ANIMALCHANGE

SEVENTH FRAMEWORK PROGRAMME

THEME 2: FOOD, AGRICULTURE AND FISHERIES, AND BIOTECHNOLOGIES

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DELIVERABLE 8.2

Deliverable title: **First version of process based estimates of mitigation and adaptation options**

Abstract:

This paper provides the first version of process based estimates of mitigation and adaptation options for animal agriculture at the field level and at the animal level (Deliverable 8.2, milestone 29). These estimates are derived from the process based models PASIM, DNDC and the Dutch Tier 3 enteric fermentation model.

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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. Mitigation options are options which reduce the emissions of greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) 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).

The present Deliverable D8.2/milestone 29 provides the first version of process based estimates of mitigation and adaptation options and is related to Tasks 8.2 and 8.3. In these tasks, process based models are used, and if necessary adapted or improved, to evaluate the effect of mitigation measures under various conditions. A set of mitigation measures and conditions have been chosen which are relevant for studies on adaptation options to climate change. Task 8.2 is targeted at intensive ruminant production systems and Task 8.3 at pasture based ruminant production systems.

For testing the effect of mitigation measures on enteric CH_4 emission a mechanistic, dynamic model has been used (Dutch Tier 3; Bannink *et al*., 2011) which requires animal characteristics (feed intake, milk composition) and feed characteristics as an input (Dijkstra *et al*., 1992 & 2008; Mills *et al*., 2001; Bannink *et al*., 2006, 2008 & 2011). The model was adapted to deliver estimates of manure composition and milk production next to that of enteric CH_4. The model identifies key aspects and processes of enteric fermentation and digestion that need to be taken into account to obtain accurate estimates of key emission parameters in relation to specific feeding and farming conditions. Adopting generic constants for emission factors (IPCC) would keep inventory methodology less complex and more transparent, however it ignores existing variation and insight in the underlying mechanisms to this variation. Process based models give insight in the causes of this variation in enteric CH_4 emission. Diets are defined in terms of level of feed intake, dietary components (roughages and concentrates), chemical composition of the diet (protein, soluble carbohydrates, starch, hemi-cellulose, cellulose, protein, fat, ash), and rumen degradation characteristics of the chemical components protein, starch, and hemi-cellulose plus cellulose (the soluble, degradable and undegradable fraction and the fractional degradation rate as intrinsic characteristics). These inputs largely correspond to those adopted in protein evaluation systems used in current practice. The details on rumen degradation are needed because enteric fermentation largely takes place in the rumen and hence these are also required to predict effects on rumen methanogenesis. The same holds for the effect of nutrition on the amount and type of nutrients absorbed from the gastrointestinal tract and available for maintenance and milk production, and on the composition and quantity of urine and faeces excreted (Reijs, 2007; Dijkstra *et al*., 2008).

Variation in emissions from soils, applied manure (both ruminants and monogastrics) and excreta from grazing animals has been explored with the mechanistic, dynamic models PaSim and DNDC. These models are the state-of-the-art and take into account the large impact of management and environmental conditions on field emissions (*e.g*. Vuichard *et al*., 2007a, b; Li *et al*., 2010). In addition, a model was developed to describe emissions from stored manure.

Comparable to the models of enteric fermentation and excretion, also the model of soil denitrification requires specific inputs on manure which has to be distinguished into several fractions, and inputs on climate and environmental conditions which are strongly related to the type of soil and to soil and farm management.

The present deliverable (Deliverable 8.2; milestone 29) describes the results of the Dutch Tier 3 enteric fermentation model at animal level and PaSim and DNDC at field level for promising options that have been identified in previous workshops and derived from Deliverable 8.1: Qualitative overview of mitigation and adaptation options and their possible synergies & trade-offs. In the coming years, the breakthrough mitigation options of WP6 and the breakthrough adaptation options of WP7 will also be evaluated by the use of process based models, where applicable. At this moment, results from the experiments in WP6 and WP7 are not yet available however.

For each model (Dutch Tier 3 on enteric fermentation model, PaSim and DNDC, the newly developed manure storage model) different options have been evaluated according to the characteristics of the model (animal level, manure pit level, field level). In this first version of the results of process based models, emission estimates are given for the different components at the farm and the field level. In the second version of process based estimates of mitigation and adaptation options (to become the next deliverable D8.3), an integrative effect on these emission will also be provided by combining the whole set of process based models. Initial steps have already been made to come to this integration (exchangeable outputs of the Dutch Tier 3 enteric fermentation model and inputs of the manure storage model and DNDC as soil models). Results are preliminary however and are not part of this deliverable.

Chapter 2 provides the first version of the effect of options on emission estimates by process based models at the *field level*. Chapter 3 provides the first version of emission estimates by a model at the *animal level*. Due to differences in output of models used, in the aspects covered by the models and in the units used to express emission estimates, results are presented in different ways in the different chapters. Finally, chapter 4 provides some concluding remarks.

2. Field level

2.1. The PaSim model

2.1.1. Model description

The Pasture Simulation model (PaSim, APP ID:IDDN.FR.001.220024.000.R.P.2012.000.10000) was developed at INRA-UREP (*e.g.* Vuichard *et al*., 2007a, b; Graux, 2011; Graux *et al*., 2011; Graux *et al*., 2013) and based on a version originally provided by Riedo *et al*. (1998). It is a process-based grassland ecosystem model based on the Hurley Pasture Model (Thornley, 1998) whose main aim is to simulate climate change impacts on grassland services, and feedbacks of this to the atmosphere by associated greenhouse gas (GHG) emissions by animals and grassland. It was first programmed in ACSL (Advanced Continuous Simulation Language) and developed at the Research Station Agroscope (Switzerland, Reckenholz) from 1997 to 2002. Since then, it is developed at the Grassland Ecosystem Research Unit of the French National Institute for Agricultural Research (France, Clermont-Ferrand). The software is now written in Fortran 90 language and contains about 60.000 lines. It is composed of submodels for plants, animals, microclimate, soil biology, soil physics and management. The 5.3 version of the model is about to be submitted at the APP (French agency for software protection).

