ANIMALCHANGE

SEVENTH FRAMEWORK PROGRAMME

THEME 2: FOOD, AGRICULTURE AND FISHERIES, AND BIOTECHNOLOGIES

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Deliverable title: **Qualitative overview of mitigation and adaptation options and their possible synergies & trade-offs**

Abstract:

This paper provides a qualitative overview of mitigation and adaptation options at the field/animal scale and their synergies and trade-offs. The long-list presented in this paper will be the basis for modelling the effect of different options at field/animal scale, farm scale and regional scale.

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1. Introduction

AnimalChange will provide scientific guidance on the integration of adaptation and mitigation objectives and design sustainable development pathways for livestock production in Europe, in Northern and Sub-Saharan Africa and Latin America. Work Package 8 of AnimalChange (integrating adaptation and mitigation options) is targeted at the field and animal scale. In WP8 the implications of mitigation on the potential to adapt to climate change are tested, and the implications of adaptation on the potential to mitigate greenhouse gas emissions are tested.

In this report (Deliverable 8.1), a qualitative overview is given of mitigation and adaptation options and their possible synergies and trade-offs. The report focuses on livestock production systems. Mitigation options are options which reduce the emissions of greenhouse gases (CO_2, N_2O and CH_4) from livestock production systems. Adaptation options describe ways for livestock production systems to adapt to future climatic conditions (global warming, larger climatic variability and increased frequency and severity of droughts and floods). Often mitigation options and adaptation options interact.

Insight in climate change is increasingly important. For example, in arid regions in Africa, people are particularly dependent on the climate for food as only a small percentage of the cultivated area is equipped for irrigation (Bryan *et al.*, 2011). Rainfed agriculture in Europe may also face higher climate-related risks in the future (Trnka *et al.*, 2011) although it will probably remain possible despite climate changes and more variability. Trnka *et al.* (2011) showed however an increasing number of unfavourable years in many climate zones in Europe have to be expected. This is a challenge for crop management and adaptive measures will be needed.

During the last decades the effects of climate change have received a lot of attention. The sources and sinks of greenhouse gas (GHG) emissions have been evaluated. Many mitigation options have been tested experimentally with results published in international overviews (e.g. Smith *et al.*, 2007b; Vergé *et al.*, 2007), in national overviews (e.g. Dalgaard *et al.*, 2011; Newell Price, 2011; Saggar et al., 2008; Schulte, 2011) and in local overviews (e.g. Van den Pol-van Dasselaar *et al.*, 2011). There exists a strong interest in developing novel GHG prediction models (and improving the existing models) to identify mitigation strategies for reducing the overall GHG balance of livestock farms. Similarly, adaptation options have been studied (e.g. Bryan *et al.*, 2011; Olesen *et al.*, 2011; Tingem *et al.* 2009). These are especially important for areas which are most vulnerable to climate change.

The (inter)national overviews and experimental results of individual research projects show numerous interactions between mitigation and adaptation in the context of different environmental and socio-economic conditions. Generally, information on the quantification and comparison of synergies and trade-offs is limited however, and there are only a few papers reporting on them (e.g. Smith and Olesen, 2010). Therefore a project like AnimalChange will greatly improve the available knowledge. Interactions between different levels (field/animal, farm, region and world) will be unravelled and our general understanding of the corresponding processes will be improved. The project AnimalChange is implemented at all levels: from field/animal level to farm level, to regional level, to global level. Within AnimalChange, the links between the different levels are studied both from large to small (global level to field/animal level) and from small to large (field/animal level to global level).

WP8 focusses on the field/animal level. In the first year of the project a list of options will be delivered which can both be used in further work at the field/animal level and at subsequent levels. The present paper (Deliverable 8.1) provides this list. The overview of mitigation and adaptation options is presented as a matrix. It is based on a review of available literature, expert judgement and additional information provided by the project partners (e.g. recent research which has not yet been published, information from other relevant European funded projects). The breakthrough mitigation options which will be tested in WP6 and the breakthrough adaptation options which will be tested in WP7 are included. The overview is also available as xls-file for use within AnimalChange, which makes it easy to select options based on different criteria and extend the list during the project with further information that becomes available.

Chapter 2 explains the definitions used and the structure chosen for the matrix, while in chapter 3 the content of the matrix is presented. Chapters 4 and 5 provide further details on the different mitigation options and adaptation options, respectively. These two chapters are not meant as a comprehensive review, but as a source of additional information to describe the options presented in the matrix in chapter 3. Finally, chapter 6 provides some concluding remarks.

2. Components of the overview

2.1. Link to N and C cycle

Options to mitigate greenhouse gas (GHG) emissions from animal production systems are strongly linked to the N and C cycles in those systems. The four key components with their respective main GHG are:

- Manure/fertiliser: mainly N_2O and CH_4
- Soil: mainly CO_2 and N_2O
- Crop/feed: mainly N_2O
- Animal: mainly CH_4 (as a result of enteric fermentation)

Similarly, options to adapt to climate change can be linked to the four key components above. We therefore distinguish four groups of options in this paper, categorised into the level of manure/fertiliser, soil, crop/feed and animal. Some options have both mitigation potential and adaptation benefits, whereas others will be only effective as either a mitigation option or an adaptation option.

2.2. Information for each option

The tables in Chapter 3 provide a qualitative overview of mitigation and adaptation options. For each option the following information is provided:

<u>Information on the option itself</u>

- Option: this column gives a short description of the option. More details are provided in Chapters 4 and 5.

<u>Mitigation and adaptation</u>

- Effects on mitigation: this column indicates whether an option has a positive effect on mitigation (+).
- Effects on adaptation: this column indicates whether an option has a positive effect on adaptation (+).

<u>Information on mitigation</u>

- Mit.pot. CH_4 (-/+/++): this column describes the CH_4 mitigation potential. There is either a negative CH_4 mitigating potential, i.e. the option increases CH_4 emissions (-), a low CH_4 mitigating potential (+) or a high potential (++). Empty cells indicate that there is no CH_4 mitigating potential.
- Mit.pot. N_2O (-/+/++): this column describes the N_2O mitigation potential. There is either a negative N_2O mitigating potential (-), a low N_2O mitigating potential (+) or a high potential (++). Empty cells indicate that there is no N_2O mitigating potential.
- Mit.pot. CO_2 (-/+/++): this column describes the CO_2 mitigation potential. There is either a negative potential (-), a low CO_2 mitigating potential (+) or a high potential (+). Empty cells indicate that there is no CO_2 mitigating potential.
- Mitigation variability (variable/robust): this column describes the variability of the mitigation potential. The mitigation potential of some options can be highly variable, i.e. the effect of the option is dependent on the situation. In that case the effect is not robust (var). For options with low variability in mitigation, the effect is robust (rob).
- Importance in mitigation (low/high): this column describes the importance of a particular option for mitigation on a global level. If a particular option has a high mitigation potential, but it can however be applied only in a small number of situations, the importance in mitigation will be low (low). Similarly, the importance in

mitigation can be high (high). If there is no mitigation potential at all, the importance in mitigation is obviously not present.

Information on adaptation

- Adaptation variability (variable/robust): this column describes the variability of the adaptation benefit. The adaptation option is either dependent on the situation (var) or robust (rob).
- Importance in adaptation (low/high): this column describes the importance of a particular option for adaptation on a global level. If a particular option has major adaptation benefits, but it can however be applied only in a small number of situations, the importance in adaptation will be low (low). Similarly, the importance in adaptation can be high (high). If there are no adaptation benefits, the importance in adaptation is obviously not present.

Information on productivity, costs and whether options will be used in practice. The information on these topics in literature is often limited. Therefore, these columns provide first estimates based on expert judgement. The project AnimalChange will deliver more information on these topics.

