AnimalChange deliverable : D9.1 Development of a modelling strategy.

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ANIMALCHANGE

SEVENTH FRAMEWORK PROGRAMME

THEME 2: FOOD, AGRICULTURE AND FISHERIES, AND BIOTECHNOLOGIES

SEVENTH FRAMEWORK PROGRAMME

Grant agreement number: FP7- 266018

DELIVERABLE 9.1

Deliverable title: Development of a modelling strategy

Abstract:

The objective of this deliverable is to develop a strategy for the farm-scale modelling that will allow the mitigation and adaptation measures developed in workpackage 8 to the assessed at the farm scale in work package 10.

Due date of deliverable: **M12** Actual submission date: **M13**

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

Organisation name of lead contractor: **AU**

Revision: 1st revision 27 January 2012

Dissemination level: **CO**

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2. Objective

The objective of this task is to develop a strategy for the farm-scale modelling that will allow the mitigation and adaptation measures developed in workpackage 8 to the assessed at the farm scale in workpackage 10.

3. Methods

At the project formulation stage, it was clear that the models available within the partnership were likely to provide uneven coverage of the farming systems included in the scope of the project. The three farm-scale models available (Melodie, FarmSim and FASSET) were largely, though not exclusively, developed from North and also for European context, whereas the project includes African and South American farming systems. Since the resources available to workpackage 9 were insufficient to support significant model construction or adaptation, a stepwise procedure was proposed in the Description of Work that was intended to achieve the best coverage possible within the constraints of the resources available.

The following procedure was be used:

1. Construction of a case matrix in which the first dimension is the farming system (ruminant dairy, ruminant meat/fibre, pig and poultry), the second dimension is the production intensity (intensive, extensive) and the third dimension is the agroclimatic zone (maritime, central European, Mediterranean, Brazilian (Campos and Cerrado) and African (S. Africa, Senegal, Tunisia)). This matrix will form the basis for designing and testing the farm-scale model. *This was undertaken in collaboration with WP8 and WP10 at a meeting in Lelystad, The Netherlands, in June 2011.*
2. Determine to what extent the elements of the matrix can be satisfied by the dynamic mechanistic models available to the consortium, i.e. whether the cases can be covered. *This was achieved by circulating a questionnaire to the main modelling groups.*

3. Description of typical farms for each cell of the matrix. *This was achieved at a meeting in Paris, France, in September 2011.*
4. Assessment of the functionality demanded from the dynamic process-based modelling farm-scale models to simulate these typical farms. This will include the livestock types, crops and soils that must be described. *This was achieved at the meeting in Paris.*
5. Preliminary identification of mitigation and adaptation measures will be undertaken, and the functionality demanded to enable the modelling of these measures (in collaboration with WP8). *A discussion paper was prepared prior to the meeting in Paris.*
6. For those cases where the functionality of the consortium models is considered inadequate or unproven, assess the scientific and technical work required to provide this functionality. Since the consortium models have been developed to describe European conditions, this will at a minimum include the definition of one or more Ph.D. studies to test and where necessary modify the models to describe conditions in Latin America and Africa. *Discussions initiated with EMBRAPA.*
7. For cases where the work required to provide the necessary functionality would be clearly excessive, assess the scientific and technical suitability of using one of the dynamic, process-based models or modules from outside the consortium (e.g. APSIM, CropSyst). *Collaboration initiated with Agresearch on using the APSIM modelling system.*
8. If any cases remain for which functionality is still lacking, identify an empirical model (if available) or propose a provisional modification of one of the consortium models to provide that functionality. *The feasibility of using simplified models was investigated.*
9. On the basis of the results of steps 5 to 8 and taking into account the resources available, define the strategy to be adopted for the modelling complex.

4. Results

The results of Steps 1 and 2 are shown in Appendix I and the results of Steps 3 and 4 are shown in Appendix II. The discussion paper developed in Step 5 shown in Appendix III. The main points to note from these results are:

- The farm models available from the project partners (Melodie, FarmSim and FASSET) provide a reasonable but not complete coverage for European livestock farms.
- For a number of situations, more than one of the models appears to be applicable. This creates opportunity for model comparison but also a degree of standardisation concerning the characterisation of model farms.
- The farm models available from the project partners provide limited or uncertain coverage of non-European livestock farms (i.e. South American or African).
- Characterisation of the farms using the level of detail shown in Appendix II was considered feasible. A greater level of detail was not considered feasible, due to the differences between models in the way they describe farms.
- The models provide a useful than not comprehensive range of mitigation measures.
- Day-to-day management is simulated by Melodie, simulated to a limited extent by FASSET and not at all by FarmSim. This will constrain our ability to simulate adaptation measures.

Progress on Step 6 has been slow, due to difficulties in communication. The discussions are now ongoing with EMBRAPA concerning a possible Ph.D. study on modelling a range of Brazilian livestock farming systems. (Space here for additional material concerning African systems).

An initial analysis of the APSIM modelling complex (Step 7) suggests that it might provide additional coverage for non-European situations. (Additional comment required here).