Grassland processes are simulated on a time step of a 1/50th of a day in order to have detailed sub-daily dynamics and ensure energy budgets stability. Simulations consider a soil-vegetation-animal-atmosphere system (with state variables expressed per m^2) and run over one or several years. Animal processes are simulated at pasture, excluding the barn or confined housing conditions.

As with other advanced biogeochemical models, PaSim simulates water, carbon (C) and nitrogen (N) cycles. Photosynthetic C is allocated dynamically to root and shoot compartments and can be lost from the modelled system through ecosystem respiration, animal milking, and enteric CH_4 emissions. Vegetation is assumed to consist of one root and of three shoot compartments (laminae, sheaths and stems, ears), each of which is further divided into four age classes. Biological N_2 fixation is modelled according to Schwinning and Parsons (1996), assuming a constant legume fraction. Vegetation is parameterized for a set of key functional traits such as the maximum specific leaf area, the light-saturated leaf photosynthetic rate in standard conditions, the fraction of fibres in ingested shoot compartments and the fraction of digestible fibres in total ingested fibres. Accumulated aboveground biomass can be utilized by cutting and grazing, or enters a litter pool. The N cycle considers three types of N inputs to the soil via atmospheric N deposition, fertilizer N addition, symbiotic N_2 fixation by legumes, and animal faeces and urine.

The inorganic soil N available for root uptake may be reduced through immobilization, leaching, ammonia volatilization and nitrification/denitrification, with the latter processes leading to N_2O emissions to the atmosphere. Management includes mineral and/or organic (*e.g.* solid manure, slurry) N fertilization, mowing and grazing and can either be set by the user or be optimized by the model according to pre-set goals.

(PaSim User’s Guide, December 2012;
https://www1.clermont.inra.fr/urep/modeles/Pasim_User_Guide-pasim_v5-3_201212.pdf).

2.1.2. Options tested

The effectiveness of three mitigation options under contrasting agro-ecological zones in France was tested with PaSim:

- N fertilization rate on N_2O emissions. A monoculture perennial ryegrass (*Lolium perenne* L.) was simulated at four sites with 0, 100, 200, 300, 400 kg N ha^{-1} for two cutting options (two [15/04, 15/08] and four [15/04, 15/06, 15/08, 15/10] cutting events per year).
- Legume fraction on N_2O emissions. An unfertilized mixed sward of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) was simulated at two contrasting sites (Avignon, Mediterranean; Mirecourt, continental), either cut two (15/04, 15/08) or four times per year (15/04, 15/06, 15/08, 15/10), and containing either 0 or 10%, 20%, 30%, 40%, 50% and 60% of legume.
- Stocking density and grazing period length on GHG (CO_2 + N_2O + CH_4) emissions. The sites of Theix (mountainous) and Rennes (maritime) were selected to represent two main production districts. The first corresponds to an upland area (Massif Central) of permanent pastures with suckling cattle. The second (located in Brittany, north-western France) matches farming systems with sown grasslands and dairy herds. For the latter, field grazing conditions were represented by dairy cows grazing a sown mixture of *Lolium perenne* L. and *Trifolium repens* L. To calculate GHG emissions (kg CO_2-C eq. per unit area and per production unit), two management options were simulated: constant (without adaptation) and flexible (with adaptation). For the latter, an automatic procedure was activated to optimize stocking rate and grazing fractional coverage (Graux, 2011). Estimated “attributed net GHG” values, Att-NGHG, were evaluated, with Att-NGHG as an equation of the additive contribution of field and barn emissions for each GHG (CO_2, N_2O, CH_4). PaSim only simulates on-site GHG-emissions. Off-site (barn) emissions were assessed according to IPCC guidelines (IPCC, 2006) and attributed to the corresponding grassland field under the assumption that harvested herbage is fully eaten by stalled cattle (Graux *et al*., 2012). This third option was tested in combination with measures to adapt to climate variability.

2.1.3. Results and discussion

2.1.3.1. Environmental settings

Climate conditions

The PaSim model was parameterized for representative grassland-livestock systems under conditions represented by 12 sites in France (Figure 1). Exemplary simulations are given for basic mitigation options at four sites, which cover contrasting agro-ecological zones (Table 1).

Three contrasting years in terms of aridity (humid, median and arid) were selected over 1970-2006 at each site (observed climate data, Table 2) according to the De Martonne-Gottmann aridity index ([extreme aridity] $0 \leq b < \infty$ [extreme humidity]).