- Productivity impacts (-/+). An option can either have a negative (-) impact on productivity, i.e. the option leads to less yield, no impact at all (empty cells) or a positive (+) impact, i.e. the option leads to higher yields.
- Costs (high/low/?/benefit). Many options have corresponding costs. These costs can either be high (high) or low (low). In contrast, some options will lead to additional benefits (ben). Sometimes the costs of an option are not clear (?). In many regions of the world, only low-cost solutions will be accepted.
- Future measure / ready to use. This column provides a first estimate whether an option can be directly used (ready) or needs further research or development (future).
- Applicability by farmers (easy/difficult). This column provides a first estimate how easy (easy) or difficult (dif) it is for farmers to apply a certain option, based on criteria like managerial capacity and technical skills needed. In many regions of the world, only simple solutions will be accepted.
- Acceptability for farmers (poor/good). This column provides a first estimate on the acceptability of the option for farmers, based on criteria like land requirement and cultural barriers. The acceptability will be either poor (poor) or good (good).

Information on other synergies and trade-offs. In the previous columns information on productivity and costs has been given. Here information on additional synergies and trade-offs will be given, e.g. less nutrient losses or erosion control. Only the most important synergies and trade-offs are described here.

- Other synergies
- Other trade-offs

Information on links with Work Packages of AnimalChange

- Part of AnimalChange. Whenever options are tested in Work Packages of AnimalChange it is indicated here (v). This means that additional information will become available in the course of the project.

2.3. Regions to be evaluated

As a first step in Work Package 8, the regions, production systems and production sites which need to be evaluated in AnimalChange were defined. This inventory (Task 8.1) was carried out as a joint action with representatives of several other WP's (WP2, WP8, WP9, WP10, WP11 and WP12) during a meeting in Lelystad, the Netherlands in June 2011. For the focus areas of AnimalChange (Europe, Africa, South-America) it was decided which regions, production systems and production sites will have to be evaluated. Five different Agro-Ecological zones were distinguished for land-based systems in Europe:

- Maritime
- Continental
- Mountain
- Mediterranean
- Boreal

For Africa and South-America, four Agro-Ecological zones were distinguished:

- Arid (mainly grassland based systems)
- Semi-Arid (mainly grassland based systems)
- Humid (mainly mixed systems)
- Tropical highlands (mainly mixed systems)

Furthermore, the most common landless systems were identified. For Europe, industrial poultry, industrial pigs and industrial beef (feedlots) were considered to be the most prevalent production systems. For Africa and South-America, the main landless systems were considered to be urban dairy, backyard swine in Africa, industrial swine in South America and industrial poultry in both Africa and South America. Farm types in each of the production systems identified in the different regions have been defined in WP9 (Farm scale modelling methodologies for mitigation and adaptation; Hutchings *et al.*, 2012).

It is clear that some options interact with regional conditions, e.g. the score for applicability by farmers will be region-specific. Also, in certain regions and farm systems certain options will be more important than in other regions and farm systems. This will be further subject of study within AnimalChange. The overview in Chapter 3 provides the first general overview. The next step in AnimalChange will be to add region as a new dimension to the evaluation.

3. Qualitative overview of mitigation and adaptation options

This chapter provides a qualitative overview of mitigation and adaptation options in the form of a matrix. Please note that this matrix is not a stand-alone product but connected/linked to the background information provided in the chapters 4 and 5. Chapters 4 and 5 provide some further details of the different mitigation and adaptation options, respectively. They are not meant as a complete review, but as a source of additional information to describe the options of the matrix in chapter 3. The overview presented here will be expanded during the course of the project AnimalChange.

3.1. Manure/fertiliser

Table 1 provides the overview of mitigation and adaptation options related to manure/fertiliser and their possible synergies and trade-offs.

Table 1. Qualitative overview of mitigation and adaption options related to manure/fertiliser and their possible synergies and trade-offs (explanation of columns in chapter 2.2, explanation of rows in chapters 4 and 5).

Option	Effects on mitigation (+)	Effects on adaptation (+)	Mit.pot. CH4 (-/+/++)	Mit.pot. N2O (-/+/++)	Mit.pot. CO2 (-/+/++)	Mitigation variability (variable/robust)	Importance in mitigation (low/high)	Adaptation variability (variable/robust)	Importance in adaptation (low/high)	Productivity impacts (-/+)	Costs (high/low/?/benefit).	Future measure / ready to use	Applicability by farmers (easy/difficult)	Acceptability for farmers (poor/good)	Other synergies	Other trade-offs	Part of AnimalChange	
Fertilisation rate	+	+	-	++		rob	high	rob	low	+	ben	ready	dif	good	less nutrient losses			
Fertiliser type	+			+		var	high			+	ben	ready	dif	good	less nutrient losses			
Fertiliser application	+			+		rob	high			+	ben	ready	dif	good	less nutrient losses			
Cover slurry stores/manure heaps	+		++	-	+	rob	low				low	ready	easy	good	less odour, less ammonia loss			
Manure cooling	+		+			rob	low				high	future	dif	poor	less odour, less ammonia loss	energy needed		
Manure treatment	+		++	-	+	rob	high				?	ready	dif	good			v	
Filtering CH4 from barns	+		+	+		var	low				high	future	dif	poor				

3.2. Soil

Table 2 provides the overview of mitigation and adaptation options related to soil.

Table 2. Qualitative overview of mitigation and adaption options related to soil and their possible synergies and trade-offs (explanation of columns in chapter 2.2, explanation of rows in chapters 4 and 5).

Option	Effects on mitigation (+)	Effects on adaptation (+)	Mit.pot. CH4 (-/+/++)	Mit.pot. N2O (-/+/++)	Mit.pot. CO2 (-/+/++)	Mitigation variability (variable/robust)	Importance in mitigation (low/high)	Adaptation variability (variable/robust)	Importance in adaptation (low/high)	Productivity impacts (-/+)	Costs (high/low/?/benefit).	Future measure / ready to use	Applicability by farmers (easy/difficult)	Acceptability for farmers (poor/good)	Other synergies	Other trade-offs	Part of AnimalChange	
Reduced/zero-tillage	+	+		-	++	rob	high	rob	high		low	ready	dif	poor	reduced leaching, biodiversity preservation, less soil erosion	more weeds, compaction, water logging, new farm equipment		
Prevent soil compaction	+			+	+	var	low			+	low	ready	dif	good	less soil erosion, improvement of soil cover			
Water management	+	+		+	+	var	low	var	low	+	low	ready	dif	good	increased water use efficiency			
Irrigation		+		+		var	low	var	low	+	low	ready	dif	good		energy needed		
Restoring degraded lands	+	+		+	++	rob	high	rob	high	+	high	ready	dif	poor	prevention of erosion	energy needed		
Pasture reclaiming/recovery	+				++	rob	high				low	ready	easy	good				
Incorporation crop residues		+		-	+	rob	low	rob	low	+	?	ready	easy	poor	less erosion	less animal feed		

3.3. Crop/feed

Table 3 and
Table 4 provide the overview of mitigation and adaptation options related to crop and feed, respectively.

Table 3. Qualitative overview of mitigation and adaption options related to crop/feed and their possible synergies and trade-offs (explanation of columns in chapter 2.2, explanation of rows in chapters 4 and 5).

