored in the soil	kg C/ha/yr	-4	18	-62	7
Precipitation	[mm/year]	800	800	800	800
Potential evapotranspiration	[mm/year]	236	236	238	238
Manure storage		Slurry	Slurry	Slurry	Slurry
Breed of animal		Holstein frisian			
Milk (kg/cow/year)	[kg/cow/year]	8129	8025	8129	7944
Milk, fat content, %		4.4			
Milk, protein content, %		3.53			
Meat	[kg LW/cow/year]	205	205	140	195
Herd size, cows [h)]	[cows]	85	85	85	85
Heifers	[heifers]	66	66	44	66
LU/animal		0.91	0.91	0.99	0.91
LU/ha	[LU/ha]b	2.79	2.79	2.79	2.79
Livestock manure excreted [c)]	[kg N/LU/year)]c	129	123	120	123
Livestock manure applied field [c)]	[kg N/ha/year)]c	309	317	307	312
Grazing	[% of herd DM-uptake]	27	27	26	15
Forage crops (%)g,f	[% of herd DM-uptake]	27	28	27	39
Maize silage (%)f	[% of herd DM-uptake]	24	24	24	24
Concentrate feed	[% of herd DM-uptake]	22	22	23	22
Grazing area	[% of ha]	40%	40%	40%	40%
Conserved grass rouhage	[% of ha]	42%	42%	42%	42%
Maize silage	[% of ha]	18%	18%	18%	18%
Plant yield. Gross i)	(t DM/year)	13.8	13.8	13.6	13.7
Total net yield (sold, grazed and conserved)	(t DM/year)	11.7	11.7	11.9	12.0
Maize - silage, low fodder quality		14.5	15.6	15.6	15.6
Permanent grass		10.3	11.6	11.1	11.1

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
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			Dutch sandy	Nitrate feeding	20% replacement	Reduced grazing
Farm	Inputs	N in fertiliser	120	120	118	118
		N deposited from atmosphere	30	30	30	30
		N in imported crop products	192	174	175	193
	Total inputs		342	323	324	341
	Outputs	N sold in crop products, incl rouhage expor	0	0	2	0
		N sold in milk	78	77	78	77
		N exported in meat	9	9	6	9
		Exported manure	22	10	16	16
	Total outputs		110	97	103	102
Farm gate balance			**232**	**227**	**221**	**239**
	Losses	Total amm-N loss	61	58	60	68
		Total denitrification	40	40	38	40
		Nitrate leaching	**132**	**129**	**130**	**131**
		Change in mineral N in soil	0	0	0	0
		Change in organic N in soil	**0**	**2**	**-6**	**1**
Herd	Inputs	Rouhage storage N-balance after storage l	137	138	138	172
		Imported livestock feed, incl rouhage impo	187	169	171	187
		Grazed	124	124	111	71
	Total inputs		449	431	420	429
	Outputs	N sold in milk	78	77	78	77
		N exported in meat	9	9	6	9
	Total outputs		88	87	85	85
Herd balance			**361**	**344**	**335**	**344**
	Efficiency of N use by livestock		**20%**	**20%**	**20%**	**20%**
		Manure deposited in housing	262	251	248	291
		Deposited in field	99	93	88	54
Housing		Gaseous loss of housing	32	30	30	35
ManureStorage		N in bedding	5	5	4	6
		Feed wastage	10	9	10	11
		Gaseous loss of manure	13	12	12	14
	Manure ex storage		233	224	220	258
		Imported manure	0	0	0	0
		Exported manure	22	10	16	16
	Manure applied		210	214	204	242
		%TAN of excreted stall-N	54.9%	53.3%	54.2%	54.3%
Field bal	Inputs	N in fertiliser	120	120	118	118
		Manure applied	210	214	204	242
		Deposited in field	99	93	88	54
		N deposited from atmosphere	30	30	30	30
	Total inputs		458	457	439	444
	Outputs	Harvested mechanically	162	162	164	201
		Grazed	124	124	111	71
		N sold in crop products, incl rouhage expor	0	0	2	0
	Total outputs		286	286	275	272
Field balance			**172**	**170**	**165**	**172**
	NEffField		62%	63%	63%	61%
Feed storage		Harvested mechanically	162	162	164	201
		N in imported crop products	192	174	175	193
		Imported rouhage	12	12	0	12
		Imported cash crops (grain, rape)	12	68	11	12
		N sold in crop products, incl rouhage expor	0	0	2	0
		N lost from processing/ stored crop product	15	15	14	18
		%loss of input	9%	9%	9%	9%

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

System		Dutch sandy	Nitrate feeding	20% replacement	Reduced grazing
GHG results per farm, kg CO2-eq/ yr [1)]					
CH4 enteric	[kg CO2-eq/ y]	390348	351132	365354	390348
CH4 manure	[kg CO2-eq/ y]	137102	143553	127850	163941
N2O manure	[kg CO2-eq/ y]	56257	54113	53151	62452
N2O field	[kg CO2-eq/ y]	175803	174996	166234	169519
Soil C changes	[kg CO2-eq/ y]	766	-3278	11205	-1190
Total direct GHG	[kg CO2-eq/ y]	760275	720516	723794	785070
Indirect from NH3-emission	[kg CO2-eq/ y]	9674	9112	9513	11012
N2O-indirect leaching	[kg CO2-eq/ y]	22787	22204	22456	22594
Total indirect GHG	[kg CO2-eq/ y]	32461	31316	31969	33606
GHG, direct + indirect	[kg CO2-eq/ y]	792736	751832	755763	818676
On farm land, ha	[ha]	49	49	49	49
GHG results per ha, kg CO2-eq/ yr [1)]					
CH4 enteric	[kg CO2-eq/ ha/ y]	7966	7166	7456	7966
CH4 manure	[kg CO2-eq/ ha/ y]	2798	2930	2609	3346
N2O manure	[kg CO2-eq/ ha/ y]	1148	1104	1085	1275
N2O field	[kg CO2-eq/ ha/ y]	3588	3571	3393	3460
Soil C changes	[kg CO2-eq/ ha/ y]	16	-67	229	-24
Total GHG per ha	[kg CO2-eq/ ha/ y]	15516	14704	14771	16022
Indirect from NH3-emission	[kg CO2-eq/ ha/ y]	197	186	194	225
N2O-indirect leaching	[kg CO2-eq/ ha/ y]	465	453	458	461
Total indirect GHG	[kg CO2-eq/ ha/ y]	662	639	652	686
GHG, direct + indirect	[kg CO2-eq/ ha/ y]	16178	15344	15424	16708
Adjustment of home-produced feed		213	213	-32	208
Output of products					
Milk, kg delivered	[kg/ y]	690954	682136	690954	675230
Meat, ton LW	[ton LW/ y]	17	17	12	17
Crop product	[ton DM]	114	114	6436	673
Input					
Fertlizer, kg N [2)]	[N/ ha]	120	120	118	118
Fixation	[N/ ha]	0	0	0	0
Manure, kg N and type	[N/ ha]	0	0	0	0
Feed [3)]					
- Cereals, kg DM	[kg DM/ ha]	1025	2070	977	1025
- Rape seed cake, kg DM	[kg DM/ ha]	0	0	0	0
- Rapeseed, kg DM	[kg DM/ ha]	0	0	0	0
- Soy bean meal, kg DM	[kg DM/ ha]	1326	379	1284	1326
- Other	[kg DM/ ha]	0	0	0	0
Diesel, l/ ha estimate	[l/ ha]	81	81	81	81
Electricity, stable estimate	[kwh/ ha]	1239	1239	1230	1239

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

		Dutch sandy	Nitrate feeding	20% replaceme	Reduce d
GHG results per farm, kg CO2-eq/yr [1)]					
On-farm total direct GHG	[kg CO2-eq/ha/y]	15516	14704	14771	16022
On-farm total indirect GHG	[kg CO2-eq/ha/y]	662	639	652	686
On farm GHG, direct + indirect	[kg CO2-eq/ha/y]	16178	15344	15424	16708
Reduction (%)			5%	5%	-3%
On farm emissions (kg/liter)					
Total GHG		1.15	1.10	1.09	1.21
Reduction (%)			4%	5%	-6%
GHG from					
- Net Feed import	[kg CO2-eq/ha/y]	370	409	679	965
- Fertilizer (N)	[kg CO2-eq/ha/y]	508	662	502	502
- Manure (N)	[kg CO2-eq/ha/y]	-95	-42	-68	-69
- Diesel	[kg CO2-eq/ha/y]	268	268	268	268
- Electricity	[kg CO2-eq/ha/y]	811	811	806	811
Total pre-chain GHG emission	[kg CO2-eq/ha/y]	1862	2107	2187	2477
Total GHG before allocation	[kg CO2-eq/ha/y]	18041	17451	17610	19185
Output of products					
Milk, ton delivered	[kg/y]	691	682	691	675
Meat, ton LW	[ton LW/y]	17	17	12	17
Allocation of GHG, %		85.5%	85.3%	90.1%	85.9%
GHG per kg product					
Kg CO2/kg milk	Kg CO2/kg milk	1093	1069	1125	1195
Reduction (%)			2%	-3%	-9%
Kg CO2/kg meat LW	Kg CO2/kg meat LW	7383	7234	7207	8034

Maritime Mixed Dairy – Dutch average sandy soil, M-EU-001

3.2.1.2. De Marke demonstration farm, S-EU- 005.

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

Country	Netherland					
person data responsible	**Gertjan Holshof**					
Agro Ecological Zone	Maritime, Europe					
Farm type	Mixed dairy					
Systems		Winter crops permanent	Nitrate feeding	Permanent grass	Biogas	Nitrification inhibitors
		Baselin	M1	M2	M3	M4
Farm number of baseline		325079-38	43	32	44	60
Crop rotation	Maize + grass/clover in rotation & permanent grass					
Ha plouging possible	[ha]	55	55	55	55	55
Soil type, FAO (2015)		Coarse sand, 2 % clay				
Soil organic material in root zone	[tonnes C/ha]	168	171	79	164	168
Soil organic material in root zone	kg C/ha/yr	0	11	-85	-67	4
Precipitation	[mm/year]	800	800	800	800	800
Irrigation	[mm/year]	0	0	171	0	0
Potential evapotranspiration	[mm/year]	243	243	274	243	243
Manure storage		Slurry	Slurry	Slurry	Slurry	Slurry
Breed of animal		Holstein dairy cows				
Milk (kg cow-1/year)	[liter/cow/year]	8334	8239	7755	8334	8334
Milk, protein content, %		3.49				
Meat	[kg LW/animal/year]	50	84	99	84	84
Herd size (cows/young stock)[h]	[cows]	84	84	84	84	84
LU/animal		0.96	0.96	0.96	0.96	0.96
LU/ha	[LU/ha]b	2.46	2.46	2.46	2.46	2.46
Livestock manure, excreted [c)]	[kg N/LU/year)]c	91	80	100	91	91
Livestock manure applied on field [c)]	[kg N/ha/year)]c	205	183	223	214	205
Grazing	[% of herd DM-uptake]	9	9	9	9	9
Grass silage crops (%)g,f	[% of herd DM-uptake]	29	29	29	29	29
Maize silage (%)f	[% of herd DM-uptake]	40	40	40	40	40
Concentrate feed	[% of herd DM-uptake]	22	22	22	22	22
Grazing area	[% of ha]	9	9	9	9	9
Conserved rouhage	[% of ha]	91	91	91	91	91
Plant yield. Gross i)	(t DM/year)	11.887	12.817	12.165	12.799	11.899
Total net yield (sold, grazed and conserv	(t DM/year)	10.461	11.394	11.134	11.394	10.464
CCM maize	(t DM/year)	9.310				
Maize silage	(t DM/year)	14.487				
Permanent grass	(t DM/year)	8.370		10.034		
Grass/clover	(t DM/year)	7.837				

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 an

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]

Systems			Winter crops permanent grass	Nitrate feeding	Permanent grass	Biogas	Nitrification inhibitors
Farm	Inputs	N in fertiliser	33	33	175	33	35
		Imported manure	0	1	0	0	0
		N fixation	39	45	0	41	33
		N deposited from atmosphere	30	30	30	30	30
		N in imported crop products	125	110	89	125	125
	Total inputs		227	219	294	230	223
	Outputs	N sold in crop products, incl rouhage export	0	0	17	15	0
		N sold in milk	71	70	66	71	71
		N exported in meat	3	3	4	3	3
		Exported manure	0	0	3	11	1
	Total outputs		74	73	90	101	75
Farm gate balance			**152**	**146**	**204**	**129**	**148**
	Losses	Total amm-N loss	40	50	57	36	40
		Total denitrification	30	29	39	25	21
		Nitrate leaching	**81**	**65**	**123**	**74**	**86**
		Change in organic N in soil	**0**	**1**	**-9**	**-6**	**0**
Herd	Inputs	Rouhage storage N-balance after storage loss	143	135	198	143	143
		Imported livestock feed, incl rouhage import)	120	105	84	120	120
		Grazed	35	30	34	35	35
	Total inputs		298	270	316	298	298
	Outputs	N sold in milk	71	70	66	71	71
		N exported in meat	3	3	4	3	3
	Total outputs		74	73	70	74	74
Herd balance			**224**	**197**	**246**	**224**	**224**
	Efficiency of N use by livestock		25%	27%	22%	25%	25%
		Manure deposited in housing	204	180	223	204	204
		Deposited in field	20	17	23	20	20
Housing		Gaseous loss of housing	23	18	26	23	23
ManureStorage		N in bedding	5	5	5	5	5
		Feed wastage	8	7	9	8	8
		Gaseous loss of manure	10	9	11	2	10
	Manure ex storage		**185**	**166**	**200**	**194**	**185**
		Imported manure	0	1	0	0	0
		Exported manure	0	0	3	11	1
	Manure applied		185	166	197	182	185
		%TAN of excreted stall-N	49%	45%	52%	78%	49%
Field balance	Inputs	N in fertiliser	33	33	175	33	35
		Manure applied	185	166	197	182	185
		Deposited in field	20	17	23	20	20
		N fixation	39	45	0	41	33
		N deposited from atmosphere	30	30	30	30	30
	Total inputs		307	292	425	307	303
	Outputs						
		Harvested mechanically	161	168	241	178	162
		Grazed	35	30	34	35	35
		N sold in crop products, incl rouhage export	0	0	17	15	0
	Total outputs		197	198	274	213	197
Field balance			**110**	**94**	**150**	**94**	**106**
	NEffField		64%	68%	65%	69%	65%
Feed storage		Harvested mechanically	161	168	241	178	162
		N in imported crop products	125	110	89	125	125
		Imported rouhage	0	0	0	0	0

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

		Winter crops permanent grass	Nitrate feeding	Permanent grass	Biogas	Nitrification inhibitors
GHG results per farm [1)]	[kg CO2-eq/y]					
CH4 enteric	[kg CO2-eq/y]	360947	320878	351465	360947	360947
CH4 manure	[kg CO2-eq/y]	169510	175244	167148	20583	169510
N2O manure	[kg CO2-eq/y]	50281	44918	54340	10056	50281
N2O field	[kg CO2-eq/y]	146033	143596	195730	152102	86621
Soil C changes	[kg CO2-eq/y]	80	-2140	17183	13428	-849
Total direct GHG	[kg CO2-eq/y]	726850	682495	785865	557116	666509
Indirect from NH3-emission	[kg CO2-eq/y]	7640	6325	10186	6239	7637
N2O-indirect leaching	[kg CO2-eq/y]	15742	12649	23669	14333	16591
Total indirect GHG	[kg CO2-eq/y]	23382	18974	33855	20571	24229
GHG, direct + indirect	[kg CO2-eq/y]	750232	701469	819720	577687	690738
On farm land, ha	[ha]	55	55	55	55	55
GHG results per ha [1)]	[kg CO2-eq/(ha y)]					
CH4 enteric	[kg CO2-eq/(ha y)]	6563	5834	6390	6563	6563
CH4 manure	[kg CO2-eq/(ha y)]	3082	3186	3039	374	3082
N2O manure	[kg CO2-eq/(ha y)]	914	817	988	183	914
N2O field	[kg CO2-eq/(ha y)]	2655	2611	3559	2765	1575
Soil C changes	[kg CO2-eq/(ha y)]	1	-39	312	244	-15
Total GHG per ha	[kg CO2-eq/(ha y)]	13215	12409	14288	10129	12118
Indirect from NH3-emission	[kg CO2-eq/(ha y)]	139	115	185	113	139
N2O-indirect leaching	[kg CO2-eq/(ha y)]	286	230	430	261	302
Total indirect GHG	[kg CO2-eq/(ha y)]	425	345	616	374	441
GHG, direct + indirect	[kg CO2-eq/(ha y)]	13641	12754	14904	10503	12559
Adjustment of home-produced feed	[kg CO2-eq/(ha y)]	2	2	-249	-306	1
Output of products						
Milk, kg delivered	[kg/y]	700083	692084	651388	700083	700083
Meat, ton LW	[ton LW/y]	7	7	8	7	7
Crop product	[ton DM]	223	303	37945	49502	871
Input						
Fertlizer, kg N [2)]	[N/ha]	33	33	175	33	35
Fixation	[N/ha]	39	45	0	41	33
Manure, kg N and type	[N/ha]	0	1	0	0	0
Feed [3)]						
- Cereals, kg DM	[kg DM/ha]	793	1442	2174	793	793
- Rape seed cake, kg DM	[kg DM/ha]	11	11	0	11	11
- Rapeseed, kg DM	[kg DM/ha]	295	295	0	295	295
- Soy bean meal, kg DM	[kg DM/ha]	649	69	0	649	649
- Other	[kg DM/ha]	1013	1013	0	1013	1013
Diesel, l/ha estimate	[l/ha]	113	113	156	113	150
Electricity, stable estimate	[kwh/ha]	1087	1087	1087	1087	1087

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

		Nl, De Marke	Nitrate feeding	Permanent grass	Biogas	Nitrification inhibito
GHG results per farm, kg CO2-eq/yr [1)]						
On-farm total direct GHG	[kg CO2-eq/(ha y)]	13215	12409	14288	10129	12118
On-farm total indirect GHG	[kg CO2-eq/(ha y)]	425	345	616	374	441
On farm GHG, direct + indirect	[kg CO2-eq/(ha y)]	13641	12754	14904	10503	12559
Reduction (%)			6%	-9%	23%	8%
On farm emissions (kg/liter)						
Total GHG		1.07	1.01	1.26	0.83	0.99
Reduction (%)			5%	-17%	23%	8%
Pre-chain GHG from						
- Net Feed import	[kg CO2-eq/(ha y)]	1418	880	697	588	615
- Fertilizer (N)	[kg CO2-eq/(ha y)]	140	275	744	140	149
- Manure (N)	[kg CO2-eq/(ha y)]	-1	2	-14	-49	-3
- Diesel	[kg CO2-eq/(ha y)]	373	373	402	373	373
- Electricity	[kg CO2-eq/(ha y)]	712	712	712	712	712
Total pre-chain GHG emission	[kg CO2-eq/(ha y)]	2643	2243	2541	1766	1847
Total GHG before allocation	[kg CO2-eq/(ha y)]	16284	14997	17445	12269	14406
Output of products						
Milk, ton delivered	[kg/y]	700	692	651	700	700
Meat, ton LW	[ton LW/y]	7	7	8	7	7
Allocation of GHG, %		94.2%	94.1%	92.6%	94.2%	94.2%
GHG per kg product						
Kg CO2/kg milk	Kg CO2/kg milk	1.205	1.123	1.387	0.908	1.066
Reduction (%)			7%	-15%	25%	12%
Kg CO2/kg meat LW-gain (sold from farr	Kg CO2/kg meat LW-gain	7.383	6.878	8.501	5.563	6.532
S-EU- 005. De Marke demonstration farm						

1.2.2. Continental Mixed Dairy – Dairy farm Lorrain, M-EU-006.

Table 1. Characteristicks of farm: Soil; Management; Herd; Crops and yields								
Country	Fr							
person data responsible	Philippe & isk							
Agro Ecological Zone	Continental							
Farm type	Grassland dairy							
System		Baseline, with all the straw cropped, except for the rapeseed	Cover crop used as fresh grass fed indoor	Feeding more fat	Feeding nitrate	Legumes (Peas)	All the heifers calving at 2 years old	Incorporating straw except for the litter require
		Baseline	M1	M2	M3	M4	M5	M6
Farm number of baseline		farm_116361_1	24	26	27	30	25	29
Farm Id		Lorrain						
Crop rotation		Cash crop & permanent grass						
Ha plouging possible	[ha]	100	100	100	100	100	100	100
Ha, permanent grassland, low productive	[ha]	41	41	41	41	41	41	41
Soil type, FAO (2015)		Clay						
Soil organic material in root zone	[tonnes C/ha]	148	159	148	148	133	148	203
Soil organic material in root zone	kg C/ha/year	-118	-61	-118	-119	-186	-118	160
Precipitation	[mm/year]	666	666	666	666	666	666	666
Potential evapotranspiration	[mm/year]	274	288	274	274	261	274	275
Manure type	Unit	Deep litter						
Breed of animal		Holstein frisian						
Milk (kg/cow/year)	[kg/cow/year]	8135	7513	9467	8092	8374	7740	8135
Meat (kg/cow/year)???		344	341	344	344	344	335	344
Herd size (cows/young stock)[h]	[cows/young stock]	56	61	56	56	59	60	56
LU/animal		0.98	0.98	0.98	0.98	0.98	0.97	0.98
LU/hab	[LU/ha]b	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Livestock manure(kg excreted N/ha/year)c	[kg N/ha/year)]c	71	80	72	74	77	72	72
Grazing	Grazed grass (% of herd DM-upta	26	29	26	26	26	26	26
Fresh grass (%)e,f	Fresh grass (% of herd DM-uptake)e,f							
Forage crops (%)g,f	Forage crops (%)g,f	48	47	54	48	54	48	54
Maize silage (%)f	Maize silage (%)f	6	6	0	6	0	6	0
Grain crops (%)f	Grain crops (%)f	20	18	19	20	20	20	20
Plant yield. Gross i)	(t DM/year)	10.7	11.3	10.7	10.7	9.7	10.7	14.2
Total net yield (sold, grazed and conserved)	(t DM/year)	9.9	10.2	9.9	9.9	9.5	9.9	7.8
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 0.41 LU= 43.3 kg N								
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			Baseline, with all the straw cropped, except for the rapeseed	Cover crop used as fresh grass fed indoor	Feeding more fat	Feeding nitrate	Legumes (Peas)	All the heifers calving at 2 years old	Incorporating straw except for the litter requirement
Farm	Inputs	N in fertiliser	128	128	128	128	92	128	128
		N fixation	0	0	0	0	9	0	0
		N deposited from atmosphere	13	13	13	13	13	13	13
		N in imported crop products	35	35	37	36	29	35	35
	Total inputs		176	176	178	177	144	176	176
	Outputs	N sold in crop products, incl rouh	94	94	96	93	76	94	76
		N sold in milk	18	18	18	18	20	18	18
		N exported in meat	4	4	4	4	4	4	4
		Exported manure	4	8	4	5	7	4	4
	Total outputs		119	124	121	120	106	119	101
Farm gate balance			**57**	**52**	**57**	**57**	**38**	**57**	**75**
	Losses	Total amm-N loss	21	22	21	21	20	21	21
		Total denitrification	20	21	20	20	17	20	21
		Nitrate leaching	35	23	35	35	25	35	23
		Change in mineral N in soil	-5	-6	-5	-5	-6	-5	-4
		Change in organic N in soil	-13	-8	-13	-13	-20	-13	14
Herd	Inputs	Rouhage storage N-balance after	32	35	29	32	41	32	32
		Imported livestock feed, incl roul	34	33	36	35	28	34	34
		Grazed	30	35	30	30	32	30	30
	Total inputs		95	104	94	97	101	95	95
	Outputs	N sold in milk	18	18	18	18	20	18	18
		N exported in meat	4	4	4	4	4	4	4
	Total outputs		22	22	21	21	23	22	22
Herd balance			73	82	73	75	78	73	73
	Efficiency of N use by livestock		**23%**	**21%**	**23%**	**22%**	**23%**	**23%**	**23%**
		Manure deposited in housing	53	59	53	55	57	53	53
		Deposited in field	20	24	20	20	21	20	20
Housing		Gaseous loss of housing	6	7	6	6	6	6	6
ManureStorage		N in bedding	1	1	1	1	1	1	1
		Feed wastage	7	8	7	7	8	7	7
		Gaseous loss of manure	4	4	4	4	4	4	4
		Runoff from storage	2	0	0	0	0	0	0
	Manure ex storage		**51**	**57**	**52**	**54**	**56**	**52**	**52**
		Exported manure	4	8	4	5	7	4	4
	Manure applied		47	48	48	48	48	48	48
		%TAN of excreted stall-N	42.8%	44.7%	43.0%	43.2%	42.1%	42.5%	42.8%
Field balar	Inputs	N in fertiliser	128	128	128	128	92	128	128
		Manure applied	47	48	48	48	48	48	48
		Deposited in field	20	24	20	20	21	20	20
		N fixation	0	0	0	0	9	0	0
		N deposited from atmosphere	13	13	13	13	13	13	13
	Total inputs		208	213	209	209	184	209	209
	Outputs	Harvested mechanically	138	142	138	138	130	138	120
		Grazed	30	35	30	30	32	30	30
		N sold in crop products, incl rouh	94	94	96	93	76	94	76
	Total outputs		168	177	168	168	162	168	150
Field balance			**40**	**35**	**41**	**41**	**22**	**41**	**60**
	NEffField		81%	83%	80%	80%	88%	80%	71%
Feed storage		Harvested mechanically	138	142	138	138	130	138	120
		N in imported crop products	35	35	37	36	29	35	35
		Imported rouhage	0	0	0	0	0	0	0
		Imported cash crops (grain, rape)	0	0	0	0	0	0	0
		N sold in crop products, incl rouh	94	94	96	93	76	94	76

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

System		Baseline, with all the straw cropped, except for the rapeseed	Cover crop used as fresh grass fed indoor	Feeding more fat	Feeding nitrate	Legumes (Peas)	All the heifers calving at 2 years old	Incorporating straw except for the litter requirement
GHG results per farm, kg CO2-eq/ yr [1)]								
CH4 enteric	[kg CO2-eq/ y]	276023	298387	262124	265061	301473	277051	276023
CH4 manure	[kg CO2-eq/ y]	32285	33791	32391	33232	35920	32251	32285
N2O manure	[kg CO2-eq/ y]	36895	40083	36681	38066	39391	36737	36895
N2O field	[kg CO2-eq/ y]	286987	308127	286925	286968	248261	287266	309058
Soil C changes	[kg CO2-eq/ y]	61254	31377	61178	61326	95982	60913	-82936
Total direct GHG	[kg CO2-eq/ y]	693444	711764	679299	684652	721027	694218	571326
Indirect from NH3-emission	[kg CO2-eq/ y]	9332	10102	9340	9574	9081	9278	9332
N2O-indirect leaching	[kg CO2-eq/ y]	17162	11226	17170	17146	12618	17169	11374
Total indirect GHG	[kg CO2-eq/ y]	26494	21328	26510	26720	21700	26446	20706
GHG, direct + indirect	[kg CO2-eq/ y]	719939	733092	705809	711372	742727	720665	592032
On farm land, ha	[ha]	141	141	141	141	141	141	141
GHG results per ha, kg CO2-eq/ yr [1)]								
CH4 enteric	[kg CO2-eq/ ha/ y]	1958	2116	1859	1880	2138	1965	1958
CH4 manure	[kg CO2-eq/ ha/ y]	229	240	230	236	255	229	229
N2O manure	[kg CO2-eq/ ha/ y]	262	284	260	270	279	261	262
N2O field	[kg CO2-eq/ ha/ y]	2035	2185	2035	2035	1761	2037	2192
Soil C changes	[kg CO2-eq/ ha/ y]	434	223	434	435	681	432	-588
Total GHG per ha	[kg CO2-eq/ ha/ y]	4918	5048	4818	4856	5114	4924	4052
Indirect from NH3-emission	[kg CO2-eq/ ha/ y]	66	72	66	68	64	66	66
N2O-indirect leaching	[kg CO2-eq/ ha/ y]	122	80	122	122	89	122	81
Total indirect GHG	[kg CO2-eq/ ha/ y]	188	151	188	190	154	188	147
GHG, direct + indirect	[kg CO2-eq/ ha/ y]	5106	5199	5006	5045	5268	5111	4199
Adjustment of home-produced feed		17	20	17	17	50	19	17
Output of products								
Milk, kg delivered	[kg/ y]	455582	455821	454409	453163	497091	460530	455582
Meat, ton LW	[ton LW/ y]	19	21	19	19	20	20	19
Crop product	[ton DM]	871175	870667	889206	862848	759472	871098	568763
Input								
Fertlizer, kg N [2)]	[N/ ha]	128	128	128	128	92	128	128
Fixation	[N/ ha]	0	0	0	0	9	0	0
Manure, kg N and type	[N/ ha]	0	0	0	0	0	0	0
Feed [3)]								
- Cerals, kg DM	[kg DM/ ha]	-3273	-3273	-3402	-3216	-3068	-3273	-2710
- Rape seed cake, kg DM	[kg DM/ ha]	0	0	0	0	0	0	0
- Rapeseed, kg DM	[kg DM/ ha]	142	139	190	125	133	138	142
- Soy bean meal, kg DM	[kg DM/ ha]	302	0	238	270	220	305	302
- Other	[kg DM/ ha]	8	9	8	40	9	9	8
Diesel, l/ ha estimate	[l/ ha]	68	68	68	68	68	68	68
Electricity, stable estimate	[kwh/ ha]	285	309	285	285	302	302	285

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

		Fr_Mixed_Dairy	Cover crop used as fresh grass fed indoor	Feeding more fat	Feeding nitrate	Legumes (Peas)	All the heifers calving at 2 years old	Incorporating straw except for the litter requirement
GHG results per farm, kg CO2-eq/ha/y [1)]								
On-farm total direct GHG	[kg CO2-eq/ha/y	4918	5048	4818	4856	5114	4924	4052
On-farm total indirect GHG	[kg CO2-eq/ha/y	188	151	188	190	154	188	147
On farm GHG, direct + indirect	[kg CO2-eq/ha/y	5106	5199	5006	5045	5268	5111	4199
Reduction (%)			-2%	2%	1%	-3%	0%	18%
On farm emissions (kg/liter)								
Total GHG		1.58	1.61	1.33	1.57	1.49	1.56	1.30
Reduction (%)			-2%	16%	1%	5%	1%	18%
- Net Feed import	[kg CO2-eq/ha/y	-1947	-1955	-2025	-1952	-1525	-1955	-1689
- Fertilizer (N)	[kg CO2-eq/ha/y	544	544	544	563	392	544	544
- Manure (N)	[kg CO2-eq/ha/y	-16	-35	-15	-23	-31	-15	-16
- Diesel	[kg CO2-eq/ha/y	224	224	224	224	224	224	224
- Electricity	[kg CO2-eq/ha/y	187	203	187	187	198	198	187
Total pre-chain GHG emission	[kg CO2-eq/ha/y	-1009	-1020	-1086	-1002	-742	-1005	-751
Total GHG before allocation	[kg CO2-eq/ha/y	4097	4179	3920	4043	4525	4106	3448
Output of products								
Milk, ton delivered	[kg/y]	456	456	454	453	497	461	456
Meat, ton LW	[ton LW/y]	19	21	19	19	20	20	19
Allocation of GHG, %		75.6%	73.8%	75.6%	75.5%	76.3%	75.0%	75.6%
GHG per kg product								
Kg CO2/kg milk	Kg CO2/kg milk	959	954	919	950	980	943	807
Reduction (%)			1%	4%	1%	-2%	2%	16%
Kg CO2/kg meat LW	Kg CO2/kg meat l	7317	7460	7019	7259	7408	7255	6159

3.2.3. Mediterranean Mixed Dairy, Italian mixed dairy – Dairy farm Po Valley, M-EU-013.

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

Country	Italien, Po Valley						
person data responsible	Jørgen E. Olesen						
Agro Ecological Zone	Meditarranien						
Farm type		Mixed dairy					
System		Baseline	Irrigated	NO3 feeding	Stall acidified slurry, broadcast	Injected biogas	Nitrification inhibitors, 100 % efficienc
			M1	M2	M3	M4	M5
Farm number of baseline	farm_78954_1	1	2	15	13	18	3
Summary spreadsheet		Farm results summary for Italien Po_farm Test_78954_1_					
Crop rotation	Cash crop, lucerne & permanent grass						
Ha plouging possible	[ha]	50	50	50	50	50	50
Soil type, FAO (2015)		Clay					
Soil organic material in root zone	[tonnes C/ha]	112	112	113	113	107	112
Clay in root zone	[%clay]	0.20	0.20	0.20	0.20	0.20	0.20
Precipitation	[mm/year]	757	757	757	757	757	757
Irrigation	[mm/year]	0	331	0	0	0	0
Potential evapotranspiration	[mm/year]	352	507	352	352	352	352
Manure type		Cattle slurry					
Manure storage		Slurrt tank with cover					
Breed of animal		Holstein frisian					
Milk	[liter/cow/year]	5840	5840	5723	5840	5840	5840
Meat	[kg LW/cow/year]	116	116	116	116	116	116
Herd size (cows/young stock)[h]	[cows]	85	85	85	85	85	85
LU/animal		0.90	0.90	0.90	0.90	0.90	0.90
LU/ha	[LU/ha]b	3.13	3.13	3.13	3.13	3.13	3.13
Livestock manure(kg excreted N/LU/year	[kg N/LU/year]c	66	66	76	66	66	66
Livestock manure applied (kg deposit-N/ha/year	[kg N/ha/year]c	195	197	225	236	216	197
Grazing	[%of herd DM-uptake]	0	0	0	0	0	0
Forage crops (%)g,f	[%of herd DM-uptake]	60	74	72	74	74	73
Maize silage (%)f	[%of herd DM-uptake]	13	13	1	0	0	1
Concentrate feed	[%of herd DM-uptake]	26	26	26	26	26	26
Grazing area	[%of ha]	22					
Conserved rouhage	[%of ha]	62					
Grain crops (%)f	[%of ha]	16					
Plant yield. Gross i)	(t DM/year)	12.1	13.3	12.2	12.4	12.4	12.2
Total net yield (sold, grazed and conserved)	(t DM/year)	11.9	13.0	11.9	12.1	12.2	11.9