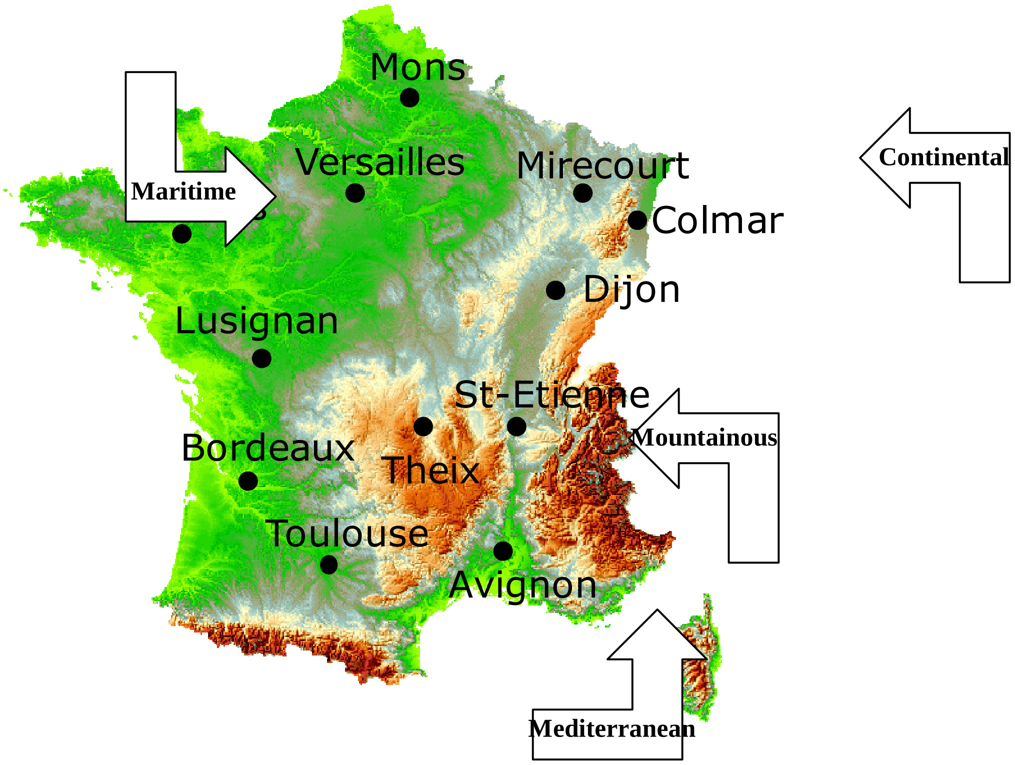


Figure 1. Location of 12 French study sites (from the ANR CLIMATOR project, http://www.international.inra.fr/research/green_book_of_the_climator_project). Four sites were selected to represent contrasting agro-ecological zones.

Table 1. Geo-location and climate type of sites presented in this study. Climate types were classified according to three complementary indicators: continentality (Emberger, 1930), Mediterraneity (Le Houérou, 2004) and aridity (De Martonne, 1942). Mean air temperatures and rainfall totals are reported for the period of available years.

Site	**Latitude**	**Longitude**	**Altitude (m a.s.l.)**	**Climate type**	**Rainfall (mm yr^{-1})**	**T_{avg} (°C)**	**Years**
Avignon	43° 54’ N	04° 54’ E	37	Sub-Mediterranean, semi-arid to arid	702	14.0	1970-2006
Mirecourt	48° 18’ N	06° 08’ E	265	Semi-continental, humid to sub-humid	877	9.2	1973-2006
Rennes	48° 06’ N	01° 42’ W	35	Lowland littoral, sub-humid to semi-arid	727	11.4	1975-2006
Theix	45° 43’ N	02° 08’ E	890	Mountain, humid to sub-humid	774	7.9	1971-2006

Table 2. Selected contrasting years in terms of aridity, based on the De Martonne-Gottmann aridity index (b).

Aridity conditions	**Humid**		**Median**		**Arid**	
Site	**Year**	***b***	**Year**	***b***	**Year**	***b***
Avignon	1996	27.1	2000	14.8	1989	6.3
Rennes	1994	26.3	1977	18.6	1989	11.9
Theix	1979	37.3	1998	25.5	1985	13.8
Mirecourt	1999	45.0	1979	28,2	2003	14.9

Soil conditions

The PaSim model was initialized with soil organic matter values (SOM) obtained by running spin-up simulations until equilibrium was reached.

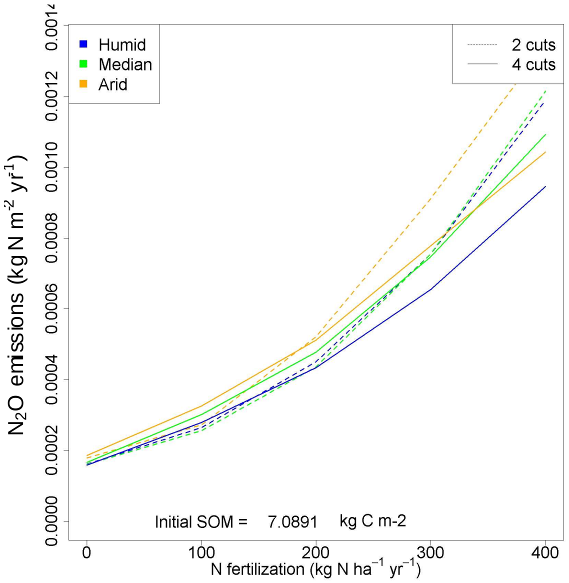
To test the three mitigation options, simulations were run on 0.8-1 m depth limestone brown soil. For the first two options, two scenarios were configured with low or high initial soil organic matter (SOM) content.

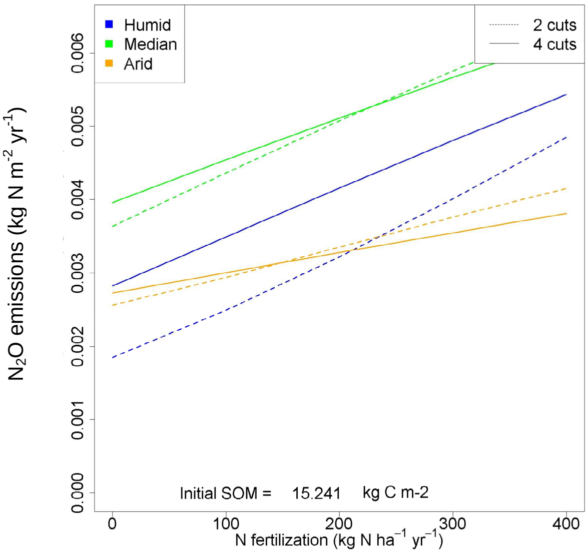
2.1.3.2. Effect of nitrogen fertilization rate on N_2O emissions

The results of the effect of N fertilization rate on N_2O emissions are illustrated in Figure 2, in which:

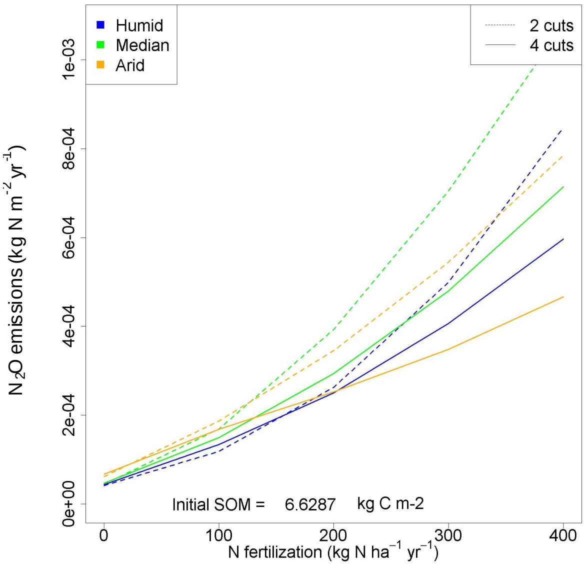
- Exponential increases of N_2O emissions with N fertilizer rate were obtained, depending on initial SOM content and cutting frequency; this increase tends to become linear under arid conditions (*e.g.* at Avignon, top-right graph).
- Similar increases of N_2O emissions with N fertilizer rate generally were simulated under maritime, mountainous and continental climates; higher levels of N_2O emissions occurred under Mediterranean conditions for humid years and continental conditions for arid years (in particular, Mediterranean conditions appear to be excessively emitting).
- N_2O emissions were lower for frequently cut grasslands established on organic-poor soils (intensive cutting tends to export more N from the plot, so that less N is available for denitrification and nitrification processes).