The results of Step 8 (see Appendix IV) suggest that the development of simplified models based on complex model simulations cannot be supported by the resources available within the work package.

5. Implementation of the modelling complex

The main conclusions from the development of the modelling strategy are that the process-based models available within the consortium give reasonable but not full coverage of the target European livestock systems but probably not for Brazilian or African systems. Using models from outwith the consortium may provide coverage for some of these non-European systems.

A major issue arising from the development of the modelling strategy is the link between WP9 and bothWP8 and WP10. The link to WP8 focuses on the way in which the knowledge gained from the use of process-based models to explore mitigation strategies within individual farm components (e.g. livestock, fields) can be included in the farm-scale modelling. Discussions concerning existing mitigation and adaptation measures have begun but WP8 must also take account of new mitigation and adaptation measures developed in WP 6 and 7. Links with WP10 are currently under-developed and need attention and in particular, there needs to be a discussion of the coverage and functionality desired from models for use in WP10 and the ability of WP9 to deliver that coverage and functionality. Success in reaching project objectives is dependent on achieving a clear and common understanding of the flow of information between these WPs, including a realistic appreciation of what is and is not feasible and a co-ordination of the timing of activities.

Appendix I Overview of the coverage of farm scale models in AnimalChange

Key:

yes = we have dynamic models.

no = we do not have dynamic models.

Possibly, not tested = we have one or more models that might cover this situation but no testing has been undertaken.

NA = situation where the farm type does not occur with sufficient frequency to justify inclusion

Europe (land-based)

	Melodie		**FarmSim**		**FASSET**	
AEZ	**Mixed**	**Grassland**	**Mixed**	**Grassland**	**Mixed**	**Grassland**
maritime	yes	Yes	yes	yes	yes	yes
continental	yes	Yes	yes	yes	yes	yes
mountain	NA	Yes	NA	yes	NA	Possibly - not tested
Mediterranean	Possibly	not tested	no	yes	Possibly - not tested	Possibly - not tested
Boreal	NA	Possibly - not tested	NA	no	NA	yes

Europe (landless)

Type of production	**Melodie**	**FarmSim***	**FASSET**
Pigs – Northern Europe	Yes		Yes
Poultry – Northern Europe	?		?
Pigs – Southern Europe	Yes		Yes
Poultry – Southern Europe	?		?

* FarmSim simulates livestock that is off pasture using an emission factor/IPCC approach, which could be adapted to describe the situations.

? = under development.

Non-Europe (land-based)

	Melodie		FarmSim		FASSET	
AEZ*	**Mixed**	**Grassland**	**Mixed**	**Grassland**	**Mixed**	**Grassland**
Arid, irrigated	NA	Possibly - not tested	no	no	Possibly - not tested	Possibly - not tested
Arid, rainfed	NA	Possibly	no	yes	Possibly - not tested	Possibly - not tested
Semi-arid	NA	Possibly	no	Yes	Possibly - not tested	Possibly - not tested
Humid	Possibly - not tested	NA	no	NA	Possibly - not tested	NA
Tropical highland	Possibly - not tested	NA	no	NA	Possibly - not tested	NA

* need better definition of categories

Non-Europe (landless/backyard)

		Melodie	FarmSim*	FASSET
Africa	Landless poultry	Possibly - not tested		Possibly**
	Backyard cattle	Possibly - not tested		Possibly - not tested
S & C America	Landless pigs	Possibly - not tested		Possibly**
	Landless dairy cattle	Possibly - not tested		Possibly - not tested
	Landless beef cattle	Possibly - not tested		Possibly - not tested
	Backyard pigs	Possibly - not tested		Possibly**

* FarmSim simulates livestock that is off pasture using an emission factor/IPCC approach, which could be adapted to describe the situations.

** FASSET treat pig (and soon poultry) as factory farming, in which animal feed and production are both well controlled and well known. This approach is less suitable for small-scale production outside Europe.

Crops

Crop	Melodie	FarmSim	FASSET
Wheat	X	X	X
Barley	X	X	X
Oats	X	X	X
Maize (for corn)	X	X	X
Maize (for fodder)	X	X	X
Rye		X	X
Rape	X	X	X
Millet	X		
Sorgham	X		
Soybean	X	X	
Single grass species	X	X	X
Mixed grass species	?	X	X
Grass/clover		X	X
Semi-natural grassland	X	X	
Browse (bushes, trees)			

X = can simulate this crop

? = untested or under development

Animals

Animal	Melodie	FarmSim	FASSET
Beef cattle (including young animals)	?	?	X
Dairy cattle (including young animals)	X	X	X
Sheep		?	
Goats			
Pigs	X		X
Poultry	?		?
Camels			

X = can simulate this crop

? = untested or under development

Modelling tactical management

	Melodie	FarmSim	FASSET
Planning crop rotation	X		
Frequency	Annual		
Fertilisation/manuring	X		
Frequency	Annual		
Livestock feeding	X		
Frequency	Annual		

Modelling operational management

	Melodie	FarmSim	FASSET
Timing arable field operations	X (?)		
Frequency	daily		
Timing grassland field operations	X		X
Frequency	daily		Daily
Livestock feeding(including grazing)	X		X
Frequency	daily		daily