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 0.4

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			Baseline	Irrigated	NO3 feeding	Stall acidified slurry, broadcast spread	Injected biogas	Nitrification inhibitors, 100 % efficiency
Farm	Inputs	N in fertiliser	56	56	15	34	45	57
		Imported manure	0	0	0	0	4	0
		N fixation	108	171	115	84	84	105
		N deposited from atmosphere	14	14	14	14	14	14
		N in imported crop products	55	54	88	54	54	55
	Total inputs		*233*	*295*	*233*	*186*	*201*	*231*
	Outputs	N sold in crop products, incl rouhage export	5	29	4	9	10	5
		N sold in milk	55	55	54	55	55	55
		N exported in meat	5	5	5	5	5	5
		Exported manure	2	2	1	2	0	2
	Total outputs		*68*	*92*	*64*	*71*	*70*	*68*
Farm gate balance			**165**	**203**	**170**	**115**	**131**	**163**
	Losses	Total amm-N loss	105	109	116	33	55	105
		Total denitrification	30	31	31	28	26	26
		Nitrate leaching	**32**	**63**	**25**	**50**	**59**	**32**
		Change in mineral N in soil	0	-2	-1	1	2	0
		Change in organic N in soil	**-1**	**2**	**0**	**3**	**-10**	**-1**
Herd	Inputs	Rouhage storage N-balance after storage los	219	220	217	220	220	220
		Imported livestock feed, incl rouhage import	47	46	80	46	46	47
	Total inputs		266	266	298	266	266	266
	Outputs	N sold in milk	55	55	54	55	55	55
		N exported in meat	5	5	5	5	5	5
	Total outputs		60	60	59	60	60	60
Herd balance			206	206	238	206	206	206
NEffHerd	**Efficiency of N use by livestock**		**23%**	**23%**	**20%**	**23%**	**23%**	**23%**
		Manure deposited in housing	206	206	238	206	206	206
Housing		Gaseous loss of housing	26	26	31	1	26	26
ManureStorage		N in bedding	8	8	8	8	8	8
		Feed wastage	30	30	33	30	30	30
		Gaseous loss of manure	20	20	24	6	2	20
	Manure ex storage		197	197	225	236	216	197
		Imported manure	0	0	0	0	4	0
		Exported manure	2	2	1	2	0	2
	Manure applied		195	195	225	234	216	195
		%TAN of excreted stall-N	48.0%	48.0%	49.6%	53.5%	78.6%	48.0%
Field balance	Inputs	N in fertiliser	56	56	15	34	45	57
		Manure applied	195	195	225	234	216	195
		N fixation	108	171	115	84	84	105
		N deposited from atmosphere	14	14	14	14	14	14
	Total inputs		373	436	369	367	359	371
	Outputs	Harvested mechanically	280	309	281	286	287	281
		N sold in crop products, incl rouhage export	5	29	4	9	10	5
	Total outputs		280	309	281	286	287	281
Field balance			**93**	**127**	**89**	**81**	**72**	**90**
	NEffField		75%	71%	76%	78%	80%	76%
Feed storage		Harvested mechanically	280	309	281	286	287	281
		N in imported crop products	55	54	88	54	54	55
		Imported cash crops (grain, rape)	21	0	0	0	0	0
		N sold in crop products, incl rouhage export	5	29	4	9	10	5
		N lost from processing/ stored crop products	26	30	26	27	27	26
		%loss of input	9%	10%	9%	9%	9%	9%

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

System		Baseline	Irrigated	NO3 feeding	Stall acidified slurry, broadc	Injected biogas	Nitrification inhibitors, 100 %
GHG results	[kg CO2-eq/y]						
CH4 enteric	[kg CO2-eq/y]	288170	288170	253808	288170	288170	288170
CH4 manure	[kg CO2-eq/y]	195314	195314	194391	69755	23717	195314
N2O manure	[kg CO2-eq/y]	50968	50968	58255	28374	10194	50968
N2O field	[kg CO2-eq/y]	124148	131777	120575	137976	141047	101922
Soil C change	[kg CO2-eq/y]	1214	-3311	308	-5292	19097	1002
Total direct G	[kg CO2-eq/y]	659813	662917	627336	518983	482224	637376
Indirect from N	[kg CO2-eq/y]	18446	18446	21035	1500	6584	18446
N2O-indirect le	[kg CO2-eq/y]	5539	11085	4313	8740	10361	5690
Total indirect	[kg CO2-eq/y]	23985	29531	25348	10241	16945	24136
GHG, direct +	[kg CO2-eq/y]	683798	692448	652684	529223	499168	661512
On farm land	[ha]	50	50	50	50	50	50
GHG results	[kg CO2-eq/ha/year]						
CH4 enteric	[kg CO2-eq/ha/year]	5763	5763	5076	5763	5763	5763
CH4 manure	[kg CO2-eq/ha/year]	3906	3906	3888	1395	474	3906
N2O manure	[kg CO2-eq/ha/year]	1019	1019	1165	567	204	1019
N2O field	[kg CO2-eq/ha/year]	2483	2636	2411	2760	2821	2038
Soil C change	[kg CO2-eq/ha/year]	24	-66	6	-106	382	20
Total GHG pe	[kg CO2-eq/ha/year]	13196	13258	12547	10380	9644	12748
Indirect from N	[kg CO2-eq/ha/year]	369	369	421	30	132	369
N2O-indirect le	[kg CO2-eq/ha/year]	111	222	86	175	207	114
Total indirect	[kg CO2-eq/ha/year]	480	591	507	205	339	483
GHG, direct +	[kg CO2-eq/ha/year]	13676	13849	13054	10584	9983	13230
Adjustment of	[kg CO2-eq/ha/year]	22	-471	21	-85	-105	15
Output of products							
Milk, kg delive	[kg/y]	496415	496415	486468	496415	496415	496415
Meat, ton LW	[ton LW/y]	10	10	10	10	10	10
Crop product	[ton DM]	37044	83115	33464	45577	47566	37126
Input							
Fertlizer, kg N	[N/ha]	56	56	15	34	45	57
Fixation	[N/ha]	108	171	115	84	84	105
Manure, kg N	[N/ha]	0	0	0	0	4	0
Feed [3)]							
- Cereals, kg	[kg DM/ha]	1402	1402	2268	1402	1402	1402
- Rape seed	[kg DM/ha]	0	0	0	0	0	0
- Rapeseed,	[kg DM/ha]	0	0	0	0	0	0
- Soy bean r	[kg DM/ha]	0	0	0	0	0	0
- Other	[kg DM/ha]	0	0	0	0	0	0
Diesel, l/ha estimate		117	130	117	117	117	117
Electricity, stable estimate		1222	1222	1222	1222	1222	1222

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

System		Italien_ Dairy	Irrigation	Nitrate feeding to the cows	Slurry acidified	Biogas	Nitrification inhibitors
GHG results per farm, kg CO2-eq/yr [1)]							
On-farm total direct GHG	[kg CO2-eq/ha/year]	13196	13258	12547	10380	9644	12748
On-farm total indirect GHG	[kg CO2-eq/ha/year]	480	591	507	205	339	483
On farm GHG, direct + indirect	[kg CO2-eq/ha/year]	13676	13849	13054	10584	9983	13230
Reduction (%)			-1%	5%	23%	27%	3%
On farm emissions (kg/liter)							
Total GHG		1.38	1.39	1.34	1.07	1.01	1.33
Reduction (%)			-1%	3%	23%	27%	3%
Pre-chain GHG from							
- Net Feed import	[kg CO2-eq/ha/year]	1508	1015	1275	644	623	744
- Fertilizer (N)	[kg CO2-eq/ha/year]	239	239	228	146	192	243
- Manure (N)	[kg CO2-eq/ha/year]	-10	-10	-3	-8	18	-10
- Diesel	[kg CO2-eq/ha/year]	388	397	388	388	388	388
- Electricity	[kg CO2-eq/ha/year]	800	800	800	800	800	800
Total pre-chain GHG emission	[kg CO2-eq/ha/year]	2926	2441	2688	1970	2022	2165
Total GHG before allocation	[kg CO2-eq/ha/year]	16602	16290	15742	12554	12005	15396
Output of products							
Milk, ton delivered	[kg/y]	496	496	486	496	496	496
Meat, ton LW	[ton LW/y]	10	10	10	10	10	10
Allocation of GHG, %		88.5%	88.5%	88.3%	88.5%	88.5%	88.5%
Total GHG per kg product							
Kg CO2/liter milk	Kg CO2/ liter milk	1480	1453	1429	1119	1071	1373
Reduction (%)			2%	3%	24%	28%	7%
Kg CO2/kg meat LW	Kg CO2/ kg meat LW	9650	9469	9337	7297	6978	8949

M-EU-013. Continental Mixed Dairy, Italian mixed dairy – Dairy farm Po Valle

4.1.1.1 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. Chapter 4.1.1 describes Maritime Grassland Beef, Chapter 4.1.2 Maritime Grassland Dairy, Chapter 4.1.3. Maritime Mixed Dairy, Chapter 4.1.4. Mediterranean Mixed Dairy and Chapter 4.1.5 Continental Mixed Dairy.

4.1.1. Maritime Grassland Beef – Irish Average National Beef, M-EU-002.

The model maritime grass-based Atlantic beef farm was a national average Irish beef farm simulated according to national statistics. As described in Foley et al. (2011) the national farm survey or NFS is the most representative measure available of current average levels of efficiency for beef farm systems in Ireland. It takes a farm accounts book approach to generate a detailed analysis of a random sample of representative farms. A subset of the NFS 2009 dataset comprising of 100 specialised suckler calf-to-beef systems was used in this analysis. The farm was a 47 ha grassland suckler calf to beef system located on a clay-ey soil. Average annual precipitation for the farm was estimated as 1085 mm and the annual average temperature was 10.5 C.

The herd consisted of 31 beef breed cows and their progeny. The mean live weight (LW) of suckler cow was 630 kg and the replacement rate was about 19%. All progeny were retained to slaughter with males finished as steers at 30 months of age and heifer finished at 26 months of age. Beef heifers average daily gain was 0.81 kg of LW/day and steers aver-aged 0.82 kg of LW gain/day. Beef heifers were finished at 690 kg of LW/animal and bulls were finished at 760 kg of LW animal. Overall, the

quantity of LW produced per ha was 463 kg. All animals were assumed to be adequately finished to industry standards.

The majority of Irish suckler beef systems are spring calving and grass-based. Thus, cows were assumed to calve in mid to late spring and graze pasture with their calves to mid-autumn. It was assumed that cows grazed in a set stocking system rather than a rotational paddock system. Suckler cows and their calves graze full time for 210 days. Replacement heifer calves were reared on-site. Surplus grass was harvested as silage mainly in May and July and fed to cows indoors during winter. On average gross yields of grass were 7.7t/DM per ha and grass utilization averaged about 70%. The grass was rainfed and requires no irrigation. The diet of suckler cows was mainly comprised of grazed grass (69%) with low levels of supplementary concentrate feed (368 kg of concentrate DM/livestock unit (LU)). Heifers and steers were finished off on grazed grass in a final third grazing period with in-creased concentrate supplementation for the final weeks.

On average 68 kg of synthetic N fertilizer was applied per ha. Organic nitrogen was mainly excreted by cattle on grass in situ. Over the winter period manure was either stored as solid manure or as slurry in underground slatted tanks. Manure was applied on pasture in spring, following the harvesting of grass silage and in autumn. On average 45-50 kg of N/ha from organic manure was applied to grassland mainly using a slurry splash plate spreader.

The simulation of the herd in FarmAc was firstly divided into 7 animal categories, namely suckler cows, beef heifers 0-1 year, steers 0-1 year, beef heifers 1-2 year, steers 1-2 year, beef heifers > 2 years and steers > 2 years. Subsequently, each category was divided into an outdoor and indoor herd. The forage diet of the herd was composed of grass silage indoors and no maize silage was fed. In total, 14 animal categories were simulated. The baseline scenario of Table 4.1.1.1.1 summarizes the key input data used to operate FarmAc for the national average Irish beef farm.

Mitigation options

Following a review of Irish research studies (e.g. Lovett et al., 2008, Foley et al., 2011) and the literature five mitigation options were tested on the showcase grass-based Atlantic beef farm using FarmAc at the farm level. The mitigation options implemented were

1. Earlier finishing of beef heifers and steers
2. Changing the grazing management – Extending the length of the grazing season
3. Improving pasture – Increasing grass and grass silage quality
4. Grass legume swards – Introducing white clover into the sward
5. Fertilisation rate – Increasing and reducing inorganic N fertiliser/ha.

The following sections describe each mitigation option and Table 4.1.1.1.1 shows the key data used to run each mitigation option in FarmAc.

Mitigation 1 (M1): Earlier finishing of beef heifers and steers

Most studies agree that reducing the age of finishing of beef cattle has a positive influence on the environment (Capper at al., 2011; Crosson et al., 2013). This is mainly because the measure increases the resource use efficiency and productivity of beef production systems. It also generally has a positive influence on farm profitability (Crosson et al., 2006).

To simulate this measure in FarmAc the average daily gain of beef heifers and steers of the baseline showcase farm was increased. Based on the analysis of Foley et al. (2011) the daily average lifetime live weight gain of growing and finishing beef cattle was increased by 3-5%, which resulted in an earlier finishing age. As a result, the feed requirements of growing and finishing animals were reduced in FarmAC by 2-3%.

Mitigation 2 (M2): Changing the grazing management

Increasing the quantity of grazed grass in the diet of cattle reduces the requirement for grass-silage in Atlantic maritime grass-based beef systems. This is reported to reduce enteric methane emissions because the grazing of pasture by cattle in temperate regions is less conducive to methanogenesis than feeding ryegrass silage (Woodward et al., 2001; Robert-son and Waghorn, 2002; O'Neill et al., 2011). In addition the strategy reduces carbon dioxide emissions from fossil fuel and improves profitability (O'Brien et al. 2014).

The length of the grazing season was increased by 5 days in FarmAc by changing the proportion of outdoor and indoor cattle in the herd. This reduced the demand for grass silage and increased the demand for grazed pasture. Based on Crosson et al. (2013) the demand of grass silage on a dry matter basis was reduced by 4% for beef cattle in the farm file of FarmAc and the demand for grazed grass was increased by 1.5-2%. This change had a minor positive influence on animal LW output (1% increase).

Mitigation 3 (M3): Improving pasture

Increasing forage quality improves the herbage feed conversion efficiency of grazing beef systems (Crosson et al. 2013). This also positively influences animal performance of grazing beef systems. This can be achieved in grazing beef system through regular monitoring of pasture. This allows grass surpluses to be identified earlier, which facilitates earlier removal thereby avoiding quick declines in grazed grass quality. Thus, this improves productivity and reduces GHG emissions and costs.

In FarmAc is was assumed improving the quality of grass increased grass digestibility and energy content. Thus, to simulate improvements in the quality of grazed grass the digestibility and energy values of the forage were modified. This was achieved similar to O'Brien et al. (2012) through increasing the energy and dry matter and digestibility values of pasture and grass silage by 1-2%.

Mitigation 4 (M4): Grass legume swards

White clover is reported to have a higher nutritive value than perennial ryegrass due to struc-tural carbohydrate content, higher digestible protein and a faster rate of

passage through the rumen. These qualities can result in higher herbage DM intake and subsequently improved animal LW performance compared to pure perennial ryegrass swards (Peyraud et al., 2009). Introducing legumes into grass swards has been reported by Hennessy et al. (2013) to im-prove herbage production at low and high N fertilizer rates. Similarly Peyraud et al. (2013) reported greater herbage production. The strategy also displaces the requirement for inorganic fertilizer from fossil fuel. This is widely reported to reduce GHG emissions from animal production systems e.g. Yan et al. (2013).

The baseline national average beef farm applied inorganic N fertiliser at a relatively low rate of 68 kg of N/ha. Based on Hennessy et al. (2013) and Enriquez-Hidalgo et al. (2014) including white clover in low N fertilized pasture (60-150 kg N/ha) increases herbage production (t DM/ha) by 15% and increases the clover content of the sward to 35%. In Farm Ac the clover grass mixture with a similar proportion (40%) as reported by Hennessy et al. (2013) was used to simulate the effect of adopting a grass legume sward. The gross grass yield of the clover grass mixture was increased by 15% to about 8.8 t/ha compared to the base and the herd size was increased in accordance with the yield change, which increased the farms stocking rate from 1.43 livestock units (LU)/ha to 1.57 LU/ha. In addition, the strategy had a positive influence on animal live weight output per animal.

Mitigation 5 (M5): Fertilisation rate

The application of synthetic N fertiliser influences herbage production and the environment. For instance, this strategy influences nitrous oxide and carbon dioxide emissions from fertiliser manufacture and also impacts on soil carbon and nitrogen fluxes. In general at low or high levels of N fertiliser Lovett et al. (2008) and O'Brien et al. (2012) have reported that re-ducing the rate of N application has a positive effect on GHG emissions. However, both of these studies assumed soil carbon did not change in response to changes in N fertiliser.

The effect of reducing N fertiliser in FarmAc was assessed by decreasing the rate of application per ha by 5%. Based on Keating and Kiely (2000) this reduced gross forage yield by 2-3%. However, according to Lovett et al. (2008) and O'Brien et al. (2012) reducing N fertilizer did not increase the net yield of grass as utilization was found to improve. Thus, within FarmAc herbage utilization was increased by 1-2%.

Additionally, we tested the effect of increasing the fertilisation rate by 5% in FarmAc. Again the forage response to increased fertilisation was modelled based on Irish research data such as Keating and Kiely (2000). In this case forage yield was increased by 1%. Thus, the herd size was also increased, but there was no change in farm size. The stocking rate therefore increased to 1.46 LU/ha.

Table 4.1.1.1.1. Key farm data used to model the national average Irish beef farm (baseline) and various mitigation options in FarmAc.

Item	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5

Farm size	47	45	47	47	47	47	45	47
Number of cows	34	34	34	34	40	34	34	39
Replacement rate, %	17	17	17	17	17	17	17	17
Livestock units (LU)	68	68	68	68	74	68	68	73
Heifer slaughter weight, kg/animal	692	692	692	692	692	692	692	692
Steer slaughter weight, kg/animal	760	760	760	760	760	760	760	760
Heifer age at slaughter, months	26	25	26	26	26	26	25	26
Steer age at slaughter, months	30	28	30	30	30	30	28	30
Live weight change, kg/LU	322	322	327	329	361	322	327	359
Gross grass yield, kg DM/ha	7696	7816	7777	7696	8837	7594	7902	8719
Grass net yield, kg DM/ha	5441	5532	5503	5441	6247	5441	5598	6164
Grazed grass, kg DM/cow	2598	2598	2666	2598	2732	2598	2666	2719
Grass silage, kg DM/cow	1188	1074	1139	1188	1250	1188	1024	1244
Concentrate, kg DM/cow	386	348	377	386	405	386	340	403
N fertiliser, kg N/ha	68	66	67	68	68	65	65	65
Manure landspread, kg N/ha	45	46	46	45	56	47	43	53

M1 = Earlier finishing M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Combined mitigation options

In addition to assessing individual mitigation options the effect of implementing more than one option together was also tested for national average Irish beef farm in FarmAc. The first combined option tested was earlier finishing and changing the grazing management and the second option tested was grass-legume swards combined with reduced fertilisation.

Results

Tables 4.1.1.1.2 to 4.1.1.1.4 show the simulated baseline N fluxes, C fluxes and GHG emissions of the national beef farm using FarmAc and the effects of the different mitigation options tested. The analysis showed that earlier finishing of beef heifers and steers reduced imported N and C onto the national average Irish beef farm and thereby influenced both N and C losses per ha from the farm. The mitigation option reduced gaseous N losses from housing 6-10% and caused a reduction in N leaching losses (3%). In addition, the strategy increased the efficiency of N use by animals by 3%. However, soil N2O emissions tended to increase (1%). The mitigation option had a positive influence on C stored in soil per ha, which increased by 25% compared to the base farm. Reducing finishing time of heifers and steers also influenced GHG emissions, which were mainly generated from enteric CH4 emissions (45%), soil N2O emissions from fields (35%) and manure (8%). The option caused a 2% reduction in total GHG emissions per ha and reduced total GHG emissions per unit of LW by 6% relative to the baseline.

Changing the grazing management by increasing the length of the grazing season 5 days slightly reduced imported N and C from feed (1%). The mitigation option caused a minor increase in gaseous N field losses, but decreased leaching losses (2%) and reduced N and C loss from manure storage. The strategy had little influence CO2 emissions from soil (1%). Extending the length of the grazing season reduced methane and N2O emissions from manure (4-5%) and ammonia emissions from housing (2-3%). Overall the strategy caused a slight reduction in total GHG emissions per ha (1%) and caused a 3% reduction in total GHG emissions per unit of LW.

Increasing the quality of pasture improved grass and silage digestibility, which slightly reduced ammonia and N2O emissions from manure (1%). The mitigation option did not influence C losses or C stored in soil. Increasing the quality of forage had little influence on enteric CH4 or total GHG emissions per ha but had a positive influence on live weight production (2%). Thus, the option reduced total GHG emissions per unit of LW by 2%.

Introducing grass-legume white clover swards had the greatest effect on C and N fluxes. The strategy caused N and C losses per ha from animals and manure to increase due to a rise in stocking rate. In addition, the farm fixed 80 kg of N/ha and the efficiency of N use increased from 6% to 7%. The combined strategy also reduced N leaching losses (13%) and caused a 3.6 fold increase in C stored in soils. Greenhouse gas emissions were increased from enteric CH4 and agricultural soils by 15% and 53%, respectively, using grass-legume swards. However, the change in C stored in soils caused total GHG emissions per ha to decrease by 10% relative to the base farm. Furthermore, the strategy increased animal LW output by 22%. Thus, grass-legume swards reduced total GHG emissions per unit of LW by more than 20% compared to the base.

The mitigation option to reduce the N fertilisation rate decreased gaseous N losses and reduced leaching losses by 2% from fertiliser, but had no effect on emissions from manure or enteric CH4. Reducing N fertiliser application reduced the quantity of

C stored in soil by 2% compared to the baseline farm. Therefore, despite reducing N2O losses from the soil, reducing N fertiliser application had no effect on total GHG emissions per ha and per unit of LW, because the strategy reduced the quantity of CO2 removed by the soil.

Combining the mitigation option extending the length of the grazing with earlier finishing of beef heifers and steers influenced both N and C losses from the national average beef farm. The combined strategy caused a minor increase in gaseous N field losses (1-2%), but decreased N leaching losses (5%) and reduced N and C loss from manure storage (5-11%). The strategies reduced the quantity of C and N imported in animal feed compared to the base farm (4-6%). The combined strategy reduced methane emissions from manure (25%) and ammonia emissions (11%) from housing. Overall simultaneously extending the length of the grazing and finishing cattle earlier reduced total GHG emissions per ha by 2% and reduced total GHG emissions per unit of LW by 9%.

The combined strategy of reducing N fertiliser per ha and adopting grass legume swards increased gaseous N losses from fields and housing, but the options increased the farms efficiency of N use from 6 to 7%. The combined strategy reduced N leaching losses and resulted in the farm fixing 78 kg of N/ha. The strategies caused a 3.4 fold increase in C storage relative to the base farm, which was less than simply adopting a grass-legume sward. Reducing N fertiliser and introducing white clover also increased animal and manure methane emissions because the strategies facilitated a higher farm stocking rate. However, the change in C stored in soil was greater than the increase in emissions. Thus, the combined strategy reduced GHG emissions per ha by 10%. In addition, adopting white clover and reducing N fertilisation increased animal LW production (21%). Thus, reducing N fertiliser and introducing white clover mitigated total GHG emissions per unit of LW by 26%. However, this was similar to the reduction obtained by simply adopting a grass-legume sward.

Table 4.1.1.1.2. FarmAC N flux results (kg N/ha) for the baseline national average Irish beef farm and the various mitigation options simulated

Scale	Item	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
Farm	Imported livestock feed	32	31	32	32	37	32	31	36
	Imported bedding	2	2	2	2	2	2	2	2
	N fixation	0	0	0	0	80	0	0	78
	N deposited from atmosphere	5	5	5	5	5	5	5	5
	N in fertiliser	68	66	67	68	68	65	65	65
	Imported	0	0	0	0	0	0	0	0
	N sold in crop products	4	4	4	4	5	3	3	5
	N sold in milk	0	0	0	0	0	0	0	0
	N exported in meat	12	13	12	12	15	12	13	15
	N in mortalities	0	0	0	0	0	0	0	0
	Exported manure	4	1	2	4	5	3	0	5
	Gaseous loss housing	8	8	8	8	10	8	7	10
	N lost from processing/stored crop products	9	8	8	9	11	9	8	11
	Gaseous loss storage	5	5	5	5	6	5	4	6
	Runoff	1	1	1	1	1	1	1	1
	Gaseous loss field	35	35	35	35	47	35	36	46
	Nitrate leaching	62	60	60	62	54	61	59	52
	Change in mineral N in soil	0	0	0	0	0	0	0	0

	Change in organic N in soil	0	0	0	0	0	0	0	0
Herd									
	Livestock feed consumed in housing	72	69	70	72	86	72	67	85
	Grazed	125	132	130	125	123	125	136	122
	Deposited in housing	55	51	53	55	66	55	50	65
	Deposited in field	130	136	135	130	129	130	141	127
	N sold in milk	0	0	0	0	0	0	0	0
	N exported in meat	12	13	12	12	15	12	13	15
	N in mortalities	0	0	0	0	0	0	0	0
	Efficiency of N use by livestock	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.07
Housing									
	Input from livestock	55	51	53	55	66	55	50	65
	Gaseous loss	8	8	8	8	10	8	7	10
	Sent to storage	46	44	45	46	56	46	42	55
Manure storage									
	Input from housing manure	46	44	45	46	56	46	42	55
	Bedding	2	2	2	2	2	2	2	2
	Feed wastage	6	6	6	6	8	6	6	8
	Gaseous loss	5	5	5	5	6	5	4	6
	Runoff from storage	1	1	1	1	1	1	1	1

Manure ex storage								
	49	46	47	49	59	49	44	58
Fields								
Manure applied								
	45	45	46	45	54	46	44	53
Harvested mechanically	59	56	56	59	72	58	53	71
Harvested by grazing								
	125	132	130	125	123	125	136	122

M1 = Earlier finishing M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Table 4.1.1.1.3. FarmAC C flux results for the baseline national average Irish beef farm and the various mitigation options simulated

Item	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
C fixed from atmosphere								
	7868	7968	7961	7868	10902	7834	8043	10757
C in imported manure								
	0	0	0	0	0	0	0	0
C in imported feed								
	455	430	448	455	522	455	425	515
C in imported bedding								
	0	0	0	0	0	0	0	0
C in exported milk								
	0	0	0	0	0	0	0	0
C in exported meat								
	107	112	110	109	131	107	115	129
C in mortalities								
	0	0	0	0	0	0	0	0
C in crop products sold								
	66	62	60	66	76	55	55	74
C in CO2 emitted by the soil								
	6311	6386	6382	6312	8411	6301	6440	8319
C in organic matter leached from the soil								
	0	0	0	0	0	0	0	0
CO-C from burning crop residues								
	0	0	0	0	0	0	0	0

CO2-C in gases from burning crop residues	0	0	0	0	0	0	0	0
Black carbon in gases from burning crop residues	0	0	0	0	0	0	0	0
Change in C stored in the soil	-145	-123	-123	-145	527	-148	-107	497

M1 = Earlier finishing M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Table 4.1.1.1.4. FarmAC greenhouse gas (GHG) results in CO_2 equivalents for the baseline national average Irish beef farm and the various mitigation options simulated

Scale	Item	Unit	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
Direct	Enteric CH_4	ha	3046	3080	3075	3046	3497	3046	3113	3451
	Manure CH_4	ha	348	279	332	348	393	348	262	388
	Manure N_2O emissions	ha	178	158	171	177	213	178	152	210
	Field N_2O emissions	ha	2343	2376	2368	2343	3596	2332	2395	3548
	Change in C stored in soil	ha	534	453	452	533	-1935	545	393	-1828
Indirect	Housing NH3 emissions	ha	39	36	38	39	47	39	35	47
	Manure storage NH3 emissions	ha	17	16	16	17	20	17	15	20
	NH3 emissions from field-applied manure	ha	25	25	26	25	30	26	24	30

	NH3 emissions from fertilisers	ha	13	12	12	13	13	12	12	12
	N2O emissions resulting from leaching of N	ha	217	211	212	217	188	214	206	184
	Total indirect emissions	ha	311	300	304	311	299	308	292	293
Total	Total GHG emissions	ha	6760	6646	6702	6758	6064	6757	6606	6062
Direct	Direct GHG emissions	Litre	13.9	13.1	13.5	13.6	10.2	13.9	12.7	10.3
Total	Total GHG emissions	Litre	14.6	13.7	14.2	14.3	10.7	14.6	13.3	10.8

M1 = Earlier finishing M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

4.1.1.2. S-EU-003 Maritime Grassland Beef – Derry Patrick

The showcase maritime grass-based Atlantic beef farm was a demonstration beef farm (Derrypatrick) located in Ireland (53°31' N, 6°39' W). The Derrypatrick farms goal is to establish a farm demonstrating optimal animal breeding, grass-based feed nutrient supply and technical efficiency. The farm is a 70 ha grassland suckler calf to beef system located on a clayey soil. Average annual precipitation for the farm is 863 mm and the annual average temperature was 10 C.

Derrypatrick farm is a spring calving system. The herd consists of 120 cows and their progeny. The first phase of the Derrypatrick Herd (2009-2012) involved a comparison of four cow breed types Limousin X Friesian (LF), Charolais X Limousin (CL), Limousin X Simmental (LS) and Charolais X Simmental (CS). For this analysis the most profitable breed type over the period (LF) was analysed. The mean live weight (LW) of this cow type was 630 kg and the replacement rate was about 10%. Beef heifers were slaughtered after a short final finishing phase at 20 months of age and bull were finished at 18 months. Bulls where kept indoors following their first grazing season whereas heifers grazed for a second season. Beef heifers average daily gain was 0.93 kg of LW/day and bulls averaged 1.24 kg of LW gain/day. Beef heifers were finished at 606 kg of LW/animal and bulls were finished at 717 kg of LW animal. Overall, the quantity of LW produced per ha was 1185 kg. All animals were finished to industry standards.

Cows calved in mid-spring and grazed pasture with their calves to mid-autumn in a rotational paddock system. Suckler cows and their calves graze full time for 240-250 days. Replacement heifer calves were reared off-site generally by a sub-contractor. Surplus grass was harvested as silage mainly in May and July and fed to cows indoors during winter. On average gross yields of grass were 12.5t/DM per ha and grass utilization averages 85%. The grass is rainfed and requires no irrigation. The diet of suckler cows was mainly comprised of grazed grass (75%) with low levels of supplementary concentrate feed (562 kg of concentrate DM/livestock unit (LU)). Bulls were finished indoors after 100 day feeding period where concentrate is offered ad libitum. Heifers were finished after a short indoor period following a second grazing period.

On average 183 kg of synthetic N fertilizer was applied per ha. Organic nitrogen was mainly excreted by cattle on grass in situ except for bulls following their first grazing season. Over the winter manure was either stored as solid manure or as slurry in underground slatted tanks. Manure was mainly applied on pasture in spring and following the harvesting of grass silage. On average 80-90 kg N/ha from organic manure is applied to grassland mainly using a slurry splash plate spreader.

The simulation of the herd in FarmAc was firstly divided into 5 animal categories, namely suckler cows, beef heifers 0-1 year, bulls 0-1 year, beef heifers 1-2 year and bulls 1-2 year. Subsequently, each category was divided into an outdoor and indoor herd. The forage diet of the herd was composed of grass silage indoors and no maize silage was fed. In total, 10 animal categories were simulated. The baseline

scenario of Table 4.1.1.2.1 summarizes the key input data used to operate FarmAc for the beef farm Derrypatrick.