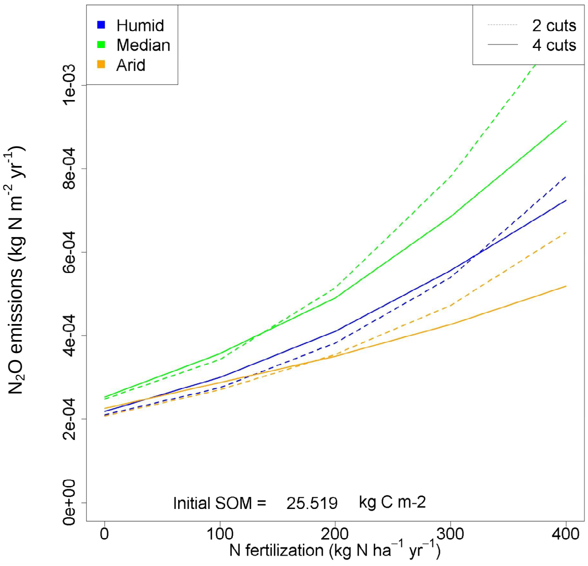
Avignon



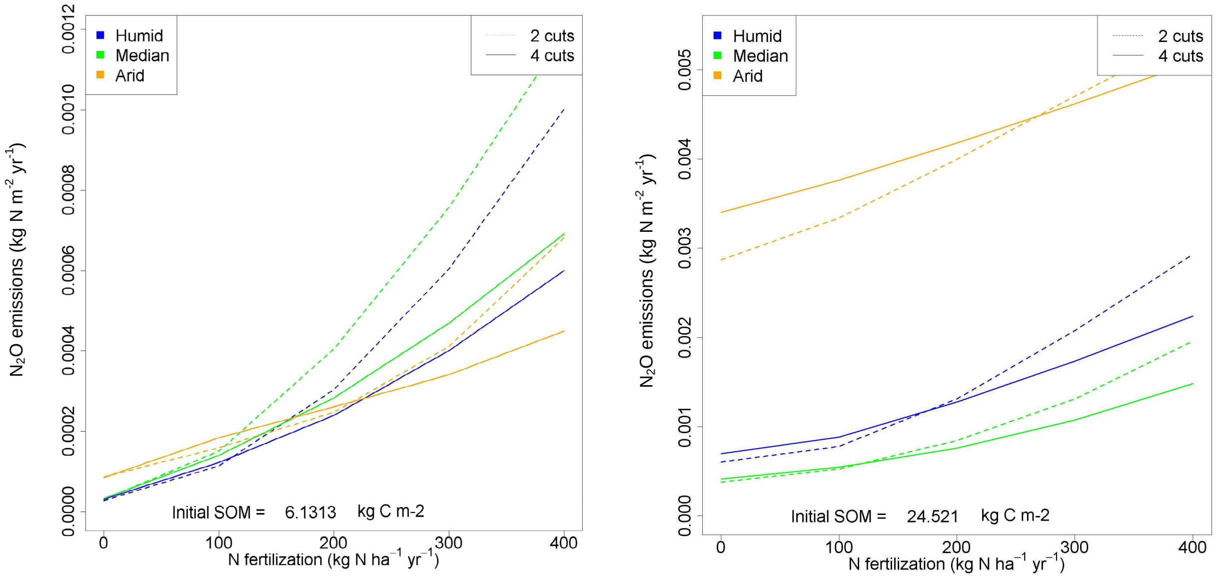


Theix





Mirecourt



Rennes

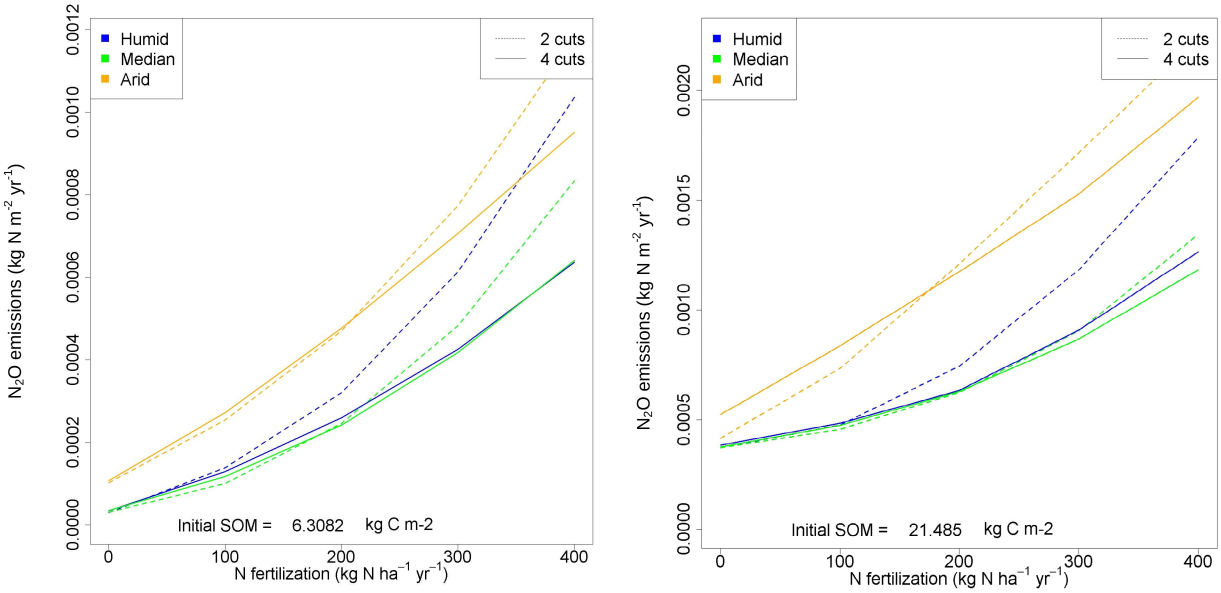


Figure 2. Annual N_2O emissions simulated by PaSim at four French sites for contrasting years (from arid to humid) and for alternative soil organic matter (SOM) initializations, and cutting and nitrogen fertilization regimes.