Mitigation measures

	Melodie	FarmSim	FASSET
Biogas		X	X (?)
Rumen kinetics via breeding			
Rumen kinetics via feeding	X		X
Reduced feed protein	X		X
Reduced fertiliser/manure N	X	X	X
Reduced fertiliser N/manure + NH_3 technologies	X	X	X
Reduced fertiliser N/manure + cover crops	X	X	X
Reduced fertiliser N/manure (crop rotations)	X	X	X
Zero tillage	X	X	X
Length of grazing period	X	X	X
Interval between pasture renovation	X	X	X
Decreased dairy cattle replacement rate	X	X	X
Change intensity of milk production	X	X	X

Adaptation measures

	Melodie	FarmSim	FASSET
Drought-tolerant crops	?	X	
Mixed v single species grassland			X
Cooling for pigs			
Increased use of conserved roughage to buffer variations in grassland production	X	X	X
Changing balance of feed sources in livestock rations (e.g. cereal supplements)	X	X	X

Appendix II Definition of model farms in agroecological zones

The objective here is to describe one or more representative livestock farms for each of the agroecological zones and cropping types (mixed cropping versus grassland only), and identify realistic mitigation and adaptation measures. The description of the farms is at an abstract level, since we will be using up to three different farm models to simulate each representative farm, and each model describes a given farm in slightly different ways.

Representative livestock farm(s) are described for each of the agroecological zones. On the basis of better knowledge, these representative livestock farms may be changed, provided the number of farms does not grow significantly. For each livestock farm type (dairy cattle, beef cattle, sheep), we have provided the framework for the information we need to parameterise the farm models. As a guide, for one example of each livestock farm type, we have attempted to provide the information.

Some of the information requested is on a continuous scale (e.g. the average number of kilograms of plant-available N applied per year). However, some other information is categorical. The categories are as follows:

- grassland crops: grass or grass/clover
- manure management: slurry or farmyard manure
- soil type: sandy, loam, clay
- lambing/calving: spring, autumn, year-round
- mitigation measures: reduced purchased N (feed protein, N fertilization), reduce proportion of roughage in the diet, increase milk/meat production, extend the grazing season
- adaptation measures: Drought-tolerant crops, mixed v single species grassland, increased use of conserved roughage to buffer variations in grassland production, changing balance of feed sources in livestock rations (e.g. cereal supplements)

AEZ	Mixed cropping	Grassland only
Maritime	*Dairy cattle* mature weight: 550 kg calving: year-round milk production: 8000 kg ECM/yr crop rotation: grass – grass – winter wheat – maize -spring barley supplements: wheat, barley, soya manure management: slurry fertilization/manuring: 140 kg plant-available N/ha/yr* soil type: loam <u>Mitigation measures</u> Reduced purchased N – 20% reduction in fertilizer application Reduce roughage in diet - increase contribution of maize silage to the diet <u>Adaptation measures</u> Increased use of cereal crops for whole-crop silage, to buffer varying grass production Use of drought-tolerant crop species/cultivars	*Beef cattle* mature weight: 550 kg: calving: spring weight at sale: 440 kg growth: 1000 g/day crop: grass supplements: barley manure management: farmyard manure fertilization/manuring: 160 kg plant-available N/ha/yr* soil type: loam <u>Mitigation measures</u> Reduced purchased N – 20% reduction in fertilizer application Reduce roughage in diet - increase contribution of imported cereal supplement to the diet <u>Adaptation measures</u> Increased use of grass silage to buffer varying grass production Use of drought-tolerant crop species/cultivars

	Beef cattle mature weight: 750 kg: calving: spring weight at sale: 440 kg growth: 1000 g/day crop: grass - maize supplements: barley, wheat, soya manure management: farmyard manure fertilization/manuring: 160 kg plant-available N/ha/yr* soil type: loam <u>Mitigation measures</u> Reduced purchased N – 20% reduction in fertilizer application <u>Adaptation measures</u> Increased use of cereal crops for whole-crop silage, to buffer varying grass production Use of drought-tolerant crop species/cultivars	*Dairy cattle* mature weight: 550 kg calving: year-round milk production: 4000 kg ECM/yr crop: grass supplements: barley, soya manure management: slurry fertilization/manuring: 140 kg plant-available N/ha/yr* soil type: loam <u>Mitigation measures</u> Reduced purchased N – 20% reduction in fertilizer application Reduce roughage in diet - increase contribution of imported cereal supplement to the diet <u>Adaptation measures</u> Increased use of grass silage to buffer varying grass production Use of drought-tolerant crop species/cultivars