Mitigation options

Following a review of Irish research studies (e.g. Lovett et al., 2008, Foley et al., 2011) and the literature five mitigation options were tested on the showcase grass-based Atlantic beef farm using FarmAc at the farm level. The mitigation options implemented were

1. Earlier finishing of beef heifers and steers
2. Changing the grazing management – Extending the length of the grazing season
3. Improving pasture – Increasing grass and grass silage quality
4. Grass legume swards – Introducing white clover into the sward
5. Fertilisation rate – Increasing and reducing inorganic N fertiliser/ha.

The following sections describe each mitigation option and Table 4.1.1.2.1 shows the key data used to run each mitigation option in FarmAc.

Mitigation 1 (M1): Earlier finishing of beef heifers and steers

Most studies agree that reducing the age of finishing of beef cattle has a positive influence on the environment (Capper at al., 2011; Crosson et al., 2013). This is mainly because the measure increases the resource use efficiency and productivity of beef production systems. It also generally has a positive influence on farm profitability (Crosson et al., 2006).

To simulate this measure in FarmAc the average daily gain of beef heifers and bulls of the baseline showcase farm was increased. Based on the analysis of Foley et al. (2011) the daily average lifetime live weight gain of growing and finishing beef cattle was increased by 3-5%, which resulted in an earlier finishing age. As a result, the feed requirements of growing and finishing animals were reduced in FarmAC by 3-5%.

Mitigation 2 (M2): Changing the grazing management

Increasing the quantity of grazed grass in the diet of cattle reduces the requirement for grass-silage in Atlantic maritime grass-based beef systems. This is reported to reduce enteric methane emissions because the grazing of pasture by cattle in temperate regions is less conducive to methanogenesis than feeding ryegrass silage (Woodward et al., 2001; Robert-son and Waghorn, 2002; O'Neill et al., 2011). In addition the strategy reduces carbon dioxide emissions from fossil fuel and improves profitability (O'Brien et al. 2014).

The length of the grazing season was increased by 5 days in FarmAc by changing the proportion of outdoor and indoor cattle in the herd. This reduced the demand for grass silage and increased the demand for grazed pasture. Based on Crosson et al. (2013) the demand of grass silage on a dry matter basis was reduced by 4% for beef

cattle in the farm file of FarmAc and the demand for grazed grass was increased by 1-2%. This change had a positive influence on animal LW output (1% increase).

Mitigation 3 (M3): Improving pasture

Increasing forage quality improves the herbage feed conversion efficiency of grazing beef systems (Crosson et al. 2013). This also positively influences animal performance of grazing beef systems. This can be achieved in rotational grazing beef system through regular monitoring of pasture. This allows grass surpluses to be identified earlier, which facilitates earlier removal thereby avoiding quick declines in grazed grass quality. Thus, this improves productivity and reduces GHG emissions and costs. In FarmAc is was assumed improving the quality of grass increased grass digestibility and energy content. Thus, to simulate improvements in the quality of grazed grass the digestibility and energy values of the forage were modified. This was achieved similar to O'Brien et al. (2012) through increasing the energy and dry matter and digestibility values of pasture and grass silage by 1-2%.

Mitigation 4 (M4): Grass legume swards

White clover is reported to have a higher nutritive value than perennial ryegrass due to struc-tural carbohydrate content, higher digestible protein and a faster rate of passage through the rumen. These qualities can result in higher herbage DM intake and subsequently improved animal LW performance compared to pure perennial ryegrass swards (Peyraud et al., 2009). Introducing legumes into grass swards has been reported by Hennessy et al. (2013) to im-prove herbage production at low and high N fertilizer rates. Similarly Peyraud et al. (2013) reported greater herbage production. The strategy also displaces the requirement for inor-ganic fertilizer from fossil fuel. This is widely reported to reduce GHG emissions from animal production systems e.g. Yan et al. (2013).

The baseline Derrypatrick farm applied inorganic N fertiliser at a rate of 190kg N/ha. Based on Hennessy et al. (2013) and Enriquez-Hidalgo et al. (2014) including white clover in moderately N fertilized pasture (150-250 kg N/ha) increases herbage production (t DM/ha) by 14% and increases the clover content of the sward to 25%. In Farm Ac the clover grass mixture with a similar proportion (20%) as reported by Hennessy et al. (2013) was used to simulate the effect of adopting a grass legume sward. The gross grass yield of the clover grass mixture was increased by 14% to about 14 t/ha compared to the base and the herd size was increased in accordance with the yield change, which increased the farms stocking rate from 2.70 LU/ha to 3 LU/ha. In addition, the strategy had a positive influence on animal live weight output per animal.

Mitigation 5 (M5): Fertilisation rate

The application of synthetic N fertiliser influences herbage production and the environment. For instance, this strategy influences nitrous oxide and carbon dioxide emissions from fertiliser manufacture and also impacts on soil carbon and nitrogen fluxes. In general at low or high levels of N fertiliser Lovett et al. (2008) and O'Brien et al. (2012) have reported that reducing the rate of N application has a positive effect

on GHG emissions. However, both of these studies assumed soil carbon did not change in response to changes in N fertiliser.

The effect of reducing N fertiliser in FarmAc was assessed by decreasing the rate of application per ha by 5%. Based on Keating and Kiely (2000) this reduced gross forage yield by 2-3%. However, according to Lovett et al. (2008) and O'Brien et al. (2012) reducing N fertilizer did not increase the net yield of grass as utilization was found to improve. Thus, within Far-mAc herbage utilization was increased by 1-2%.

Additionally, we tested the effect of increasing the fertilisation rate by 5% in FarmAc. Again the forage response to increased fertilisation was modelled based on Irish research data such as Keating and Kiely (2000). In this case forage yield was increased by 2%. Thus, the herd size was also increased, but there was no change in farm size. The stocking rate therefore increased to 2.76 LU/ha.

Table 4.1.1.2.1. Key farm data used to model Derrypatrick farm (baseline) and various mitigation options in FarmAC.

Item	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
Farm size	70	68	70	70	70	70	68	70
Number of cows	120	120	120	120	136	120	120	133
Replacement rate, %	10	10	10	10	10	10	10	10
Livestock units (LU)	189	189	189	189	215	189	189	210
Heifer slaughter weight, kg/animal	606	606	606	606	606	606	606	606
Steer slaughter weight, kg/animal	717	717	717	717	717	717	717	717
Heifer age at slaughter, months	20	19	20	20	20	20	19	20
Steer age at slaughter, months	18	17	18	18	18	18	17	18
Live weight change, kg/LU	413	413	413	420	435	413	412	435
Gross grass yield, kg DM/ha	12329	12380	12382	12329	13998	12055	12435	13687
Grass net yield, kg DM/ha	10429	10498	10500	10429	11840	10429	10572	11577

Grazed grass, kg DM/cow	2625	2633	2682	2625	2625	2625	2690	2625
Grass silage, kg DM/cow	1235	1166	1184	1235	1235	1235	1115	1235
Concentrate, kg DM/cow	562	499	554	562	562	562	491	562
N fertiliser, kg N/ha	183	184	184	183	183	174	184	174
Manure landspread, kg N/ha	89	84	88	89	102	91	82	100

M1 = Earlier finishing M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Combined mitigation options

In addition to assessing individual mitigation options the effect of implementing more than one option together was also tested for Derrypatrick farm in FarmAc. The first combined option tested was earlier finishing and changing the grazing management and the second option tested was grass-legume swards combined with reduced fertilisation.

Results

Tables 4.1.1.2.2 to 4.1.1.2.4 show the simulated baseline N fluxes, C fluxes and GHG emissions of Derrypatrick farm using FarmAc and the effects of the different mitigation options tested. The analysis showed that earlier finishing of beef heifers and steers reduced imported N and C onto Derrypatrick and thereby influenced both N and C losses per ha from the farm. The mitigation option reduced gaseous N losses from housing 5-14% and caused a minor reduction in N leaching losses (1%). In addition, the strategy increased the efficiency of N use by animals by 2%. However, soil N2O emissions tended to increase (1%). The mitigation option had a positive influence on C stored in soil per ha, which increased by 8% compared to the base farm. Reducing finishing time of heifers and steers also influenced GHG emissions, which were mainly generated from enteric CH4 emissions (52%) and soil N2O emissions from fields (42%). The option caused a minor reduction in total GHG emissions per ha (1%) and reduced total GHG emissions per unit of LW by 3% relative to the baseline.

Changing the grazing management by increasing the length of the grazing season 5 days slightly reduced imported N and C from feed (1%). The mitigation option caused a minor increase in gaseous N field losses and increased leaching losses (3%) but reduced N and C loss from manure storage. In addition, the strategy positively influenced C stored in soil (13%). Extending the length of the grazing season reduced methane and N2O emissions from manure (2-3%) and ammonia emissions from housing (2-3%). Overall the strategy had little or no influence on total GHG

emissions per ha but caused a minor decrease in total GHG emissions per unit of LW by 1%.

Increasing the quality of pasture improved grass and silage digestibility, which slightly reduced ammonia and N2O emissions from manure (1%). The mitigation option did not influence C losses or C stored in soil. Increasing the quality of forage had little influence on enteric CH4 or total GHG emissions per ha but had a positive influence on live weight production (2%). Thus, the option reduced total GHG emissions per unit of LW by 2%.

Adopting grass-legume white clover swards had the greatest effect on C and N fluxes. The strategy caused a 2.9 fold increase in the quantity of C stored in soil mainly driven by the fixation of N of 23 kg N/ha. Per ha, N and C losses from animals and manure increased due to an increase in stocking rate using white clover. The strategy also increased N leaching losses. However, the efficiency of N use on an animal basis increased from 7% to 9%. Greenhouse gas emissions were increased from enteric CH4 and agricultural soils by 14% and 27%, respectively, using grass-legume swards. However, the increase in live weight production from grass-legume swards was greater (20%) than the rise in total GHG emissions per ha (7%). Therefore, grass-legume swards reduced total GHG emissions per unit of LW by 11%.

The mitigation option to reduce the N fertilisation rate decreased gaseous N losses and reduced leaching losses by 2% from fertiliser, but had no effect on emissions from manure or enteric CH4. Reducing N fertiliser application reduced the quantity of C stored in soil by 35% compared to the baseline farm. Therefore, despite reducing N2O losses from the soil, reducing N fertiliser application caused total GHG emissions per ha and per unit of LW to increase by 2%, because the strategy reduced the quantity of CO2 removed by the soil.

Combining the mitigation option extending the length of the grazing with earlier finishing of beef heifers and steers influenced both N and C losses from the Derrypatrick farm. The combined strategy caused a minor increase in gaseous N field losses (1-2%) and increased N leaching losses (4%) but reduced N and C loss from manure storage (5-13%). The strategies had an additive influence on increasing C stored in soil (23%) and reduced the quantity of C and N imported in animal feed compared to the base farm. The combined strategy reduced methane emissions from manure (16%) and ammonia emissions (10%) from housing. Overall simultaneously extending the length of the grazing and finishing cattle earlier reduced total GHG emissions per ha by 2% and reduced total GHG emissions per unit of LW by 4%.

The combined strategy of reducing N fertiliser per ha and adopting grass legume swards increased gaseous N losses from fields and housing, but the options increased the farms efficiency of N use from 7 to 9%. The combined strategy increased N leaching losses and resulted in the farm fixing 26 kg of N/ha. The strategies caused a 2.5 fold increase in C storage relative to the base farm, which was less than simply adopting a grass-legume sward. Reducing N fertiliser and introducing white clover also increased animal and manure me-thane emissions because the strategies facilitated a higher farm stocking rate. However, there was a

greater increase in live weight production (17%) than total GHG emissions per ha (7%). Thus, reducing N fertiliser and introducing white clover mitigated total GHG emissions per unit of LW by 9%. However, this was less than the reduction obtained by only adopting a grass-legume sward.

Table 4.1.1.2.3. FarmAC C flux results for the baseline Derrypatrick beef farm and the various mitigation options simulated

Item	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
C fixed from atmosphere	15250	15338	15356	15250	17308	14895	15453	16919
C in imported manure	0	9	2	0	0	0	0	0
C in imported feed	1178	1099	1167	1178	1340	1217	1094	1311
C in imported bedding	0	0	0	0	0	0	0	0
C in exported milk	0	0	0	0	0	0	0	0
C in exported meat	259	264	260	263	310	259	266	303
C in mortalities	0	0	0	0	0	0	0	0
C in crop products sold	2	7	5	2	2	2	2	2
C in CO2 emitted by the soil	11914	11972	11995	11916	13135	11700	12074	12884
C in organic matter leached from the soil	0	0	0	0	0	0	0	0
CO-C from burning crop residues	0	0	0	0	0	0	0	0
CO2-C in gases from burning crop residues	0	0	0	0	0	0	0	0
Black carbon in gases from burning crop residues	0	0	0	0	0	0	0	0
Change in C stored in the soil	204	220	230	205	598	130	252	517

M1 = Earlier finishing M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Table 4.1.1.2.2. FarmAC N flux results (kg N/ha) for the baseline Derrypatrick beef farm and the various mitigation options simulated

Scale	Item	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
Farm	Imported livestock feed	79	75	79	79	90	82	75	88
	Imported bedding	3	3	3	3	4	3	3	4
	N fixation	0	0	0	0	23	0	0	26
	N deposited from atmosphere	5	5	5	5	5	5	5	5
	N in fertiliser	183	184	184	183	183	174	184	174
	Imported	0	1	0	0	0	0	0	0
	N sold in crop products	0	1	0	0	0	0	0	0
	N sold in milk	0	0	0	0	0	0	0	0
	N exported in meat	29	30	29	30	35	29	30	34
	N in mortalities	0	0	0	0	0	0	0	0
	Exported manure	13	13	11	13	16	11	8	18
	Gaseous loss housing	15	14	15	15	17	15	14	17
	N lost from processing/stored crop products	16	15	15	16	18	15	14	18
	Gaseous loss storage	10	9	9	10	11	10	9	11
	Runoff	2	2	2	2	2	2	2	2
	Gaseous loss field	82	82	83	82	92	80	83	89
	Nitrate leaching	104	103	107	104	114	102	108	109

	Change in mineral N in soil	0	0	0	0	0	0	0	0
	Change in organic N in soil	0	0	0	0	0	0	0	0
Herd									
	Livestock feed consumed in housing	154	148	151	154	177	154	144	173
	Grazed	250	256	256	250	219	250	263	214
	Deposited in housing	112	105	108	111	128	112	101	125
	Deposited in field	263	269	270	263	234	263	277	229
	N sold in milk	0	0	0	0	0	0	0	0
	N exported in meat	29	30	29	30	35	29	30	34
	N in mortalities	0	0	0	0	0	0	0	0
	Efficiency of N use by livestock	0.07	0.07	0.07	0.07	0.09	0.07	0.07	0.09
Housing									
	Input from livestock	112	105	108	111	128	112	101	125
	Gaseous loss	15	14	15	15	17	15	14	17
	Sent to storage	96	90	93	96	110	96	87	108
Manure storage									
	Input from housing manure	96	90	93	96	110	96	87	108
	Bedding	3	3	3	3	4	3	3	4
	Feed wastage	14	13	13	14	16	14	13	16

	Gaseous loss							
		10	9	9	10	11	10	9	11
	Runoff from storage	2	2	2	2	2	2	2	2
	Manure ex storage	102	96	99	102	117	102	93	114
Fields									
	Manure applied								
		89	84	88	89	102	91	85	97
	Harvested mechanically	104	101	101	104	121	102	97	118
	Harvested by grazing	250	256	256	250	219	250	263	214

M1 = Earlier finishing M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Table 4.1.1.2.4. FarmAC greenhouse gas (GHG) results in CO_2 equivalents for the baseline Derrypatrick beef farm and the various mitigation options simulated

Scale	Item	Unit	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
Direct	Enteric CH_4	ha	5853	5857	5887	5853	6645	5853	5893	6498
	Manure CH_4	ha	614	530	601	615	685	614	515	670
	Manure N_2O emissions	ha	353	317	343	352	404	353	306	395
	Field N_2O emissions	ha	4696	4738	4753	4695	5956	4620	4792	5825
	Change in C stored in soil	ha	-749	-808	-844	-752	-2192	-478	-923	-1897
Indirect	Housing NH3 emissions	ha	71	67	69	71	82	71	64	80
	Manure storage NH3 emissions	ha	31	29	30	31	35	31	28	35

	NH3 emissions from field-applied manure	ha		43	41	43	43	49	45	41	47
	NH3 emissions from fertilisers	ha		90	90	90	90	90	82	89	82
	N2O emissions resulting from leaching of N	ha		364	362	376	365	401	358	380	385
	Total indirect emissions	ha		600	589	608	600	657	588	603	628
Total	Total GHG emissions	ha		11367	11223	11347	11363	12156	11550	11185	12120
Direct	Direct GHG emissions		Litre	9.66	9.33	9.58	9.48	8.61	9.83	9.24	8.80
Total	Total GHG emissions		Litre	10.20	9.85	10.12	10.01	9.10	10.36	9.76	9.28

M1 = Earlier finishing M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

4.1.2. Maritime Grassland Dairy

4.1.2.1. Maritime Grassland Dairy – Greenfield, M-EU-003.

The model maritime grass-based Atlantic dairy farm M-EU-00 was the greenfield demonstration farm located in Ireland (52°39' N, 7°14' W). The aims of the greenfield farm include

1. To demonstrate best practise in the design, construction and operation of a low cost grass based milk production system to Irish dairy farmers within the constraints of commercial farm practise.
2. To provide a financial return in excess of capital costs and the opportunity costs of risk free investment.
3. To actively seek labour productivity gains through the adoption of technologies and practices that reduce labour requirement or make the work environment more satisfying
4. To operate an efficient and well organised business unit
5. To use environmental and animal welfare best practice, while enhancing profitability.

The total area of the greenfield farm is 117 ha of which 113 ha is usable permanent grassland. The farm is located on a sandy loam soil. Rainfall averages about 850 mm per annum and the annual average temperature was 10 C. The greenfield dairy farm is a spring calving herd where cows are turned out to pasture directly post calving and annually achieve an average grazing season of 270-285 full days. All male calves are sold at 2 weeks. Re-placement heifer calves are removed a few weeks after birth and replacement heifer calves are contract reared off farm. Typically contract reared heifers calve at 24-25 months of age.

The herd size in 2012 averaged 295 cows and cows produced about 4870 kg of milk per cow/year that consisted of 4.56% milk fat and 3.67% milk protein. This was equivalent to about 400 kg of milk solids per cow. The herd was largely comprised of New Zealand Holstein Friesian cows, crossbred New Zealand Holstein Friesian and Jersey cows and Norwegian Red cows. The mean live weight was 500 kg and the replacement rate was 24%. Cows calved in early spring and grazed from late January/early February to early November. Sur-plus grass was harvested as silage mainly as first cut silage in May and second cut silage in July and fed to cows indoors during winter. Baled grass silage was purchased when necessary to supply sufficient forage over the winter period. On average gross yields of grass were 12.4t/DM per ha and grass utilization averaged 85%. The grass is rainfed and requires no irrigation. The total diet of cows was mainly comprised of grazed grass (75%) with low levels of supplementary concentrate feed (307 kg DM/cow per year). On average 260 kg of syn-thetic N fertilizer was applied per ha. Organic nitrogen is mainly excreted by cows on grass in situ. Over winter manure is stored in manure is stored in a lagoon and applied to pasture in early spring and summer using an umbilical system. On

average 45 kg N/ha from slurry is applied to grassland using an umbilical system of application.

The simulation of the herd in FarmAc was divided into an outdoor and indoor herd. The forage diet of the herd was composed of grass silage indoors and no maize silage was fed. The majority of milk was produced by grazing cows and concentrate was fed to cows in early spring and mid to late autumn. Therefore the majority of concentrate was consumed by the outdoor herd. The baseline scenario of Table 4.1.2.1.1 summarizes the key input data used to operate FarmAc for the greenfield dairy farm.

Mitigation options

Following a review of Irish research studies (e.g. Lovett et al., 2008, Foley et al., 2011) and the literature five mitigation options were tested on the showcase grass-based Atlantic dairy farm using FarmAc at the farm level. The mitigation options implemented were

1. Improving total genetic merit of dairy cows
2. Changing the grazing management – Extending the length of the grazing season
3. Improving pasture – Increasing grass and grass silage quality
4. Grass legume swards – Introducing white clover into the sward
5. Fertilisation rate – Increasing and reducing inorganic N fertiliser/ha.

The following sections describe each mitigation option and Table 4.1.2.1.1 shows the key data used to run each mitigation option in FarmAc.

Mitigation 1 (M1): Improving total genetic merit of dairy cows

In general, research studies (e.g. Schils et al., 2005; Lovett et al., 2006; Weiske et al., 2006; Beukes et al., 2010) indicate that improving the genetic merit of dairy cows for fertility, survival and milk yield reduces emissions per unit of milk. This is mainly because the measure increases the efficiency and productivity of dairy production systems, which is widely reported to reduce greenhouse gas (GHG) emissions per unit of production (Capper et al. 2009; O'Brien et al. 2010). It also has a positive impact on farm profitability (O'Brien et al. 2014).

To simulate this measure in FarmAc the genetic merit of dairy cows was firstly related to milk produced, live weight, fertility and health. The milk performance per cow was increased by 5% without adversely effecting cow fertility, longevity and survival. Milk performance was changed in the parameter file of Farm AC by reducing the average maintenance requirements of dairy cows.

Mitigation 2 (M2): Changing the grazing management

Increasing the quantity of grazed grass in the diet of dairy cows reduces the requirement for grass-silage in Atlantic maritime grass-based dairy systems. This is reported to reduce enteric methane emissions because the grazing of pasture by cows in temperate regions is less conducive to methanogenesis than feeding ryegrass silage (Woodward et al., 2001; Robertson and Waghorn, 2002; O'Neill et al.,

2011). In addition the strategy reduces carbon dioxide emissions from fossil fuel and improves profitability (O'Brien et al. 2014).

The length of the grazing season was increased by 5 days in FarmAc by changing the proportion of outdoor and indoors cows in the herd. This reduced the demand for grass silage and increased the demand for grazed pasture. Based on Lovett et al. (2008) the demand of grass silage on a dry matter basis was reduced by 4-6% for dairy cattle in the farm file of FarmAc and the demand for grazed grass was increased by 1-2%. This change had a positive influence on milk output (1.5% increase).

Mitigation 3 (M3): Improving pasture

Increasing forage quality improves the digestibility of forage, which positively influences animal performance of grazing dairy systems (Beukes et al. 2010). This can be achieved in rotational grazing dairy system through regular monitoring of pasture. This allows grass surpluses to be identified earlier, which facilitates earlier removal thereby avoiding quick declines in grazed grass quality. Thus, this improves productivity and reduces GHG emissions and costs.

In FarmAc is was assumed improving the quality grass increased grass digestibility and energy content. Thus, to simulate improvements in the quality of grazed grass the digestibility and energy values of the forage were modified. This was achieved similar to O'Brien et al. (2012) through increasing the energy and dry matter and digestibility values of pasture and grass silage by 1-2%.

Mitigation 4 (M4): Grass legume swards

White clover is reported to have a higher nutritive value than perennial ryegrass due to structural carbohydrate content, higher digestible protein and a faster rate of passage through the rumen. These qualities can result in higher herbage DM intake and subsequently increased milk production compared to pure perennial ryegrass swards (Harris et al, 1997; Woodfield and Clark, 2009). Introducing legumes into grass swards has been reported by Hennessy et al. (2013) to improve herbage production at low and high N fertilizer rates. In addition, the study reported improved milk performance by including legumes. The strategy also displaces the requirement for inorganic fertilizer from fossil fuel. This is widely reported to reduce GHG emissions from animal production systems e.g. Yan et al. (2013).

The baseline greenfield farm used relatively high level of N fertiliser/ha (260kg N/ha). Based on Hennessy et al. (2013) and Enriquez-Hidalgo et al. (2014) including white clover in high N fertilizer pasture (>250 kg N/ha) increases herbage production (t DM/ha) by 8% and increases the clover content of the sward to 20%. In Farm Ac the clover grass mixture with the same proportion reported by Hennessy et al. (2013) was used to simulate the effect of adopting a grass legume sward. The gross grass yield of the clover grass mixture was increased by 8% to about 13.1 t/ha compared to the base and the herd size was increased in accordance with the yield change, which increased the farms stocking rate to 2.76 cow/ha. In addition, changing the diet to clover grass mixture increase milk output per cow by 3% similar to the results of Enriquez-Hidalgo et al. (2014).

Mitigation 5 (M5): Fertilisation rate

The application of synthetic N fertiliser influences herbage production and the environment. For instance, this strategy influences nitrous oxide and carbon dioxide emissions from fertiliser manufacture and also impacts on soil carbon and nitrogen fluxes. In general at low or high levels of N fertiliser Lovett et al. (2008) and O'Brien et al. (2012) have reported that re-ducing the rate of N application has a positive effect on GHG emissions. However, both of these studies assumed soil carbon did not change in response to changes in N fertiliser.

The effect of reducing N fertiliser in FarmAc was assessed by decreasing the rate of application per ha by 5%. Based on Keating and Kiely (2000) this reduced gross forage yield by 2-3%. However, according to Lovett et al. (2008) and O'Brien et al. (2012) reducing N fertilizer did not increase the net yield of grass as utilization was found to improve. Thus, within Far-mAc herbage utilization was increased by 1-2%.

Additionally, we test the effect of increasing the fertilisation rate by 5% in FarmAc. Again the forage response to increased fertilisation was modelled based on Irish research data such as Keating and Kiely (2000). In this case forage yield was increased by 2%. Thus, the herd size was also increased, but there was no change in farm size. The stocking rate therefore increased to 2.67 cows/ha.

Table 4.1.2.1.1. Key farm data used to model greenfield farm (baseline) and various mitigation options in FarmAc.

Item	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
Farm size	113	113	113	113	113	113	113	113
Number of cows	295	295	295	295	312	295	295	309
Replacement rate, %	24	24	24	24	24	24	24	24
Milk yield, kg/cow	4877	5121	4932	5009	5057	4877	5180	5057
Gross grass yield, kg DM/ha	12411	12411	12438	12411	13130	12145	12438	12984
Grass net yield, kg DM/ha	10523	10523	10564	10523	11133	10523	10564	11009
Grazed grass, kg DM/cow	3255	3255	3315	3255	3255	3255	3315	3258
Grass silage, kg DM/cow	773	773	732	773	773	773	732	773
Concentrate, kg DM/cow	307	307	308	307	307	307	308	307
N fertiliser, kg N/ha	265	265	268	265	265	252	268	251

Manure landspread, kg N/ha	45	45	45	45	45	45	45	45

M1 = Genetic improvement M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Combined mitigation options

In addition to assessing individual mitigation options the effect of implementing more than one option together was also tested for the greenfield farm in FarmAc. The first combined option tested was genetic improvement and changing the grazing management and the second option tested was grass-legume swards combined with reduced fertilisation.

Results

Tables 4.1.2.1.2 to 4.1.2.1.4 show the simulated baseline N fluxes, C fluxes and GHG emissions of the greenfield farms using FarmAc and the effects of the different mitigation options tested. The analysis showed that improving genetic merit of dairy cows had little or no effect on the N or C losses per ha from the farm, but the strategy improved animal milk performance (5%) and increased the efficiency of N used by animal to 20.5%. Thus, per unit of milk N and C losses to the environment were reduced. Improving genetic merit had a minor effect on total GHG emissions per ha, which were mainly composed of enteric CH4 emissions (51%) and soil N2O emissions from the field (43%). However, per unit of milk the mitigation option reduced total GHG emissions by approximately 5%.

Changing the grazing management by increasing the length of the grazing season 5 days caused a minor increase in gaseous N field losses and increased leaching losses (1-2%) but reduced N and C loss from manure storage. In addition, the strategy positively influenced C stored in soil (10%) and slightly improved milk production (1%). The strategy reduced me-thane emissions from manure (5%) and ammonia emissions from housing (5%). Overall the strategy had little or no influence on total GHG emissions per ha but caused a minor reduction in total GHG emissions per unit of milk (1%).

Increasing the quality of pasture improved grass and silage digestibility, which reduced ammonia and N2O emissions from manure by 1-2%. The mitigation option did not influence C losses or C stored in soil. Increasing the quality of forage had little influence on enteric CH4 or total GHG emissions per ha but had a positive influence on animal milk performance (3%). As a result, the option reduced total GHG emissions per unit of milk by 3%.

Implementing grass-legume white clover swards affected both C and N fluxes. The strategy caused a 2 fold increase in the quantity of C stored in soil mainly driven by the fixation of N of 21 kg N/ha. The N and C losses per ha from animals and manure increased due to an increase in stocking rate using white clover. However, the efficiency of N use on animal basis increased to 23%. The strategy increase the quantity of N stored in soil, which explains in part the decline in N leaching losses.

Greenhouse gas emissions were increased from enteric CH4 and agricultural soils by 6% and 17%, respectively, using grass-legume swards. However, the increase in milk production from grass-legume swards was greater than the rise in total GHG emissions per ha. Therefore, grass-legume swards reduced total GHG emissions per unit of milk by 5%.

The mitigation option to reduce the N fertilisation rate decreased gaseous N losses by 2% from fertiliser and reducing leaching losses by 4%. However, the mitigation option had no effect on emissions from manure or enteric CH4. Reducing N fertiliser application also reduced the amount of N stored in soil compared to the baseline greenfield farm. Thus, the mitigation option reduced the quantity of C stored in soil by 35% compared to the baseline farm. Therefore, despite reducing N2O losses from the soil, reducing N fertiliser application caused total GHG emissions per ha and per unit of milk to slightly increase (1%), because the strategy reduced the quantity of CO2 removed by the soil relative to the base farm.

The combined mitigation option extending the length of the grazing and improving genetic merit of dairy cows influenced N and C losses from the farm. The combined strategy caused a minor increase in gaseous N field losses (1-2%) but reduced N and C loss from manure storage (5-6%) and had no effect on N leaching. The strategies increased C stored in soil (10%) and improving milk production (6%) compared to the base farm. The combined strategy reduced methane emissions from manure (5%) and ammonia emissions (6%) from housing. Overall the combined strategy had a minor influence on total GHG emissions per ha (1%), but reduced total GHG emissions per unit of milk by 6%.

Combining the option reducing N fertiliser per ha and adopting grass legume swards in-creased gaseous N losses from fields and housing, but the options increased the farms efficiency of N use to 23%. Furthermore, N leaching losses were reduced by 30% and soil C and N storage increased. As a result, the increase in C storage was less than simply adopting a grass-legume sward. Reducing N fertiliser and introducing white clover also increased methane emissions because the strategies facilitated a higher farm stocking rate. However, there was a greater increase in milk production than total GHG emissions per ha. Thus, the strategy reduced total GHG emissions per unit of milk by 4%, which was similar to the reduction obtained by only adopting a grass-legume sward.