Option	Effects on mitigation (+)	Effects on adaptation (+)	Mit.pot. CH4 (-/+/++)	Mit.pot. N2O (-/+/++)	Mit.pot. CO2 (-/+/++)	Mitigation variability (variable/robust)	Importance in mitigation (low/high)	Adaptation variability (variable/robust)	Importance in adaptation (low/high)	Productivity impacts (-/+)	Costs (high/low/?/benefit).	Future measure / ready to use	Applicability by farmers (easy/difficult)	Acceptability for farmers (poor/good)	Other synergies	Other trade-offs	Part of AnimalChange	
Crop rotation	+	+	+	+	++	rob	low	var	low		low	ready	easy	good	maintaining soil fertility, control insects/mite pest	less grazing	v	
Perennial crops	+			+	+	rob	low				low	ready	easy	good	capture dissolved nitrogen, outcompete weeds		v	
Legumes and mixtures	+		-	++	+	rob	low			+	ben	ready	easy	good	less N losses		v	
New pasture species	+		+			var	low			+	low	future	dif	good			v	
Improved crop varieties	+		+	+		var	low			+	low	future	dif	good	less plant diseases			
Novel crops	+	+	+			var	low	var	low		low	future	dif	poor			v	
Cover crops	+	+		+	++	rob	low	rob	low	+	low	ready	easy	poor	erosion control, less nitrate leaching	water consumption		
Conversion to grass	+				++	rob	low				low	ready	easy	good	less soil erosion and runoff			
Reforestation	+				+	var	low			-	high	ready	dif	poor	providing shade and shelter, reducing run-off			
Optimal forage management	+		+		+	var	low			+	ben	ready	easy	good			v	
Biodiversity		+						var	high	+	low	ready	easy	poor	less weeds and diseases			
Plant breeding		+						rob	high	+	high	future	easy	good	less plant diseases		v	
Use climate forecasting		+						var	high	+	ben	ready	easy	good	less nutrient losses			
Different planting dates		+						var	low	+	low	ready	easy	good				

Table 4. Qualitative overview of mitigation and adaption options related to crop/feed and their possible synergies and trade-offs (continued) (explanation of columns in chapter 2.2, explanation of rows in chapters 4 and 5).

Option	Effects on mitigation (+)	Effects on adaptation (+)	Mit.pot. CH4 (-/+/++)	Mit.pot. N2O (-/+/++)	Mit.pot. CO2 (-/+/++)	Mitigation variability (variable/robust)	Importance in mitigation (low/high)	Adaptation variability (variable/robust)	Importance in adaptation (low/high)	Productivity impacts (-/+)	Costs (high/low/?/benefit).	Future measure / ready to use	Applicability by farmers (easy/difficult)	Acceptability for farmers (poor/good)	Other synergies	Other trade-offs	Part of AnimalChange	
Conservation as a buffer		+						rob	low		low	ready	easy	good				
Mixed versus single species grass		+						var	low	+	low	ready	easy	good			v	
Agroforestry		+			++	rob	high	rob	low		high	ready	dif	poor	reduced erosion, livelihood diversification			
Optimal grazing	+	+			+	var	low	var	high	+	ben	ready	dif	good	increased biodiversity, less weeds		v	
Increased feed digestibility	+		++			rob	high			+	high	ready	dif	good				
Feed analysis	+		+	+		rob	low				high	ready	easy	good	improved animal health			
Improving roughage quality	+		+			rob	high			+	low	ready	dif	good				
More concentrates	+		+	+	-	rob	high			+	high	ready	easy	good				
Improving grass quality	+		+			rob	high			+	low	ready	dif	good				
Use of silage maize	+		++		-	rob	low				low	ready	easy	good				
Additives in general	+					var	low				high	future	easy	poor			v	
Additive nitrate	+		++			rob	low				high	ready	easy	poor		increased N excretion, animal health	v	
Matching supply and demand	+		+	+		rob	high			+	ben	ready	dif	good				
Supplemental feeding		+	+			var	low	rob	high	+	high	ready	easy	good				

3.4. Animal

Table 5 provides the overview of mitigation and adaptation options related to animal.

Table 5. Qualitative overview of mitigation and adaption options related to animals and their possible synergies and trade-offs (explanation of columns in chapter 2.2, explanation of rows in chapters 4 and 5).

Option	Effects on mitigation (+)	Effects on adaptation (+)	Mit.pot. CH4 (-/+/++)	Mit.pot. N2O (-/+/++)	Mit.pot. CO2 (-/+/++)	Mitigation variability (variable/robust)	Importance in mitigation (low/high)	Adaptation variability (variable/robust)	Importance in adaptation (low/high)	Productivity impacts (-/+)	Costs (high/low/?/benefit).	Future measure / ready to use	Applicability by farmers (easy/difficult)	Acceptability for farmers (poor/good)	Other synergies	Other trade-offs	Part of AnimalChange	
Rumen control via breeding	+		+			var	low				high	future	dif	poor			v	
Immunological control	+		+			var	low				high	future	dif	poor	improved animal health		v	
Less consumption animal products	+		++	+		rob	low					ready	easy	poor				
Increased production in general	+		++	+		rob	high			+	ben	future	dif	good	less nutrient losses	higher replacement rate		
Incr prod extensive systems	+		++	-		rob	high			+	ben	ready	easy	good	less deforestation			
Incr prod intensive systems	+		+			rob	high			+	ben	future	dif	good				
Animal breeding	+	+	+	+		var	low	var	high		high	future	dif	good	improved animal health		v	
Animal management	+		+			var	low				ben	ready	dif	good	improved animal health			
Animal manipulation	+		+	+		var	low				high	ready	easy	poor		not accepted by society		
Replacement rate cattle	+		++	+		rob	high			+	ben	future	dif	good	less nutrient losses			
Cooling of animals		+						rob	high		high	ready	easy	good	animal health and welfare		v	
Livestock mobility		+						var	high		low	ready	dif	good		individuation of communal grazing, desire of settling	v	
Animal health		+						var	low	+	low	future	dif	good			v	

4. Description of mitigation options in animal production systems

4.1. Manure/fertiliser

4.1.1. Optimal fertilization

Fertilisation rate

In general, N fertilisation leads to N_2O emissions and generic fixed coefficients are used for inventory purposes and many other studies directed at mitigation. Based on such coefficient estimates a reduction of fertilisation leads to less N_2O emission, especially in intensive production systems. However, regions with a nutrient deficiency will act differently. Whenever there is a deficiency, adding nutrients may lead to a higher N utilisation and a reduction of GHG emissions. Also, measures which lead to an increased N efficiency may lead to less N_2O emissions. The efficiency of N utilisation can be improved by adjusting the application rates to local conditions (Schulte *et al.*, 2011) and to local fertilisation advices. When application rates or the moment and method of application are suboptimal and improved with improved farming practices, N fertilisation may be reduced without loss in production which will lead to less GHG emissions.

Fertiliser type

There are many effects of type of fertiliser on GHG emissions. Peak values in (labile) soil N should be avoided. Controlled release fertilisers may therefore affect a more optimal utilisation of fertiliser and reduce GHG emissions. During wet conditions, using NH_4^+ fertilizer instead of NO_3^- fertilizer will lead to decreased emissions (Velthof *et al.*, 1996). Also, emissions can be reduced when slurry applications are separated from fertiliser applications by several days. The use of nitrification inhibitors can strongly reduce both N_2O emissions and nitrate leaching. Nitrification inhibitors can artificially be added. There are also some inhibitors available, which are produced naturally by plants.

Fertiliser application

Optimal fertiliser application will lead to minimal GHG emissions. This includes split fertilisation (avoid high N in soil), precision fertilisation (avoid high-risk areas) and optimal timing (avoid high-risk times). Furthermore, the application technique itself will be of influence, e.g. injection or other techniques to incorporate manure into the soil will lead to less GHG emissions. Manure run-off should be avoided just as fertilisation in wet conditions.

4.1.2. Manure management

Cover slurry stores and manure heaps

Installing covers on slurry stores and covering manure heaps will decrease CO_2 and CH_4 emissions (Berg *et al.*, 2006). Since NH_3 emissions will also greatly decrease, a bit more N_2O emissions can be expected at manure application. However, since the overall N use efficiency increases, covering could also lead to less manufactured fertiliser N inputs. The effect of a natural crust is similar but somewhat smaller.

Manure cooling

Cooling manure covered surfaces and cooling of slurry will lead to less CH_4 emissions because the activity of methanogenic bacteria is reduced under cold temperatures. Cooling elements could also be introduced in slurry channels. This technique is of course only possible in certain regions. Reducing indoor storage in general can also decrease CH_4 emissions (Vergé *et al.*, 2007).