Continental	*Dairy cattle* mature weight: 550 kg calving: year-round milk production: 6000 kg ECM/yr crop rotation: grass – maize supplements: wheat, barley, soya manure management: slurry fertilization/manuring: 140 kg plant-available N/ha/yr* soil type: loam <u>Mitigation measures</u> Reduced purchased N – 20% reduction in fertilizer application Reduce roughage in diet - increase contribution of maize silage to the diet <u>Adaptation measures</u> Increased use of cereal crops for whole-crop silage, to buffer varying grass production Use of drought-tolerant crop species/cultivars	*Beef cattle* mature weight: 750 kg: calving: spring weight at sale: 440 kg growth: 1200 g/day crop: grass supplements: barley manure management: farmyard manure fertilization/manuring: 160 kg plant-available N/ha/yr* soil type: loam <u>Mitigation measures</u> Reduced purchased N – 20% reduction in fertilizer application Reduce roughage in diet - increase contribution of imported cereal supplement to the diet <u>Adaptation measures</u> Increased use of grass silage to buffer varying grass production Use of drought-tolerant crop species/cultivars

	Beef cattle mature weight: 550 kg: calving: spring weight at sale: 440 kg growth: 1000 g/day crop: grass supplements: barley manure management: farmyard manure fertilization/manuring: 160 kg plant-available N/ha/yr* soil type: loam <u>Mitigation measures</u> Reduced purchased N – 20% reduction in fertilizer application Reduce roughage in diet - increase contribution of imported cereal supplement to the diet <u>Adaptation measures</u> Increased use of grass silage to buffer varying grass production Use of drought-tolerant crop species/cultivars	

Mountain	NA	*Sheep* mature weight: 75 kg lambing: spring weight at sale: 50 kg growth: 140g/day crop: grass supplements: barley manure management: farmyard manure fertilization/manuring: None soil type: clay <u>Mitigation measures</u> None <u>Adaptation measures</u> Feeding bought-in roughage Sale of livestock

		Beef cattle mature weight: 550 kg: calving: spring weight at sale: 440 kg growth: 500 g/day crop: grass supplements: barley manure management: farmyard manure fertilization/manuring: 50 kg plant-available N/ha/yr* soil type: loam Mitigation measures None Adaptation measures Feeding bought-in roughage Sale of livestock

Mediter-ranean	*Dairy cattle* mature weight: 550 kg calving: year-round milk production: 5000 kg ECM/yr crop rotation: grass – grass – winter wheat – maize -spring barley supplements: wheat, barley, soya manure management: slurry fertilization/manuring: 140 kg plant-available N/ha/yr* soil type: loam <u>Mitigation measures</u> Reduced purchased N – 20% reduction in fertilizer application Reduce roughage in diet - increase contribution of maize silage to the diet <u>Adaptation measures</u> Increased use of cereal crops for whole-crop silage, to buffer varying grass production Use of drought-tolerant crop species/cultivars	*Sheep* mature weight: 60 kg lambing: spring weight at sale: 35 kg growth: 230 g/day crop: grass supplements: barley manure management: Farmyard manure fertilization/manuring: 60 kg plant-available N/ha/yr* soil type: clay <u>Mitigation measures</u> None <u>Adaptation measures</u> Provision of shade/housing Provision of watering sites

Boreal	NA	*Sheep* mature weight: 60 kg lambing: spring weight at sale: 35 kg growth: 230 g/day crop: grass supplements: barley manure management: Farmyard manure fertilization/manuring: 60 kg plant-available N/ha/yr* soil type: clay Mitigation measures None Adaptation measures None required

NA = not applicable

* plant-available N = fertilizer N + ammonium in manure

Landless systems

Pigs – Northern Europe

- slaughter weight: 110kg
- age at slaughter: 160 days
- feed ration: mixed cereals
- manure management: slurry

Poultry – Northern Europe

- broiler chickens, slaughter weight: 1.9 kg
- age at slaughter: 40 days
- feed ration: mixed cereals
- manure management: solid

Pigs – Southern Europe

- slaughter weight: 100kg
- age at slaughter: 160 days
- feed ration: mixed cereals
- manure management: slurry

Poultry – Southern Europe

- broiler chickens, slaughter weight: 1.9 kg
- age at slaughter: 40 days
- feed ration: mixed cereals
- manure management: solid

Appendix III Analysis of the GHG mitigation and climate change adaptation measures on livestock farms

1. Introduction

The objectives of the farm-scale modelling within the project are to assess the whole-farm impact of measures designed to enable livestock systems to adapt to climate change or mitigate greenhouse gas emissions, and to assess the interactions between these two types of measures.

This document reflects on the nature of the livestock systems we will be considering, on the extent to which they will be affected by climate change and on the implementation of mitigation and adaptation measures (both proven and novel/speculative). The implications for the models that we would wish to employ are then considered. Note the emphasis on 'wish'; once we have done this, we will need to consider to what extent these wishes can be fulfilled.

2. Non-ruminant livestock systems

A large (and increasingly large) proportion of non-ruminant production is from livestock are housed all year round. The main direct sources of GHGs on such farms are the emissions of CH_4 and N_2O from the manure in animal housing and manure storage, and the N_2O emissions from the soil. Indirect sources of GHGs are the emission of NH_3 from manure in animal housing and manure storage, NH_3 emissions from manure and fertiliser applied to the land and NO_3 leaching from the soil. On farms with poor management, runoff of manure may also contribute to GHG emissions. The soil can also be a source or sink of CO_2, due to changes in the amount of C sequestered in soil organic matter; C sequestrated in soils must also be taken into account.