Table 4.1.2.1.3. FarmAc C flux results for the baseline greenfield dairy farm and the various mitigation options simulated

Item	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
C fixed from atmosphere	15504	15505	15585	15505	16648	15198	15586	16462
C in imported manure	24	26	36	28	0	24	38	0

C in imported feed	552	552	540	552	511	562	540	506
C in imported bedding	0	0	0	0	0	0	0	0
C in exported milk	637	669	643	654	699	637	676	691
C in exported meat	6	6	6	6	6	6	6	6
C in mortalities	0	0	0	0	0	0	0	0
C in crop products sold	2	2	3	2	3	2	3	1
C in CO2 emitted by the soil	12191	12192	12251	12193	12816	11965	12253	12707
C in organic matter leached from the soil	0	0	0	0	0	0	0	0
CO-C from burning crop residues	0	0	0	0	0	0	0	0
CO2-C in gases from burning crop residues	0	0	0	0	0	0	0	0
Black carbon in gases from burning crop residues	0	0	0	0	0	0	0	0
Change in C stored in the soil	197	197	216	198	404	128	217	370

M1 = Genetic improvement M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Table 4.1.2.1.2. FarmAc N flux results (kg N/ha) for the baseline greenfield dairy farm and the various mitigation options simulated

	Item	Baseline	M1	M2	M3	M4	M5	Scale	M4+M5
Farm	Imported livestock feed	43	43	43	43	42	43	43	42
	Imported bedding	2	2	2	2	2	2	2	2
	N fixation	0	0	0	0	21	0	0	21
	N deposited from atmosphere	5	5	5	5	5	5	5	5
	N in fertiliser	265	265	268	265	265	252	268	251
	Imported	4	4	5	4	0	4	6	0
	N sold in crop products	0	0	0	0	0	0	0	0
	N sold in milk	73	77	74	75	80	73	78	79
	N exported in meat	1	1	1	1	1	1	1	1
	N in mortalities	0	0	0	0	0	0	0	0
	Exported manure	0	0	0	0	5	0	0	5
	Gaseous loss housing	6	5	5	5	7	6	5	7
	N lost from processing/stored crop products	7	7	7	7	10	7	7	10
	Gaseous loss storage	2	2	2	2	3	2	2	3
	Runoff	0	0	0	0	0	0	0	0
	Gaseous loss field	87	87	88	87	91	85	88	89
	Nitrate leaching	119	116	121	118	84	114	118	76

	Change in mineral N in soil	6	6	6	6	5	6	6	5
	Change in organic N in soil	17	17	19	17	49	11	19	51
Herd									
	Livestock feed consumed in housing	79	79	77	79	93	79	77	92
	Grazed	299	299	304	299	245	299	304	242
	Deposited in housing	42	42	40	41	51	42	40	51
	Deposited in field	263	259	267	261	205	263	267	203
	N sold in milk	73	77	74	75	80	73	74	79
	N exported in meat	1	1	1	1	1	1	1	1
	N in mortalities	0	0	0	0	0	0	0	0
	Efficiency of N use by livestock	0.20	0.20	0.20	0.20	0.24	0.20	0.20	0.24
Housing									
	Input from livestock	42	42	40	41	51	42	40	51
	Gaseous loss	6	5	5	5	7	6	5	7
	Sent to storage	37	36	35	36	45	37	35	44
Manure storage									
	Input from housing manure	37	36	35	36	45	37	35	44
	Bedding	2	2	2	2	2	2	2	2
	Feed wastage	5	5	5	5	7	5	5	7

	Gaseous loss	2	2	2	2	3	2	2	3
	Runoff from storage	0	0	0	0	0	0	0	0
	Manure ex storage	41	41	39	41	50	41	39	50
Fields									
	Manure applied	45	45	45	45	45	45	45	45
	Harvested mechanically	50	50	47	50	68	49	47	67
	Harvested by grazing	299	299	304	299	245	299	304	242

M1 = Genetic improvement M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Table 4.1.2.1.4. FarmAc greenhouse gas (GHG) results in CO_2 equivalents for the baseline greenfield dairy farm and the various mitigation options simulated

Scale	Item	Unit	M1	M2	M4	M5	M1+M2	M4+M5
Direct	Enteric CH_4	ha	6074	6098	6427	6074	6098	6351
	Manure CH_4	ha	679	643	776	679	643	766
	Manure N_2O emissions	ha	203	194	248	204	192	245
	Field N_2O emissions	ha	5084	5152	5976	4983	5137	5871
	Change in C stored in soil	ha	-724	-793	-1480	-471	-794	-1357
Indirect	Housing NH3 emissions	ha	26	25	33	26	24	32
	Manure storage NH3 emissions	ha	2	2	3	2	2	3
	NH3 emissions from field-applied manure	ha	23	22	23	23	22	23
	NH3 emissions from fertilisers	ha	125	126	125	122	126	122

	N2O emissions resulting from leaching of N	ha	408	426	295	401	415	267
	Total indirect emissions	ha	583	601	478	574	590	447
Total	Total GHG emissions	ha	11899	11895	12424	12044	11867	12323
Direct	Direct GHG emissions	Litre	0.85	0.88	0.85	0.90	0.83	0.86
Total	Total GHG emissions	Litre	0.89	0.92	0.89	0.95	0.88	0.89

M1 = Genetic improvement M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

4.1.2.2. Maritime Grassland Dairy – Irish Average National Dairy, M-EU-004.

The model maritime grass-based Atlantic dairy farm M-EU-004 was a national average Irish dairy farm modelled using national statistics. Spring calving grass-based dairy farms are the dominant milk production system in Ireland. The main data source employed in this analysis was the Irish national farm survey or NFS (Hennessy et al., 2011). The NFS was established in 1972 and has been published on an annual basis since then. Overall, there are approximately 900-1,100 farms in the NFS each year. Each farm is assigned a national aggregation or weighting factor, calculated using data from the central statistics office, but only farms that have a gross output of €4,000/farm are included in the sample. In 2011, 1,022 farms participated in the survey and were weighted to represent a population of 105,535 farms. Many farmers stay in the sample for several years, but after a certain period, farms drop out and new farms are introduced to keep the sample representative. Farms are classified into farming systems, based on the dominant farm enterprise which is calculated on a standard gross output basis. The NFS distinguishes between six farming systems: dairying, mixed livestock, cattle rearing, cattle other, mainly sheep and tillage.

For the model average Irish national dairy farm only spring dairy farming systems were considered as this is the dominant method of milk production (90%). The farm size was estimated as 35 ha and assumed to be located on clay soil type. Rainfall was estimated as 1080 mm per annum and the annual temperature was 11 C. The mean date of calving was taken to be mid-March. Cows were generally turnout to grass after calving for 220-240 days. It was assumed that all male calves were sold after 1 month. Replacement heifer calves were assumed to be raised off the milking platform or contract reared off farm. Typically replacement heifers calve at 24-26 months of age.

The herd size was 66 cows producing approximately 4980 kg of milk per cow that was comprised of 3.94% milk fat and 3.36% milk protein. This was equivalent to 363 kg of milk solids per cow. The herd was assumed to comprise of Holstein Friesian cows. The mean live weight was 550 kg and the replacement rate was estimated at 25%. The farm stocking rate was 1.8 cows/ha. Grass silage was harvested primarily as first cut silage in May and second cut silage in July. On average gross yields of grass were 8.6 t/DM per ha and grass utilization averaged 82%. The grass is rainfed and requires no irrigation. The total diet of cows was mainly comprised of grazed grass (60%) with moderate levels of supplementary concentrate feed (875 kg DM/cow per year). On average 148 kg of synthetic N fertilizer was applied per ha. Organic nitrogen was mainly excreted by cows on grass in situ.

A survey of manure management systems shows that slurry tanks under slatted cubical buildings are the most common method of storing manure. Slurry is applied to pasture in spring and after first and second cut grass silage in summer. On average 55 kg N/ha from slurry is applied to grassland typically using a slurry splash spreader.

The simulation of the herd in FarmAc was divided into an outdoor and indoor herd. The forage diet of the herd was composed of grass silage indoors and no maize

silage was fed. The majority of milk was produced by grazing cows and concentrate was fed to cows throughout spring and mid to late autumn. Therefore the majority of concentrate was consumed by the outdoor herd. The baseline scenario of Table 4.1.2.2.1 summarizes the key input data used to operate FarmAc for the national average Irish dairy farm.

Mitigation options

Following a review of Irish research studies (e.g. Lovett et al., 2008, Foley et al., 2011) and the literature five mitigation options were tested on the showcase grass-based Atlantic dairy farm using FarmAc at the farm level. The mitigation options implemented were

1. Improving total genetic merit of dairy cows
2. Changing the grazing management – Extending the length of the grazing season
3. Improving pasture – Increasing grass and grass silage quality
4. Grass legume swards – Introducing white clover into the sward
5. Fertilisation rate – Increasing and reducing inorganic N fertiliser/ha.

The following sections describe each mitigation option and Table 4.1.2.2.1 shows the key data used to run each mitigation option in FarmAc.

Mitigation 1 (M1): Improving total genetic merit of dairy cows

In general, research studies (e.g. Schils et al., 2005; Lovett et al., 2006; Weiske et al., 2006; Beukes et al., 2010) indicate that improving the genetic merit of dairy cows for fertility, survival and milk yield reduces emissions per unit of milk. This is mainly because the measure increases the efficiency and productivity of dairy production systems, which is widely reported to reduce greenhouse gas (GHG) emissions per unit of production (Capper et al. 2009; O'Brien et al. 2010). It also has a positive impact on farm profitability (O'Brien et al. 2014).

To simulate this measure in FarmAc the genetic merit of dairy cows was firstly related to milk produced, live weight, fertility and health. The milk performance per cow was increased by 5% without adversely effecting cow fertility, longevity and survival. Milk performance was changed in the paramater file of Farm AC by reducing the average maintenance requirements of dairy cows.

Mitigation 2 (M2): Changing the grazing management

Increasing the quantity of grazed grass in the diet of dairy cows reduces the requirement for grass-silage in Atlantic maritime grass-based dairy systems. This is reported to reduce enteric methane emissions because the grazing of pasture by cows in temperate regions is less conducive to methanogenesis than feeding ryegrass silage (Woodward et al., 2001; Robertson and Waghorn, 2002; O'Neill et al., 2011). In addition the strategy reduces carbon dioxide emissions from fossil fuel and improves profitability (O'Brien et al., 2014).

The length of the grazing season was increased by 5 days in FarmAc by changing the proportion of outdoor and indoors cows in the herd. This reduced the demand for

grass silage and increased the demand for grazed pasture. Based on Lovett et al. (2008) the demand of grass silage on a dry matter basis was reduced by 4-6% for dairy cattle in the farm file of FarmAc and the demand for grazed grass was increased by 1-2%. This change had a positive influence on milk output (1.5% increase).

Mitigation 3 (M3): Improving pasture

Increasing forage quality improves the digestibility of forage, which positively influences animal performance of grazing dairy systems (Beukes et al. 2010). This can be achieved in rotational grazing dairy system through regular monitoring of pasture. This allows grass surpluses to be identified earlier, which facilitates earlier removal thereby avoiding quick declines in grazed grass quality. Thus, this improves productivity and reduces GHG emissions and costs.

In FarmAc is was assumed improving the quality grass increased grass digestibility and energy content. Thus, to simulate improvements in the quality of grazed grass the digestibility and energy values of the forage were modified. This was achieved similar to O'Brien et al. (2012) through increasing the energy and dry matter and digestibility values of pasture and grass silage by 1-2%.

Mitigation 4 (M4): Grass legume swards

White clover is reported to have a higher nutritive value than perennial ryegrass due to structural carbohydrate content, higher digestible protein and a faster rate of passage through the rumen. These qualities can result in higher herbage DM intake and subsequently increased milk production compared to pure perennial ryegrass swards (Harris et al, 1997; Woodfield and Clark, 2009). Introducing legumes into grass swards has been reported by Hennessy et al. (2013) to improve herbage production at low and high N fertilizer rates. In addition, the study reported improved milk performance by including legumes. The strategy also displaces the requirement for inorganic fertilizer from fossil fuel. This is widely reported to reduce GHG emissions from animal production systems e.g. Yan et al. (2013).

The baseline national average Irish dairy farm used a moderate level of N fertiliser/ha (148 kg N/ha). Based on Hennessy et al. (2013) and Enriquez-Hidalgo et al. (2014) including white clover in high N fertilizer pasture (150-250 kg N/ha) increases herbage production (t DM/ha) by 14% and increases the clover content of the sward to 25%. In Farm Ac the clover grass mixture with a similar proportion (20%) reported by Hennessy et al. (2013) was used to simulate the effect of adopting a grass legume sward. The gross grass yield of the clover grass mixture was increased by 14% to about 9.9 t/ha compared to the base and the herd size was increased in accordance with the yield change, which increased the farms stocking rate to 2.12 cow/ha. In addition, changing the diet to clover grass mixture increase milk output per cow by 4% similar to the results of Enriquez-Hidalgo et al. (2014).

Mitigation 5 (M5): Fertilisation rate

The application of synthetic N fertiliser influences herbage production and the environment. For instance, this strategy influences nitrous oxide and carbon dioxide emissions from fertiliser manufacture and also impacts on soil carbon and nitrogen

fluxes. In general at low or high levels of N fertiliser Lovett et al. (2008) and O'Brien et al. (2012) have reported that re-ducing the rate of N application has a positive effect on GHG emissions. However, both of these studies assumed soil carbon did not change in response to changes in N fertiliser.

The effect of reducing N fertiliser in FarmAc was assessed by decreasing the rate of application per ha by 5%. Based on Keating and Kiely (2000) this reduced gross forage yield by 2-3%. However, according to Lovett et al. (2008) and O'Brien et al. (2012) reducing N fertilizer did not increase the net yield of grass as utilization was found to improve. Thus, within FarmAc herbage utilization was increased by 1-2%.

Additionally, we test the effect of increasing the fertilisation rate by 5% in FarmAc. Again the forage response to increased fertilisation was modelled based on Irish research data such as Keating and Kiely (2000). In this case forage yield was increased by 3%. Thus, the herd size was also increased, but there was no change in farm size. The stocking rate therefore increased to 1.92 cows/ha.

Table 4.1.2.2.1. Key farm data used to model national average Irish dairy farm (baseline) and various mitigation options in FarmAc.

Item	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
Farm size	35	35	35	35	35	35	35	35
Number of cows	66	66	66	66	75	66	66	73
Replacement rate, %	25	25	25	25	25	25	25	25
Milk yield, kg/cow	4971	5219	5033	5114	5180	4971	5284	5180
Gross grass yield, kg DM/ha	8686	8686	8714	8686	9862	8464	8714	9609
Grass net yield, kg DM/ha	7244	7244	7282	7244	8225	7244	7282	8014
Grazed grass, kg DM/cow	2725	2725	2781	2725	2725	2725	2781	2718
Grass silage, kg DM/cow	1139	1139	1093	1139	1139	1139	1093	1136
Concentrate, kg DM/cow	732	732	735	732	732	732	735	732
N fertiliser, kg N/ha	148	148	148	148	148	141	148	141
Manure landspread, kg	55	55	54	55	55	55	54	55

N/ha

M1 = Genetic improvement M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Combined mitigation options

In addition to assessing individual mitigation options the effect of implementing more than one option together was also tested for national average Irish dairy farm in FarmAc. The first combined option tested was genetic improvement and changing the grazing management and the second option tested was grass-legume swards combined with reduced fertilisation.

Results

Tables 2 to 4 show the simulated baseline N fluxes, C fluxes and GHG emissions of the national average Irish dairy farm using FarmAc and the effects of the different mitigation options tested. The analysis showed that improving genetic merit of dairy cows had little or no effect on the N or C losses per ha from the farm, but the strategy improved animal milk performance (5%) and increased the efficiency of N used by animal by 1% to 17%. Thus, per unit of milk N and C losses to the environment were reduced. Improving genetic merit caused a minor increase in C stored in soil (1%). Total GHG emissions per ha did not change by increasing genetic merit, which were mainly composed of enteric CH4 emissions (48%), soil N2O emissions from the field (36%) and methane from manure (8%). However, per unit of milk the mitigation option reduced total GHG emissions by approximately 5%.

The change in grazing management by increasing the length of the grazing season 5 days caused a minor increase in gaseous N field losses (1%) and increased leaching losses (2%) but reduced N and C loss from manure storage. Furthermore, the strategy had a minor positive influenced on C stored in soil (1%) and slightly improved milk production (1%). The strategy reduced methane emissions from manure (4%) and ammonia emissions from housing by 4%. Overall the strategy had little or no influence on total GHG emissions per ha but reduced total GHG emissions per unit of milk by 1%.

Increasing the quality of pasture improved the digestibility of grass and silage, which slightly reduced ammonia and N2O emissions from manure (1%). The mitigation option did not influence C losses, but did cause a minor increase in C stored in soil (1%). Increasing the quality of forage had little influence on enteric CH4 or total GHG emissions per ha but had a positive influence on animal milk performance (3%). Thus, the option reduced total GHG emissions per unit of milk by 3%.

Adopting grass-legume white clover swards has the greatest effect on C and N fluxes. The strategy increase in the quantity of C removed by the soil from 37 kg of C/ha to 298 kg of C/ha. This was mainly driven by the change in the fixation of N. The N and C losses per ha from animals and manure increased due to an increase in stocking rate using white clover. However, the efficiency of N use on animal basis increased to 20%. The strategy had a positive effect on soil organic N which explains

in part the decline in N leaching loss. Greenhouse gas emissions were increased from enteric CH4 and agricultural soils by 13% and 24%, respectively, using grass-legume swards. However, the increase in milk production from grass-legume swards was greater than the rise in total GHG emissions per ha. Therefore, grass-legume swards reduced total GHG emissions per unit of milk by 11%.

The mitigation option to reduce the N fertilisation rate decreased gaseous N losses by 2% from fertiliser, but had little or no effect on N leaching or emissions from manure or enteric CH4. Reducing N fertiliser application also reduced the amount of N stored in soil compared to the baseline national average Irish dairy farm. Thus, the mitigation option reduced the quantity of C stored in soil by 58% compared to the baseline farm. Therefore, despite reducing N2O losses from the soil reducing N fertiliser application caused total GHG emissions per ha and per unit of milk to slightly increase (1%), because the strategy reduced the quantity of CO2 removed by the soil.

Combining the mitigation option extending the length of the grazing with improving genetic merit of dairy cows influenced N and C losses from the farm. The combined strategy caused a minor increase in gaseous N field losses and increased N leaching losses (1-2%) but reduced N and C loss from manure storage (5-6%). The strategies had an additive influence on increasing C stored in soil (43%) and improving milk production (6%) compared to the base. The combined strategy reduced methane emissions from manure (4%) and ammonia emissions (5%) from housing. Overall the combined strategy reduced total GHG emissions per ha by 1% and reduced total GHG emissions per unit of milk by 7%.

Simultaneously reducing N fertiliser per ha and adopting grass legume swards increased gaseous N losses from fields and housing, but the options increased the farms efficiency of N use to 20%. In addition, N leaching losses were reduced and soil C and N storage in-creased. However, N fixation was lower. Thus, the increase in C storage was less than simply adopting a grass-legume sward. Reducing N fertiliser and introducing white clover also increased methane emissions because the strategies facilitated a higher farm stocking rate. However, there was a greater increase in milk production than total GHG emissions per ha. Thus, the strategy reduced total GHG emissions per unit of milk by 9%, but this was less than the reduction obtained by only adopting a grass-legume sward.

Table 4.1.2.2.3. FarmAc C flux results for the baseline national average Irish dairy farm and the various mitigation options simulated

Item	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
C fixed from atmosphere	10741	10741	10809	10741	12193	10467	10809	11893
C in imported manure	12	13	21	14	0	12	22	0

C in imported feed	730	730	737	730	830	755	737	808
C in imported bedding	0	0	0	0	0	0	0	0
C in exported milk	466	489	473	479	551	466	497	537
C in exported meat	4	4	4	4	5	4	4	5
C in mortalities	0	0	0	0	0	0	0	0
C in crop products sold	1	1	6	1	1	1	6	1
C in CO2 emitted by the soil	8551	8552	8619	8553	9379	8364	8605	9208
C in organic matter leached from the soil	0	0	0	0	0	0	0	0
CO-C from burning crop residues	0	0	0	0	0	0	0	0
CO2-C in gases from burning crop residues	0	0	0	0	0	0	0	0
Black carbon in gases from burning crop residues	0	0	0	0	0	0	0	0
Change in C stored in the soil	37	38	38	38	298	-22	53	244

M1 = Genetic improvement M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Table 4.1.2.2.2. FarmAc N flux results (kg N/ha) for the baseline national average Irish dairy farm and the various mitigation options simulated

Scale	Item	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
Farm	Imported livestock feed	67	67	68	67	76	69	68	75
	Imported bedding	1	1	1	1	2	1	1	2
	N fixation	0	0	0	0	8	0	0	6
	N deposited from atmosphere	5	5	5	5	5	5	5	5
	N in fertiliser	148	148	148	148	148	141	148	141
	Imported	2	2	3	2	0	2	3	0
	N sold in crop products	0	0	0	0	0	0	0	0
	N sold in milk	49	52	50	51	58	49	52	57
	N exported in meat	0	0	0	0	1	0	0	1
	N in mortalities	0	0	0	0	0	0	0	0
	Exported manure	0	0	0	0	5	0	0	4
	Gaseous loss housing	8	8	7	8	9	8	7	9
	N lost from processing/stored crop products	10	10	10	10	12	10	10	11
	Gaseous loss storage	6	6	6	6	6	6	5	6
	Runoff	0	0	0	0	0	0	0	0
	Gaseous loss field	62	62	63	62	68	61	62	67
	Nitrate leaching	110	108	112	110	74	111	109	74

	Change in mineral N in soil	-25	-25	-25	-25	-30	-25	-25	-32
	Change in organic N in soil	3	3	3	3	37	-2	5	0
Herd									
	Livestock feed consumed in housing	116	116	115	116	134	116	115	131
	Grazed	180	180	184	180	158	180	184	154
	Deposited in housing	58	57	56	57	65	58	56	64
	Deposited in field	189	187	193	188	167	189	193	163
	N sold in milk	49	52	50	51	58	49	50	57
	N exported in meat	0	0	0	0	1	0	0	1
	N in mortalities	0	0	0	0	0	0	0	0
	Efficiency of N use by livestock	0.17	0.18	0.17	0.17	0.20	0.17	0.17	0.20
Housing									
	Input from livestock	58	57	56	57	65	58	56	64
	Gaseous loss	8	8	7	8	9	8	7	9
	Sent to storage	50	50	48	50	57	50	48	55
Manure storage									
	Input from housing manure	50	50	48	50	57	50	48	55
	Bedding	1	1	1	1	2	1	1	2
	Feed wastage	7	7	7	7	8	7	7	8

	Gaseous loss							
		6	6	6	6	6	6	6	6
	Runoff from storage	0	0	0	0	0	0	0	0
	Manure ex storage	53	53	51	53	60	53	51	59
Fields									
	Manure applied								
		55	55	54	55	55	55	54	55
	Harvested mechanically	66	66	64	66	77	65	64	76
	Harvested by grazing	180	180	184	180	158	180	184	154

M1 = Genetic improvement M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Table 4.1.2.2.4. FarmAc greenhouse gas (GHG) results in CO_2 equivalents for the baseline national average Irish dairy farm and the various mitigation options simulated

Scale	Item	Unit	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
Direct	Enteric CH_4	ha	4620	4620	4649	4620	5244	4620	4649	5123
	Manure CH_4	ha	798	798	768	798	879	798	768	859
	Manure N_2O emissions	ha	275	274	265	273	312	275	263	305
	Field N_2O emissions	ha	3456	3447	3496	3452	4300	3380	3479	4210
	Change in C stored in soil	ha	-137	-138	-139	-139	-1093	80	-196	-898
Indirect	Housing NH3 emissions	ha	36	36	35	36	41	36	35	40
	Manure storage NH3 emissions	ha	16	16	15	16	18	16	15	17

	NH3 emissions from field-applied manure	ha		27	27	27	27	27	27	27	27
	NH3 emissions from fertilisers	ha		85	85	84	85	85	84	84	84
	N2O emissions resulting from leaching of N	ha		387	381	394	385	259	388	382	259
	Total indirect emissions	ha		552	545	556	548	430	552	543	427
Total	Total GHG emissions	ha		9564	9546	9594	9553	10073	9705	9507	10026
Direct	Direct GHG emissions		Litre	0.97	0.92	0.96	0.94	0.87	0.98	0.90	0.89
Total	Total GHG emissions		Litre	1.03	0.98	1.01	1.00	0.91	1.04	0.96	0.93

M1 = Genetic improvement M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

4.1.2.3. Maritime Grassland Dairy – Curtins, S-EU-004.

The showcase maritime grass-based Atlantic dairy farm was a research farm (Curtins farm) located in Ireland (52°16' N, 8°25' W). The aims of Curtins farm include evaluating the effect of stocking rate and genetic merit of dairy cattle on various economic, technical and environmental indicators. The farm is a 48 ha grassland Irish dairy farm on a sandy loam soil. Rainfall averaged about 1020 mm per annum and the annual temperature was 10 C. Curtins farm is a spring calving herd where cows are turned out to pasture directly post calving and annually achieve an average grazing season of 270 full days. All male calves are sold at 2 weeks and replacement heifer calves are contract reared off farm. Typically contract reared heifers calve at 24-25 months of age.

The herd size is subject to scientific requirements and varies from 120-140 cows producing about 5500 kg of milk per cow/year that consists of 4.17% milk fat and 3.6% milk protein. The herd is comprised of New Zealand Holstein Friesian. The mean live weight is 550 kg and the replacement rate varies between 16-20%. Surplus grass is harvested as silage mainly in May and July and fed to cows indoors during winter. On average gross yields of grass are 14t/DM per ha and grass utilization averages 85%. The grass is rainfed and requires no irrigation. The diet of milking cows is mainly comprised of grazed grass (70%) with low levels of supplementary concentrate feed (450 kg DM/cow per year). On average 250 kg of synthetic N fertilizer is applied per ha. Organic nitrogen is mainly excreted by cows on grass in situ. Over winter manure is stored in overground tanks and broadcast on pasture mainly in spring. On average 55-60 kg N/ha from slurry is applied to grassland using a slurry splash plate.

The simulation of the herd in FarmAc was divided into an outdoor and indoor herd. The forage diet of the herd was composed of grass silage indoors and no maize silage was fed. The majority of milk was produced by grazing cows and concentrate was fed to cows in early spring and mid to late autumn. Therefore the majority of concentrate was consumed by the outdoor herd. The baseline scenario of Table 4.1.2.3.1 summarizes the key input data used to operate FarmAc for Curtins dairy farm.

Mitigation options

Following a review of Irish research studies (e.g. Lovett et al., 2008, Foley et al., 2011) and the literature five mitigation options were tested on the showcase grass-based Atlantic dairy farm using FarmAc at the farm level. The mitigation options implemented were

1. Improving total genetic merit of dairy cows
2. Changing the grazing management – Extending the length of the grazing season
3. Improving pasture – Increasing grass and grass silage quality
4. Grass legume swards – Introducing white clover into the sward
5. Fertilisation rate – Increasing and reducing inorganic N fertiliser/ha.

The following sections describe each mitigation option and Table 4.1.2.3.1 shows the key data used to run each mitigation option in FarmAc.

Mitigation 1 (M1): Improving total genetic merit of dairy cows

In general, research studies (e.g. Schils et al., 2005; Lovett et al., 2006; Weiske et al., 2006; Beukes et al., 2010) indicate that improving the genetic merit of dairy cows for fertility, sur-vival and milk yield reduces emissions per unit of milk. This is mainly because the measure increases the efficiency and productivity of dairy production systems, which is widely report-ed to reduce greenhouse gas (GHG) emissions per unit of production (Capper et al. 2009; O'Brien et al. 2010). It also has a positive impact on farm profitability (O'Brien et al. 2014).

To simulate this measure in FarmAc the genetic merit of dairy cows was firstly related to milk produced, live weight, fertility and health. The milk performance per cow was increased by 5% without adversely effecting cow fertility, longevity and survival. Milk performance was changed in the paramater file of Farm AC by reducing the average maintenance requirements of dairy cows.

Mitigation 2 (M2): Changing the grazing management

Increasing the quantity of grazed grass in the diet of dairy cows reduces the requirement for grass-silage in Atlantic maritime grass-based dairy systems. This is reported to reduce enteric methane emissions because the grazing of pasture by cows in temperate regions is less conducive to methanogenesis than feeding ryegrass silage (Woodward et al., 2001; Robertson and Waghorn, 2002; O'Neill et al., 2011). In addition the strategy reduces carbon dioxide emissions from fossil fuel and improves profitability (O'Brien et al. 2014).

The length of the grazing season was increased by 5 days in FarmAc by changing the proportion of outdoor and indoors cows in the herd. This reduced the demand for grass silage and increased the demand for grazed pasture. Based on Lovett et al. (2008) the demand of grass silage on a dry matter basis was reduced by 4-6% for dairy cattle in the farm file of FarmAc and the demand for grazed grass was increased by 1-2%. This change had a positive influence on milk output (1.5% increase).

Mitigation 3 (M3): Improving pasture

Increasing forage quality improves the digestibility of forage, which positively influences ani-mal performance of grazing dairy systems (Beukes et al. 2010). This can be achieved in rotational grazing dairy system through regular monitoring of pasture. This allows grass sur-pluses to be identified earlier, which facilitates earlier removal thereby avoiding quick declines in grazed grass quality. Thus, this improves productivity and reduces GHG emissions and costs.

In FarmAc is was assumed improving the quality grass increased grass digestibility and energy content. Thus, to simulate improvements in the quality of grazed grass the digestibility and energy values of the forage were modified. This was achieved similar to O'Brien et al. (2012) through increasing the energy and dry matter and digestibility values of pasture and grass silage by 1-2%.

Mitigation 4 (M4): Grass legume swards

White clover is reported to have a higher nutritive value than perennial ryegrass due to struc-tural carbohydrate content, higher digestible protein and a faster rate of passage through the rumen. These qualities can result in higher herbage DM intake and subsequently increased milk production compared to pure perennial ryegrass swards (Harris et al, 1997; Woodfield and Clark, 2009). Introducing legumes into grass swards has been reported by Hennessy et al. (2013) to improve herbage production at low and high N fertilizer rates. In addition, the study reported improved milk performance by including legumes. The strategy also displaces the requirement for inorganic fertilizer from fossil fuel. This is widely reported to reduce GHG emissions from animal production systems e.g. Yan et al. (2013).

The baseline Curtins farm used relatively high level of N fertiliser/ha (250kg N/ha). Based on Hennessy et al. (2013) and Enriquez-Hidalgo et al. (2014) including white clover in high N fertilizer pasture (>250 kg N/ha) increases herbage poduction (t DM/ha) by 8% and increases the clover content of the sward to 20%. In Farm Ac the clover grass mixture with the same proportion reported by Hennessy et al. (2013) was used to simulate the effect of adopting a grass legume sward. The gross grass yield of the clover grass mixture was increased by 8% to about 15 t/ha compared to the base and the herd size was increased in accordance with the yield change, which increased the farms stocking rate to 2.70 cow/ha. In addition, changing the diet to clover grass mixture increase milk output per cow by 3% similar to the results of Enriquez-Hidalgo et al. (2014).

Mitigation 5 (M5): Fertilisation rate

The application of synthetic N fertiliser influences herbage production and the environment. For instance, this strategy influences nitrous oxide and carbon dioxide emissions from ferti-liser manufacture and also impacts on soil carbon and nitrogen fluxes. In general at low or high levels of N fertiliser Lovett et al. (2008) and O'Brien et al. (2012) have reported that re-ducing the rate of N application has a positive effect on GHG emissions. However, both of these studies assumed soil carbon did not change in response to changes in N fertiliser.

The effect of reducing N fertiliser in FarmAc was assessed by decreasing the rate of applica-tion per ha by 5%. Based on Keating and Kiely (2000) this reduced gross forage yield by 2-3%. However, according to Lovett et al. (2008) and O'Brien et al. (2012) reducing N fertilizer did not increase the net yield of grass as utilization was found to improve. Thus, within Far-mAc herbage utilization was increased by 1-2%.

Additionally, we test the effect of increasing the fertilisation rate by 5% in FarmAc. Again the forage response to increased fertilisation was modelled based on Irish research data such as Keating and Kiely (2000). In this case forage yield was increased by 2%. Thus, the herd size was also increased, but there was no change in farm size. The stocking rate therefore increased to 2.54 cows/ha.

Table 4.1.2.3.1. Key farm data used to model Curtins farm (baseline) and various mitigation options in FarmAc.

Item	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
Farm size	48	48	47.9	48	48	48	48	48
Number of cows	120	120	120	120	130	120	120	127
Replacement rate, %	16	16	16	16	16	16	16	16
Milk yield, kg/cow	5544	5823	5596	5693	5737	5544	5877	5737
Gross grass yield, kg DM/ha	14033	14033	14067	14033	15168	13783	14067	14898
Grass net yield, kg DM/ha	11826	11826	11878	11826	12783	11826	11878	12554
Grazed grass, kg DM/cow	3643	3643	3710	3643	3643	3643	3710	3635
Grass silage, kg DM/cow	1088	1088	1030	1088	1088	1088	1030	1085
Concentrate, kg DM/cow	464	464	467	464	464	464	467	464
N fertiliser, kg N/ha	250	250	252	250	250	238	252	238
Manure landspread, kg N/ha	54	54	55	54	54	54	55	54

M1 = Genetic improvement M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Combined mitigation options

In addition to assessing individual mitigation options the effect of implementing more than one option together was also tested for Curtins farm in FarmAc. The first combined option tested was genetic improvement and changing the grazing management and the second option tested was grass-legume swards combined with reduced fertilisation.

Results

Tables 4.1.2.3.2 to 4.1.2.3.4 show the simulated baseline N fluxes, C fluxes and GHG emissions of Curtins farms using FarmAc and the effects of the different mitigation

options tested. The analysis showed that improving genetic merit of dairy cows had little or no effect on the N or C losses per ha from the farm, but the strategy improved animal milk performance (5%) and increased the efficiency of N used by animal by 1% to 19%. Thus, per unit of milk N and C losses to the environment were reduced. Improving genetic merit had a minor effect on total GHG emissions per ha, which were mainly composed of enteric CH4 emissions (52%) and soil N2O emissions from the field (41%). However, per unit of milk the mitigation option reduced total GHG emissions by approximately 5%.

Changing the grazing management by increasing the length of the grazing season 5 days caused a minor increase in gaseous N field losses and increased leaching losses (2%) but reduced N and C loss from manure storage. In addition, the strategy positively influenced C stored in soil (11%) and slightly improved milk production (1%). The strategy reduced me-thane emissions from manure (5%) and ammonia emissions from housing. Overall the strategy had little or no influence on total GHG emissions per ha but reduced total GHG emissions per unit of milk by 2%.

Increasing the quality of pasture improved grass and silage digestibility, which slightly reduced ammonia and N2O emissions from manure (1%). The mitigation option did not influence C losses or C stored in soil. Increasing the quality of forage had little influence on enteric CH4 or total GHG emissions per ha but had a positive influence on animal milk performance (3%). Thus, the option reduced total GHG emissions per unit of milk by 2%.

Adopting grass-legume white clover swards has the greatest effect on C and N fluxes. The strategy caused a 2.5 fold increase in the quantity of C stored in soil mainly driven by the fixation of N of 68 kg N/ha. Per ha, N and C losses from animals and manure increased due to an increase in stocking rate using white clover. However, the efficiency of N use on animal basis increased to 21%. The strategy also improved N stored in soil, which explains in part the decline in N leaching losses. Greenhouse gas emissions were increased from enteric CH4 and agricultural soils by 8% and 25%, respectively, using grass-legume swards. However, the increase in milk production from grass-legume swards was greater than the rise in total GHG emissions per ha. Therefore, grass-legume swards reduced total GHG emissions per unit of milk by 6%.