Manure treatment

There is a wide range of liquid manure treatment processes available such as anaerobic digestion with capture of biogas, physical and chemical separation technologies, and acidification. These technologies not only lead to energy production and/or more effective nutrient management, but they also reduce the biodegradation of slurry organic matter. Thereby they reduce the potential for GHG emissions during subsequent storage and field application, whereas any solid fractions must be handled to prevent composting (e.g. Wulf *et al.*, 2002; Clemens *et al.*, 2006; Amon *et al.*, 2006a; Amon *et al.*, 2006b). Promising technologies of manure treatment will be tested within WP6 of AnimalChange.

Filtering CH_4 from barns

It is technically possible to filter CH_4 from barns (Hilhorst *et al.*, 2001). Air filtering for gaseous emissions, whilst extremely effective, is primarily restricted to forced ventilation systems, usually deployed in pig and poultry systems (Amon *et al.* 2006b). However, dairy barns are mostly naturally ventilated making it very complex to filter CH_4 from barns.

4.2. Soil

Reduced tillage or zero-tillage

Reduced cultivation or zero-tillage may increase C sequestration and mitigate CO_2 emissions in that way. Furthermore, CO_2 emissions from use of machineries are also reduced since less power is required. In contrast, it may lead to increased N_2O emissions (Rees *et al.*, 2005). The overall effect on GHG emissions is expected to be positive. The increased C sequestration under reduced cultivation or zero-tillage is however debatable. SOC in soils under no-till or minimum till is concentrated near the surface, while in tilled soils it is found deeper in the profile, so that the apparent SOC gains from no-till that are based only on near-surface samples disappear when deeper samples are also included (Van Den Bygaart 2003; Carter, 2005; Dolan *et al.*, 2006). In contrast, Davis *et al.* (2010) found increases in soil C but concluded increases were due to promotion of fallow season volunteer growth.

Reduced tillages should only be applied where soil structural problems have been alleviated. It is probably most effective in water-limited ecosystems (e.g. in South Europe). The effects appear to be limited in Northern and Atlantic regions. The effect of reduced tillage is also seen when increasing the interval between pasture renovation. Vellinga *et al.* (2004) showed that ploughing of intensively managed grassland leads to emissions of N_2O and CO_2. However, pasture renovation should not be delayed when the sward is deteriorating.

A trade-off of reduced tillage or zero-tillage is that it may increase weed populations. Locke *et al*. (2002) found a general increase in perennial weeds and grass species and, consequently, proper weed management will generally be essential for the success of conservation tillage systems. Furthermore, the need for new farm equipment may be an economic constraint (Vergé *et al.*, 2007). Also this practice is highly dependent on field area, with smaller fields (and an increased proportion in turning area for machinery) resulting in greater compaction and the need for occasional deep ploughing (negating the effect of the zero till).

Prevent soil compaction

The productivity of a soil will increase with optimal soil management. For example compacted soil layers should be loosened to increase productivity. As a result of improved soil aeration, direct N_2O emissions are likely to be reduced and sink activity should increase.

Furthermore, soil compaction and soil erosion will be prevented (Drewry *et al.* 2008). Optimal soil management will lead to a higher productivity of the soil, which in turn will lead to less GHG emissions per unit product produced.

Water management

Many soils throughout the world do not have optimal water management. This will decrease productivity and increase the amount of GHG emitted per unit of output. Wherever possible, water management should be improved, e.g. by irrigation or drainage. Specific options are available in specific local situations. Drainage of sensitive areas like wetlands should be avoided. For peat soils maintaining a shallower water table will lead to less emission.

Restoring degraded lands

Avoiding soil degradation or recovering of farm soil is in many parts of the world one of the best mitigation options. In Brazil, for example, it is estimated that there are 100-188 Mha of degraded soil (Bai *et al.*, 2008). Soils are often degraded due to excessive or improper use, erosion, the loss of organic material, high salt contents or low pH. Soil productivity can be recovered by planting pasture, proper nutrient selection, the application of organic substrates such as some wastes or composts, less tillage (direct planting), keeping farm wastes on the soil and moisture retention.

Pasture reclaiming/recovery

Pasture reclaiming or pasture recovery is seen as one of the main components regarding mitigation in countries like Brazil. It will lead to less GHG emissions and a vital agriculture. There are large areas available which could be reclaimed or recovered for pasture.

4.3. Crop/feed

4.3.1. Roughage

Crop rotation

Improved crop/fallow rotation or rotation with legumes will lead to short term losses due to reduced cropping intensity. However, in the medium- to long-term increased soil fertility and yields are expected due to N fixing in soils. Furthermore, the improved soil fertility and water holding capacity will increase resilience to climate change. The mitigation potential is high, particularly for crop rotation with legumes (Bryan *et al.*, 2011). Crop rotation may also lead to an improved grass quality which in turn leads to less CH_4 emissions from enteric fermentation.

Perennial crops

The use of perennial crops reduces the release of carbon consequent to ploughing and can enhance carbon sequestration. Soussana *et al.* (2004) showed that C sequestration rates are higher in long-term grasslands compared to short-term leys in rotation with arable crops. However, there is still significant uncertainty associated with grassland C sinks. WP3 and WP6 of AnimalChange will study carbon sequestration.

Legumes and mixtures

Forage based systems utilising perennial legumes (e.g. white clover, red clover and alfalfa) may reduce the need for nitrogen fertilisers and hence could significantly decrease GHG emissions associated with the manufacture and use of artificial nitrogen fertilisers (Schulte *et al.*, 2011). Whether grass-legume mixtures will show less emissions compared to heavily fertilised grass swards having the same DM yield will be tested in WP6 of AnimalChange. 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. In that way a buffer mechanism is provided against fluctuations in soil mineral N. Indeed, comparisons between grass-based and grass/clover-based systems in Ireland have shown a 50% decrease in N_2O emissions for the grass/clover system without any impact on milk yields (Li *et al.*, 2011). Also both N utilisation and total yields in grass-legume mixtures have been shown to be optimised relative to monocultures (Kirwan *et al.*, 2007; Nyfeler *et al.*, 2009; Nyfeler *et al.*, 2011). This is due to a higher degree of niche occupation within these ecosystems, resulting in transgressive overyielding and greater N utilisation between grass and legumes throughout the growing season.

<u>New pasture species/high sugar grasses</u>
Introduction of new pasture species may be an option to mitigate GHG emissions. For example, high sugar grasses are claimed to increase the efficiency of nitrogen in the rumen, which will lead to a reduced N and C excretion from the animal. However, the role of high sugar grasses in decreasing CH_4 and N_2O emissions is still under debate, and observed effects on CH_4 are confounded with effects on feed intake, energy value and animal productivity. It will be studied in WP6 of AnimalChange.

<u>Improved crop varieties</u>
Plant breeding may lead to varieties with improved nitrogen use efficiency, which will lead to less N_2O emission. Another example is where plant breeding leads to less CH_4 emissions, e.g. silage maize with more starch or higher oil content, or grass varieties with a high digestibility despite a lower N fertilisation to mitigate N_2O. The role of plant breeding in mitigation is expected to be small because the effect of local growing conditions on crop characteristics is far higher than the effects of breeding. In contrast, a much bigger effect and higher importance is expected for plant breeding in adaptation.

<u>Novel crops</u>
Different plant materials in different parts of the world (including local shrubs, herbs and grasses) may contain a wide range of plant secondary compounds capable of manipulating rumen fermentation. Thus far, only a few compounds have been identified that show a significant effect on GHG emissions. However, many believe in the potential strength of these resources. Novel crops and plants from tropical animal production will be studied in WP6 of AnimalChange. More in particular, there will be a screening of local saponins and tannin-rich plant material from Africa and South America for their effect on CH_4 production and protein degradation. The study will also include monogastrics. Growing pigs will be fed protein mainly from locally produced Faba beans, lupines, sunflowers or rape seed.

<u>Cover crops</u>
Bare soil should be avoided to prevent GHG emissions. In situations of annual forage crops, e.g. silage maize, the establishment of cover crops in autumn/winter is a good option to limit the amount of soil N being available for GHG emissions. The cover crop will use the available soil N in autumn and winter, thus reducing nitrate leaching and indirect N_2O emissions. In addition, the reduction of winter fallow by either cover cropping or the planting of winter crops will reduce soil C loss from the ecosystem (Ceschia *et al.*, 2010).