The main effect of climate change on the livestock will be by changes in temperature stress. The main indirect effects of climate change are via changes in the feed supply, the availability of water for animals and irrigation, the frequency and severity of animal diseases and the ability to perform field operations (ploughing, haymaking etc). Although a proportion of the feed for these animals may be produced on the farm, the majority is often bought on the market. As such, animal nutrition is to some extent buffered from changes in the local crop growth environment. The confinement of livestock means that disease outbreaks may be serious but also means that biosecurity is more easily achievable and it is easier to detect and treat disease outbreaks than for grazing ruminant livestock. In contrast, the prevalence of annual crops on non-ruminant farms requires more tillage operations and more trafficking of bare soils than on most ruminant livestock farms, so have a greater sensitivity to changes in the workability and trafficability of the soil.

2.1 Mitigation measures on non-ruminant farms

Mitigation measures on non-ruminant farms focus on the manure management system and the soil. Emissions of CH_4, N_2O and NH_3 from animal housing where manure is managed slurry can be reduced by introducing cooling elements into the slurry channels or by acidification of the slurry. Since housing for this category of livestock usually includes for forced ventilation, NH_3 emissions from both slurry and solid-based systems can also be reduced by scrubbing the exhaust gases. CH_4, N_2O and NH_3 emissions from manure storage can be reduced by acidification of the slurry. CH_4 emissions from manure storage can be reduced by anaerobic digestion, with the capture of the biogas. NH_3 emissions from slurry tanks and lagoons can be reduced by covering the slurry with an impermeable tent or membrane, or by ensuring the formation of continuous crust (e.g. by spreading a layer of chopped straw). Closely covering solid manure heaps will also reduce NH_3 emissions. Emissions of NH_3 from field-applied manure can be reduced by rapid incorporation, slurry injection or slurry acidification. NH_3 emissions from susceptible nitrogenous fertilisers (in particular urea) can be reduced by rapid incorporation or by switching to a non-susceptible fertiliser. Both NO_3 leaching and N_2O emissions might be reduced by the use of nitrification inhibitors. NO_3 leaching can be reduced by balancing the supply of N to the uptake capacity of the crops, and by introducing cover crops into the rotation. Losses of N_2O, NH_3 and NO_3 can in general reducing the amount of N circulating within the farm by matching the supply of protein in animal feed and the demand of the animals for this protein. Many of these measures are only feasible because the livestock are confined to animal housing or livestock pens. This means that the livestock and the manure are concentrated in small areas for which mitigation technologies can be developed.

Measures available for increasing or reducing the decline of the sequestration of C in the soil include the use of cover crops, the incorporation or crop residues or the addition of organic manures.

2.2 Adaptation measures on non-ruminant livestock farms

Changes in temperature stress in livestock could be counteracted by altering the cooling or heating of animal housing. As noted earlier, impacts on feed supply are likely to be buffered by the market and so production may be little affected (though the economics of production might be much more so). Changes in climate could be advantageous or disadvantageous crop production. For changes to be advantageous, a number of conditions must be met:

- The quantity and/or quality of crop products must improve all the cultivation of new crops or varieties must become possible.
- The new climate must not decrease the chances of successfully harvesting the crop.
- The interaction between climate and soil must permit the necessary field operations to occur.

Disadvantageous changes have the opposite effect. Adaptation to advantageous changes in climate could therefore include changing to more profitable crop rotations. Adaptation to disadvantageous changes could include changes in crop rotation to avoid the need to till the soil at times when the soil is too dry or too wet to be workable, the use of low ground pressure machinery to permit trafficking and avoid soil damage at times when the soil is too wet, the introduction or expansion of irrigation systems or the introduction or expansion of grain drying systems.

3. Ruminant livestock systems

In contrast to non-ruminant livestock systems, there is a large range of ruminant livestock production systems. At one end of that range are the production systems that are similar to the non-ruminant systems; livestock spend all year either in animal housing or stock pens and the animal feed is bought on the market. On farms where livestock are confined year-round, the sources of direct and indirect GHG emissions previously described for non-ruminant systems are present, plus the major additional source resulting from enteric fermentation. At the other end of the range are production systems in which livestock are on pasture all year round, with little or no supplementary feeding. In these systems, enteric fermentation is the main source of GHG emissions. The sources of direct and indirect GHG emissions from manure management are absent, although there will be NH_3 emission from excreta deposited on the pasture.