The mitigation option to reduce the N fertilisation rate decreased gaseous N losses and reducing leaching losses by 2% from fertiliser, but had no effect on emissions from manure or enteric CH4. Reducing N fertiliser application also reduced the amount of N stored in soil compared to the baseline Curtins farm. Thus, the mitigation option reduced the quantity of C stored in soil by 25% compared to the baseline farm. Therefore, despite reducing N2O losses from the soil reducing N fertiliser application caused total GHG emissions per ha and per unit of milk to slightly increase (1%), because the strategy reduced the quantity of CO2 removed by the soil.

Combining the mitigation option extending the length of the grazing with improving genetic merit of dairy cows influenced N and C losses from the farm. The combined strategy caused a minor increase in gaseous N field losses and increased N leaching

losses (1-2%) but reduced N and C loss from manure storage (5-6%). The strategies had an additive influence on increasing C stored in soil (16%) and improving milk production (6%) compared to the base farm. The combined strategy reduced methane emissions from manure (5%) and ammonia emissions (6%) from housing. Overall the combined strategy slightly reduced total GHG emissions per ha (1%) and reduced total GHG emissions per unit of milk by 6%.

Simultaneously reducing N fertiliser per ha and adopting grass legume swards increased gaseous N losses from fields and housing, but the options increased the farms efficiency of N use to 21%. In addition, N leaching losses were reduced and soil C and N storage increased. However, N fixation was lower (41 kg N/ha). Thus, the increase in C storage was less than simply adopting a grass-legume sward. Reducing N fertiliser and introducing white clover also increased methane emissions because the strategies facilitated a higher farm stocking rate. However, there was a greater increase in milk production than total GHG emissions per ha. Thus, the strategy reduced total GHG emissions per unit of milk by 4%, but this was less than the reduction obtained by only adopting a grass-legume sward.

Table 4.1.2.3.2. FarmAc N flux results (kg N/ha) for the baseline Curtins dairy farm and the various mitigation options simulated

Scale	Item	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
Farm	Imported livestock feed	64	64	64	64	61	64	63	60
	Imported bedding	2	2	1	2	2	2	1	2
	N fixation	0	0	0	0	68	0	0	41
	N deposited from atmosphere	5	5	5	5	5	5	5	5
	N in fertiliser	250	250	252	250	250	238	252	238
	Imported	0	1	4	1	0	0	5	0
	N sold in crop products	0	0	0	0	0	0	0	0
	N sold in milk	78	82	79	80	87	78	82	85
	N exported in meat	1	1	1	1	1	1	1	1
	N in mortalities	0	0	0	0	0	0	0	0

	Exported manure	0	0	0	0	13	0	0	12
	Gaseous loss housing	7	7	7	7	9	7	6	9
	N lost from processing/stored crop products	10	10	9	10	14	10	9	14
	Gaseous loss storage	5	5	5	5	7	5	5	7
	Runoff	0	0	0	0	0	0	0	0
	Gaseous loss field	86	86	87	86	93	85	87	91
	Nitrate leaching	110	107	112	108	92	104	112	92
	Change in soil mineral N	6	6	6	6	5	6	6	5
	Change in soil organic N	19	19	22	19	65	14	23	60
Herd									
	Livestock feed consumed in housing	111	111	109	111	133	111	109	131
	Grazed	321	321	327	321	268	321	327	264
	Deposited in housing	57	57	54	57	72	57	54	71
	Deposited in field	296	293	303	295	241	296	299	237
	N sold in milk	78	82	79	80	87	78	82	85
	N exported in meat	1	1	1	1	1	1	1	1
	N in mortalities	0	0	0	0	0	0	0	0
	Efficiency of N use by livestock	0.18	0.19	0.18	0.19	0.22	0.18	0.19	0.22
Housing									

	Input from livestock	57	57	54	57	72	57	54	71
	Gaseous loss	7	7	7	7	9	7	6	9
	Sent to storage	50	50	48	50	63	50	47	62
Manure storage									
	Input from housing manure	50	50	48	50	63	50	47	62
	Bedding	2	2	1	2	2	2	1	2
	Feed wastage	7	7	7	7	9	7	7	9
	Gaseous loss	5	5	5	5	7	5	5	7
	Runoff from storage	0	0	0	0	0	0	0	0
	Manure ex storage	54	54	51	53	67	54	51	66
Fields									
	Manure applied	54	54	55	54	54	54	55	54
	Harvested mechanically	65	65	62	65	96	65	63	94
	Harvested by grazing	321	321	327	321	268	321	327	264

M1 = Genetic improvement M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Table 4.1.2.3.3. FarmAc C flux results for the baseline Curtins dairy farm and the various mitigation options simulated

Item	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
C fixed from atmosphere	17208	17203	17315	17206	19151	16946	17394	18819
C in imported manure	2	4	28	5	0	2	30	0

C in imported feed	772	772	762	772	673	776	746	660
C in imported bedding	0	0	0	0	0	0	0	0
C in exported milk	693	728	701	712	775	693	736	761
C in exported meat	6	6	6	6	6	6	6	6
C in mortalities	0	0	0	0	0	0	0	0
C in crop products sold	0	0	1	0	0	0	1	1
C in CO2 emitted by the soil	13472	13470	13564	13473	14535	13275	13615	14341
C in organic matter leached from the soil	0	0	0	0	0	0	0	0
CO-C from burning crop residues	0	0	0	0	0	0	0	0
CO2-C in gases from burning crop residues	0	0	0	0	0	0	0	0
Black carbon in gases from burning crop residues	0	0	0	0	0	0	0	0
Change in C stored in the soil	228	227	254	228	563	168	264	503

M1 = Genetic improvement M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

Table 4.1.2.3.4. FarmAc greenhouse gas (GHG) results in CO_2 equivalents for the baseline Curtins dairy farm and the various mitigation options simulated

Scale	Item	Unit	Baseline	M1	M2	M3	M4	M5	M1+M2	M4+M5
Direct	Enteric CH_4	ha	6971	6971	7003	6971	7535	6971	7003	7417
	Manure CH_4	ha	855	855	812	855	1002	855	812	987
	Manure N_2O emissions	ha	278	276	264	275	347	278	262	342
	Field N_2O emissions	ha	5486	5470	5548	5479	6634	5379	5542	6519
	Change in C stored in soil	ha	-836	-834	-930	-836	-2063	-615	-969	-1847
Indirect	Housing NH3 emissions	ha	32	32	31	32	43	32	30	42
	Manure storage NH3 emissions	ha	14	14	14	14	19	14	14	19

	NH3 emissions from field-applied manure	ha		24	24	25	24	25	24	25	25
	NH3 emissions from fertilisers	ha		97	97	98	97	97	94	98	94
	N2O emissions resulting from leaching of N	ha		385	375	392	381	324	367	392	324
	Total indirect emissions	ha		552	542	559	547	507	532	558	504
Total	Total GHG emissions	ha		13306	13279	13256	13291	13962	13400	13208	13922
Direct	Direct GHG emissions		Litre	0.92	0.87	0.91	0.90	0.87	0.93	0.86	0.88
Total	Total GHG emissions		Litre	0.96	0.91	0.95	0.93	0.90	0.97	0.90	0.91

M1 = Genetic improvement M2 = Changing the grazing management M3 = Improving pasture M4 = Grass legume swards M5 = Fertilisation rate

4.2.3. Maritime Mixed Dairy

Maritime Mixed Dairy is represented by showcase farm ‘De Marke’ and model farm ‘Dutch sandy soil’. Chapter 4.2.3.1 and Chapter 4.2.3.2. evaluate the seperate farms whereas Chapter 4.2.3.3 combines those evaluations to farmtype.

4.2.3.1. Maritime Mixed Dairy – Dutch average sandy soil, M-EU-001.

The Average farm has 85 milking cows (yearly base), 32 older young stock (1 year to first calving) and 34 calves (0-1 year). The replacement rate of the herd is 30%. The Holstein Frisian cows produce 8100 kg milk with 3.53 % protein and 4.4% fat (8580 kg FPCM). The farm has 40 ha grassland on a sandy soil with groundwater table VI, which means just slightly sensitive for drought (the Marke had groundwater table VII to VIII). There is also 9 ha permanent maize for silage.

The cows have a limited grazing system (only access to the paddock during daytime) and are fed with silage (TMR of maize and grass silage) during the evening and night. Calves were grazed on aftermath after the first cut until the first of September. Older young stock and milking cows will graze during the whole growing season (half of April until end of October). The farm has a mixed grassland system: paddocks are used for grazing as well as mowing for silage. All the mown grass was pre wilted for 1 or two days and ensilaged in batches (first cut separate). Gross grass yield is 12.5 ton DM/ha and gross maize yield 16.5 ton DM/ha. The farm had to buy 45 ton DM (maize) while it is not sufficient for roughage. The milking cows also get 1980 kg (product, DM% = 90) concentrates per cow per year, exclusive young stock (2115 kg inclusive young stock).

The herd produce 2300 ton slurry. The farm had to remove 190 ton slurry (800 kg N), due to legislation. Grassland was applied with 122 kg N from artificial fertiliser and 90 kg effective N from slurry (total N application with slurry was 200 kg N/ha grassland). Maize was applied with 100 kg N from artificial fertiliser and 47 kg effective N from slurry (total N application with slurry was 75 kg N/ha). The N content of the slurry before injection (so before NH3 losses during application) was 4.21 kg total-N/ton slurry.

The total average daily feed intake of the cows and young stock is shown in Table 4.2.3.1.1. The intake is recalculated to an average intake for 365 days. Grass intake of the cows (exclusive dry cows) was 8.6 kg DM per cow per day during the grazing season. The average is calculated inclusive dry cows.

Table 4.2.3.1.1 Daily feed intake herd Dutch average farm

Feed/herd	Cows (incl. dry cows)	Young stock 1-2 year	Calves 0-1 year
Grazed grass (kg DM)	4.37	4.27	1.12
Grass silage (kg DM)	4.96	2.76	1.52
Maize silage (kg DM)	4.80	1.18	0.65
Concentrates (kg)	5.41	0.09	0.57

To run FarmAC proparly, the FarmAC simulated milk production was reduced by 14% and low digestibility of feed is assumed. Alternatively the feed uptake could be reduced by 23%, with low roughage yield as a consequence

The Dutch average farm has more opportunities for implementing mitigation options, because there were no special objectives like for the Marke. Therefore the effects of 3 mitigation options were calculated for the average farm. The implemented mitigations are:

1. Feeding nitrate
2. Lower replacement value of 20% (less young stock; older cows)
3. Less grazing; more supplemental feeding with silage during grazing season
4. Less N from artificial fertiliser combined with the introduction of white clover

Mitigation 1 (M1) Feeding nitrate ($CaNO_3$)

This mitigations is comparable with feeding nitrate on the Marke (see 4.2.3.2). The diet on the Average farm differs slightly from the Marke, so probably some (other) effects can be found.

Mitigation 2 (M2) Lower replacement with heifers (from 30 to 20%)

To lower the replacement rate, less young stock is needed. Therefore more calves can leave the farm in an early stage and less feed is necessary. In the baseline, the farm has a shortage of 45 ton roughage. Instead the maize-area is increased by 33% so no maize-import is necessary, and the farm is self supported with homegrown roughage. To bred less young stock less feed had to be imported and less manure is produced. The average age of the total herd is higher (more older cows).

Mitigation 3 (M3) Less grazing

On the Marke grazing is in the baseline situation already very limited. In the baseline situation on the Average farm it is also limited if you compare to day and night grazing, but there are some possibilities to reduce the grazing time. In this mitigation grazing time is reduced to about 4 hours per day. Fresh grass in the diet is replaced by maize and grass silage (50:50 on DM base).

Mitigation 4 Less N from artificial fertiliser combined with the introduction of white clover

Although the roughage supply is insufficient, a lower N input can still have some environmental advantages. The N level is lowered to zero N from artificial fertilisers, so only the on farm produced slurry will be applied. Due to the lower N level it is possible to introduce white clover. So this mitigation is a combined effect of lower N input and the introduction of white clover (overall 30%). Unfortunately FarmAc did not manage to calculate this mitigation properly. Therefore this mitigation has been dropped from the list and will not be further discussed.

Table 4.2.3.2. N effects (kg N/ha/yr) calculated by FarmAC for 3 mitigations on the Dutch average farm

Farm	Item	Baseline	M1 Feeding Nitrate	M2 Less young stock	M3 Less grazing
	Imported livestock feed	188.4	168.9	121.5	187.0
	Imported bedding	5.0	4.9	3.1	5.8
	N fixation	0.0	0.0	0.0	0.0
	N deposited from atmosphere	30.0	30.0	21.3	30.0
	N in fertiliser	118.8	119.6	83.9	118.1
	Imported manure	0.0	0.0	0.0	0.0
	N sold in crop products	4.2	0.1	4.4	0.4
	N sold in milk	79.6	77.4	55.7	76.6
	N exported in meat	7.8	9.2	4.5	8.8
	N in mortalities	0.0	0.0	0.0	0.0
	Exported manure	15.2	9.9	8.7	54.2
	Gaseous loss housing	28.8	30.0	21.3	35.3
	N lost from processing/stored crop products	11.2	14.7	10.4	18.1
	Gaseous loss storage	11.0	12.1	8.4	14.0
	Runoff	0.0	0.0	0.0	0.0
	Gaseous loss field	37.0	41.7	28.7	37.6
	Nitrate leaching	161.9	129.0	89.8	100.6
	Change in mineral N in soil	0.0	0.1	0.1	-0.2
	Change in organic N in soil	-11.3	1.5	-0.7	-2.6
	Balance	-3.3	-2.2	-1.5	-1.8
Herd					
	Livestock feed consumed in housing	288.6	306.7	219.5	358.5
	Grazed	107.0	124.4	78.8	71.0
	Deposited in housing	228.1	251.4	176.0	290.6
	Deposited in field	80.1	93.1	62.2	53.5
	N sold in milk	79.6	77.4	55.7	76.6
	N exported in meat	7.8	9.2	4.5	8.8
	N in mortalities	0.0	0.0	0.0	0.0
	Efficiency of N use by livestock	0.0	0.0	0.0	0.0
Housing					
	Input from livestock	228.1	251.4	176.0	290.6
	Gaseous loss	28.8	30.0	21.3	35.3
	Sent to storage	199.3	221.4	154.6	255.2
ManureStorage					
	Input from housing manure	199.3	221.4	154.6	255.2
	Bedding	5.0	4.9	3.1	5.8
	Feed wastage	8.9	9.5	6.8	11.1
	Gaseous loss	11.0	12.1	8.4	14.0
	Runoff from storage	0.0	0.0	0.0	0.0
	Manure ex storage	202.1	223.8	156.0	258.2
Fields					
	N fixation	0.0	0.0	0.0	0.0

	N deposited from atmosphere	30.0	30.0	21.3	30.0
	N in fertiliser	118.8	119.6	83.9	118.1
	Manure applied	186.9	213.9	147.4	204.0
	Gaseous loss fields	37.0	41.7	28.7	37.6
	Nitrate leaching	161.9	129.0	89.8	100.6
	Harvested mechanically	124.5	162.0	119.6	201.1
	Harvested by grazing	107.0	124.4	78.8	71.0
	Change in mineral N in soil	0.0	0.1	0.1	-0.2
	Change in organic N in soil	-11.3	1.5	-0.7	-2.6

Table 4.2.3.1.2 shows the N effects of the implemented mitigations with the baseline as reference. The mitigations ‘M2 less young stock’ and ‘M3 less grazing’ have the strongest effect on N losses. All three mitigations have a positive effect on N losses but on farm scale the profit is not high.

In the ‘less grazing’ scenario, this is the most important reason for de decrease in nitrate leaching. In the scenario with less animals this is also the case. On herd-scale there are some changes between the places losses took place. Part of the problems are replaced from the paddock to the stable (see mitigation: less grazing), but the total level did not change . Due to more time inside, there will be more manure in storage.

The same effects are seen in the field (less grazing, so less nitrate leaching, but more N from manure, more N fixation by clover and less by fertiliser). Overall less young stock (read: reducing number of animals) will lead to the best benefits.

Besides N effects, also the C effects were calculated with FarmAC. The C effects are shown in Table 4.2.3.1.3.

Table 4.2.3.1.3 C effects (kg C/ha/yr) calculated by FarmAC for 3 mitigations on the Dutch Model farm

	Baseline	M1 Feeding Nitrate	M2 Less young stock	M3 Less grazing
C fixed from atmosphere	9864.6	13056.1	12902.2	12803.4
C in imported manure	0.0	0.0	0.0	0.0
C in imported feed	2242.1	2255.5	1688.8	2243.2
C in bedding	0.0	0.0	0.0	0.0
C in exported milk	716.0	696.1	705.1	689.0
C in exported meat	69.8	82.5	56.3	78.4
C in mortalities	0.0	0.0	0.0	0.0
C in crop products sold	56.7	1.0	117.2	5.9
C in exported manure	85.9	71.4	80.2	388.6
C in enteric methane emissions	196.8	215.2	223.9	239.2
C in CO_2 emitted by livestock	2950.4	3398.9	3134.2	3366.3
C in CO_2 emitted from animal housing	156.4	190.3	176.9	217.4
C in methane emitted by manure	61.8	88.0	78.4	100.5
C in CO_2 emitted by manure	61.8	88.0	78.4	100.5
C in biogas methane	0.0	0.0	0.0	0.0
C in biogas CO_2	0.0	0.0	0.0	0.0
C in CO_2 lost from stored crop products	206.5	280.1	295.2	350.0
C in CO_2 emitted by the soil	7657.8	10181.8	9656.6	9537.5
C in organic matter leached from the soil	0.0	0.0	0.0	0.0

CO-C from burning crop residues	0.0	0.0	0.0	0.0
CO_2-C in gases from burning crop residues	0.0	0.0	0.0	0.0
Black carbon in gases from burning crop residues	0.0	0.0	0.0	0.0
Change in C stored in the soil	-113.1	18.2	-11.4	-26.6
C lost to the environment	11291.5	14442.3	13643.6	13911.4

Different mitigations show different effects on C. The largest losses are at mitigation 'less grazing' and 'Feeding nitrate'. Importing feed leads to extra C input, so when yield production on the farm will decrease, more C from outside is imported. Of course less animals will reduce C import, but do not give a significant reduction of C losses to the environment, due to higher emitted CO_2 by the herd. All three mitigations leads to higher C emissions by the soil. Three scenario's give a lower C soil content (negative C storing in the soil), but only the mitigation M1, feeding nitrate will led to an increase of C in the soil.

Table 4.2.3.1.4 and 4.2.3.1.5 show the greenhouse gas production for the whole farm (table 3) and per ha (table 4)

Table 4.2.3.1.4 GHG results per mitigation, kg CO_2-eq/yr

	Baseline	Feeding Nitrate	Less young stock	Less grazing
CH_4 enteric	321055	351132	365354	390348
CH_4 manure	100821	143553	127850	163941
N_2O manure	48916	54113	53151	62452
N_2O field	151689	174996	169762	161970
Soil C changes	20321	-3278	2045	4774
Total direct GHG	642801	720516	718162	783484
Housing NH_3 emissions	6611	6887	6892	8108
Manure storage NH_3 emissions	574	604	602	709
NH_3 emissions from field-applied manure	483	523	516	508
NH_3 emissions from fertilisers	1090	1098	1084	1084
N_2O emissions resulting from leaching of N	27859	22204	21760	17311
Total indirect GHG	36616	31316	30855	27721
GHG, direct + indirect	679417	751832	749017	811205

The effect of the different mitigations on GHG is also presented, but other mitigations are responsible for this effects than for the N effects. Overall all the mitigations will increase GHG emissions. Less grazing will lead to the highest increase. The effects are especially seen in the indirect emission. All the 3 mitigations will reduce nitrate leaching, which is mainly responsible for the indirect GHG production. Only the mitigations 'Feeding nitrate' will increase the Carbon in the soil.

Table 4.2.3.1.5 GHG results per ha, kg CO_2-eq/yr

	Baseline	Feeding Nitrate	Less young stock	Less grazing
CH_4 enteric	6552	7166	7456	7966
CH_4 manure	2058	2930	2609	3346
N_2O manure	998	1104	1085	1275
N_2O field	3096	3571	3465	3306
Soil C changes	415	-67	42	97
Total GHG per ha	13118	14704	14656	15989
Housing NH_3 emissions	135	141	141	165
Manure storage NH_3 emissions	12	12	12	14
NH_3 emissions from field-applied manure	10	11	11	10
NH_3 emissions from fertilisers	22	22	22	22
N_2O emissions resulting from leaching of N	569	453	444	353
Total indirect GHG	747	639	630	566
GHG, direct + indirect	13866	15344	15286	16555

Table 4.2.3.1.5 shows the same effects, but recalculated to ha scale. Because the size of the farm did not chance in one of the mitigations, the effects did not changed. Compared to the Showcasefarm ‘The Marke, the Dutch average farm has a slightly higher GHG production than the Marke (and his mitigations).

4.2.3.2. De Marke demonstration farm, S-EU- 005.

De Marke is a dairy farm with as purpose: very low losses to the environment. From the early 90's the management on the farm was adapted to this objective. The Marke had a (poor) sandy soil with low organic matter content, a very deep groundwater level (> 3 meter) and therefore sensitive for nitrate leaching. The farm has 55 hectare of land, divided in 22 ha grass/clover, with a very low clover content (average 10-15 % of volume), 11 ha permanent grassland and 22 ha maize (6 ha as CCM and 18 ha as maize silage). There is a possibility to irrigate, but this is limited.
The C and N characteristics are presented in Table 4.2.3.2.1

Table 4.2.3.2.1 C/N content soil on the Marke

	C-content	C kg/ha	N kg/ha	C/N
0-20	2.4	62400	3822	16.3
20-40	1.85	48100	3120	15.4
40-60	0.6	15600	1170	13.3
60-100	0.4	10400	1040	10.0
20-100		74100	5330	13.9

There are 84 milking cows and 56 young stock (0-2 year). The basic data of the farm are presented in Table 4.2.3.2.2.

Table 4.2.3.2.2 Basic characteristics farm The Marke

	no	ha	Kg	Kg/ha	%	
Milking cows	84					
Calves 0-1 yr	31					
Older young stock 1-2 yr	25					
Replacement rate herd					29	
Milk production (cow/yr)			8341			
Protein content					3.49	
Milk production			700644	12739		
Used N from art fertiliser				56 (on grass)		
Area grassland		33				
Area arable land		22				
Grazing system						Very limited grazing
Concentrate use (per cow incl. young stock , total)			1762, 148000			
Milking system						AMS

There is only very limited grazing, to avoid high nitrate leaching outside the growing season. Heifers 1-2 year will only graze for 50 days. The milking cows will graze for 149 days, but only a few hours per day.
The farm has a special crop rotation system. During the thirst 3 years there is grassland mixed with clover (re-sown in year 1). The grassland is applied with slurry and artificial N fertiliser. This three year period is used to build up a buffer of organic N for the next three years, when the grassland is replaced by maize. To flatten the effect, every year 1/3 of the grass/clover land is ploughed in spring for maize. The first year after ploughing, maize will not be applied with manure. Artificial N fertiliser is only applied on grassland, on average 51 kg N/ha/yr on permanent grassland and grass/clover. Besides this 51 kg N also 294 kg N (total N, only about 50% will be

efficient) is applied as slurry. Maize only gets N in year two and three (on average 54 kg total N/ha) from slurry.

The maize is partly harvested as CCM. The remaining straw/stover will be ensilaged in combination with autumn grass and mainly fed to the older young stock. The total average maize gross yield for silage maize is 14 ton DM/ha and CCM/straw 12 ton DM/ha. The average gross yield of grassland is 9 ton DM/yr. The diet of the herd consist mainly of grass silage, maize silage and concentrates. The detailed diet is shown in Table 4.2.3.2.3 (recalculated to yearly base: average intake in 365 days). The table showed the daily intake for groups of animals and as average for the milking cows and all the young stock, used as input for the calculations with FarmAC.

Table 4.2.3.2.3 Feeding ration herd

Feed (kg DM/animal/day)/Group	Milking cows	Dry cows	Av. cows	Calves <1 yr	Heifers 1-2 yr	Av. Young stock
Grazed grass	1.62	0	1.4	0.0	1.1	0.47
Grass silage	5.76	5.1	5.7	2.4	4.1	3.14
Maize silage	6.52	2.8	6.0	1.5	0.0	0.83
CCM	1.72	0.0	1.5	0.4	0.0	0.22
Maize straw	0	2.6	0.3	0.0	2.7	1.19
Concentrates	5.39	0.6	4.8	1.2	0.0	0.66
Total intake	21.02	11.1	19.7	5.5	7.8	6.52

The input for the baseline FarmAC calculations is the outline of the Marke as presented. From this baseline different mitigations were planned and the effect on farm level was calculated with FarmAC. The mitigations should be applicable on the Marke. Because of the project objectives, a lot of changes already were implemented on the Marke, like cover crops in winter, low N fertilisation.

Results are highly dependent of the soil fertility (level of soil-C and –N). I FarmAC simulations soils with initial equilibrium in baseline was chosen, and 100 years adaptation period with present production-level had the result of 135 ton C/ha in the maize/grass-clover crop rotation, and 250 ton C/ha after 100 year permanent grass. Further investigation has to be conducted into this aspect. And the below results heavily depend on this assumption, as soil-N changes has big impact on the results shown.

The following mitigations were implemented :

- M1. Feeding nitrate
- M2. Change crop rotation: from 2/3 grass and 1/3 maize to 100% grass
- M3. Implement biogas
- M4. Using N inhibitors

Mitigation 1 Feeding Nitrate

A meta-analysis of *in vivo* data on nitrate supplementation by Jolien Veneman (PhD thesis 2015) showed a clear dose response relationship, showing that nitrate decreases methane emissions by 2.0g per 10g of nitrate/kg feed DM, which is 77% of its stoichiometric efficiency. Earlier work by Van Zijderveld ea (2011) showed that dietary nitrate is an effective and persistent strategy to mitigate emission of enteric methane. For every 1% NO3 in the diet, emission of enteric CH4 drops by approximately 10%. However, an overdose of NO3 is dangerous as methemoglobinemia (nitrite toxicity) can arise. Within Animal Change it was, therefore, agreed not to exceed 1.5% NO3 in the diet DM, allowing for a methane reduction of 15%. A technical challenge is to mix 1.5% NO3 homogeneously in the

diet. That is particularly an issue under smallholder conditions and this does, at the moment, cause a barrier to application in small scale farming. Showcase Farm De Marke in The Netherlands demonstrated in a pilot study that a feed mixer wagon is a very effective aid in homogeneously mixing the nitrate into the Total Mixed Ration (Newsletter KTC De Marke, No 4, May 2013).

The nitrate source used in all trials has the formula 5Ca(NO3)2.NH4NO3.10H2O and contains 63% nitrate. It is produced by fertilizer company Yara and has the trade name Bolifor CNF. This product contains 15.5% N, 18.9% Ca and 16% water. Nitrate in the diet usually replaces urea as NPN source and limestone as calcium source. Per unit of N, nitrate is more expensive than urea which means that without incentives to reduce emission of GHG, farmers will not embrace the technology. Contrary to expectation, a reduction of loss of methane by the animal has only in one trial led to increased feed conversion efficiency (Newbold e.a., 2014).

The nitrate concept has been reviewed by Lee and Beachemin (2014) and they conclude that supplementary nitrate is a viable means of mitigating enteric methane emissions due to its consistent and persistent efficacy. Risk of toxicity can be lowered by gradual acclimation of animals to nitrate. However, lowered methane production may not re-direct additional metabolizable energy towards animal production. This is currently being studied at the University of New England in Australia where a PhD student sponsored by Provimi works on it. Already in 2009, Provimi applied for a patent on using NO3 and SO4 as mitigators of emission of enteric methane (Perdok e.a., 2011).

At De Marke a yearlong demonstration started in December 2014. Up to 1.5% NO3 is included in the diet DM of lactating cows. To avoid adaptation problems, all dry cows and pregnant heifers are fed 0.5% NO3. The Dutch Dairy Association NZO has studied the possible effect that NO3 has on milk and dairy products and no sensory differences were detected between pasteurized milk or yoghurt from cows supplied with nitrate compared to the same products produced from reference milk (Van Adrichem ea 2015). Food companies may want a Consumer acceptance study to be done before accepting wide scale use of nitrate in diets for food producing animals.

Mitigation 2: Only grass in crop rotation

The object of this mitigation is to calculate the effect of implementing (more) maize. Because The Marke has already a large part of maize in the crop rotation as well in the ration, a mitigation without maize is chosen to compare with. Because of the nitrate objective on the Marke, the grazing time is still limited to about 5 hours a day and 150 grazing days. All the maize in the ration was replaced by grass silage.

Mitigation 3 Implement biogas

By implementing biogas, part of the produced CH4 can be used for energy. This will influence CH4 as well as the CO2 production and losses in a positive way. Probably manure composition and efficiency will change too. All these effects are calculated by FarmAc.

Mitigation 4: using nitrate inhibitors in manure

Using inhibitor in combination with slurry, ammonium losses should be reduced, especially in a wet spring.

The N losses (ammonium, nitrate) CO_2, CH_4 and GHG losses/production was calculated for the mitigations implemented and compared with the baseline and with each other. There is no financial/economic calculation made.

Results

Table 4.2.3.2.4 N effects (kg N/ha/year) of 4 mitigations on farm level

Farm	Item	Baseline	Feeding	Grass only	Biogas	Nitrate

			Nitrate			inhibitor
	Imported livestock feed	126.4	123.5	96.2	126.2	126.5
	Imported bedding	5.4	5.4	5.4	5.4	5.4
	N fixation	21.6	22.1	0.0	23.1	21.7
	N deposited from atmosphere	30.0	30.0	30.0	30.0	30.0
	N in fertiliser	32.9	33.1	175.0	33.1	32.9
	Imported	0.9	3.5	0.0	0.0	0.6
	N sold in crop products	0.2	0.2	0.0	0.2	0.2
	N sold in milk	70.8	69.9	70.9	70.8	70.8
	N exported in meat	6.6	6.6	7.6	6.6	6.6
	N in mortalities	0.0	0.0	0.0	0.0	0.0
	Exported manure	0.0	0.0	1.3	7.0	0.0
	Gaseous loss housing	22.0	21.6	25.5	22.0	22.0
	N lost from processing/stored crop products	25.2	25.4	34.4	25.2	25.2
	Gaseous loss storage	9.7	9.7	10.6	1.6	9.7
	Runoff	0.0	0.0	0.0	0.0	0.0
	Gaseous loss field	27.4	27.4	38.8	26.6	27.3
	Nitrate leaching	60.8	61.0	106.9	70.7	60.8
	Change in mineral N in soil	0.5	0.5	0.2	0.3	0.5
	Change in organic N in soil	-1.2	0.1	15.4	-8.6	-1.2
	Balance	-4.9	-4.9	-5.4	-4.9	-4.9
Herd						
	Livestock feed consumed in housing	263.1	261.3	281.9	263.1	263.1
	Grazed	35.4	35.4	39.0	35.4	35.4
	Deposited in housing	201.3	201.0	220.1	201.3	201.3
	Deposited in field	19.8	19.3	22.3	19.8	19.8
	N sold in milk	70.8	69.9	70.9	70.8	70.8
	N exported in meat	6.6	6.6	7.6	6.6	6.6
	N in mortalities	0.0	0.0	0.0	0.0	0.0
	Efficiency of N use by livestock	0.0	0.0	0.0	0.0	0.0
Housing						
	Input from livestock	201.3	201.0	220.1	201.3	201.3
	Gaseous loss	22.0	21.6	25.5	22.0	22.0
	Sent to storage	179.3	179.3	194.6	179.3	179.3
ManureStorage						
	Input from housing manure	179.3	179.3	194.6	179.3	179.3
	Bedding	5.4	5.4	5.4	5.4	5.4
	Feed wastage	8.1	8.1	8.7	8.1	8.1
	Gaseous loss	9.7	9.7	10.6	1.6	9.7
	Runoff from storage	0.0	0.0	0.0	0.0	0.0
	Manure ex storage	183.1	183.2	198.1	191.2	183.1
Fields						
	N fixation	21.6	22.1	0.0	23.1	21.7
	N deposited from atmosphere	30.0	30.0	30.0	30.0	30.0
	N in fertiliser	32.9	33.1	175.0	33.1	32.9
	Manure applied	184.0	186.7	196.8	184.2	183.7
	Gaseous loss fields	27.4	27.4	38.8	26.6	27.3
	Nitrate leaching	60.8	61.0	106.9	70.7	60.8
	Harvested mechanically	170.3	171.4	228.8	170.5	170.1
	Harvested by grazing	35.4	35.4	39.0	35.4	35.4

Change in mineral N in soil	0.5	0.5	0.2	0.3	0.5
Change in organic N in soil	-1.2	0.1	15.4	-8.6	-1.2

Table 4.2.3.2.4 presents the data of N effects calculated by FarmAC for the different mitigations on the Dutch showcase farm. They are presented for the whole farm expressed in kg N per hectare land. To present the data in this way it is easier to compare farms of different size.