With respect to France, annual N fertilization is usually about 100 kg N ha^{-1} yr^{-1} and does not exceed 200 kg N ha^{-1} yr^{-1}. In particular, Mediterranean grasslands are extensively managed. With the aim to mitigate N_2O emissions, these simulations indicate that 1) N fertilization on organic-rich soils needs to be limited, keeping it below 200 kg N ha^{-1} yr^{-1}, and 2) advantage needs to be taken of enhanced forage production due to temperature and CO_2 rises from climate change by increasing grass exports from the field (*e.g.* via cutting intensification).

With respect to the latter, a combination of warming, drought and elevated CO_2 may lead to important short-term N_2O losses in extensively managed grasslands (Cantarel *et al.*, 2011). Questions still standing out are how to establish the maximum acceptable level for annual N_2O emissions and what is the relationship between N_2O emissions and N fertilization rates under a variety of conditions. The reason for this is the difficulty to link N_2O emissions with the aridity of climate as they closely depend on soil water content and soil temperature fluctuations (*e.g.* Flechard *et al.*, 2007).

2.1.3.3. *Effect of legume fraction on N_2O emissions*

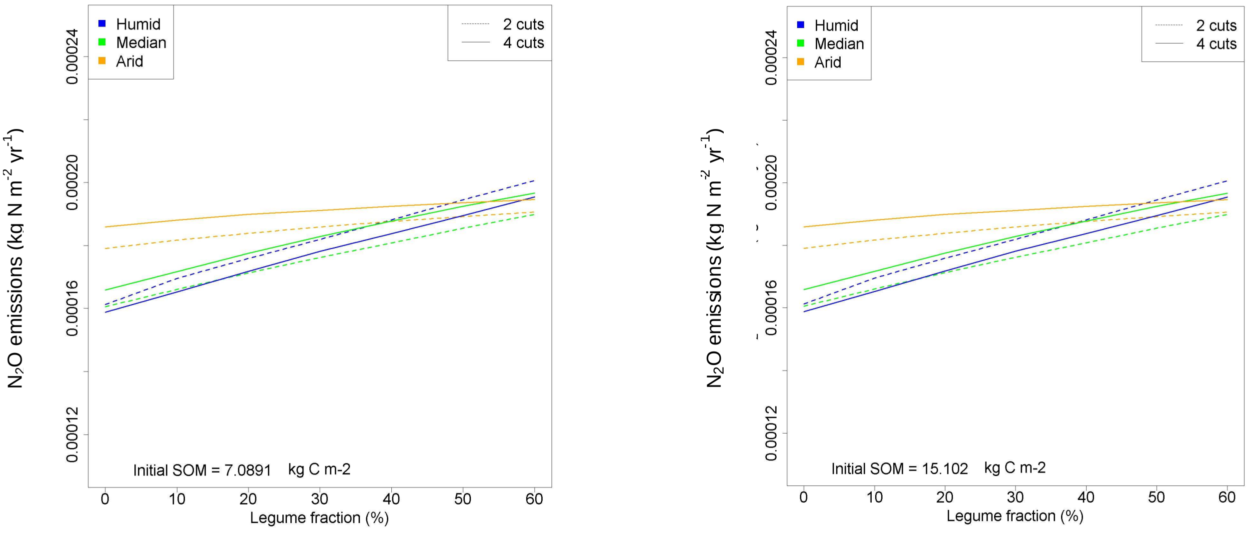
The results are illustrated in Figure 3, in which:

- An increase of N_2O emissions was obtained in response to legume fraction, the progression changing from linear to exponential as moving from arid to humid climate conditions.
- Simulated N_2O emissions were higher under arid conditions.

Symbiotic fixation by legumes is an input to the N cycle. The magnitude of soil N_2O emissions may thus depend on biological N fixation by legumes (*e.g.* Mosier *et al.*, 1998). The simulations indicate that N_2O emissions are expected to rise with proportion of clover in grassland becoming higher than 20-30% (when focusing on humid and intermediate arid years). This proportion is therefore identified as an upper threshold for N_2O mitigation purposes.

A limitation of the present study is that in the current version of PaSim the legume fraction is kept as a constant proportion in the sward, without a response to changing environmental and management conditions (*e.g.* cutting frequency, grazing pressure, water and nutrient availability, CO_2 concentration increase). Model improvements are in progress to clarify the dynamics of the legume component of a grass-legume mixture and incorporate this in the model representation.