The main effects of climate change on confined ruminant livestock systems that import all the animal feed are similar to those for the non-ruminant livestock systems. For ruminant livestock systems that produce all the roughage feed requirements for the herd on the farm, the main effects will be via the impact on the growth and quality of the range of roughage crops grown. For ruminant livestock systems that rely solely on pasture for feed, the main effects will be via the impact on herbage growth and the availability of drinking water. For systems that lie between these two extremes, management strategies can vary considerably. In these systems, the livestock will not rely solely on grassland to supply the demand for feed for all or part of the year. For short periods where the livestock demand for feed exceeds the supply from the pasture, supplementary roughage or herbage energy concentrates may be fed at pasture. However, during prolonged periods of low production, the livestock will often be housed or kept in stock pens. Farmers here have a degree of choice concerning the management of the interplay between livestock nutrition and on-farm production of roughage and energy supplements. This choice expresses itself most clearly in the main part of the growing season, where at one extreme, farmers permit their livestock to obtain all their roughage intake by grazing whereas at the other extreme, farmers harvest all the roughage mechanically and then feed it to the confined livestock. A consequence of this complexity in management is that the effects of climate change on the production and environmental emissions are variable and difficult to predict.

3.1 Mitigation measures on ruminant livestock farms

Mitigation measures on farms where the livestock are confined for all or part of the year will include many of the options as previously described for non-ruminant livestock systems. However, reducing NH_3 emission from ruminant livestock housing is less easy, since forced ventilation is rarely used in such housing. The measures specifically applicable to ruminant livestock systems include reducing the CH_4 emission associated with enteric fermentation by dietary manipulation, breeding or vaccination (although the efficacy of the latter two measures is still being debated). It is possible that GHG emissions from legume-based pastures will be lower than from N-fertilised pastures with the same productivity, because the former may avoid peaks in the concentration of protein in the herbage associated with fertiliser applications and because the N fixation in legumes tends to decrease as the availability of soil mineral N increases, so providing a buffer mechanism against fluctuations in soil mineral N. Since grasses are often productive for all or a large part of the growing season and because their growth form in the vegetative stage leads to a significant input of senescent leaf material into the soil, an increase in the proportion of grassland in the crop rotation is likely to increase C sequestration in the soil. However, there may be a trade-off with cereal production, since the cereal grain can be used to counteract the excess of N that is common in the diets of grass-fed cattle. Since tillage encourages oxidation of soil C, increasing the duration of grass or grass/legume leys would also increase C sequestration.

The use of dietary manipulation to reduce CH_4 and N excretion implies that the farmer has a good degree of control over the diet. The use of such techniques may require that the livestock are in a confined facility. The mitigation provided by the dietary manipulation will therefore be partly offset by the increase in GHG emissions from the manure management system. For those systems where livestock are at pasture year-round, the need to invest in a suitable manure management system is likely to make this option expensive.

3.2 Adaptation measures on ruminant livestock farms

Mitigation measures on farms where the livestock are confined for all or part of the year will include many of the options as previously described for non-ruminant livestock systems. Systems that rely on on-farm sources for all roughage feed will be more sensitive to local climatic extremes than those that do not. This is because these feeds are expensive to transport and will tend to be sourced locally, where the buffering effect of the market is less effective. In most ruminant livestock systems, the supply of roughage feed from local sources will vary with the seasons, with periods of low growth associated with extremes of temperature or limited water availability. The demand for feed may also vary seasonally, if the production of offspring is not evenly distributed across the year. These seasonal variations in roughage feed supply are often buffered by using conservation methods (e.g. hay- and silage making) to preserve surplus production during the growing season. The reliance on on-farm roughage production and on the ability to perform the field operations associated with conserving roughage feed mean that these farming systems are more sensitive to climatic change and extremes than non-ruminant systems. However, since they already have a range of management mechanisms to respond to existing year-to-year variations in climate, they should be more resilient to climatic extremes than those systems that are unable to buffer seasonal variations in roughage feed supply by conservation methods. These systems must rely on livestock using body reserves to buffer the variations in the supply of energy and nutrients.

As for non-ruminant systems, climate change may be advantageous or disadvantages. The diverse and complex management of most ruminant livestock farms means that the criteria that must be fulfilled for a change to be advantageous extends beyond those identified for non-ruminant systems and vary from system to system. Similarly, single adaptation measures are unlikely to be applicable to all such farms. However, the measures specific to ruminant livestock systems might include:

- The use of multi-species pasture, novel plant species and plant breeding to provide resilience against drought or disease.
- Increased use of confinement, to enable livestock to be fed with imported feed and to shelter stock (particularly juveniles) from extremes of weather.
- Animal breeding to increase temperature tolerance or disease resistance.
- The sale or purchase of livestock to match long-term trends in the productive capacity of the land.

4. Functionality desirable in livestock farming system models

This section deals with the functionality desirable in farm-scale models that specifically relates to the objectives of the AnimalChange project. It does not consider aspects that are more generally desirable in farm-scale models (e.g. closure of nutrient balances) or technical issues such as programming paradigm or coding language.

The objective of AnimalChange is to investigate the response of livestock farming systems to climate change (both the mean change and variability), how a range of mitigation and adaptation measures might operate within the context of the whole farm, and the extent to which co-implementation of such measures would result in synergy or antagonism.

Two main subsystems can be identified; the biophysical and management. The biophysical subsystem includes the animals, crops, soils, animal housing etc whereas the management subsystem includes the strategic, tactical and operational (planning and implementation).