<u>Conversion to grass</u>
Conversion of cropland to either pasture or unharvested perennial vegetation will lead to a decrease in soil C losses and possibly N_2O emissions (Rees *et al.*, 2005, Newell Price *et al.*,

2011; Eagle *et al.*, 2012). This is also true for extending the perennial phase of crop rotations and reducing bare fallow. The effect of conversion to grassland is primarily caused by an increased soil carbon storage that follows on from enhanced aggregate stabilisation. The organic C content of grassland is higher due to lack of disturbance, greater return of plant residues, high root biomass, manure application and the return of dung during grazing. In the long term, a new soil carbon equilibrium will be reached. There are, however, also indications that the projected increasing frequency of drought and heat wave events may turn grasslands into C sources, contributing to positive carbon-climate feedbacks (Ciais *et al*., 2005; Soussana *et al*., 2007). Converting cropland to grassland may lead to crop production elsewhere in the world and a merely displacement of the emissions. Therefore, this option is most feasible on marginal croplands.

Reforestation

Deforestation for livestock production is seen as a major source of GHG emissions (Cohn *et al.*, 2011). Reforestation will in general counteract the effect and reduce national GHG emissions. It is not necessarily true, however, that the effect equals the original deforestation effect. The local circumstances (like management practices, market and regulatory context) will affect the net influence on agricultural extent and forest cover. Also in countries with expanding agricultural area, reforestation may cause leakages to further deforestation and it may cause systemic overall loss of C. Also the loss of biodiversity is rarely compensated.

Optimal forage management

When conditions for roughage, e.g. pH, cutting and grazing regime, are kept at an optimum for plant growth and forage can grow efficiently, this will generally lead to less GHG emissions per unit output and increased carbon sequestration. There is however significant uncertainty associated with C sink activity (Gottschalk *et al.*, 2007). C source/sink strength has previously been shown to be dependent on climate, soil type, land-use and/or land management practices. Initial results in temperate grasslands show that by reducing the intensity of herbage utilisation through grazing and cutting and by maintaining adequate nutrients status (N and P), soil carbon sequestration rates can be increased (Soussana *et al.*, 2007). WP6 of AnimalChange will investigate the duration of carbon storage, since there are questions with respect to the carbon stocks in the soil. Carbon stocks in labile soil organic carbon pools will be released faster than carbon stocks in resistant soil organic carbon pools.

4.3.2. Grazing

Optimal grazing

Annual forage productivity is often greater in grazed grasslands than in ungrazed grasslands or, in contrast, than in overgrazed grasslands. Also, in most cases, grassland with appropriately managed grazing stores more soil C than ungrazed natural grassland (Eagle *et al.*, 2012). Grazing can result in higher soil C than ungrazed grass due to more rapid turnover of shoot material and also due to changes in species composition (Rees *et al.*, 2005). Grazing leads to more N_2O emissions (especially from urine patches) and less CH_4 emissions than zero-grazing. The CH_4 reduction is related to less manure storage. There are different views on the overall effect of grazing on total GHG emissions. Some promote extending the grazing season (e.g. Schulte *et al.*, 2011), while others claim that restricted grazing is the optimal situation (Van den Pol-van Dasselaar et al., 2008). A precise delineation of conditions and effects on GHG emission seems required to make such a distinction. Optimal grazing also includes reduction in field stocking rates when soils are wet and adapting the length of the grazing period to the forage available. Smith *et al.* (2008) conclude that the influence of grazing intensity is not well established and that this depends on the many types of grazing practices employed and the diversity of plant species, soils and climates involved.

4.3.3. Feed

Increased feed digestibility

The majority of CH_4 emissions from livestock production result from enteric fermentation. Increasing the feed digestibility is in many parts of the world the best mitigation measure, especially in developing countries (Vergé *et al.*, 2007). Also in intensive systems feed digestibility remains a main determinant of ruminant productivity and CH_4 emission.

Feed analysis

Knowing that CH_4 emissions can be influenced by adapting the dietary composition and feeding strategy, a precise analysis of the different components of feed will help in optimizing the ration not only with respect to energy value and ruminant productivity, but also with respect to CH_4 emission.

In general, CH_4 emissions are lowest with diets low in sugar, high in starch, high in protein and high in fat. An increase of the sugar content of the diet is, according to the stoichiometry of rumen fermentation derived for the rumen, thought to deliver relatively more CH_4. Compared to starch as an alternative rapidly fermentable carbohydrate, sugars are almost completely fermented in the rumen and do not bypass to the intestine. Per unit weight, sugars therefore deliver more CH_4 than starch, whereas they deliver similar amounts of energy to the ruminant. Eliminating sugars from the diet may limit CH_4 emission in the rumen. Depending on the starch source fed, starch is partly resistant against degradation in the rumen whereas the resistant starch is almost fully digestible and becomes digested well in the intestine, contributing to the energy requirements of the ruminant. The more resistant the starch source against rumen degradation, the less CH_4 is formed. Maize starch hence delivers less CH_4 than cereal grain starches which are almost fully degraded in the rumen.

Low protein diets limit N-excretion. At the same time protein degraded in the rumen and fermented by micro-organisms delivers relatively less CH_4 compared to all carbohydrates. This means that high-protein diets may be emitting low amounts of CH_4.

Fat is not fermented in the rumen and as such delivers no CH_4. Fat is digested in the intestine however and delivers per unit weight more than three times as much energy to the ruminant. There are limits in increasing the proportion of fat in the diet; negative effects on fibre degradation should be prevented.

For a precise evaluation of the effects of feed organic matter on CH_4, an analysis is required of all carbohydrates degraded in the rumen (sugars, starch, fibre), of protein degraded in the rumen, and of fat nondegraded in the rumen. Evaluation of the effect on CH_4 per unit animal product requires an analysis of 1) the amounts of these substrates degraded in the rumen and leading to CH_4 production, 2) the amounts bypassing the rumen (including microbial matter) and becoming digested in the small intestine, and 3) substrates becoming degraded in the large intestine leading to an additional 10% of CH_4 (Bannink et al., 2011).

Improving roughage quality

The quality of the different roughages and the type of roughage affects CH_4 emissions. Fermentation of sugars and cell walls lead to more CH_4 than fermentation of starch and proteins. Fermentation products like organic acid and fat lead to little or no CH_4. Sugars provide in most conditions even more CH_4 than cell walls (Bannink *et al.*, 2010). Where starch (maize) and protein (soya) are not degradable in the rumen, they will not produce CH_4. When degraded in the intestines of dairy cattle, they will provide energy for milk production.

More concentrates in the ration

Concentrates generally lead to less CH_4 emissions in comparison with roughage. This is especially true for concentrates with a high content of starch, protein or fat. However, the amount of concentrates should not be too high to avoid rumen acidosis, and a reduced digestibility and utilization of the diet by the ruminant.

Improving grass quality

Improving grass quality leads to a higher roughage intake by ruminants, an altered chemical composition (more protein, less cell walls, more degradable cell walls and protein), an improved total digestibility of the components and hence a higher feeding value, leading in turn to a higher animal production (Valk *et al*., 2000). Model simulations demonstrated that an improved grass quality leads to less CH_4 emission (Bannink *et al*., 2010). Grass quality can be improved by management, in particular by a more optimal application of fertiliser and manure, and by a more optimal cutting regime and conservation measures. A higher grass quality as a result of a higher N fertilisation and early cutting at low yields leads to less CH_4 emission. In contrast, a lower grass quality as a result of less N fertilisation (with the aim to reduce N_2O emission) or mowing at a higher dry matter yield per ha leads to a higher CH_4 emission (Bannink *et al*., 2010) counterbalancing the sparing effect on N_2O emission. Furthermore, grass quality can be improved by inoculation, chemical treatment and/or mechanical treatment when harvesting and ensiling.