Avignon



Mirecourt

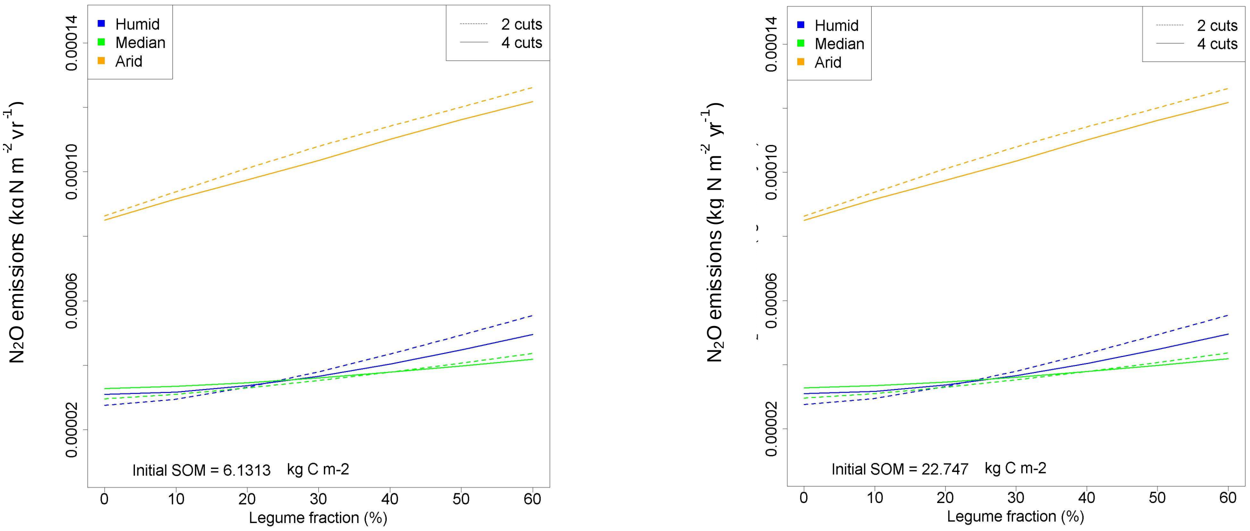


Figure 3. Annual N_2O emissions estimated by PaSim at two French sites for contrasting years (from arid to humid) and alternative options of soil organic matter (SOM) initialization, cutting and nitrogen fertilization.

2.1.3.4. Effect of stocking density / grazing period length on GHG emissions

Simulation results are presented in the form of exceedence probability distributions, calculated over a 30-year period from 1970 to 1999, for both the grazing length (Figure 4, upper graphs) and stocking density (Figure 4, lower graphs), and attributed net GHG per unit area (Figure 5; upper graphs) and per unit product (Figure 5; lower graphs).

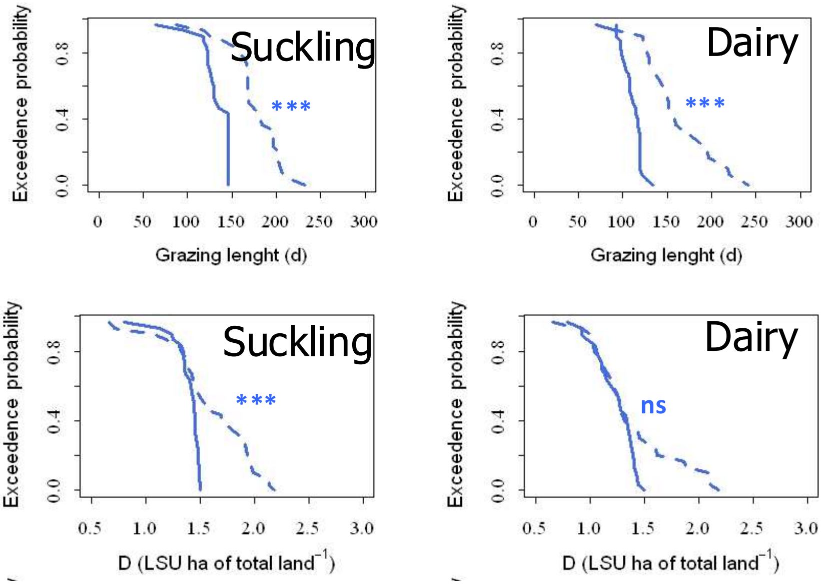


Figure 4. Exceedence probability distributions of grazing period length (d, top) and cow stocking density (D, bottom) (LSU, Livestock unit) for a ***suckling cow system*** *(Theix, mountainous zone; left panel) and a* ***dairy farm*** *(Rennes, maritime zone; right panel) beef enterprises. Continuous line: constant management; dashed line: flexible management. ***: p<0.001, ns: p≥0.05 (Kolmogorov-Smirnov test).*

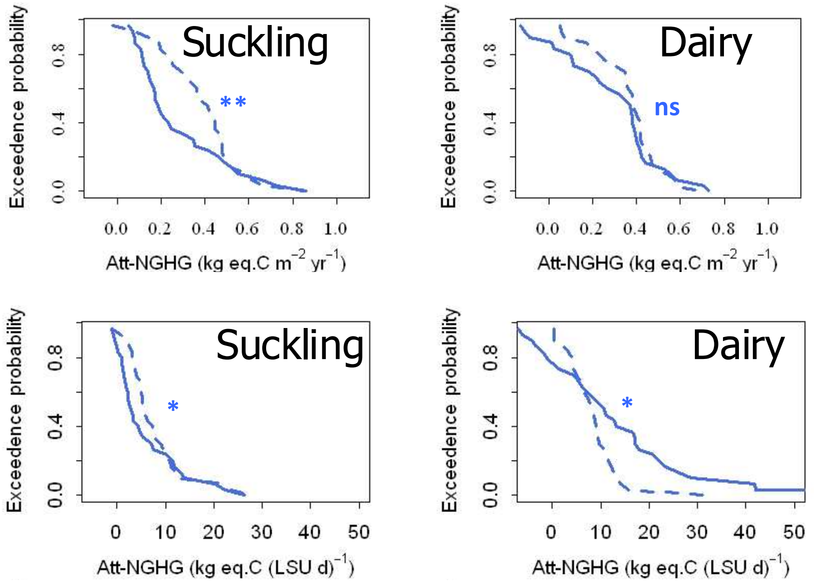


Figure 5. Exceedence probability distributions of attributed net GHG budget (Att-NGHG) for alternative grazing period lengths and cow stocking density for a ***suckling cow system*** *(Theix, mountainous zone; left panel) and a* ***dairy farm*** *(Rennes, maritime zone; right panel). Att-NGHG is either given per unit area of the field (top) or per production unit (bottom). Continuous line: constant management; dashed line: flexible management. **: 0.001<p<0.01, *: 0.01<p<0.05, ns: p≥0.05 (Kolmogorov-Smirnov test).*

These preliminary results indicate that 1) an improved (flexible) management is needed (longer grazing time, higher stocking rate) to optimize grazing options with respect to year-to-year variability, and 2) with optimization, some additional risk of GHG emissions tends to be associated with suckling cattle systems in mountainous zones.