4.1 The biophysical subsystem

Models of the components of the biophysical subsystem need to respond to the direct effect of changes in the weather. Since we are interested changes in the mean and variation of climate (particularly extreme events), the models need to respond to these changes. The response of farm components to climate is often non-linear and sometimes discontinuous, so we would like the models to respond to short-term conditions (i.e. with time steps of days or weeks, not months). The interaction between farm components increases in terms of complexity and speed, in the order non-ruminant livestock systems < confined ruminant systems < grazing livestock systems. There is a particular focus on grazing livestock systems in the project, so the time steps for the interaction between model components should also be short-term.

The livestock types to be modelled are cattle (dairy and beef), sheep (and goats?), pigs and poultry, listed here approximately in order of importance. The models should describe production and CH_4 emissions. The manure management systems should include forced ventilated and naturally ventilated animal housing and both solid and liquid manure management. These models should describe the emission of direct and indirect GHGs, and the quantity and quality of the manure produced. The crop models need to simulate both the quantity and quality of the production, including quality variables relevant to the use of the crop products as animal feed. The crop models also need to be capable of extracting nutrients and water from the soil and returning crop residues. Since we wish to investigate the use of mixed species swards to improve resilience, the crop models need to describe the competitive balance between the species. The soil models need to be capable of describing the nutrient and water dynamics.

Modelling grazed pasture is a particular challenge. The pasture model needs to have the ability to describe vegetative and reproductive growth and the spatial heterogeneity in herbage quality and nutrient dynamics (e.g. due to selective grazing or uneven return of excreta). The models of livestock grazing should also describe diet selection, since this can mean that the quality of the diet of the livestock differs substantially from the mean quality of the herbage present in the pasture.

4.2 The management subsystem

The response of management to climate change is particularly important in this project, since we are interested in the effect of climate change on production and GHG emissions, the adaptation measures that could be made and the response of these systems to climatic extremes. Like the biophysical system, the management subsystem needs to describe both the long and short term responses. Management decisions are here considered to be classified according to the timescale over which they operate; strategic decisions relate to the choice of production sector (e.g. arable, beef cattle, dairy cattle etc), tactical decisions are those that are taken at periods between several months and a year (e.g. the choice of crops to sow, whether to sell young stock after weaning or fatten them on the farm) and operational decisions that are taken at periods between a few days and a few weeks (e.g. when to plough, when to sow). Since AnimalChange specifically deals with livestock farms and is already quite ambitious enough, strategic decisions will not be considered.

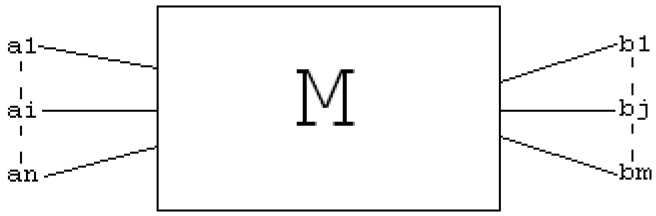
The complexity of management generally increases in the order arable < non-ruminant livestock < confined ruminant livestock < grazing ruminant livestock, although grazing livestock systems in which animals are turned out onto a very extensive rangeland and thereafter left untended would be an exception. The complexity of management in most grazing livestock systems arises because farmers try over the short and long-term to match the varying nutritional demands of the livestock with the varying quantity and quality of animal feed the farm is capable of producing. These systems must cope with some rigid constraints (e.g. the daily need to feed and water the livestock, the requirement to utilise or dispose of animal manure) but also contain some flexibility (e.g. to choose between zero grazing, rotational grazing or continuous grazing).

Mitigation measures typically involve tactical management. This is because the measures have medium to long-term consequences for both the environment and for the farm economics. In some cases, this is obvious (e.g. changes in the choice of crop rotation or the use of manure treatment technologies) and in some cases less so (e.g. a decision to chop and incorporates straw, rather than sell it for use as animal bedding). In contrast, adaptation measures can involve both tactical and operational management. Tactical measures would include the choice of decision to sow drought-resistant crops species, varieties or mixtures or the planned accumulation of roughage to buffer effects on roughage production of increased to climatic variability. Operational measures would include decisions to provide supplementary feed at pasture to compensate for short-term reductions in pasture growth, to start/stop irrigation and to bring forward or to delay harvesting in response to extreme weather conditions. Common to both mitigation and adaptation measures is that they will interact with both tactical and operational farm management, creating constraints or increasing choices, and producing side-effects. The frequent interactions between the management of livestock, land and manure on grazing livestock farms will generate particularly complex effects. These considerations highlight the need for models to adequately describe the tactical and operational management, and how they both respond to variations in climate and weather.

Appendix IV Feasibility of using simplified models

Resume of the discussion with Jean-André Vital & Romain Lardy.