The largest N effect is seen by mitigation 2: only grass. There is no N fixation in this scenario, while the crop rotation is a pure grass rotation without white clover. To keep the total yield in line with the baseline calculations much more N is used on farm scale, partly to compensate the N from fixation, partly to no utilization of soil-N in maize left after accumulated in grass/clover. More (only) grass also will led to a higher N content of the diet and more nitrate leaching.

The other 3 mitigations do not have much N effect on farm scale.

Besides the N effects, also the C effects had been calculated. The C effects in kg C/ha/year are shown in Table 4.2.3.2.5.

Table 4.2.3.2.5 C effects.Kg C per ha per year for baseline situation and 4 mitigation options

Item	Baseline	Feeding Nitrate	Grass only	Biogas	Nitrate inhibitor
C fixed from atmosphere	10833.8	10906.5	12671.1	10894.6	10826.9
C in imported manure	5.7	23.2	0.0	0.0	3.9
C in imported feed	1759.6	1876.4	1748.7	1755.2	1762.4
C in bedding	0.0	0.0	0.0	0.0	0.0
C in exported milk	637.0	628.6	637.2	637.0	637.0
C in exported meat	58.7	58.7	68.1	58.7	58.7
C in mortalities	0.0	0.0	0.0	0.0	0.0
C in crop products sold	7.4	7.4	0.0	7.8	7.4
C in exported manure	0.0	0.0	8.6	24.3	0.0
C in enteric methane emissions	197.1	175.6	191.9	197.1	197.1
C in CO_2 emitted by livestock	2957.4	3021.6	2883.0	2957.4	2957.4
C in CO_2 emitted from animal housing	193.6	199.5	184.5	193.6	193.6
C in methane emitted by manure	79.7	84.8	72.2	9.7	79.7
C in CO_2 emitted by manure	79.7	84.8	72.2	9.7	79.7
C in biogas methane	0.0	0.0	0.0	474.1	0.0
C in biogas CO_2	0.0	0.0	0.0	474.1	0.0
C in CO_2 lost from stored crop products	601.0	607.3	591.5	601.8	600.5
C in CO_2 emitted by the soil	7799.4	7935.6	9527.3	7095.5	7794.5
C in organic matter leached from the soil	0.0	0.0	0.0	0.0	0.0
CO_2-C from burning crop residues	0.0	0.0	0.0	0.0	0.0
CO_2-C in gases from burning crop residues	0.0	0.0	0.0	0.0	0.0
Black carbon in gases from burning crop residues	0.0	0.0	0.0	0.0	0.0
Change in C stored in the soil	-11.9	2.0	183.3	-91.1	-12.3
C lost to the environment	11907.8	12109.3	13522.6	11064.7	11902.4
Net C balance	0.0	0.0	0.0	0.0	0.0

Overall the effect of the mitigation 1 ‘Nitrate feeding’, mitigation 3 ‘Biogas’ and 4 ‘Using inhibitor’ do not differ so much from the baseline. A farm with permanent

grass has the highest C fixation from the atmosphere and is the only mitigations that builds up C in the soil. On the other hand C as emitted CO_2 by the soil is also the highest (+25 kg C/ha). The 'grass only' mitigation is the best adaption to avoid C losses.

Table 4.2.3.2.6 and 4.2.3.2.7 show the greenhouse gas production for the whole farm and per ha.

Table 4.2.3.2.6 GHG results per farm, kg CO_2-eq/yr

	Baseline	CaNO3 feeding	permanent grass	Biogas	Nitrate inhibitors
CH_4 enteric	360947	321699	351465	360937	360937
CH_4 manure	145945	155401	132197	17722	145947
N_2O manure	49664	49670	53750	9933	49665
N_2O field	151322	151853	185005	157050	151221
Soil C changes	2393	-413	-62846	18365	2489
Total direct GHG	710271	678210	659571	564007	710259
Indirect from NH_3-emission	6979	6873	9477	6075	6974
N_2O-indirect leaching	11746	11784	20449	13659	11741
Total indirect GHG	18724	18657	29925	19733	18715
GHG, direct + indirect	728995	696867	689497	583741	728975

The effect of the different mitigations on GHG is larger than the N effects. Overall biogas will reduce the GHG the most, mainly by the reduced CH_4 and N_2O emissions from manure. Using a biogas manure product, soil C is changing in a negative way. A scenario with permanent grass will be the scenario the highest GHG level, due to high N-fertilization resulting in high denitrification and high indirect GHG production. Especially C deplition in the soil is a negative aspect of this mitigation. Other assumptions regarding initial level soil-C would have high impact on the result. I present simulations high fertility after permanent grass has been assumed, with the result that soil-N is depleted. These results should be seen in perspective of more maize. More maize will give a better N efficiency and slightly higher GHG production.

Feeding nitrate reduces the CH_4 emission due to the effect in the diet.

Table 4.2.3.2.7 GHG results per ha, kg CO_2-eq/yr

	Baseline	CaNO3 feeding	permanent grass	Biogas	Nitrate inhibitors
CH_4 enteric	6563	5849	6390	6562	6562
CH_4 manure	2654	2825	2404	322	2654
N_2O manure	903	903	977	181	903
N_2O field	2751	2761	3364	2855	2749
Soil C changes	44	-8	-1143	334	45
Total GHG per ha	12914	12331	11992	10255	12914
Indirect from NH_3-emission	127	125	172	110	127
N_2O-indirect leaching	214	214	372	248	213
Total indirect GHG	340	339	544	359	340
GHG, direct + indirect	13254	12670	12536	10613	13254

Table 4.2.3.2.7 shows the same effects, but recalculated to ha scale. Because the size of the farm did not chance in one of the mitigations, the effects did not changed.

4.2.3.3. Mitigation options evaluated across mitigation option from Maritime Mixed Dairy farms

The implemented mitigations on the Model farm are:

1. Feeding nitrate
2. Lower replacement value of 20% (less young stock; older cows)

3. Less grazing; more supplemental feeding with silage during grazing season
4. Less N from artificial fertiliser combined with the introduction of white clover

From those mitigations, not all the effects pointed in the same direction. Overall less animals are reducing losses in common, so mitigation 2 had the most promising results

The implemented mitigations on the showcase farm are:

- M1. Feeding nitrate
- M2. Change crop rotation: from 2/3 grass and 1/3 maize to 100% grass
- M3. Implement biogas
- M4. Using N inhibitors

There was no best solution. Al the mitigations do have some advantages and disadvantages according to reducing losses. In common the effects are small, due to the standard base line who had already relatively low losses.

4.2.4. Continental Mixed Dairy – Dairy farm Lorraine, M-EU-006.

General description

This model is a typical mixed dairy farm of the Eastern part of France (Lorraine). Its position is assumed to be 48.797041 N, 5.065865 E. Its description comes from the analysis of the survey of farms carried out by the Livestock Institute and the Agricultural Chambers and designed as BL-10-EST. The main type of soil is clayey-silty soil, followed by clayey or silty soil. In this eastern part of France, some areas have predominantly clayey soils, which are not common in France. Soil organic matter in 0-75 cm estimated around 85 ton C/ha and clay fraction around 0.33.

No irrigation is present. With both cultivated land (80 ha crops and 20 ha maize forage) and permanent grasslands (41 ha). The average use of N mineral fertilizer is about 127 kg N/ha due to the large area of crops. The production is close to 7T of grain/ha for cereals, to 3.5 T for rapeseed and to 11 T/ha of DM for the maize silage production. The straw required for the litter is cropped, but the rest is incorporated in the soil. The rest of the crop rotation and manure or fertilization management is mainly derived from the description of the model farm.

The mixed dairy farm produces 454 000 litres of industrial milk with 56 Holstein cows, supplemented with 105 tons concentrate per year, of which 40% correspond to cereals produced on the farm. The barn is based on a deep litter system producing 780 T of solid manure per year. Some farms combine mixed deep litter with slurry, but the farm simulated a complete deep litter system. The high proportion of deep litter systems was very common in mixed dairy farms due to the availability of straw. The farm is managed by 2.5 persons.

Simulation of the herd was divided in several groups (changing characteristics of existing groups to be consistent with the interface). The 56 dairy cows are splitted in 3 groups, lactating dairy indoor, lactating dairy outdoor, and dry cows. The separation between outdoor and indoor is dedicated to the use of supplement for the mitigation options, which are considered as applicable only during non grazing periods. The dry

cows are considered separately with no concentrate at all and their proportion is calculated assuming calving to calving intervals of 14 months, with 12 months of lactation. With 56 dairy cows, it means 8 dry cows during the year. The rest of the 48 cows was separted in 28 indoor due to long winter period, and 20 outdoor during the grazing period. The males are sold just after birth and are not reared on the farms. However, all the dairy heifers are reared until their first calving at 26-27 months.

Mitigation options of the Continental mixed dairy

Five mitigation options were considered here, both at the crop level (cover crops, legumes in the rotation) and at the animal level (feeding more fat or additive nitrate, earlier age at first calving). As this farm is a mixed dairy farm, some crops-related mitigation options could have been simulated irrespective of the animals. However, we considered that the problem should be tackled at the farm scale level and we deliberately used options that had consequences on the diet of herd (e.g. for a cover crop: Italian Ryegrass sward fed to the animals instead of white mustard cover incorporated to the soil). In these cases, we re-enforced the self-sufficiency of the farm and prioritized home-grown products. Doing that, we ensured that the diet had the same characteristics (even defaults) as the baseline scenario.

Mitigation 1 – Cover crops in the rotation

Cover crop was introduced in the rotation between the harvest of winter wheat (23/07) and the sowing of maize (initially 23/04, postponed to 30/04 without consequence on harvest date, on the 23/09). This represents an area of 20 ha.

Cropping sequence, yields, fertilization and characteristics of the crop

We simulated an Italian Ryegrass (Lolium multiflorum) sward, sown without mineral fertiliza-tion on the 15/08 after wheat harvest, a part being grazed twice by the dairy heifers or dry cows (12 ha), in autumn and spring, and another part being harvested and fed fresh to dairy cows in autumn and spring (8 ha). This practice and consequences on nitrate leaching were described in Brittany (Western part of France, oceanic climate) by Besnard and Hanocq (2010, Fourrages 203, 22-224).

In autumn, the harvest was from 01/10 to 31/10 with an average yield of 1.2 tDM/ha for cut and 1.0 tDM/ha for grazing (= 1.2 x 0.85).

In spring, the harvest was from 15/03 to 15/04 (15/03 for technical reasons in FarmAC, owing to following manure application on bare soil before maize sown on 30/04) with an average yield of 0.8 tDM/ha for cut and 0.7 tDM/ha for grazing (= 0.8 x 0.85). We thus assumed that the grazing period could start earlier than actually performed in this part of France. The yield of 1.5 tDM/ha grazed grass can be obtained around mid-April (21/04) in this Eastern part of France (Küng-Benoît 1991~~, Fourrages 127, 273-286~~). Assuming a grass growth of 25 kgDM/ha before this date (Fiorelli et al. 2009~~, Journées AFPF~~), we can expect a yield of about 1 tDM/ha on the 1st of April. Thus a yield of 0.8 tDM/ha is highly realistic. Overall, the total yield of 2 tDM grass/ha over winter is realistic.

During the two phases (winter period), the potential yield was set to 100 kgDM/ha (1 kg DM/ha harvested as grazed grass).

There is no fertilization. The grass during winter is consider as crop and given daily indoor.

Due to the higher forage production, the number of cows that can be fed has be increased, but the amount of concentrate used by the herd is maintain more or less similar to the Base-line scenario in order to compare them. The numbers of animals and the diet composition have been adapted to eat all the available forages.

Mitigation 2 – Feeding more fat

This mitigation option was described by Philippe Faverdin and Michel Doreau (technical note "MitigationOption-Lipids_Ruminants.docx" for animal change, and Pellerin et al. 2013)~~on DropBox, and in INRA 2013 Quelle contribution de l'agriculture française à la réduction des émissions de gaz à effet de serre? Fiche n°7~~).

For winter cows, cereals, soybean meal and rape seed meal were partly replaced by linseed extracted (INRA feedstuff CT0170) in order to increase the fat content (ether extract) of the diet up to 5% of the diet DM. This increases the proportion of energy sourced from fat, to the detriment of carbohydrates. The methane conversion factor parameter (entericTier2MCF in parameters.xml) was reduced by 4% per 1% added fat. The methane conversion factor de-fault value was set to 6.5% of the gross energy intake used for enteric methane production (Ym coefficient in IPCC 2006 Volume4 Chapter10 Table10.12 and Equation10.21). The new value was calculated as follow:

entericTier2MCFmitigation (%) = entericTier2MCFbaseline * [1 – 0.04 * (%Fatmitigation – %Fatbaseline)]

with entericTier2MCFbaseline set to 6.5 %.

The baseline and the mitigation diets are in Table 3. The new diet was obtained with Excel solver, allowing changes in feedstuff proportions in the concentrate (including linseed ex-tracted and rapeseed extracted) and minimizing the changes in UFL, PDIN and PDIE con-tents of the diet (+2% UFL, +1% PDIN, -1% PDIE). Rapeseed had a too high fat content (4.6%) to find a solution with minor changes in energy content.

With a change by 2.4 % in the fat content of the diet, the new entericTier2MCF coefficient was set to 5.9% for the dairy cows fed indoor.

Mitigation 3 – Additive nitrate

This mitigation option was described by Philippe Faverdin and Michel Doreau (technical note "MitigationOption-Nitrate_Ruminants.docx" for animal change ~~on DropBox~~, and ~~in INRA 2013 Quelle contribu-tion de l'agriculture française à la reduction des emissions de gaz à effet de serre? Fiche n°7)~~ Pellerin et al. 2013).

For winter cows, winter barley, winter wheat, soybean meal and rape seed meal were partly replaced by formaldehyde-treated soybean meal, peas (that could be produced on the farm according to mitigation option 4) and nitrate. Nitrates can substitute other sources of highly fermentable N proteins or non-protein nitrogen (urea), at a maximum dose of 1.5 % of the diet DM.

This is assumed to reduce linearly the enteric methane emissions by 10 % per 1 % nitrate in the diet. The value was calculated as follow:

The new diet was obtained with Excel solver, allowing changes in feedstuff proportions in the concentrate (including peas and formaldehyde-treated soybean meal) and minimizing the changes in UFL, PDIN and PDIE contents of the diet (1% UFL, +4% PDIN, +0% PDIE). We managed to keep energy, rumen degradable N and metabolisable protein contents similar to the baseline diet, with 0.4 kg of nitrate in the diet. The fat content of the diet remained un-changed (2.5 to 2.4%).

Mitigation 4 – Legumes in the rotation

Winter pea replaced winter wheat once in the crops rotation (20 ha). Both peas and straw pea were harvested and fed to dairy cows, increasing the self-sufficiency of the farm.

Cropping sequence, yields, fertilization and characteristics of the crop

The initial and the new cropping sequence are detailed in Table ~~1~~4. Winter pea can directly replace winter wheat in the rotation, without increasing the bare soil duration and associated winter leaching~~, (~~conversely to spring pea, that is sown between the 20th of February and the 15th of March in Lorraine~~,) source: (~~Arvalis, 201~~34~~). This cropping sequence fulfils the require-ments of at least 4 years between each pea cropping to reduce parasitism pressure ~~(INAPG 2003, Le pois protéagineux, online course, 18pages; (~~Arvalis, 201~~1~~4), all the more since the winter pea is more resistant to parasitism than the spring pea.

Cultivars are now able to support cold temperatures during winter in the Eastern part of France (Arvalis, 201~~1~~4). The yield is around 4.1 tFM/ha, i.e. 4.1*0.84 = 3.4 tDM/ha (Arvalis, 201~~1~~4; NB: the spring pea yields 4.4 tFM/ha in Champagne-Ardenne, Agreste, 2011).

There is no fertilization for pea. The following crop receives a reduced N fertilization, according to the results obtained in the Casdar “Amélioration des performances économiques et environnementales de systèmes de culture avec pois, colza et blé” (RTR CETIOM Zone Est, 2011).

Table 1. Baseline cropping sequence and new cropping sequence including a legume crop in farm 2

Table . Baseline cropping sequence and new cropping sequence including a legume crop in farm 2

Crop in original cropping seq.	Fertilization (kgN/ha)	Main yield (tFM/ha and tDM/ha)	Crop in new cropping seq.	Fertilization (kgN/ha)
Maize	organic 247	31.4 / 11.0	Maize	Organic 247
Winter wheat	mineral 180	7.3 / 6.2	Winter wheat	mineral 180
Winter barley	mineral 140	7.0 / 6.0	Winter barley	mineral 140
Winter rape	mineral 170	3.5 / 3.2	Winter pea	0
Winter wheat	mineral 180	7.3 / 6.2	Winter rape	mineral 100

Consequences on the feeding system and land use

Both peas and pea straw were included in the diet of dairy cows in winter. At grazing, only peas were used in the concentrate. Baseline and new diets are detailed in Table 45.

Table 5. Feedstuffs nitrate content and amount in the diet of winter-fed dairy cows for the baseline and the mitigation option scenario in farm 2

Feedstuff	Baseline WINTER diet (kgDM/d/cow)	Mitigation WINTER diet (kgDM/d/cow)	Baseline GRAZING diet (kgDM/d/cow)	Mitigation GRAZING diet (kgDM/d/cow)
Maize silage	12.4	11.8 (-)	4.3	3.3 (-)
Hay 1st cut	1.2	0 (-)		
Grazed grass			8.7	9.3 (+)
Pea straw	0	2.4 (+)		
Winter wheat	1	0 (-)	1.4	1.4 (≈)
Winter barley	1	0.5 (-)	1	1 (≈)
Soybean meal	2.8	2.2 (-)	1.1	0.3 (-)
Rapeseed meal	1.4	1.2 (-)	0.5	0.5 (≈)
Peas	0	2.3 (+)	0	1.3 (+)
Total DM intake (kg/d/cow)	19.8	20.4 (+)	17.0	17.1 (≈)

- + = ≈ indicate the evolution between baseline scenario and mitigation scenario

Pea straw substituted hay in the diet of dairy cows in winter. The reduction in hay consumption cows allowed an increase in the grazing area in spring: first cut hay area was reduced from 11 to 7 ha. We consequently increased the grazed grass intake of dairy cows in Mai and June, thereby reducing their maize silage intake.

The use of peas in the concentrate decreased the use of cereals and soybean meal and increased sold cereals, but of course, the rapeseed is no more produced and not sold.

Consequences on the herd structure

Pea straw yielded 35 tDM. This increase in forage on the farm permitted to feed additional cows, as for mitigation option 1. In this simulation 6% more animals are possible with the option.

Feedstuffs and diets

Peas represented up to 12% of DM intake of dairy cows in winter. Peas can represent up to 30% of the DM of a maize silage-based diet without digestive or intake troubles **(Hoden et al. 1992).** The inclusion of peas required the use of formaldehyde-treated soybean meal to in-crease the metabolisable protein supply and reach diet characteristics similar to the baseline diet (Table 4).

The pea straw has a poor energy content (0.53 UFL/kg DM), but a correct CP content (66 g/kg DM) in regard to energy. Its ingestibility is similar to poor hay (1.14 UEL/kg

DM). As we substituted good hay with pea straw, the DM intake was reduced in winter. So that both forage and concentrate intakes are affected.

The farm produced 67 tDM peas and 30 tDM pea straw. Almost all the straw was fed to animals (minus losses) and about 60% of peas were consumed.

Mitigation 5 – Reduce the fertilization rate

It appears to be very difficult to simulates an overuse of mineral fertilizer with Farm AC due to the linear response of the model. This mitigation option is replaced by the next one.

Mitigation 5bis – Reduce the age at first calving

In France, the average age of Holstein cows at first calving is generally comprised between 29 and 30 months. This is due to the fact that the period of calving of heifers is generally grouped (2-3 months) to simplify reproduction management of the heifers and to maintain a period with more milk in the year (generally in winter, due to the highest price of milk during this period). However, the cows are calving all year long, considering the problems of repro-duction. Consequently, to group the heifers for the reproduction, there is in fact two peaks of age, one around 2 years old, and a second much wider with heifers being to young and obliged to wait one year more (26-36 months at first calving). This is not optimal and oblige to fed heifers too long. It is both a source of extra GHG production and global inefficiency of the herd (considering the heifers can finish their growth during first lactation).

This was simulated for this model farm as a fifth mitigation option. It seems to be reasonable in practice because the management of the reproduction (heat observation of heifers for example) is facilitated by precision livestock design and also because the use of sexed semen becomes more and more efficient, which permits to inseminate most of the heifers with females to maintain grouped claving. However, the description of this model farm considered has a lower number of old heifers at first calving with a average age of 26 to 27 months at first calving. Consequently, the impacts are limited compared to other farm.

To make it comparable with the other situations, it is assumed that the replacement rate is the same, but of the heifers are managed to calve at the same age of 2 years old. However, with less heifers, more forages are available to produce milk using more cows. The diets have been reconsidered to use more or less the same amount of concentrates at herd level to assume the increase of milk production comes from the reduction of roughage consumption of the old heifers of the baseline scenario.

The fact to change the age at first calving also changes the characteristics of the animals. The heifers were considered to have a lower average body weight (370 kg vs 400 kg for the baseline scenario) and had to recover more weight in lactation. So the expected weight gain in lactating cows was increased from 10 to 40 kg per year.

Mitigation 6 – Incorporating straw in the soil

Considering the results, the GHG emissions are very sensitive to C change in soil. To assess this effect a last mitigation was tested to reincorporate straw in soil, except

the part required for litter. Of course, it does not consider the changes of the possible effects of the exported straw, but it generates the best reduction of GHG emissions of the system.

Results

Animal management M2, M3, M5

The mitigation options based on feeding management (fat or nitrate) are induced positive small improvement in terms of GHG emissions. The global effect at farm level is about 1 to 2 % reduction in GHG emissions without affecting production of crops or milk. This small effect is due to the fact that the enteric emissions are only 40% of the total GHG emissions on farm. Moreover, the emissions of the cows represent only half of the enteric emissions and the period during feed supplement can be used in practice is also half of it. This small fraction explains the limited impacts of these mitigations options.

The option of reducing the age of the heifers at first calving has positive but limited impacts on GHG emissions at farm levels. This is due, like in the cover crop scenario, to a reduction in milk yield per cow due to the principle to use the same amount of concentrate at farm level, but a higher total milk and meat productions. Moreover, the model farm tested here is not the best one for this mitigation option because only a limited number of heifers are calving at more than 24 months. The impact is however as a little higher that for the feed management option.

Crop management (with animal management consequences) M1, M4

The cover crop option, with the use of the grass produced due to the cover crop to feed more animals has finally contradictory effects. As expected, it helps to reduce nitrate leaching of 35% at farm level, but tends to increase the NH3 emissions. However, it reduces the milk production per cow to use all the forages without using more concentrate, and tends to in-crease enteric methane emissions. However, a little more amount of meat is produced. It also slightly increases the C losses from the soil. At the end the final GHG balance of this scenario is not positive. However, if the increase in meat is considered, the global impact on GHG compared to the production is more or less the same, the main benefit concerning the N leaching.

The use of legumes in the rotation affects a lot of things and is more difficult to interpret. The first result is a reduction of 28% in the use of N mineral fertilizers, associated with a similar reduction in N nitrate leaching of about 26%. However, the exportation of crops is reduced (no more rapeseed), but partly compensated by a reduction in concentrate use, which reduces the amount of concentrates bought and increases the amount of cereals sold. But at the end, the compensation is only half of the baseline difference. Milk and meat production are increased. At the end, there is an increase of 4% of total GHG emissions, but related to the milk and meat yield, it represents a 6% reduction. The reduction of crop sold has also to be considered to globally assess this option which has in any case positive effect on N cycle.

Crop management (without animal management consequences) M6

The final option was just tested to assess the impact of C restitution to the soil from the crop in such a system. This option is the most significant with a reduction of about 18% of the emissions. Of course, this conclusion is biased by the fact that future of the straw is not simulated in case of straw exportation. However, it confirms that at farm levels, even in a dairy farm, the management of C soil is one of the most sensitive options to modify GHG emission at this scale.

Table 2: Results per ha of the N fluxes for the continental mixed dairy farm with the different mitigation options.

Table . Results per ha of the N fluxes for the continental mixed dairy farm with the different mitigation options

	Item		Baseline, with all the straw cropped, except for the rapeseed	Cover crop used as fresh grass fed indoor	Feeding more fat	Feeding nitrate	Legumes (Peas)	All the heifers calving at 2 years old	Incorporating straw except for the litter requirement
Farm	Imported livestock feed	kgN/ha/yr	33.9	33.7	35.9	34.8	28.2	34.0	33.9
	Imported bedding	kgN/ha/yr	1.3	1.4	1.3	1.3	1.4	1.3	1.3
	N fixation	kgN/ha/yr	0.0	0.0	0.0	0.0	9.4	0.0	0.0
	N deposited from atmosphere	kgN/ha/yr	13.1	13.1	13.1	13.1	13.1	13.1	13.1
	N in fertiliser	kgN/ha/yr	128.9	128.9	128.9	128.9	92.9	128.9	128.9
	Imported manure	kgN/ha/yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	N sold in crop products	kgN/ha/yr	94.5	94.4	96.8	93.5	76.3	94.5	76.0
	N sold in milk	kgN/ha/yr	18.1	18.1	18.0	18.0	19.7	18.3	18.1
	N exported in meat	kgN/ha/yr	3.6	3.8	3.6	3.6	3.8	3.7	3.6
	N in mortalities	kgN/ha/yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Exported manure	kgN/ha/yr	3.9	8.3	3.6	5.5	7.3	3.7	3.9
	Gaseous loss housing	kgN/ha/yr	6.2	7.0	6.2	6.4	6.5	6.1	6.2
	N lost from processing/stored crop products	kgN/ha/yr	5.7	5.7	5.7	5.7	5.5	5.7	5.7
	Gaseous loss storage	kgN/ha/yr	3.7	4.1	3.7	3.8	3.9	3.7	3.7
	Runoff	kgN/ha/yr	1.5	1.6	1.5	1.6	1.7	1.5	1.5
	Gaseous loss field	kgN/ha/yr	25.0	26.6	25.0	25.0	21.9	25.0	26.3
	Nitrate leaching	kgN/ha/yr	34.9	22.8	34.9	34.9	25.7	34.9	23.1
	Change in mineral N in soil	kgN/ha/yr	-5.2	-6.1	-5.2	-5.2	-5.7	-5.2	-4.4
	Change in organic N in soil	kgN/ha/yr	-13.5	-8.2	-13.5	-13.6	-20.2	-13.5	14.3
	Balance	kgN/ha/yr	-1.0	-1.0	-1.0	-1.0	-1.4	-1.0	-0.8
Herd									
	Livestock feed consumed in housing	kgN/ha/yr	65.7	69.4	65.4	67.5	69.7	65.8	65.7
	Grazed	kgN/ha/yr	29.8	35.2	29.8	29.8	32.6	29.8	29.8
	Deposited in housing	kgN/ha/yr	53.8	59.0	53.5	55.6	57.4	53.5	53.8
	Deposited in field	kgN/ha/yr	20.1	23.7	20.1	20.1	21.3	20.2	20.1
	N sold in milk	kgN/ha/yr	18.1	18.1	18.0	18.0	19.7	18.3	18.1
	N exported in meat	kgN/ha/yr	3.6	3.8	3.6	3.6	3.8	3.7	3.6
	N in mortalities	kgN/ha/yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Efficiency of N use by livestock								
	balance	kgN/ha/yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Housing									
	Input from livestock	kgN/ha/yr	53.8	59.0	53.5	55.6	57.4	53.5	53.8
	Gaseous loss	kgN/ha/yr	6.2	7.0	6.2	6.4	6.5	6.1	6.2
	Sent to storage	kgN/ha/yr	47.6	52.0	47.3	49.2	50.9	47.4	47.6
	balance	kgN/ha/yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ManureStorage									
	Input from housing manure	kgN/ha/yr	47.6	52.0	47.3	49.2	50.9	47.4	47.6
	Bedding	kgN/ha/yr	1.3	1.4	1.3	1.3	1.4	1.3	1.3
	Feed wastage	kgN/ha/yr	7.3	7.7	7.3	7.5	7.7	7.3	7.3
	Gaseous loss	kgN/ha/yr	3.7	4.1	3.7	3.8	3.9	3.7	3.7
	Runoff from storage	kgN/ha/yr	1.5	1.6	1.5	1.6	1.7	1.5	1.5
	Manure ex storage	kgN/ha/yr	51.0	55.4	50.7	52.6	54.5	50.8	51.0
	balance	kgN/ha/yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fields									
	N fixation	kgN/ha/yr	0.0	0.0	0.0	0.0	9.4	0.0	0.0
	N deposited from atmosphere	kgN/ha/yr	13.1	13.1	13.1	13.1	13.1	13.1	13.1
	N in fertiliser	kgN/ha/yr	128.9	128.9	128.9	128.9	92.9	128.9	128.9
	Manure applied	kgN/ha/yr	47.1	47.1	47.1	47.1	47.1	47.1	47.1
	Gaseous loss fields	kgN/ha/yr	25.0	26.6	25.0	25.0	21.9	25.0	26.3
	Nitrate leaching	kgN/ha/yr	34.9	22.8	34.9	34.9	25.7	34.9	23.1
	Harvested mechanically	kgN/ha/yr	139.4	143.5	139.3	139.4	131.0	139.3	120.9
	Harvested by grazing	kgN/ha/yr	29.8	35.2	29.8	29.8	32.6	29.8	29.8
	Change in mineral N in soil	kgN/ha/yr	-5.2	-6.1	-5.2	-5.2	-5.7	-5.2	-4.4
	Change in organic N in soil	kgN/ha/yr	-34.6	-32.9	-34.6	-34.7	-42.9	-34.7	-6.6

Table 3: Results per ha of the C fluxes and final indicators for the continental mixed dairy farm with the different mitigation options.