It would be interesting to run the model under projected conditions of climate change because both suckler and dairy livestock systems may benefit from the increase in annual herbage production as a result of a changed climate which is to be expected with higher temperature and CO_2 concentration. Increased herbage production would also allow an extended grazing period and increased stocking density. An adapted farm management may help to mitigate GHG emissions (either when expressed per unit area or per unit of product) while benefiting from increased availability of herbage.

2.1.3.5. Overall remarks

The present simulation results refer to contrasting grassland systems run with alternative management options and in different agro-ecological zones of France. The results indicate that:

- Reduction of N fertilization can be an option on organic-rich soils as well as an intensification of cutting can reduce N_2O emissions from grassland soils.
- Such a reduction can be accompanied by introduction of legumes into grasslands to an upper limit of 20-30% of legume in the grass/legume sward.
- Current climate conditions allow for an extension of the length of the grazing season and an increased stocking density, but that this could be accompanied by increased GHG emissions from suckler cow systems in mountainous areas.

2.2. The DNDC model

2.2.1. Model description

For the work presented in this Deliverable the version 9.5 of the DNDC model was used. The User's Guide for the DNDC Model (Version 9.5) of August 2012 provides the following extensive description of DNDC.

The Denitrification-Decomposition (DNDC) model is a process-oriented computer simulation model of carbon and N biogeochemistry in agro-ecosystems. The model consists of two components. The first component, consisting of the soil climate, crop growth and decomposition sub-models, predicts soil temperature, moisture, pH, redox potential (Eh) and substrate concentration profiles driven by ecological drivers (*e.g.*, climate, soil, vegetation and anthropogenic activity). The second component, consisting of the nitrification, denitrification and fermentation sub-models, predicts emissions of carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), nitric oxide (NO), nitrous oxide (N_2O) and dinitrogen (N_2) from the plant-soil systems. Classical laws of physics, chemistry and biology, as well as empirical equations generated from laboratory studies, have been incorporated in the model to parameterize each specific geochemical or biochemical reaction. The entire model forms a bridge between the C and N biogeochemical cycles and the primary ecological drivers (Figure 6).

Plant growth plays an important role in regulating the soil C, N and water regimes, which could further affect a series of biochemical or geochemical processes occurring in the soil. A sub-model was built in DNDC to simulate the crop growth. A group of crop parameters can be provided or modified by the users to define their own crop. The crop parameters include maximum yield, biomass portioning, C/N ratio, season accumulative temperature, water demand, and N fixation capacity. The crop growth will be simulated driven by the accumulative temperature, N uptake, and water stress at a daily time step. The modelled daily photosynthesis, respiration, C allocation, and water and N uptake are recorded so that the users can check the modelled results against their observations to make sure the crops are simulated correctly. All the crop parameters are accessible on the user's input interface so that the users can modify the parameters in a prompt mode. Crop demand for N is calculated based on the optimum daily crop growth and the plant C/N ratio. The actual N uptake by crop could be limited by N or water availability during the growing season. After harvest, all the root biomass is left in the soil profile, and a user-defined fraction of the above-ground crop residue remains as stubble in the field until next tilling application, which incorporates the stubble onto (for no-till) or into (for conventional tillage) the soil profile. The crop residue incorporated in the soil will be partitioned into three soil litter pools, namely very labile, labile and resistant litter pools, based on its C/N ratio. The litter incorporation provides essential input for the soil organic matter (SOM) storage and hence integrates the plant and soil into a biogeochemical system.

In DNDC, SOM resides in four major pools: plant residue (*i.e.*, litter), microbial biomass, humads (*i.e.*, active humus), and passive humus. Each pool consists of two or three sub-pools with different specific decomposition rates. Daily decomposition rate for each sub-pool is regulated by the pool size, the specific decomposition rate, soil clay content, N availability, soil temperature, and soil moisture. When SOC in a pool decomposes, the decomposed carbon is partially lost as CO_2 with the rest allocated into other SOC pools. Dissolved organic carbon (DOC) is produced as an intermediate during decomposition, and can be immediately consumed by the soil microbes. During the processes of SOC decomposition, the decomposed organic N partially transfers to the next organic matter pool and is partially mineralized to ammonium (NH_4^+). The free NH_4^+ concentration is in equilibrium with both the clay-adsorbed NH_4^+ and the dissolved ammonia (NH_3). Volatilization of NH_3 to the atmosphere is controlled by NH_3 concentration in the soil liquid phase and subject to soil environmental factors (*e.g.*, temperature, moisture, and pH). When a rainfall occurs, NO_3^- is leached into deeper layers with the soil drainage flow. A simple

kinetic scheme “anaerobic balloon” in the model predicts the soil aeration status by calculating oxygen or other oxidants content in the soil profile. Based on the predicted redox potential, the soil in each layer is divided into aerobic and anaerobic parts where nitrification and denitrification occur, respectively. When the anaerobic balloon swells, more substrates (*e.g.*, DOC, NH_4^+, and N oxides) will be allocated to the anaerobic microsites to enhance denitrification.
When the anaerobic balloon shrinks, nitrification will be enhanced due to the reallocation of the substrates into the aerobic microsites. Gases NO and N_2O produced in either nitrification or denitrification are subject to further transformation during their diffusion through the soil matrix. Long-term (*e.g.*, several days to months) submergence will activate fermentation, which produces hydrogen sulfide (H_2S) and CH_4 driven by decreasing of the soil Eh.

The entire model is driven by four primary ecological drivers, namely climate, soil, vegetation, and management practices. It is inherently important for a successful simulation to obtain adequate and accurate input data about the four primary drivers. The model predicts emissions of N_2O, CO_2 and (soil) CH_4 related to the predicted responses of vegetation, SOM, and soil nitrification/denitrification processes.