Use of silage maize

Silage maize is a fodder which results in relatively low enteric CH_4 emissions due to the high starch content (Tamminga *et al.*, 2007). Increasing the percentage of maize in the ration leads to less N and P excretion and less CH_4 emissions. Vellinga *et al.* (2011) estimated that the mitigation of methane emissions can be offset by land use change. In particular, soil organic carbon (SOC) loss associated with maize production when compared with either pasture or a broad range of other tillage systems is high, ranging from 4 – 6 t C ha^{-1} yr^{-1} (Ceschia *et al*., 2010). Although such effects may partly off-set the reduction in CH_4 emission achieved on the short term, the long term effects remain beneficial.

Additives in general

Feed additives have been tested to manipulate the rumen microbial population in order to mitigate enteric methane. These additives are substances which, directly or indirectly, decelerate the activity of methanogens in the rumen or reduce the amount of hydrogen produced as a substrate for methanogens. Various additives have been tested, e.g. ionophores, propionate precursors, hexose partitioning, probiotics like yeast products, alternative hydrogen acceptors like unsaturated fatty acids, halogenated methane analogues, organic acids, naturally occurring plant compounds like essential oils and saponins, certain enzymes, acetogens, directly fed microbes like acetogens and methane oxidisers, antimethanogens, defaunating agents and immunogenic approaches to eliminate methanogens. However, the effect of the additives is highly variable. Often mainly temporary effects are shown instead of persistency, which could qualify them as not robust. Several compounds could act as a hydrogen sink in the rumen and successfully reduce CH_4 according to the theoretical mode of action. This indeed has been demonstrated for nitrate and sulphate (Van Zijderveld *et al*., 2010). Also for monensin (used in the United States and Canada but not allowed in Europe) a reducing effect on CH_4 has been demonstrated. Recently, Ellis *et al*. (2012) showed that this can for a large part be attributed to a changed fermentation profile in the rumen, a change towards more propionate production and hence less hydrogen production. Also for some organic acids like fumarate it has been postulated that it would serve as a precursor for propionate production and would serve as a sink of hydrogen. In vivo trials do not demonstrate a clear reduction of CH_4 however despite the promising effects found in vitro. Further research will be carried out in WP6 of AnimalChange which may lead to promising new options.

Additive nitrate

Recently it was shown that adding nitrate to the ration invariably leads to strongly reduced CH_4 emissions (Van Zijderveld et al., 2010). Nitrate becomes reduced to nitrite and subsequently ammonium, extracting hydrogen from the rumen environment which can no longer be used as a substrate by methanogens. A disadvantage of adding nitrate is that the N excretion increases, especially in rations with high protein contents. On the other hand, adding nitrate to rations with a very low protein content may lead to an improved digestibility of the whole ration and an improved feed efficiency. Nitrate addition may be applied as an alternative to urea addition which is already practised under many production conditions. A further notable limitation to the use of nitrate is the fact that with high dosage the intermediate nitrite may accumulate and become absorbed into blood where it has a toxic effect.

Matching supply and demand

Phase feeding, e.g. feeding animals in groups on the basis of their individual feed requirements, will lead to better balanced rations for the animals, an improved retention of feed N in animal protein and lower N excretion and manure being produced. The latter leads to lower losses of N_2O and CH_4. Matching the supply of protein in animal feed and the demand of the animals for this protein will lead to less N losses, including N_2O emissions.

4.4. Animal

4.4.1. Rumen control

Rumen control via breeding

Within the rumen, microbial activity drives methane production. This microbial activity also strongly affects the extent of degradation of dietary protein, the conversion of plant N into microbial protein which can be digested by the ruminant as a host, and the extent of N digestion and the partition of N excretion with urine (digested unretained N) and faeces (undigested N). There is a large variation in rumen function and microbial activity with variation in dietary composition and diet characteristics. The microbial population in the rumen, including rumen bacteria and methanogens, determine to a large extent the effects of different rations on enteric CH_4 emissions and rumen N metabolism and subsequent N retention into animal product and N-excretion, the latter affecting animal-related N_2O emissions. There may be a genetic compound in rumen function and the amount of CH_4 produced, but selection via breeding is up to know an uncertain option and its efficacy is difficult to verify. In WP6 of AnimalChange the variability in ruminant livestock is studied using rumen microbial profiling data (microbial studies, animal measurements) for causal relationships and predictors.

Immunological control

Immunisation of the animal is an option to control the rumen microbiota. Immunisation could be performed with rumen methanogens, or with antigens derived from such microbes, as a manner to decrease CH_4 emissions from ruminant livestock. A similar approach might be applicable to control the microbes in the rumen responsible for protein degradation and ultimately N_2O emissions from the excreta. Vaccines have been proven successful recently in controlled experiments performed by New Zealand researchers. Their usefulness for European ruminants will be tested in WP6 of AnimalChange.

4.4.2. Production level

Less consumption of animal products

If the global consumption of animal products would decrease, this would lead to a reduction in the number of animals and a corresponding reduction of GHG emissions (FAO, 2006; Stehfest *et al.*, 2009). Less animals or restructuring of the herd size is also mentioned in some national studies as an effective mitigation option (e.g. Schulte *et al.*, 2011). However, this option is seen as unrealistic as world food demand is expected to increase because of continued population growth (Tubiello *et al.*, 2007). Less animals in a particular area will probably lead to more animals in another area (replacement). Extensification would mean, other things being equal, that a reduction in production in one area would result in increased production elsewhere. Furthermore, in many parts of the world where production of human edible crops is not feasible, ruminants serve as a constant and secure supply of a high-value protein source. Ruminants cannot easily be replaced by other agricultural methods in such regions. Therefore, inventories on effects of a reduction of global consumption of animal products need to take into account the regional differences, potentials and limits for various alternative agricultural systems.

Increased animal production in general

Intensification of production is likely to lead to higher levels of GHG emissions both per animal and per unit area, however likely not per unit of animal output. The impact of rising global food demands mean that intensification is in principle an important mitigating measure to be considered. An increased productivity of animals may be a good option to mitigate greenhouse gas emissions. As a result of an increased productivity, CH_4 emission per unit of milk production produced decreases (Chadwick *et al.*, 2007). Further advantages are that increased production will in general lead to more efficiency and a higher profit. A prerequisite is that animals remain robust. The ultimate goal is a ”sustainable intensification” (Garnett, 2011), where yields are improved without damaging ecosystems, animal integrity and consumers concerns. This concept may raise some environmental and ethical concerns however, such as the loss of biodiversity with further intensification (Garnett, 2011).

Increased production in extensive systems

The effect of an increased production in extensive animal production systems could be large (e.g. Van den Pol-van Dasselaar et al., 2011). For example, if a unit of beef in Brazil is produced using the semi-intensive technologies available in Brazil, it is most likely that these emissions will be measurably less than the emissions from typical extensive production. If forage land is in fact spared, questions do arise, however, about the soil carbon that could be lost in the conversion from pasture to cropland (Fargione *et al.*, 2008). More intensive cattle rearing as a result of improvement of pasture management is seen as one of the main mitigation options for Brazil. This would require enhanced productivity through genetic screening of the types of pastures used, fire management and irrigation, as well as improved pasture nutrition, which in turn requires more precise fertilizer use. It may also lead to less deforestation.

Increased production in intensive systems

The effect of an increased production in intensive animal production systems will be relatively less than that in extensive systems, but still significant (Vergé *et al.*, 2007).

Animal breeding

Genetic improvement may have impact on GHG emissions by increasing production efficiency and thus decreasing emissions per unit product. Animal breeding can lead to less GHG emissions and a higher productivity by selection for a higher feed intake, a higher feed conversion efficiency and a higher productivity. Also selection for animals with lower emissions per unit of dietary intake, given a certain genetic merit for feed intake, feed efficiency and production, may lead to a lower CH_4 emission. The former type of breeding would be more a continuation of the on-going process of genetic improvement that already has been taken place during the last decades in intensive systems. The latter is momentarily under investigation and it is still uncertain how much reduction in CH_4 can be achieved by selecting for individuals which perform comparable to others but demonstrate low CH_4 production in the rumen. Improvement of the genetic merit of animals is an option for the medium to long-term (Schulte et al., 2011).