The problem can be design like that:

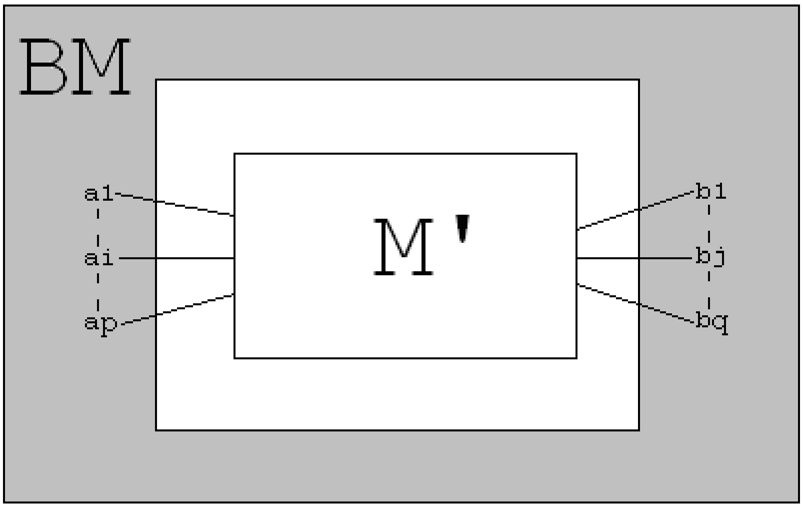


where M is the model to integrate in an other model, $a_1 \ldots a_i \ldots a_n$ the inputs and $b_1 \ldots b_j \ldots b_m$ the outputs. We have $M(a_1 \ldots a_i \ldots a_n) = (b_1 \ldots b_j \ldots b_m)$

The idea is to find a model M' that can be integrate in a bigger model (BM) which allows to take some inputs $(a_1 \ldots a_i \ldots a_p)$ and needs some outputs $(b_1 \ldots b_j \ldots b_q)$ in order that

$$M'(a_1 \ldots a_i \ldots a_p) \approx (b_1 \ldots b_j \ldots b_q) \text{ with } (a_1 \ldots a_i \ldots a_p) \subseteq (a_1 \ldots a_i \ldots a_n)$$

$$(b_1 \ldots b_j \ldots b_q) \subseteq (b_1 \ldots b_j \ldots b_m)$$



- If $(a_1 \ldots a_i \ldots a_p) = (a_1 \ldots a_i \ldots a_n)$

In other term, BM contains all the input needed by the model M, then the best option is to keep M and don't try to simplify it (a simplification means often a degradation of the prevision).

- If $(a_1 \ldots a_i \ldots a_p) \subset (a_1 \ldots a_i \ldots a_n)$

In other term, BM doesn't contain all the input needed by the model M.

At this point, two options exist:

i. Realize a regression of the model M

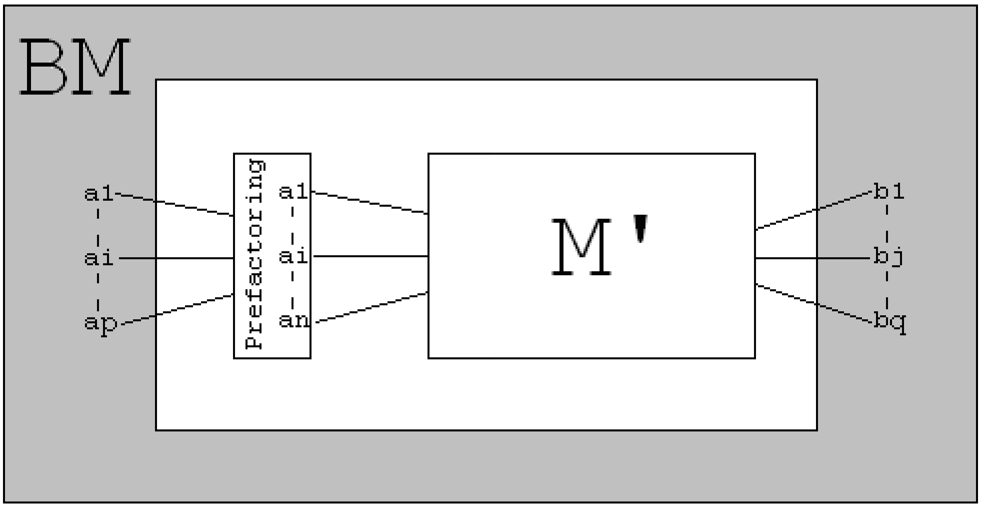
This regression can be :

- linear
- non linear
  - Neural network
  - SVM
  - Fuzzy logic
  - ANFIS
  - Soft computation

Jean-André Vital presented briefly to me all these methods and the thing is there are not miraculous solutions. In fact, if we decide to use regressions, we need someone, for at least one month, which study model per model dynamic and choose what the best method to use is.

ii. Create new inputs in order to allow running M

If BM doesn't provide some inputs, we have to firstly test if these inputs are important for the model M by a sensibility analysis. If their are, we can set them to a value corresponding to standard data, according to other condition like type of animal, type of given forage, etc. After this operation, we can use, as the option i) directly the model M.



2. Discuss with the PaSim-group the idea of linking modules of models

Two models of the WP8 can be eventually integrated into PaSim:

- The manure model will be difficult to integrate because we don't deal with manure storage into PaSim but only fertilization. On the other side, it can be fully integrated to FarmSim model.
- The digestion model can be integrated but it needs a complementary study.