Table . Results per ha of the C fluxes and final indicators for the continental mixed dairy farm with the different mitigation options

Cbalance	Item		Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	Cfixed from atmosphere	kg C/ha/yr	1478718.308	1589852.116	1477814.1	1478718.308	1302251.704	1479778.132	1920813.194
	Cin imported manure	kg C/ha/yr	0	0	0	0	0	0	0
	Cin imported feed	kg C/ha/yr	41188.8833	41758.1327	46882.0386	38291.1535	40217.2973	41269.2292	41188.8833
	Cin bedding	kg C/ha/yr	0	0	0	0	0	0	0
	Cin exported milk	kg C/ha/yr	22779.0929	22791.0567	22720.4746	22658.1467	24854.573	23026.5149	22779.0929
	Cin exported meat	kg C/ha/yr	4463.1314	4799.9643	4463.1314	4463.1314	4730.9193	4619.2815	4463.1314
	Cin mortalities	kg C/ha/yr	0	0	0	0	0	0	0
	Cin crop products sold	kg C/ha/yr	374605.3136	374386.8233	382358.6388	371024.4863	326572.8818	374572.2727	244568.1059
	Cin exported manure	kg C/ha/yr	5274.0224	10871.4892	4916.0016	7456.5103	10371.061	4996.3143	5274.0224
	Cin enteric methane emissions	kg C/ha/yr	8288.9922	8960.5591	7871.586495	7959.7815	9053.2448	8319.8627	8288.9922
	Cin CO2 emitted by livestock	kg C/ha/yr	126530.1712	137986.2905	124362.7265	125606.4264	135960.8776	126338.1001	126530.1712
	Cin CO2 emitted from animal housing	kg C/ha/yr	6721.7456	7004.2383	6631.5328	6746.3371	7315.4896	6726.823	6721.7456
	Cin methane emitted by manure	kg C/ha/yr	969.5277	1014.7408	972.7125	997.946	1078.6788	968.4956	969.5277
	Cin CO2 emitted by manure	kg C/ha/yr	969.5277	1014.7408	972.7125	997.946	1078.6788	968.4956	969.5277
	Cin biogas methane	kg C/ha/yr	0	0	0	0	0	0	0
	Cin biogas CO2	kg C/ha/yr	0	0	0	0	0	0	0
	Cin CO2 lost from stored crop products	kg C/ha/yr	23862.41	23874.8836	23862.41	23862.41	23124.1698	23876.8586	23862.41
	Cin CO2 emitted by the soil	kg C/ha/yr	963344.0087	1048609.428	963444.2235	963156.8677	826169.9821	964364.8802	1496155.279
	Cin organic matter leached from the soil	kg C/ha/yr	0	0	0	0	0	0	0
	CO-Cfrom burning crop residues	kg C/ha/yr	0	0	0	0	0	0	0
	CO2-Cin gases from burning crop residues	kg C/ha/yr	0	0	0	0	0	0	0
	Black carbon in gases from burning crop residues	kg C/ha/yr	0	0	0	0	0	0	0
	Change in Cstored in the soil		-16704.1054	-8556.4654	-16683.3657	-16723.8815	-26174.6591	-16611.2571	22616.7184
FarmDirect(	Item		Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	Enteric methane emissions	kg CO2 equiv	276023.4401	298386.6169	262123.8291	265060.7232	301473.0503	277051.4284	276023.4401
	Manure methane emissions	kg CO2 equiv	32285.2719	33790.8701	32391.327	33231.6032	35920.0035	32250.9033	32285.2719
	Manure N2O emissions	kg CO2 equiv	36894.579	40082.8637	36680.6807	38065.959	39390.608	36736.9112	36894.579
	Field N2O emissions	kg CO2 equiv	286987.1208	308126.7998	286925.0138	286967.6353	248261.0386	287265.5576	309058.0004
	Change in Cstored in soil	kg CO2 equiv	61253.9545	31376.5585	61177.902	61326.4733	95982.475	60913.4796	-82935.5063
	Total GHG emissions	kg CO2 equiv	693444.3663	711763.7091	679298.7526	684652.394	721027.1754	694218.2801	571325.785
FarmIndire(	Item		Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	Housing NH3 emissions	kg CO2 equiv	4041.8309	4578.1427	4037.9807	4215.8718	4251.3047	4005.526	4041.8309
	Manure storage NH3 emissions	kg CO2 equiv	956.6895	1072.9096	954.9269	993.8737	1009.5561	952.1592	956.6895
	NH3 emissions from field-applied manure	kg CO2 equiv	2642.9719	2760.7421	2656.4047	2673.4938	2602.0367	2629.4279	2642.9719
	NH3 emissions from fertilisers	kg CO2 equiv	1690.563	1690.563	1690.563	1690.563	1218.5166	1690.563	1690.563
	N2O emissions resulting from leaching of N	kg CO2 equiv	17162.3391	11225.5246	17170.027	17146.1047	12618.445	17168.5694	11374.2041
	Total indirect emissions	kg CO2 equiv	26494.3944	21327.882	26509.9023	26719.907	21699.8591	26446.2456	20706.2595
Indicators	Item		Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	Total farm milk production	kg/yr	455581.8571	455821.1333	454409.4925	453162.9347	497091.4595	460530.2974	455581.8571
	Total farm meat production	Tons liveweig	19.2376	20.6895	19.2376	19.2376	20.3919	19.9107	19.2376
	Farm milk production per head	kg/yr	8135.390305	7513.535143	8114.4552	8092.195286	8374.182257	7740.004971	7740.004971
	Milk production per unit area	kg/ha/yr	3231.077	3232.774	3222.7624	3213.9215	3525.4713	3266.1723	3231.077
	Meat production per unit area	kg/ha/yr	0.1364	0.1467	0.1364	0.1364	0.1446	0.1412	0.1364
	Item		Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	Direct GHG/litre	kg CO2 equiv	1.522107071	1.561497827	1.494904406	1.510830524	1.45049198	1.507432375	1.254057369
	Indirect GHG/litre	kg CO2 equiv	0.058155069	0.046790025	0.058339235	0.058963134	0.043653655	0.057425637	0.045450141
			1.580262141	1.608287851	1.553243642	1.569793658	1.494145635	1.564858012	1.29950751

4.2.5. Mediterranean Mixed Dairy. Italian Mixed Dairy-Po Valley, M-EU-013.

General description

This model farm is located in the Po Valley and corresponds to the Italian conventional diary model farm used in the MIDAIR project (Olesen et al., 2006). The soil is a loam with 25 % clay and more than 4 meter to the ground water table, and the climate is a Mediterranean with an annual mean temperature of 13.6 ^{o}C, an annual rainfall of 757 mm, and dominated by hot and dry summers.

The model farm is defined to have a utilised agricultural area of 50 ha, and the milk yield of the cows is set to 5840 kg/year (ECM, Energy Corrected Milk) corresponding to the regional average. The stocking density is set to be higher than for a self-sufficient farm with imported feed in concentrates. All bull calves are exported from the farm. The stock density thus includes dairy cows and young female stock. All

surplus heifers are kept until pregnant and then sold. Cows are all Holstein-Friesians or a similar heavy breed. All cattle are kept indoors and the manure is managed as slurry. The slurry is applied in the field by broad spreading, even if local regulations prescribe otherwise. Farm management is assumed to be efficient so that manure management, silage production etc. is carried out with a minimum of losses (best practice).

The crop rotation of the total 50 ha farm is divided into 10 ha of permanent grass-clover and 40 ha in a rotation of lucerne, lucerne, lucerne, silage maize and wheat (each 8 ha). The grass and lucerne are cut and fed to the cattle either fresh or as silage. The farm has 85 dairy cattle and associated 89 young stock and heifers. The manure is stored in a slurry tank with a natural crust.

Mitigation options of the Mediterranean mixed dairy

Five mitigation options were considered here as some that would be of particular relevance for a housing-based dairy system under conditions where rainfall may be limiting crop production. The mitigation options implemented were

1. Irrigation
2. Nitrate feeding to the cows
3. Slurry acidification in the house
4. Biogas of the manure
5. Nitrification inhibitors

The following sections describe each mitigation option and Table 4.2.5.1 shows the key characteristics of the farm for each mitigation scenario. The overall farm structure was not changed, i.e. the number of livestock and in most cases also the feeding and the associated milk production was kept constant in the scenarios. Therefore any change in productivity was reflected in the amount of crop products sold from the farm. These crop products was mostly in the form of green fodder, which could have been used on-farm for increasing or reducing milk production (or on other farms).

Table 4.2.5.1. Key farm data and production used in the scenarios for the Italian mixed dairy farm.

Item	Baseline	M1	M2	M3	M4	M5
Farm size (ha)	50	50	50	50	50	50
Number of cows	85	85	85	85	85	85
Milk yield (kg/cow)	5840	5840	5730	5840	5840	5840
Crops sold (kg/ha)	741	1662	669	912	943	743

M1: Irrigation, M2: Nitrate feeding, M3: Slurry acidification, M4: Biogas, M5: Nitrification inhibitors.

Mitigation 1 (M1) – Irrigation

The baseline farm was set to be non-irrigated (rainfed). In reality several farms in the region applies irrigation. We therefore applied the simple decision rules in FarmAC to determine the amount of irrigation needed. As average of the 50 ha crop rotation 331 mm was applied in irrigation water.

Mitigation 2 (M2) – Nitrate feeding

The nitrate feeding option involved adding nitrate to the feed. In this case 0.4 kg $CaNO_3$ per cow per day was added to all feed to the cattle. This was possible, because cows were kept indoor allowing nitrate addition to all the feed. Nitrate feeding is known to reduce the methane in proportion to the added amount of nitrate added in the feed (Lee and Beauchemin, 2014). The extra nitrate N-feeding is compensated by exchange of rape with wheat grain.

Mitigation 3 (M3) – Slurry acidification in the house

Acidification of manure (slurry) with sulphuric acid not only substantially reduces ammonia emissions. It also has a marked and lasting effect on methane emission with measured effects of 67-87% in experiments with cattle slurry and above 90% in experiments with pig slurry (Petersen et al., 2012, 2014). I practice an effect of about 60% may be assumed. However, the maximum effect will only be achieved if the acidification is performed in the animal house in a slurry based system with slatted floor, which is what is assumed in the current setup.

Mitigation 4 (M4) - Biogas

Biogas reduces the methane emissions from storage of the manure by degrading the organic matter and thus reducing the substrate for methane production in the manure storage. The effect of biogas is especially high, if the manure is rapidly removed from the house and transferred to the biogas digester. Here we have assumed an on-farm digester with rapid transfer of the manure to the digester. The effect is also particularly high in warm climates such as the current Mediterranean farm, where the warm temperatures favour methane production in untreated slurry (Sommer et al., 2009). The biogas digestion also increases the mineral N content in the slurry and thus its available and use efficiency by the plants.

Mitigation 5 (M5) – Nitrification inhibitors

With this measure, nitrification inhibitors are added to both mineral fertilisers and manure before field application. The nitrification inhibitors block the nitrification of ammonium to nitrate in the soil, which prevents added ammonium from being a source of nitrous oxide both from the nitrification and from the denitrification. However, the nitrification inhibitors break down over time and therefore the effect on N_2O emissions diminishes accordingly. The FarmAC model simulates this process and here we applied an initial inhibitor effect of 1.0. This is assumed to give overall emission N_2O reductions of 30-40% in line with what has been found experimentally (Akiyama et al., 2010).

Results

Table 4.2.5.2 shows the carbon flows in various scenarios, Tables 4.2.5.3 and 4.2.5.4 gives the nitrogen flows and Table 4.2.5.5 gives an overview of the GHG emissions at farm scale. Of the total baseline farm emissions in CO_2-equivalents, 42% originate from enteric fermentation, 36% from manure management and 23% from fields. The largest effects on GHG emissions were obtained with the manure management options, and both slurry acidification and biogas reduced farm GHG emissions by

more than 20%, whereas irrigation had little effect and nitrate feeding and nitrification inhibitors only reduced emissions by about 3%.

Irrigation enhanced biomass production and biological N fixation. The resulting biomass was exported, but could alternatively have been used to enhance milk production. Based on the carbon and nitrogen flows, this enhanced production may be estimated to have been able to enhance milk production by 15%. The small increase in greenhouse emissions is primarily due to higher N_2O emissions from recycling of more N residues and from enhanced nitrate leaching.

Nitrate feeding reduced enteric methane emissions by 12%. However, this meant an increase in the import of nitrogen to the farm and in the manure, because the nitrate feeding could not fully substitute other N in the feed, due to low level of import of rape for concentrate feeding. Therefore overall nitrous oxide emissions increased by 3%. Manure emissions were not substantially affected, and therefore the overall farm GHG emissions were only reduced by 3%.

Slurry acidification reduces ammonia volatilisation and methane from the manure management. In total manure emissions was reduced by 86%. However, lower ammonia volatilisation increase N in the manure, resulting in increased nitrous oxide by 12% from the field application of the manure. This resulted in a total reduction of GHG emissions of 23% at farm scale.

Biogas reduces ammonia volatilisation from the manure storage, because the manure is treated and stored in covered tanks. However, in contrast to slurry acidification there is no ammonia reduction in the house. Biogas reduced manure methane emissions by 88%, which is above what has been found in other studies (Weiske et al., 2006). However, here we did not include the emissions reductions from the fossil fuel substitution that can be obtained by using the biogas for fuel or electricity production. The greater amount of mineral N applied to field slightly increased N leaching and associated emissions. In contrast the lower return of organic matter to the soil meant a small reduction in soil organic matter. The reduction in total farm GHG emissions from treating the manure in a biogas digester was 28%. This reduction is likely higher than can be obtained in cooler climates, because of the large methane emissions from the slurry store in the baseline conditions.

The use of nitrification inhibitors reduced nitrous oxide emissions from the field by 18%. This is lower than what may be expected from the field applications of fertilisers and manure with addition of nitrification inhibitors. However, the crop rotation with a large part of the land area in grass-clover and lucerne meant that there was a large input of N in crop residues, which also is a source of nitrous oxide emissions, but which is only marginally affected by the addition of nitrification inhibitors in the fertiliser and manure. Overall this measure only reduced farm emissions by 3%.

Table 4.2.5.2. Farm C flows (kg C/ha) in the different scenarios.

Item	Baseline	M1	M2	M3	M4	M5
Fixed from atmosphere	11310	12465	11338	11576	11615	11327

Imported manure	0	0	0	0	0	0
Imported feed	1505	1490	1611	1490	1490	1501
Imported bedding	0	0	0	0	0	0
Exported milk	496	496	486	496	496	496
Exported meat	46	46	46	46	46	46
Mortalities	0	0	0	0	0	0
Exported crops	319	715	288	392	406	319
Enteric methane	173	173	152	173	173	173
Livestock respiration	2455	2455	2455	2455	2455	2455
Respiration in housing	189	189	194	189	189	189
Methane from manure	117	117	117	42	14	117
CO_2 from manure	117	117	117	42	14	117
Methane in biogas	0	0	0	0	698	0
CO_2 in biogas	0	0	0	0	698	0
Respiration in stored crop	501	566	503	513	515	502
Soil respiration	8384	9037	8406	8671	7526	8393
Change in soil C	-7	18	-2	29	-105	-5

M1: Irrigation, M2: Nitrate feeding, M3: Slurry acidification, M4: Biogas, M5: Nitrification inhibitors.

Table 4.2.5.3. Farm N balance (kg N/ha) in the different scenarios.

Item	Baseline	M1	M2	M3	M4	M5
Imported livestock feed	47	46	80	46	46	47
Imported bedding	8	8	8	8	8	8
Biological N fixation	108	171	115	84	85	105
Atmospheric deposition	14	14	14	14	14	14
Imported mineral fertiliser	56	56	15	34	45	57
Imported manure	0	0	0	0	0	0
Sold crop products	5	29	4	9	10	5
Sold milk	55	55	54	55	55	55
Sold meat	5	5	5	5	5	5
Mortalities	0	0	0	0	0	0
Exported manure	2	2	1	2	0	2
Gaseous loss, house	26	26	31	1	26	26
Loss, crop storage	26	30	26	27	27	26
Gaseous loss, manure	20	20	24	6	2	20
Runoff	0	0	0	0	0	0
Gaseous loss, field	62	64	66	27	28	59
Nitrate leaching	32	63	25	50	58	32
Change soil mineral N	0	-2	-1	1	2	0
Change soil organic N	-1	2	0	3	-10	-1

M1: Irrigation, M2: Nitrate feeding, M3: Slurry acidification, M4: Biogas, M5: Nitrification inhibitors.

Table 4.2.5.4. Farm N flows (kg N/ha) within the farm in the different scenarios.

Item	Baseline	M1	M2	M3	M4	M5
Livestock feed in house	266	266	298	266	266	266
Grazed	0	0	0	0	0	0
Deposited in house	206	206	238	206	206	206
Deposited in field	0	0	0	0	0	0
Manure to storage	180	180	208	205	180	180
Bedding	8	8	8	8	8	8
Feed waste to manure	30	30	33	30	30	30
Manure ex storage	197	197	225	236	216	197
Manure applied	195	195	225	234	220	195
Harvested mechanically	280	309	281	286	287	281
Harvested by grazing	0	0	0	0	0	0
Livestock N efficiency	0.227	0.227	0.199	0.227	0.227	0.227

M1: Irrigation, M2: Nitrate feeding, M3: Slurry acidification, M4: Biogas, M5: Nitrification inhibitors.

Table 4.2.5.5.

FarmAC greenhouse gas (GHG) emissions in CO_2 equivalents and for the various mitigation scenarios for the Italian dairy farm

Item	Baseline	M1	M2	M3	M4	M5
Direct emissions (kg/ha)						
Enteric CH_4	5763	5763	5076	5763	5763	5763
Manure CH_4	3906	3906	3888	1396	484	3906
Manure N_2O	1019	1019	1165	567	204	1019
Field N_2O	2483	2636	2411	2760	2813	2038
Change in soil C	24	-66	6	-106	384	20
Indirect emissions (kg/ha)						
N_2O from NH_3	369	369	421	30	139	369
N_2O from N leaching	111	222	86	175	205	114
Total GHG	13676	13846	13054	10584	9982	13230
Reduction (%)		-1	5	23	27	3
Emissions (kg/liter)						
Total GHG	1.37	1.39	1.34	1.07	1.01	1.33
Reduction (%)		-1	3	23	28	3

M1: Irrigation, M2: Nitrate feeding, M3: Slurry acidification, M4: Biogas, M5: Nitrification inhibitors.

5.1.1.1 Conclusions mitigation options

In Table 5.1a and Table 5.1b, the effect of the different mitigation options was analyzed across farms when whole chain (including pre-chain) was included, and this total GHG emission was allocated between milk and meat following the allocation method from IDF (2010).

Actually some of the mitigation options did not work as mitigation option as GHG emission per kg milk was increased (2-15%). These mitigation options were: Reduced replacement, reduced grazing, permanent grass and legumes. Using reduced replacement at the same time reduce amount of milk and meat produced on the farm. However, these 4 mitigation options were only tested at one farm each.

The most efficient mitigation options with the highest reduction were biogas and stall acidified slurry that reduce GHG emission per kg milk and meat by 24-28% and without reduction in the amount of milk and meat produced per farm.

Mitigation options that cause a medium reduction were use of nitrification inhibitors and 'incorporating straw (except for the litter required) that reduce GHG emission per kg milk and meat by 7-16% and without reduction in the amount of milk and meat produced per farm.

The mitigation option 'nitrate feeding' was tested on 4 farms and in all cases GHG emission per kg milk and meat was reduced by 1-7% and without reduction in the amount of milk and meat produced per farm.

The mitigation options 'feeding more fat' and 'heifers calving at 2 years' reduced GHG emission per kg milk and meat by 1-4% and 'feeding more fat' did not reduce amount of milk and meat produced per farm and 'heifers calving at 2 years' even increased amount of milk and meat produced per farm.

In Table 5.2, the effect of the different mitigation options were analyzed across farms when only on-farm emissions were included and the total on-farm emission was not allocated to the different products.

In general very much the same picture was seen as for the whole chain emissions. Though, 2 mitigation options change effect. When only looking at farm gate, 'reduced replacement rate' seems to be a mitigation option (5% reduction), but not when also pre-chain emissions were included. Opposite for 'cover crop used as fresh grass fed indoor, at farm gate it was not a mitigation option, but when also pre-chain emissions were included there was a small mitigation effect (1%).

Still, reduced grazing, permanent grass and legumes did not work as mitigation option as on-farm GHG emission was increased (3-9%) and still the most efficient mitigation options with the highest reduction were biogas and stall acidified slurry that reduce GHG emission by 23-27%. A medium reduction from use of nitrification inhibitors (3-8%) and 'incorporating straw (18%). At farm level, 'nitrate feeding' cause 1-5%. Finally, 'feeding more fat' and 'heifers calving at 2 years' reduced on-farm GHG emission by 2 and 0% respectively.

Table 5.1a. Effect of different mitigation options on **GHG emissions** (relative to basic farm without any mitigation option) – including GHG from pre-chain

Farm		Dutch Grasland Dairy Average	Dutch Mixed Dairy De Marke	Grench Mixed dairy Lorraine	Italy Mixed dairy
	Milk				
	Total GHG emission from milk	Rel. CO2, g/kg milk			
Mitigation option					
Basic		100	100	100	100
M1	Nitrate feeding	98	93	99	97
M2	Reduced replacement	103			
M3	Reduced grazing	109			
M4	Permanent grass		115		
M5	Biogas		75		72
M6	Nitrification inhibitors		88		93
M7	Cover crop used as fresh grass fed indoor			99	
M8	Feeding more fat			96	
M9	Legumes (pea)			102	
M10	Heifers calving at 2 years old			98	
M11	Incorporating straw except for the litter required			84	
M12	Irrigated				98
M13	Stall acidified slurry				76
	Meat				
	Total GHG emission from meat	Rel. CO2, g/kg meat LW			
Basic		100	100	100	100
M1	Nitrate feeding	98	93	99	97
M2	Reduced replacement	98			
M3	Reduced grazing	109			
M4	Permanent grass		115		
M5	Biogas		75		72
M6	Nitrification inhibitors		88		93
M7	Cover crop used as fresh grass fed indoor			102	
M8	Feeding more fat			96	
M9	Legumes (pea)			101	
M10	Heifers calving at 2 years old			99	
M11	Incorporating straw except for the litter required			84	
M12	Irrigated				98
M13	Stall acidified slurry				76

Table 5.1b. Effect of different mitigation options on total on-farm **production** (relative to basic farm without any mitigation option)

Farm		Dutch Grasland Dairy Average	Dutch Mixed Dairy De Marke	Grench Mixed Dairy Lorraine	Italy Mixed Dairy
	Milk	Milk production, rel. ton per farm			
Mitigation option					
Basic		100	100	100	100
M1	Nitrate feeding	100	100	100	100
M2	Reduced replacement	71			
M3	Reduced grazing	100			
M4	Permanent grass		114		
M5	Biogas		100		100
M6	Nitrification inhibitors		100		100
M7	Cover crop used as fresh grass fed indoor			111	
M8	Feeding more fat			100	
M9	Legumes (pea)			105	
M10	Heifers calving at 2 years old			105	
M11	Incorporating straw except for the litter required			100	
M12	Irrigated				100
M13	Stall acidified slurry				100
	Meat	Meat production, rel. ton per farm			
Basic		100	100	100	100
M1	Nitrate feeding	100	100	100	100
M2	Reduced replacement	71			
M3	Reduced grazing	100			
M4	Permanent grass		114		
M5	Biogas		100		100
M6	Nitrification inhibitors		100		100
M7	Cover crop used as fresh grass fed indoor			111	
M8	Feeding more fat			100	
M9	Legumes (pea)			105	
M10	Heifers calving at 2 years old			105	
M11	Incorporating straw except for the litter required			100	
M12	Irrigated				100
M13	Stall acidified slurry				100

Table 5.2. Effect of different mitigation options on GHG emissions (relative to basic farm without any mitigation option) – only including **on-farm emission**

Farm		Dutch Grasland Dairy Average	Dutch Mixed Dairy De Marke	French Mixed dairy Lorraine	Italy Mixed dairy
	Total GHG on farm	Rel. kg CO2/ha			
Mitigation option					
Basic		100	100	100	100
M1	Nitrate feeding	95	93	99	95
M2	Reduced replacement	95			
M3	Reduced grazing	103			
M4	Permanent grass		109		
M5	Biogas		77		73
M6	Nitrification inhibitors		92		97
M7	Cover crop used as fresh grass fed indoor			102	
M8	Feeding more fat			98	
M9	Legumes (pea)			103	
M10	Heifers calving at 2 years old			100	
M11	Incorporating straw except for the litter required			82	
M12	Irrigated				101
M13	Stall acidified slurry				77

6.1.1.1 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 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 project farms of Europe, both showcase farms and model farms. Annex 2 provides the country, the farm type and the farm name of these farms. The farm typology (Annex 5) defined in the AnimalChange project (Stienezen et al., 2012) has been used.

For 13 farms, there was a selection of the four best adaptation measures available (Annex 4). For 12 out of the 13 farms, additional information on expected impact from climate change (Annex 7) and farm 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 ten different adaptation measures were identified by the local experts from Europe 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).

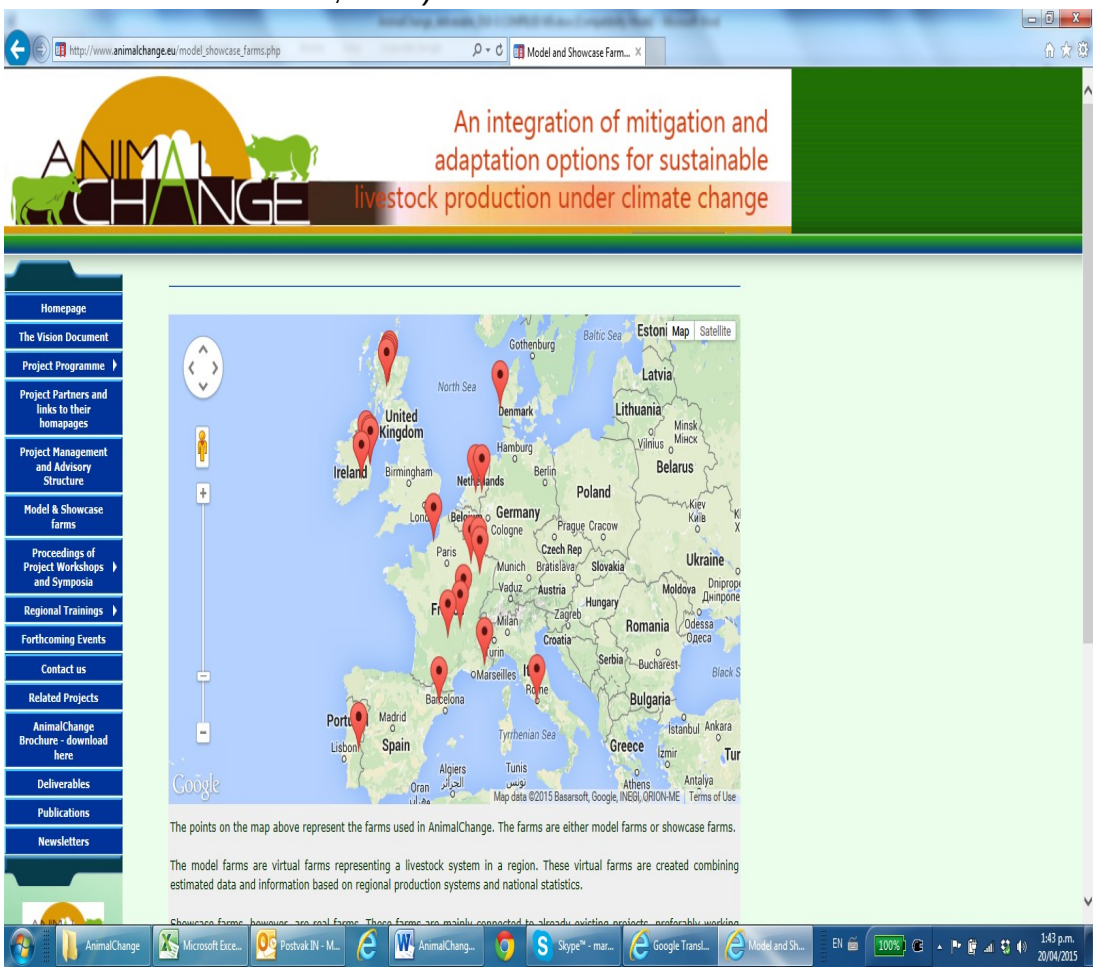

Figure 6.1. European model farms and showcase farms of AnimalChange. Source: http://www.animalchange.eu/model_showcase_farms.php

Table 6.2. Adaptation measures that have been identified as one of the best four options for the European farms within AnimalChange by local experts.

1	Fertilisation rate
2	Water management (water storage for livestock)
3	Water management (irrigation)
4	Use of mixtures of plant species
5	Feed storage
6	Cooling of animals (housing)
7	Animal breeding (local breeds)
8	Animal breeding (change breeds)
9	Supplemental feeding
10	Use of plants more resistant to drought, flooding, pests and diseases

For all farms, the adaptation measures selected by local experts were selected because the measures were expected 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).

The adaptation measures

- “Feed storage”,
- “Use of mixtures of plant species” and
- “Water management”

were appointed for respectively 10, 9 and 9 farm types out of the 13, to be one of the four best adaptation measures (Table 6.3). With respect to the adaptation measure "Water management" it has to be taken into account that the local experts indicated that water management is not only needed in periods of drought (irrigation) but also necessary in periods of water surplus (e.g. drainage).

The adaptation measures

- “Fertilisation rate”,
- “Supplemental feeding” and
- the two measures on “Animal breeding”, measure 7. & 8.,

were selected by respectively 5, 6 and 7 (3 plus 4) farms (Table 6.3).

The farm types “Maritime grassland dairy”, “Maritime mixed dairy” and “Maritime mixed beef” are represented by more than one farm in the database and therefore more than four adaptation measures are listed (Table 6.3.). For the Southern European pig farm five measures are listed because the two breeding measures were considered as one.
The farm types “Continental mixed dairy”, “Continental mixed beef”, “Continental grassland beef”, “Mountain grassland beef”, “Mountain grassland sheep”, “Mediterranean grassland sheep”, “Mediterranean mixed dairy” and “Northern European pig” are each represented in the database by one farm. Table 6.2 confirms the conclusion of Top et al. (2015) that the best adaptation measures are dependent on the farming system. However, it appeared 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 the farm types “Maritime grassland dairy” and “Maritime mixed dairy” (Table 6.4).

And even within a farm type, the implementation can be different, for example at “Maritime mixed dairy” the farm implementation is different between regions (The Netherlands vs. Scotland) (Table 6.4). There may even be implementation differences between farms of the same farm type within one region as a result of site differences, but due to the limited number of farms this could not be shown. Only from the maritime zone farm types were represented by more than one farm. 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 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

- “Feed storage”,
- “Use of mixtures of plant species” and
- “Water management”

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	Farm type													
	Number of farm types adaptation measure is selected as being one of the four best options	Maritime grassland beef	Maritime grassland dairy	Maritime mixed dairy	Maritime mixed beef	Continental mixed dairy	Continental mixed beef	Continental grassland beef	Mountain grassland beef	Mountain grassland sheep	Mediterranean grassland sheep	Mediterranean mixed dairy	Northern European pig	Southern European pig	
1. Fertilisation rate	5	x	x	x	x								x		
2. Water management (water storage for livestock)	1													x	
3. Water management (irrigation)**	9	x	x	x		x	x	x			x	x	x		
4. Use of mixtures of plant species	9		x	x	x	x	x	x			x	x	x		
5. Feed storage	10			x	x	x	x	x	x	x	x	x	x		
6. Cooling of animals (housing)	2			x										x	
7. Animal breeding (local breeds)	3	x	x											x	
8. Animal breeding (change breeds)	4		x	x	x									x	
9. Supplemental feeding	6	x	x	x	x							x		x	
10. Use of plants more resistant to drought, flooding, pests and diseases	2		x								x				

** Adaptation measure "Water management (irrigation)" was used by the local experts to indicate that water management is not only needed in periods of drought (irrigation) but also as necessary in periods of surplus of water (e.g. drainage).

Table 6.4. Implementation method of the adaptation measure **“Fertilisation rate”** in relation to farm type, country/farm and 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

Farm type	Country+Region	Farm	Thermal growing season	Drought	Heat stress	Water logging	Heat stress	Diseases	Land accessibility	Thermal growing season	Drought	Heat stress	Water logging	Heat stress	Diseases	Land accessibility	Thermal growing season	Drought	Heat stress	Water logging	Heat stress	Diseases	Land accessibility
			Crops				Livestock			Crops				Livestock			Crops				Livestock		
			+	0/-	0	--	0/-	-	--	+	0	0	-	0	-	-	+	0/-	0	0	0	0	0/-
Maritime mixed dairy	Nether-lands	De Marke	Due to increase of the temperature growing season will be elongated. For this reason use of nitrogen can be increased to meet increased demand from plants.																				
		Dutch average sandy soil	Due to increase of the temperature growing season will be elongated. For this reason use of nitrogen can be increased to meet increased demand from plants.																				
	Scotland	Stewart Tower								Soil analysis, nutrient budgetting, better use of organic manure, reduce bagged N applied to spring barley crops													
Maritime mixed beef	Scotland	Glenkilrie / Upper Nisbet								Soil analysis, nutrient budgetting, better use of organic manure, reduce P and K applied to grassland reduce bagged N applied to crops													
	France-Normandie	Fattened oxen Haute-Normandie															--						
Maritime grassland dairy	Ireland	Curtins	--																				
		Greenfield	Precision technology to match fertiliser to plant needs.																				
		Irish average national dairy	Precision technology to match fertiliser to plant needs.																				
	Scotland	Torr								New slurry store applied, undertaking nutrient budgeting													

7.1.1.1 References

Akiyama, H., Yan, X., Yagi, K., 2010. Evaluation of effectiveness of enhanced-efficiency fertilizers as mitigation options for N2O and NO emissions from agricultural soils: meta-analysis. Global Change Biology 16, 1837-1846.

Arvalis – Institut du végétal, UNIP, 2014. Pois protéagineux de printemps et d'hiver – Guide de culture 2014-2015. Arvalis Editions, 40pp.

Besnard A., Hanocq D.,2010. Effet du pâturage hivernal des couverts sur la lixiviation du nitrate. Fourrages 203, 22-224.

Beukes, P. C., P. Gregorini, A. J. Romera, G. Levy, and G. C. Waghorn. 2010. Improving production efficiency as a strategy to mitigate greenhouse gas emissions on pastoral dairy farms in New Zealand. Agriculture, Ecosystems & Environment 136(3-4):358-365.

Capper, J. L. 2011. The environmental impact of beef production in the United States: 1977 compared with 2007. J. Anim Sci. 89:4249-4261.

Connolly, L., Kinsella, A., Quinlan, G., Moran, B., 2009. National Farm Survey 2008. Teagasc, Farm Surveys Department, Athenry, Co. Galway, Ireland.

Crosson, P., O´Kiely, P., O´Mara, F. P., and Wallace, M. 2006. The development of a math-ematical model to investigate Irish beef production systems. Agricultural Systems 89:349-370.

Crosson, P., Murphy, P., Brennan, P., 2013b. Reducing GHG emissions for beef cattle sys-tems. TResearch, 8 (2): 16-17.

Dalgaard, R. L. and N. Halberg (2007). How to account for emissions from manure? Who bears the burden? 5th International Conference "LCA in Foods" 25-26 April 2007, Gothenburg, Sweden**:** 1-3.

Elsgaard, L., et al. (2010). Greenhouse gas emissions from cultivation of winter wheat and winter rapeseed for biofuels and from production of biogas from manure, see http://pure.au.dk/portal/files/43999218/726859.pdf . **:** 1-34.

Enriquez-Hidalgo, D., Gilliland, T., Deighton, M.H., O'Donovan, M., Hennessy, D. 2014. Milk production and enteric methane emissions by dairy cows grazing fertilized perennial ryegrass pasture with or without inclusion of white clover. Journal of Dairy Science, 97:1400-1412.

EU (2013). Annex II: product environmental footprint (PEF) guide. Draft.