Animal management

Production can also be increased by day-to-day animal management, e.g. by direct dietary interventions through both changing dietary inputs and the use of dietary supplements. Measures like reducing beef finishing times are also a good option (Schulte *et al.*, 2011). Other possibilities to decrease GHG emissions while maintaining or increasing farm profitability are e.g. increased milking frequency, maintaining high animal health using good agricultural practices and responsible use of antibiotics.

Animal manipulation

Planned selection of male/female at insemination (embryo and sperm sexing) may be an option to avoid CH_4 emissions from bull calves. With planned selection the number of animals may decrease. There are also other options for animal manipulation available, including steroids and bovine somatotropin (BST). The latter are however not legal in many parts of the world.

Replacement rate of cattle / longevity of cattle

Good agricultural practices may lead to a decrease in replacement rates of cattle. This means that less calves are needed for a certain production. This will lead to less CH_4 emissions of the total herd while maintaining herd production. This could also be achieved by an increased fertility of animals which will lead to a reduced number of followers required (Chadwick et al., 2007). Increasing the longevity of cattle is an attractive option for farmers, since it will increase the profitability of the farm.

5. Description of adaptation options for animal production systems

5.1. Manure/fertiliser

Fertilisation rate
Appropriate use of fertilisers and manure will lead to productive fields. An improved productivity increases resilience to climate change (Bryan *et al.*, 2011). Appropriate fertilizer/manure use also has a high mitigation potential, both in situations of over fertilization (where the amount should be reduced) as in situations where fertiliser is underutilized such as for example in Sub Saharan Africa.

5.2. Soil

Reduced/zero tillage
Reduced/zero tillage will lead to increased yields over the long term due to greater water holding capacity of soils, particularly in areas prone to persistent drought. In the short term however there will be limited effects due to trade-offs in terms of weed management and potential waterlogging. Reduced/zero tillage may lead to increased resilience to climate change due to improved soil fertility and water holding capacity. With respect to mitigation, there is mitigation potential through reduced soil carbon losses (Bryan *et al.*, 2011).

Crop residues
Incorporation of crop residues will lead to higher yields due to improved soil fertility and water retention in soils. The improved soil fertility and water holding capacity will increase the resilience to climate change. However there is also a trade-off since the crop residues can no longer be used as animal feed. Incorporation of crop residues is also a mitigation option since it will lead to increased soil carbon sequestration (Bryan *et al.*, 2011). N_2O emissions will however increase slightly.

Irrigation
In situations where irrigation is possible, it will lead to higher yield and less variability in yield (Bryan *et al.*, 2011) and thus increase the resilience to climate change. In that way it also contributes to mitigation per unit product produced. When irrigation is needed and water is scarce, irrigation during the night will lead to higher water use efficiency than irrigation during the day. In situations where irrigation is energy intensive more CO_2 emissions may occur which may counteract the positive mitigation potential as described above.

Water management
Other water management options, like terraces, mulching, ditches and grass strips can be used to conserve soil water and in that way act as adaptation options. They will reduce the yield variability due to better soil quality and rainwater management and lead to increased yields due to reduced runoff and soil erosion and due to an increased soil moisture content. The improved productivity will lead to positive mitigation benefits as well (Bryan *et al.*, 2011).

Restoring degraded lands
Degraded lands are an enormous threat for the world. These lands are needed to feed the growing world population. Restoring degraded lands via re-vegetation, applying nutrient

amendments and proper soil management will have both adaptation and mitigation benefits via yield improvement and reduced variability in yields (Bryan *et al.*, 2011).

5.3. Crop/feed

5.3.1. Roughage

Biodiversity

Biodiversity is an important tool as this regional wealth can be at the origin of new crop varieties better adapted to regional conditions. Introduction of greater diversity into pastures (i.e. forage mixtures) will not only improve biodiversity but increase N-use efficiency and productivity due to transgressive overyielding as well (Kirwan *et al.*, 2007). Di Falco *et al.* (2010) found that increasing the number of crop variety increases production. Plant genetic resources contain traits that will allow crops to cope with climate change, pests and diseases, as well as to increase crop yields to feed the growing human population (Vergé *et al.*, 2007). According to Letourneau *et al.* (2011) biodiversity leads to a reduction in crop damage and an enhancement of natural enemies of herbivores.

Plant breeding

Plant breeding can lead to improved crop varieties and/or types (e.g. early maturing, drought resistant varieties or crop types) which are resilient against drought or disease. These will increase crop yields and reduce yield variability (Bryan *et al.*, 2011). In WP7 of AnimalChange the adaptation potential of new species and new cultivars that are able to cope with the increased heat and drought stresses (e.g. by increased summer dormancy to prevent damage by summer drought) will be tested. Also, pastures degraded by severe droughts could be resown or oversown with new species and new cultivars that are able to cope with increased heat and drought stresses. This will be evaluated in WP7 of AnimalChange.

Use climate forecasting to reduce production risk

Climate and weather forecasting can be used in farm management, e.g. timing of field operations, to reduce the production risk.

Different planting dates

Changing planting dates will reduce the likelihood of crop failure (Tingem *et al.*, 2008). This adaptation option will maintain production under changing rainfall patterns, such as changes in the timing of rains or erratic rainfall patterns (Bryan *et al.*, 2011). No effect on mitigation potential is expected.

Conservation as a buffer

An increase in seasonal variation in roughage feed supply as a result of a changing climate can be counteracted by conserving surplus production during another part of the year. In this way seasonal variations in roughage feed supply are buffered by conservation methods. Conserved roughage could either originate on-farm or be bought on the market.

Cover crops

The use of cover crops will increase yields due to erosion control and reduced nutrient leaching. The improved soil fertility and water holding capacity will increase resilience to climate change. Furthermore, there is a high mitigation potential through increased soil carbon sequestration (Bryan *et al.*, 2011).

Mixed versus single species grassland

Mixed swards in general, and especially mixed swards with legumes, offer an important option for adaptation to expected climatic change. Grass-legume swards have important yield advantages compared to monocultures of either grasses or legumes (Kirwan *et al.*, 2007; Lüscher *et al.*, 2008; Nyfeler *et al.*, 2009). Moreover, legumes species are well-adapted to future conditions that reflect global climatic change, since they have higher temperature optima than grasses and strong positive responses to elevated CO_2-concentrations (Lüscher *et al.*, 2004; Soussana and Lüscher, 2007). The optimal proportion of the different species is not clear yet. WP 7 of AnimalChange will test the effects of legume proportions. It will analyse stability of yield and resistance to weed invasion of monocultures and of mixed grass-legume swards when grown over the whole range of European climatic conditions from the Mediterranean to the Arctic. Furthermore, it will determine the optimal legume proportion in grass legume swards and test the stability of yield under drought stress and the resilience of yield after drought stress.

Crop rotation

Improved crop/fallow rotation or rotation with legumes will lead to short term losses due to reduced cropping intensity. However, in the medium-term to long-term increased soil fertility and yields are expected due to N fixing in soils. Furthermore, the improved soil fertility and water holding capacity will increase the resilience to climate change. Finally, there is a high mitigation potential, particularly for crop rotation with legumes (Bryan *et al.*, 2011). There is a potential trade-off due to less grazing in mixed crop-livestock systems. In WP7 the applicability of intercropping using adapted forage legume species will be tested under African conditions.

Novel crops

Climate changes together with breed selection have made it possible to produce legumes such as Faba bean, lupine, soy bean and sunflower in Northern Europe. Dietary manipulation using different upcoming protein sources can be an adaptation option which may also lead to reduced GHG emissions. Here the genetic resources and biodiversity are optimally used. The genetic variation in seasonality of growth among diversity gradients of populations and cultivars in several continents provides a natural resource to adapt grassland vegetation to climate change. For example, Mediterranean populations/cultivars are characterised by summer dormancy and/or winter growth potential, in contrast to currently grown Mid-European types, which show larger winter dormancy. Another possibility is to choose for crops which are less vulnerable to plant diseases and weeds. The possibilities of these natural genetic resources will be evaluated in WP7 of AnimalChange. This option is not only valuable for pasture based animal production. Recently, Eriksen *et al.* (2009) observed that the composition of pig diets can influence the CH_4 emission during manure storage.

Agroforestry

Agroforestry and silvopastoral systems (a combination of tree and crops) will lead to increased resilience to climate change due to improved soil conditions and water management, reducing evapotranspiration and allowing for better water control and a higher water holding capacity of the soil. It also has a mitigation potential through increased soil carbon sequestration. Finally, agroforestry may lead to greater yields on adjacent cropland due to improved rainwater management and reduced erosion (Vergé *et al.*, 2007; Bryan *et al.*, 2011).

5.3.2. Grazing

Optimal grazing

Optimal grazing is not only a mitigation option, but also an adaptation option. Improved grazing and cutting management will avoid vegetation degradation and weed invasion. As such it will protect against repeated exposure to heat waves and droughts and against soil erosion from flash flooding. Overgrazing should be avoided and the number of animals should be adapted to the productive capacity of the land available.

As a result of climate change, changes in the seasonality and intensity of grazing and mowing should occur to adapt to these changing climatic conditions. In periods of summer droughts, forage stocks should be available in summer. Winter grazing might also be an adaptation option. In some periods the stocking density should be adjusted.

In WP7 of AnimalChange the following hypothesis will be tested: light grazing and infrequent cutting will increase resilience to severe droughts, compared to heavy grazing and frequent cutting by allowing for a greater rooting depth and by creating a favourable microclimate in the canopy that may reduce the heat stress and protect plant meristems from desiccation and mortality. Also the ability to overtop and shadow weed species which often occurs during periods of drought stress will increase.

5.3.3. Feed

Supplemental feeding

In situations with a loss in forage quality and quantity, supplemental feeding should be provided. This adaptation option will lead to changes in the balance of feed sources in livestock rations (e.g. more cereals in the ration). Furthermore, supplementation will increase costs and might lead to less profit for the farmer. Supplemental feeding could also come from buffer grazing areas which are used to cope with a possible drought.

5.4. Animal

Animal breeding

Heat tolerant breeds are needed. The introduction of more heat tolerant breeds could replace native bred livestock. Since climate is expected to be more variable, the animals should also be robust. A first step would be to identify and strengthen local breeds that have adapted to local climatic stress and feed sources. A second step would be to improve local genetics through cross-breeding with heat and disease tolerant breeds. Especially breeds which are resistant to novel diseases in a certain area are needed. Improved breeds should lead to increased productivity per animal for the resources available (Bryan *et al.*, 2011).

Cooling of animals

In situations of heat and heat stress, cooling of animals is desirable. Cooling can best be done in confinement where the livestock is concentrated in relatively small areas. But providing shadow via a simple shelter or roof also contributes to reducing the effects of excess heat. The ventilation in buildings could be improved and additional equipment could be installed in buildings and/or outdoor areas like cooling pads, fans systems and water sprayers. In situations of heat stress, it is important to ensure adequate access to water to aid the thermoregulation of the animals. In WP7 of AnimalChange several options to reduce the effects of excess heat in pig production systems will be evaluated:

- reduce building ambient temperature (fan, evaporative cooling system)

- facilitate the animal heat loss (drip cooling, floor cooling, snout cooling)
- adapt feeding strategy (low heat increment diets, energy supplementation)

Livestock mobility

Livestock mobility is an important adaptation factor. Herds move from extreme dry situations or extreme wet situations (e.g. waterlogged fields) to more favourable areas. These strategies are inherent to many agro-pastoral systems in some of the most vulnerable regions like the Mediterranean and Sub-Saharan Africa. Mobility remains the most important adaptation to spatial and temporal variations in rainfall for the extensive pastoralist, and in drought years many communities make use of fall-back grazing areas unused in ‘‘normal’’ dry seasons because of distance, land tenure constraints, animal disease problems, or conflicts. However, encroachment on and individuation of communal grazing lands and the desire to settle to access human services and food aid have severely limited pastoral mobility (Morton *et al.*, 2007). Research in livestock mobility is part of WP10 of AnimalChange.

Manage animal health

Under global warming, gastro-intestinal parasites will be amplified. The parasite species already present at the North will be favoured and at the same time the species currently present at the South (like Haemonchus sp., very pathogenic) will probably extend more to the North (Wall and Morgan, 2009). The options to reduce the disease implications of hot weather are not clear yet. WP7 of AnimalChange will study the adaptation of animal husbandry to improve animal health under climate change. More in particular, WP7 will study three options of integrated control policies of gastro-intestinal parasites (helminths) for production of small ruminants at pasture:

- Reducing the population of helminths by mixed grazing of small ruminants with cattle, favourable to the dilution of helminths in pastures and the reduction of their impact.
- Use the anthelmintic properties of local plant resources to reduce parasitism effect (impact on the parasite and the host), with a focus on some plant having a feeding interest (source of proteins) or an interest for the reduction of CH_4 production (rich in saponins, condensed tannins).
- Evaluate the use of vermicompost (organic soil conditioner from livestock or vegetable wastes) containing earthworms, which could contribute to limit the population of helminths at pasture, while providing nutrients to soil.

6. Concluding remarks

This report focuses on options at the field and the animal scale. It is important to have a clear understanding of the possible options at that scale, since it is the scale where farmers make their day-to-day decisions. However, it is also important not to forget the regional and global effects, since decisions at the scale of field and animal will affect the global scale as well. For example, the impact of rising food demands means, other things being equal, that a reduction in food production in a certain region would result in increased food production elsewhere. This can result in net increase in global GHG emissions, if the countries expanding food production were unable to produce food with low emissions intensity (Schulte *et al.*, 2011).

There are many synergies and trade-offs among food production, adaptation and mitigation. Recently the term “climate-smart agriculture” has been introduced (FAO, 2010). This term describes a type of agriculture which “seeks to maximize benefits and minimize negative trade-offs across the multiple objectives that agriculture is being called on to address: food security, development, climate change adaptation, and mitigation. Key elements include increasing productivity and the resilience of agricultural systems, reducing GHG emissions or enhancing sequestration, and managing interfaces with other land uses” (Meridian Institute, 2011).

Climate change may reduce the efficacy of mitigation strategies. It may lead to lower yields due to elevated temperatures and fluctuations in water availability. The interactions between food production, adaptation and mitigation are complex and often dependent on the local situation. Furthermore, there are many constraints to implementation of options in agriculture (e.g. Smith *et al.*, 2007a; Smith and Olesen, 2010). Mitigation and adaptation options need therefore to be tailored to specific contexts. Furthermore, in many countries, especially in Africa, the impact of agriculture on climate is an issue far less important than addressing famine (Vergé *et al.*, 2007).

Within AnimalChange the effects of mitigation and adaptation options will be further studied and quantified for a range of systems and regions. Since it is nearly impossible to study all available options, choices have to be made. Moran *et al.* (2011) suggested for the project AnimalChange three basic criteria to be used to guide research on mitigation and adaptation measures:

- Technical effectiveness (which helps to define the measures that actually work in a variety of farm environments)
- Economic efficiency (preferably cost-beneficial)
- Equity (of the impacts of measures)

In the end, the most promising options will be those options which have a positive impact on the three issues mitigation, adaptation and profitability.

This is the challenge for the project AnimalChange: to deliver a consolidated overview of tested mitigation and adaptation options, including breakthrough options researched in AnimalChange, with their applicability range in terms of farming systems and agro-ecological zones and net effects on productivity and GHG emissions. The qualitative overview of mitigation and adaptation options and their possible synergies and trade-offs presented in this report contributes to this challenge.

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