Fiorelli J.L., Bazard C., Echampard L., Lavé R., Trommenschlager J.M., 2009. Production des prairies permanentes conduites selon le cahier des charges de l'Agriculture Biologique. Le cas du système herbager de Mirecourt de 2005 à 2008. Journées AFPF, 25 mars 2009, « Des fourrages de haute qualité pour des élevages à hautes performances économiques et environnementales ».

Fitzgerald, J. B., A. J. Brereton, and N. M. Holden. 2009. Assessment of the adaptation po-tential of grass-based dairy systems to climate change in Ireland-The maximised production scenario. Agricultural and Forest Meteorology 149(2):244-255.

Foley, P. A., P. Crosson, D. K. Lovett, T. M. Boland, F. P. O'Mara, and D. A. Kenny. 2011. Whole-farm systems modelling of greenhouse gas emissions from pastoral suckler beef cow production systems. Agric. Ecosyst. Environ. 142:222-230.

Hennessy, T., B. Moran, A. Kinsella, and G. Quinlan. 2011. National farm survey 2011. Teagasc agricultural economics and farm surveys department. Athenry, Co. Galway.

Hennessy, D., Enriquez-Hidalgo, D., and Egan, M. 2013. Using white clover to increase herbage DM production and animal performance. Teagasc national dairy

conference 2013 – Strategies for sustainable success. Available on http://www.teagasc.ie/publications/2013/2989/Dairy%20conference%20proceedingsWeb.pdf

Hoden A., Delaby L., Marquis B., 1992. Pois protéagineux comme concentré unique pour vaches laitières. INRA Productions animales, 1992, 5 (1), pp.37-42.

Hutchings, N.J., 2013. Scientific and technical documentation of the modelling complex. AnimalChange Deliverable report 9.2.

Keating T, O'Kiely P. Comparison of old permanent grassland, Lolium perenne and Lolium multiflorum swards grown for silage 3. Effects of varying fertiliser nitrogen application rate. Ir J Agric Food Res 2000; 39: 35-53.

Kristensen, I. S. (2006). Estimating of N-surplus and -losses in Denmark using "Farm-N". Summary in Plant Production Congress 2006. 10.-11. Jan., Herning Kongrescenter. p 461-463. Precentation: https://www.landbrugsinfo.dk/Planteavl/Goedskning/Naeringsstoffer/Kvaelstof-N/Sider/plk06_95_3_I_S_Kristensen.pdf ?download=true.

Kristensen, I. S., Kelm, M. og Kristensen, T. (2004). Effects of grassland renovation on farm-gate nitrogen balances and losses. In "Land Use Systems in Grassland Dominated Regions". Eds. Lüscher,A.; Jeangros,B.; Kessler,W.; Huguenin,O.; Lobsiger,M.; Millar,N.; Suter,D. Proceedings of the 20th General Meeting of the European Grassland Federation, Luzern, Switzerland, 21-24. June 2004.

Kristensen, I. S. og Kristensen, T. (2007). N-balances and model calculated N-losses from typical intensive dairy farms in Northern Europe. Eds. Vliegher De, A. and Carlier,L.. Proceedings of the 14th Symposium of the European Grasland Federation. Gent, Belgium. 3-5 September 2007. page 311-314. See http://www.europeangrassland.org/fileadmin/media/EGF2007_GSE_vol12.pdf.

Kristensen, T., et al. (2011). "Effect of production system and farming strategy on greenhouse gas emissions from commercial dairy farms in a life cycle approach. see http://ac.els-cdn.com/S1871141311000850/1-s2.0-S1871141311000850-main.pdf?_tid=be3fa984-d153-11e4-af47-00000aacb361&acdnat=1427112013_58eb3aa37a31b0ce7472301c79ce530b ." Livestock Science **140**(1-3): 136-148.

Küng-Benoît A., 1991. Croissance printanière de la prairie permanente en Lorraine : lois de croissance potentielle. Fourrages 127, 273-286.

Lee, C., Beauchemin, K.A., 2014. A review of feeding supplementary nitrate to ruminant animals: nitrate toxicity, methane emissions, and production performance. Canadian Journal of Animal Science 94, 557-570.

Lovett, D. K., L. Shalloo, P. Dillon, and F. P. O'Mara. 2008. Greenhouse gas emissions from pastoral based dairying systems: The effect of uncertainty and management change under two contrasting production systems. Livestock Science 116(1-3):260-274.

Mogensen, L., et al. (2014). "Carbon footprint of cattle feeds – a method to include contribution from soil carbon changes. ." Journal of Cleaner Production. **73**: 40-51.

NaturErhvervstyrelsen (2014). Vejledning om gødsknings- og harmoniregler. 2014/15. see http://naturerhverv.dk/fileadmin/user_upload/NaturErhverv/Filer/Landbrug/Goedningsregnskab/Vejledning_om_goedsknings-_og_harmoniregler_nyeste.pdf . , Ministeriet for Fødevarer, Landbrug og Fiskeri. NaturErhvervsstyrelsen.**:** 1-170.

Nielsen, P. H., et al. (2003). LCA Food data Base. Online at: www.LcaFood.dk.

O'Brien, D., L. Shalloo, C. Grainger, F. Buckley, B. Horan, and M. Wallace. 2010. The influ-ence of strain of Holstein-Friesian cow and feeding system on greenhouse gas emissions from pastoral dairy farms. Journal of dairy science 93(7):3390-3402.

O'Brien, D., L. Shalloo, J. Patton, F. Buckley, C. Grainger, and M. Wallace. 2012. Evaluation of the effect of accounting method, IPCC v. LCA, on grass-based and confinement dairy sys-tems' greenhouse gas emissions. Animal 6(9):1512-1527.

O'Brien, D., L. Shalloo, P. Crosson, T. Donnellan, N. Farrelly, J. Finnan, K. Hanrahan, S. Lalor, G. Lanigan, F. Thorne, and R. Schulte. 2014. An evaluation of the effect of greenhouse gas accounting methods on a marginal abatement cost curve for Irish agricultural greenhouse gas emissions. Environmental Science & Policy, 39:107-118.

Olesen, J.E., Schelde, K., Weiske, A., Weisbjerg, M.R., Asman, W.A.H. & Djurhuus, J. (2006). Modelling greenhouse gas emissions from European conventional and organic dairy farms. Agriculture, Ecosystems and Environment 112, 207-220.

Pellerin S., Bamière L., Angers D., Béline F., Benoît M., Butault J.P., Chenu C., Colnenne-David C., De Cara S., Delame N., Doreau M., Dupraz P., Faverdin P., Garcia-Launay F., Hassouna M., Hénault C., Jeuffroy M.H., Klumpp K., Metay A., Moran D., Recous S., Samson E., Savini I., PardonL., 2013. How can French agriculture contribute to reducing greenhouse gas emissions? Abatement potential and cost of ten technical measures. Synopsis of the study report, INRA (France), 92 pp. see http://institut.inra.fr/en/Missions/Inform-public-decision-making/Advanced-Studies/All-the-news/Study-on-reduction-of-GHG-in-agriculture

Petersen, S.O., Andersen, A.J., Eriksen, J., 2012. Effects of slurry acidification on ammonia and methane emission during storage. Journal of Environmental Quality 41, 88-94.

Petersen, S.O., Højberg, O., Poulsen, M., Schwab, C., Eriksen, J., 2014. Methanogenic community changes, and emissions of methane and other gases, during storage of acidified and untreated slurry. Journal of Applied Microbiology 117, 160-172.

Sommer, S.G., Olesen, J.E., Petersen, S.O., Weisbjerg, M.R., Valli, L., Rodhe, L., Béline, F., 2009. Region-specific assessment of greenhouse gas mitigation with different manure management strategies in four agroecological zones. Global Change Biology 15, 2825-2837.

Stienezen, M.W.J and A. van den Pol-van Dasselaar. 2012. Compiled database on characteristic livestock farms for use in Task 10.3. Deliverable 10.1 AnimalChange project.

Topp et al., 2015. Report on synergies between mitigation and adaptation options. Kairsty Topp (SRUC), Donal O'Brien (TEAGASC), Marcia Stienezen (DLO), Gertjan Holshof (DLO), Anita Wreford (SRUC), Jorgen Olesen (AU). Deliverable 11.4 AnimalChange project.

Van den Pol – van Dasselaar. A. (2012). Qualitative overview of mitigation and adaptation options and their possible synergies & trade-offs. Deliverable 8.1 AnimalChange project.

Weiske, A., Vabitsch, A., Olesen, J.E., Schelde, K., Michel, J., Friedrich, R. & Kaltschmitt, M. (2006). Mitigation of greenhouse gas emissions in European conventional and or-ganic dairy farming. Agriculture, Ecosystems and Environment 112, 221-232.

Yan MJ, Humphreys J, Holden NM (2013a) The carbon footprint of pasture-based milk pro-duction: Can white clover make a difference? J Dairy Sci 96 (2):857-865.

Annex 1. Farm type definitions

For the European farms farm typology is used as described in Deliverable 10.3 of the AnimalChange project (Stienezen et al., 2012).

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 2. Farms initially identified for use in FarmAC

Country	Farm type	Farm	Farm ID
Netherlands	Maritime mixed dairy	Dutch common dairy	**M-EU-001**
Ireland	Maritime grassland beef	Average National Beef Farm	**M-EU-002**
Ireland	Maritime grassland dairy	Greenfield	**M-EU-003**
Ireland	Maritime grassland dairy	Average National Dairy farm	**M-EU-004**
France	Maritime mixed beef	Fattened oxen HauteNormandie	**M-EU-005**
France	Continental mixed dairy	Dairy farm Lorraine	**M-EU-006**
France	Continental mixed beef	Fattened young bulls Lorraine	**M-EU-007**
France	Continental grassland beef	Fattened calves Bourgogne	**M-EU-008**
France	Mountain grassland beef	Grazing calves Auvergne	**M-EU-009**
France	Mountain grassland sheep	Sheep Auvergne	**M-EU-010**
France	Mediterranean grassland sheep	SP01 Canjuerspaca	**M-EU-011**
France	Mediterranean grassland sheep	SP05 Canjuerspaca	**M-EU-012**
Italy	Mediterranean mixed dairy	Italian mixed dairy	**M-EU-013**
Denmark	Northern European pig	Danish conventional pig	**M-EU-014**
Spain	Southern European pig	Catalunya typical farm	**M-EU-015**
France	Continental mixed dairy	INRA ASTER Mirecourt	**S-EU-001**
France	Continental grassland dairy	INRA ASTER Mirecourt	**S-EU-002**
Ireland	Maritime grassland beef	Derry Patrick	**S-EU-003**
Ireland	Maritime grassland dairy	Curtins	**S-EU-004**
Netherlands	Maritime mixed dairy	De Marke	**S-EU-005**
Scotland	Maritime mixed dairy	Stewart Tower farm	**S-EU-006**
Scotland	Maritime grassland beef	Glenkilrie farm	**S-EU-007**
Scotland	Maritime grassland based dairy	Torr Farm	**S-EU-008**
Scotland	Maritime grassland beef	Upper Nisbet farm	**S-EU-009**
Portugal	Mediterranean grassland sheep	Herdade dos Esquerdos	**S-EU-010**

Annex 3. Five best mitigation options initially identified farms

Farm ID	Fertilisation rate	Nitrification inhibitors	Grass-legume swards	Legumes in the rotation	Cover crops	Irrigation	Restoring degraded lands	Improving pastures	improving roughage quality	Feeding maize and less grass	Feeding more fat	Additive nitrate	Balancing amno acids and reduce CP	Increasing housing (grass constant)	Replacemnt rate cattle	Cover slury stores & manure heaps	Manure acidification	Anaerobic digestion	Agroforestry	Genetic improvement in dairy cattle	Start the feedlot fattening period at a younger age	Change the grazing management	Clean the pasture from unwanted species	Reducing age at first calving	Optimizing calving dates	Integrate livestock and crop production
S-EU-001[a]	-	-	-	2	3	-	-	-	-	-	-	-	-	-	-	4	-	5	-	-	-	-	-	-	-	1
S-EU-002[b]	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	4	-	5	-	2	-	1	-	-	-	-
S-EU-003	-	-	4	-	-	-	-	5	3	-	-	-	-	-	1	-	-	-	-	2	-	-	-	-	-	-
S-EU-004	5	-	4	-	-	-	-	3	-	-	-	-	-	-	2	-	-	-	-	1	-	-	-	-	-	-
S-EU-005[c]	-	-	-	-	-	-	-	-	4	3	-	2	-	-	-	-	-	1	-	5	-	-	-	-	-	-
S-EU-006	1	-	1	1	-	-	-	1	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
S-EU-007	1	-	1	-	-	-	-	1	1	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-
S-EU-008	-	-	1	1	-	-	-	1	1	-	-	-	-	-	1	-	-	-	-	1	-	1	-	-	-	-
S-EU-009	1	-	1	-	-	-	-	1	1	1	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-
S-EU-010[d]	-	-	4	-	-	2	1	5	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-
M-EU-001	-	-	-	5	-	-	-	-	-	2	-	-	-	4	1	-	-	-	-	3	-	-	-	-	-	-
M-EU-002	-	-	4	-	-	-	-	5	3	-	-	-	-	-	1	-	-	-	-	2	-	-	-	-	-	-
M-EU-003	5	-	4	-	-	-	-	3	-	-	-	-	-	-	2	-	-	-	-	1	-	-	-	-	-	-
M-EU-004	5	-	4	-	-	-	-	3	-	-	-	-	-	-	2	-	-	-	-	1	-	-	-	-	-	-
M-EU-005	2	-	-	-	-	-	-	-	-	3	4	-	-	-	-	-	-	-	-	-	5	-	-	1	-	-
M-EU-006	5	-	-	4	1	-	-	-	-	-	2	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M-EU-007	-	-	-	4	-	-	-	-	2	-	3	-	-	-	-	-	-	-	-	-	-	-	-	1	5	-
M-EU-008	-	-	3	-	-	-	-	-	2	4	-	-	-	-	-	-	-	-	-	-	-	-	-	1	5	-
M-EU-009	-	-	3	-	-	-	-	4	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	5	-
M-EU-010	5	-	2	1	-	-	-	-	3	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M-EU-011	-	-	-	-	-	-	2	1	4	-	-	-	-	-	-	-	-	-	5	-	-	3	-	-	-	-
M-EU-012	-	-	-	-	-	-	4	5	2	-	-	-	-	-	-	-	-	-	-	-	-	1	3	-	-	-
M-EU-013																										
M-EU-014	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	X	X	X	-	-	-	-	-	-	-	-
M-EU-015	-	5	-	-	-	3	-	4	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[a] Already working on: Integrated crop-livestock system

[b] Already working on: Grazing maximised on permanent pastures

[c] Already working on: Cover slurry stores & manure heaps, Replacement rate cattle, Improving pastures, Cover crops, Grass-legume swards, Fertilisation rate, Improving roughage quality, Feeding maize and less grass, Additive nitrate, Anaerobic digestion, Genetic improvement in dairy cattle

[d] Already working on: Carbon sequestration through Biodiverse Legume Rich Pastures and the Use of legumes to fix nitrogen

Annex 4. Four best adaptation options for initially identified farms

Farm ID	Fertilisation rate	Water management (water storage for livestock)	Water management (irrigation)	Use of mixtures of plant species	Feed storage	Cooling of animals (housing)	Animal breeding (local breeds)	Animal breeding (change breeds)	Supplemental feeding	Use of plants more resistant to drought, flooding, pests and diseases		
S-EU-001	-	-	-	-	-	-		-	-	-		
S-EU-002	-	-	-	-	-	-		-	-	-		
S-EU-003	4	-	1	-	-	-	2	-	3	-		
S-EU-004	-	-	1	-	-	-	2	-	4	3		
S-EU-005	1	-	-	2	3	-	-	-	4	-		
S-EU-006	1	-	-	3	-	-	-	4	2	-		
S-EU-007	1	-	-	3	-	-	-	4	2	-		
S-EU-008	1	-	-	3	-	-	-	4	2	-		
S-EU-009	1	-	-	3	-	-	-	4	2	-		
S-EU-010	-	-	4	1	3	-	-	-	-	2		
M-EU-001	4	-	2	-	-	3	-	-	1	-		
M-EU-002	3	-	1	-	-	-	2	-	4	-		

and methods of implementation

M = Model farm, S = Showcase farm (real farm) and EU = Europe.

Farm ID	Adaptation ID	Why adaptation measure chosen?	How measure implemented on the farm?
S-EU-003	1	Opportunities may be available to reduce the N fertiliser rate if the improvements in climate conditions for grass growth are realised. The rate of fertilisation will also be important to cope with increases in the seasonal variability of grass growth.	Precision technology to match fertiliser to plant needs. As the conditions for grass growth are likely to improve, fertiliser applications are likely to increase
	3	The showcase farm contains some clay soils that are vulnerable to waterlogging. This is expected to increase in frequency. Strategies to adapt to this change include drainage of land and construction of reservoirs e.g. lagoons.	drainage of land and construction of reservoirs e.g. lagoons.
	7	Animal breeding will improve the durability and robustness of beef animals in terms of health and survival. This will improve the ability of grass-based beef production systems to adapt to greater variability in weather conditions and forage quality or supply.	Breeding robust breeds in terms of health and survival
	9	Based on the projected increases in the frequency of extreme weather events such as flooding and drought it is expected that supplemental feeding will be necessary during these periods. It is expected that this will mainly be in the form of conserved forage held on farm as reserves. This will be harvested from surpluses of grass growth that are expected to be larger under future climate change conditions in this region (Fitzgerald et al. 2009).	Correct supplementation will positively impact herbage production by reducing soil damage under extreme weather conditions and also benefit animals.
S-EU-004	3	To maintain productivity under drought conditions.	Adoption of sprinkler systems
	7	To be less vulnerable with animal performance under the expected change in weather conditions	Breeding robust breeds in terms of health and survival
	9	By using supplemental feeding being less vulnerable to expected variablility in day to day weather conditions.	Correct supplementation will positively impact herbage production by reducing soil damage under extreme weather conditions and also benefit
	10	To be less vulnerable with plant production under the expected change in weather conditions	Grass/legume swards are more suitable under warmer conditions, but legumes not suited to water logging.
S-EU-005	1	Increase use efficiency of N	Due to increase of the temperature growing season will be elongated. For this reason use of nitrogen can be increased to meet increased demand
	4	By using more species less vulnerable in plant production and quality to changing weather conditions	Irrigation might be of interest in periods of drought depending on costs from irrigation and feed prices
	5	Increasing feed storage to have supplemental feeding available for periods of reduced plant growth or in periods of extreme wet conditions when animals cannot graze.	Increasing feed storage towards the current level for winter supply
	9	By using supplemental feeding being less vulnerable to expected variablility in day to day weather conditions.	This will become more flexible, not explicit feeding more supplements. The level of concentrates fed will not necessarily increase.
S-EU-006	1	Simplicity of measure, farm grows cereals, benefits well documented	Soil analysis, nutrient budgetting, better use of organic manure, reduce bagged N applied to spring barley crops
	4	Relevant to farm, grows cereals	Grows range of cereal varieties suited to farm, crop rotation implemeted
	8	Dairy farm, breeding choice is an important aspect of management	Progressively moved towards higher yielding Holstein cows
	9	To meet animal requirements and maintain production	Purchased feed is required

Farm ID	Adaptation ID	Why adaptation measure chosen?	How measure implemented on the farm?
S-EU-007	1	'Simplicity of measure, benefits of nutrient management are well documented	Soil analysis, nutrient budgetting, better use of organic manure, reduce P and K applied to grassland
	4	Predominatley grassland farm	Grass varieties chosen suitable to land, clover included in grass mixtures
	8	Upland hill farm, breeding choice in an important aspect of management	over extended period purchases suitable breeding stock
	9	To meet animal requirements and maintain production	Purchased feed is required
S-EU-008	1	Organic farm, making best use of organic manure is essential	New slurry store applied, undertaking nutrient budgeting
	4	Relevant to farm	White clover included in grass mixtures, red clover silage grown, arable silage mixtures used
	8	Dairy farm, breeding choice is an important aspect of management	Aims for maximum milk off grass - cow breed selected accordingly
	9	To meet animal requirements and maintain milk production	Purchased feed is required
S-EU-009	1	Simplicity of measure, farm grows cereals, benefits well documented	Soil analysis, nutrient budgetting, better use of organic manure, reduce bagged N applied to spring barley crops
	4	Relevant to farm, grows cereals	Grows range of cereal varieties suited to farm, crop rotation implemented
	8	Relevant to farm, lowland suckler cows	Selection of suitable breeds to farm and system
	9	To meet animal requirements and maintain production	Purchased feed is required
S-EU-010	3	Because we cannot have long periods without water. So, we have to ensure that we will have sufficient water for crop's development.	By irrigation systems
	4	Because the mixtures increase biodiversity, contributing for a better adaptation of climate and soil condition	Using different species of plants on the same mixture
	5	Storaging feed is indispensable for some periods of shortage food.	Sow some crops for cutting and conservation
	10	Because these plants tolerate extreme conditions	Using genetic resources to find new solutions for climate changes problems.
M-EU-001	1	Increase use efficiency of N	Due to increase of the temperature growing season will be elongated. For this reason use of nitrogen can be increased to meet increased demand from plants. In the Netherlands this issue will be raised.
	3	To maintain productivity under drought conditions.	Irrigation might be of interest in periods of drought depending on costs from irrigation and feed prices
	6	To maintain animal production under extreme warm conditions	Cooling of the animals will be done by changing grazing period during extreme warm periods during the year and by adjusting the stable .
	9	By using supplemental feeding being less vulnerable to expected variablility in day to day weather conditions.	This will become more flexible, not explicit feeding more supplements. The level of concentrates fed will not necessarily increase.

Farm ID	Adaptation ID	Why adaptation measure chosen?	How measure implemented on the farm?
M-EU-002	1	Opportunities may be available to reduce the N fertiliser rate if the improvements in climate conditions for grass growth are realised. The rate of fertilisation will also be important to cope with increases in the seasonal variability of grass growth.	Precision technology to match fertiliser to plant needs. As the conditions for grass growth are likely to improve, fertiliser applications are likely to increase
	3	A significant proportion of farms in the region are located on soils that are vulnerable to waterlogging, which is expected to increase in frequency. Strategies to adapt to this change include drainage of land and construction of reservoirs e.g. lagoons.	drainage of land and construction of reservoirs e.g. lagoons.
	7	Animal breeding will improve the durability and robustness of beef animals in terms of health and survival. This will improve the ability of grass-based beef production systems to adapt to greater variability in weather conditions and forage quality or supply.	Breeding robust breeds in terms of health and survival
	9	Based on the projected increases in the frequency of extreme weather events such as flooding and drought it is expected that supplemental feeding will be necessary during these periods. It is expected that this will mainly be in the form of conserved forage held on farm as reserves. This will be harvested from surpluses of grass growth that are expected to be larger under future climate change conditions in this region (Fitzgerald et al. 2009).	Correct supplementation will positively impact herbage production by reducing soil damage under extreme weather conditions and also benefit animals.
M-EU-003	1	Opportunities may be available to reduce the N fertiliser rate if the improvements in climate conditions for grass growth are realised. The rate of fertilisation will also be important to cope with increases in the seasonal variability of grass growth.	Precision technology to match fertiliser to plant needs. As the conditions for grass growth are likely to improve, fertiliser applications are likely to increase
	3	The majority of the farm contains loam soils and sandy loam soils that are vulnerable to water deficits or drought. This is expected to increase in frequency. The main strategies to adapt to this change include construction of reservoirs e.g. lagoons and irrigation.	construction of reservoirs e.g. lagoons and irrigation. (adoption of sprinkler systems)
	7	Animal breeding will improve the durability and robustness of dairy animals in terms of health and survival. This will improve the ability of grass-based dairy production systems to adapt to greater variability in weather conditions and forage quality or supply.	Breeding robust breeds in terms of health and survival
	9	Based on the projected increases in the frequency of extreme weather events such as flooding and drought it is expected that supplemental feeding will be necessary during these periods. It is expected that this will mainly be in the form of conserved forage held on farm as reserves. This will be harvested from surpluses of grass growth that are expected to be larger under future climate change conditions in this region (Fitzgerald et al. 2009).	Correct supplementation will positively impact herbage production by reducing soil damage under extreme weather conditions and also benefit animals.
M-EU-004	1	Opportunities may be available to reduce the N fertiliser rate if the improvements in climate conditions for grass growth are realised. The rate of fertilisation will also be important to cope with increases in the seasonal variability of grass growth.	Precision technology to match fertiliser to plant needs. As the conditions for grass growth are likely to improve, fertiliser applications are likely to increase
	3	A significant proportion of farms in the region are located on loam soils and sandy loam soils that are vulnerable to water deficit or drought, which is expected to increase in frequency. The main strategies to adapt to this change include construction of reservoirs	include construction of reservoirs e.g. lagoons and irrigation. Adoption of sprinkler systems
	7	Animal breeding will improve the durability and robustness of dairy animals in terms of health and survival. This will improve the ability of grass-based dairy production systems to adapt to greater variability in weather conditions and forage quality or supply.	Breeding robust breeds in terms of health and survival
	9	Opportunities may be available to reduce the N fertiliser rate if the improvements in climate conditions for grass growth are realised. The rate of fertilisation will also be important to cope with increases in the seasonal variability of grass growth.	Correct supplementation will positively impact herbage production by reducing soil damage under extreme weather conditions and also benefit animals.

Farm ID	Adaptation ID	Why adaptation measure chosen?	How measure implemented on the farm?
M-EU-005	5	In this region, variation in forage production can be an increasing problem. Period with shortage in grass could be a problem to maintain oxen production	As it is a mixed farm, cropping system can be adjusted in order to maintain sufficient feed storage to face reduction in forage production
M-EU-006	3	The mixed dairy farm has an important part of crop in the land use. Investment in irrigation can be managed to garantee a sufficient amount of maize production, but alos to stabilize the cereals productions	Investment for irrigation has to be planned, but can be rentabilized with an increase in crop production if late spring and summer rainfall decrease. If drilling water or wells can be used, this option become possible. It is very rare today due to good rainfall, but sometimes feasible.
	4	It is possible that to stabilize grass productionand to extent grazing season with more frequent drought in summer, introduction of new speciesin grassland will become appropriate (legumes). It is also a mtigation option.	When grassland is regenerated, more complex mixture of seeds can be used to increased resilience of grass production. A diversity of grassland can also help to graze more days in the year. True permanent grassland will be more difficult to improve.
	5	This is the most feasible solution in this model farm. The use of maize, a double purpose crop, will facilitate this option. One or two silos of silage will enable the model farm to face summer drought or very wet periods reduing the grazing duration	The proportion of maize in the system can increase with a reduction of cereals. The extra production will not be used for silage after good summer period, but sold as grain. Otherwise, the whole maize will be used as silage and rebuild the storage used in bad periods
M-EU-007	3	The mixed beef farm has an important part of crop in the land use. Investment in irrigation can be managed to garantee a sufficient amount of maize production, but alos to stabilize the cereals productions	Investment for irrigation has to be planned, but can be rentabilized with an increase in crop production if late spring and summer rainfall decrease. If drilling water or wells can be used, this option become possible. It is very rare today due to good rainfall, but sometimes feasible.
	4	It is possible that to stabilize grass productionand to extent grazing season with more frequent drought in summer, introduction of new speciesin grassland will become appropriate (legumes). It is also a mtigation option.	When grassland is regenerated, more complex mixture of seeds can be used to increased resilience of grass production. A diversity of grassland can also help to graze more days in the year. True permanent grassland will be more difficult to improve.
	5	This is the most feasible solution in this model farm. The use of maize, a double purpose crop, will facilitate this option. One or two silos of silage will enable the model farm to face summer drought or very wet periods reduing the grazing duration	The proportion of maize in the system can increase with a reduction of cereals. The extra production will not be used for silage after good summer period, but sold as grain. Otherwise, the whole maize will be used as silage and rebuild the storage used in bad periods

Farm ID	Adaptation ID	Why adaptation measure chosen?	How measure implemented on the farm?
M-EU-008	3	I don't remember why it has been choosen. I think that the water availability for irrigation and cost make this solution not feasible in this model farm.	
	4	It is possible that to stabilize grass productionand to extent grazing season with more frequent drought in summer, introduction of new speciesin grassland will become appropriate (legumes). It is also a mtigation option.	When grassland is regenerated, more complex mixture of seeds can be used to increased resilience of grass production. A diversity of grassland can also help to graze more days in the year. True permanent grassland will be more difficult to improve.
	5	In this area and with this system, increasing feed storage is probably the most appropriate option to face possible extreme events, with the lowest cost.	Two option can be considered: One consists to increase the hay storage in this system, assuming an small higher production of grassland on average, a second relies on buying maize for silage to the important crop farm in the region, but the cost is much higher.
M-EU-009	5	In this mountain area, the number of option to face extreme events are rare. It is mainly increasing the forage storage that the system will find an adaptation, mainly hay.	Normally, a higher production of grass can be expected in this region with climate change, with more grazing days too. This will give an opportunity to constitute hay reserve for extreme events without changing stocking rate
M-EU-010	5	In this mountain area, the number of option to face extreme events are rare. It is mainly increasing the forage storage that the system will find an adaptation, mainly hay.	Normally, a higher production of grass can be expected in this region with climate change, with more grazing days too. This will give an opportunity to constitute hay reserve for extreme events without changing stocking rate
M-EU-013	3	To maintain plant productivity under drought conditions to ensure animal performance.	Reduced summer rainfall and increasing evapotranspiration at higher temperatures will greatly increase need for irrigation to maintain productivity of feed crops, in particular alfalfa and maize
	4	To maintain plant productivity under drought conditions to ensure animal performance.	A mixture of forage crops with greater drought tolerance is a possible option. This may be particularly relevant for the part of the farm in permanent grassland
	5	To maintain feed availability under drought conditions to ensure animal performance.	Conservation of feed as buffer will be an additional strategy to cope with more variability in summer droughts. The feed for conservation will be silage of alfalfa and maize
	9	To maintain feed availablity under drought conditions to ensure animal performance.	Import of concentrates for supplemental feeding may be an attractive option in case of successive droughts
M-EU-014	1	Effecient (regarding production, economy and climate) with optimal fertilization, as amount of N in the system has huge effect on amount of emissions	Farmers must add fertilizer at the right time. Eg spring cereals: at the moment they add fertilizer before seeding, eventually wait to after seeding to avoid risk of leaching
	3	In case of more often droughts: it is importent to secure that farmers with sandy soil has possibility for irrigation. At clay soil this is not nessecary	They need to buy equipment for irrigation
	4	A positiv effect of a mixture of cereals and legumes (for mature) to reduce risk of crop production failing	Can easily be implemented
	5	Not so relevant at a pig farm. They are supposed to be able to buy the feed they need	If wanted they need more land to be more selfsufficient during the year

Annex 6. Estimated impact of climate change on farms

Farm ID	Farm type	Farm	Thermal growing season	Drought	Heat stress	Water logging	Heat stress	Diseases	Land accessibility
			Crop impacts				Livestock impacts		
S-EU-003	Maritime grassland beef	Derry Patrick	+	0/-	0	--	0/-	-	--
S-EU-004	Maritime grassland dairy	Curtins	+	0/-	0	--	0/-	-	--
S-EU-005	Maritime mixed dairy	De Marke	+	0/-	0	--	0/-	-	--
S-EU-006	Maritime mixed dairy	Stewart Tower farm	+	0	0	-	0	-	-
S-EU-007	Maritime mixed beef	Glenkilrie farm	+	0	0	-	0	-	-
S-EU-008	Maritime grassland dairy	Torr Farm	+	0	0	-	0	-	-
S-EU-009	Maritime mixed beef	Upper Nisbet farm	+	0	0	-	0	-	-
S-EU-010	Mediterranean grassland sheep	Herdade dos Esquerdos	-	--	--	--	-	--	0
M-EU-001	Maritime mixed dairy	Dutch common dairy	+	0/-	0	--	0/-	-	--
M-EU-002	Maritime grassland beef	Average National Beef Farm	+	0/-	0	--	0/-	-	--
M-EU-003	Maritime grassland dairy	Greenfield	+	0/-	0	--	0/-	-	--
M-EU-004	Maritime grassland dairy	Average National Dairy farm	+	0/-	0	--	0/-	-	--
M-EU-005	Maritime mixed beef	Fattened oxen HauteNormandie	+	0/-	0	0	0	0	0/-
M-EU-006	Continental mixed dairy	Dairy farm Lorraine	+	-	0	0	-	-	0/-
M-EU-007	Continental mixed beef	Fattened young bulls Lorraine	+	-	0	0	0/-	0/-	0/-
M-EU-008	Continental grassland beef	Fattened calves Bourgogne	+	-	0	0/-	0/-	0/-	0/-
M-EU-009	Mountain grassland beef	Grazing calves Auvergne	+	0	0	0	0	0	-
M-EU-010	Mountain grassland sheep	Sheep Auvergne	+	0/-	0	0	0	0/-	0/-
M-EU-013	Mediterranean mixed dairy	Italian mediterranean mixed dai	+	-	-	0/-	0	-	0/-
M-EU-014	Northern European pig	Danish conventional pig farming	+	-	-	0	0/-	0	0

M = Model farm, S = Showcase farm (real farm) and EU = Europe.

++ strong positive effect -- strong negative effect + positive effect - negative effect 0 no effect

References from italy, to be included in references:

References