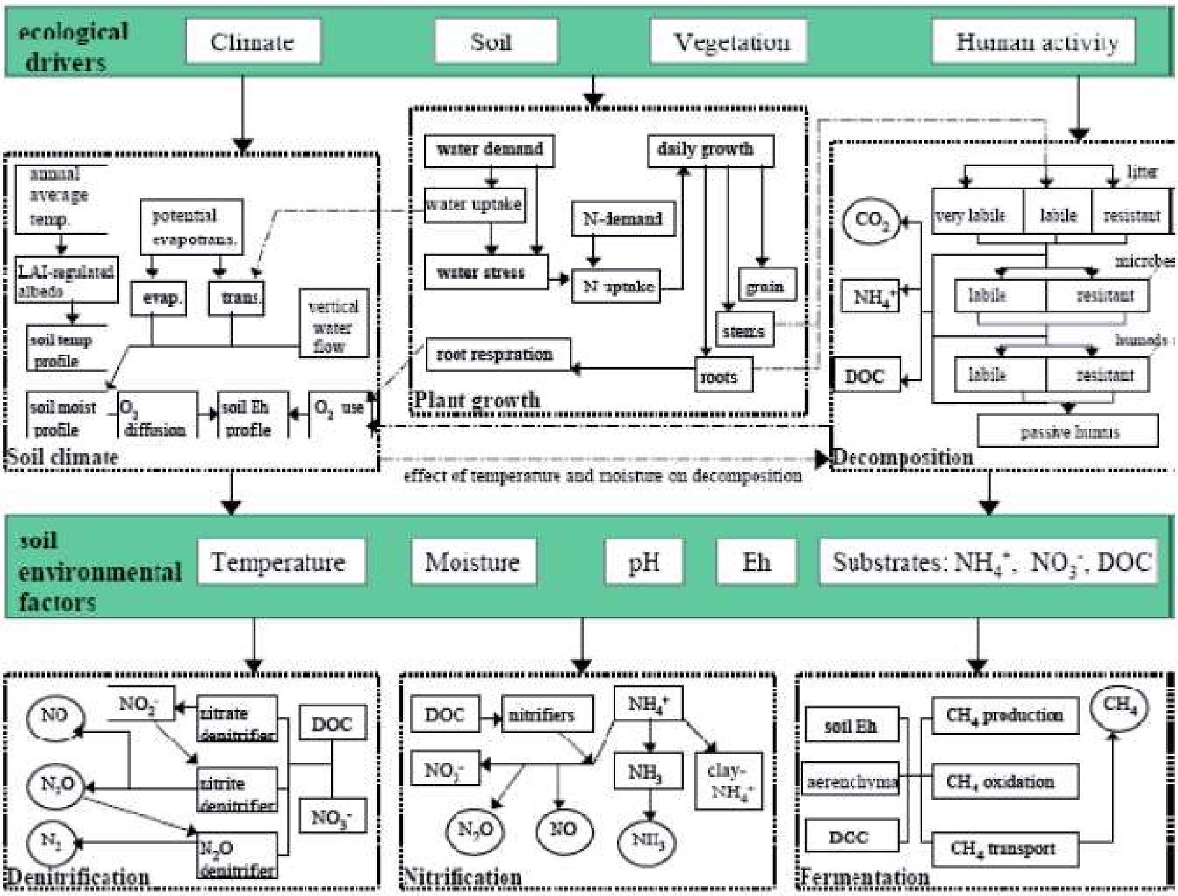


Figure 6. Diagram of model structure of DNDC, version 9.5.

2.2.2. Options tested

A baseline needs to be defined before being able to test the effect of various options. The following baseline was made in the present study: 2.9 LU ha^{-1}, 226 kg N ha^{-1}, total N input = 458 kg N ha^{-1} (LU=Livestock Units; 1 LU is the grazing equivalent of 1 adult dairy cow producing 3000 kg of milk annually, without additional concentrated foodstuffs).

The effect of the following options was tested:

- Reduction in stocking rate (by 1 LU ha^{-1}), with a fertiliser input of 156 kg N ha^{-1}, and a total N input of 308 kg N ha^{-1}
- A higher proportion of clover, with slurry application of 30 t ha^{-1}, no additional fertiliser application, 1.9 LU ha^{-1}, a total N input of 305 kg N ha^{-1} (= 66 kg N from slurry, or 39 kg TAN), and 80 kg N ha^{-1} input from N fixation
- Addition of an extra 60 t slurry (or 90 kg TAN); note that mineral fertiliser is reduced at the same time
- Application of nitrification inhibitors.

2.2.3. Results and discussion

Results are shown in the Table 3. The emission factors calculated with the process based model DNDC clearly differed from the IPCC emission factors. Nitrification inhibitors halved N_2O emission which is not accounted for when IPCC emission factors are applied. Reduced stocking rate, increasing the proportion of clover and applying additional slurry all had profound effects on the simulated emission factors. Simulated factors strongly varied, and were on average lower than IPCC emission factors for several options. Only the average of the emission factors simulated compare to the IPCC emission factor. For the extremes in the whole range of model inputs tested with the individual options differences were profound (Table 3).

Modelling with DNDC provides further insight in the effect of several management options at the field level, and more importantly, in dependency of the precise conditions and management factors in place, on the variation to be expected for site-specific emission factors. Explaining variation is prerequisite to evaluate mitigation and adaptation options and their effect on N_2O emission in an integrated manner with other sources and sinks of GHG emission, and to identify possible trade-offs between various sources and sinks of GHG emission and system production indicators.

Changes in net CO_2 ecosystem exchange (NEE) occurred in response to with altered management. Reducing density of grazing from 2.9 to 1.9 LU ha^{-1} reduced NEE marginally be 0.2- 0.4 tC ha^{-1} yr^{-1}, whilst increasing organic inputs increased sequestration rates by both direct C input and an increase in gross primary productivity (GPP, see Table 3). Reducing stocking rate not only reduced the absolute amount of N lost but also the N_2O emission factor (EF). Likewise the EF was lower for clover, due to better N utilisation between legume and grass as well as reduced N input. However, similar to PASIM there was no way of altering legume proportion. We may deal with this in future by treating the grass/legume mixture as a super-species. Reductions in sequestration under lower stocking rates were principally due to a reduction in GPP due to lower N inputs. However, this reduction in NEE was cancelled out by a reduction in reactive N loss, with substantial reductions in N_2O and NH_3.

The marginal management effects on NEE were superseded by the inter-annual variation in C sequestration rates, with an observed variance of over 28% across a 10 year period.

Table 3. Summary of results for various options tested with the DNDC model

Description of the option	**IPCC emission factor**	**Range within literature**	**Main source of variability**	**Main source of uncertainty**	**Change of C sequestration (tonnes of C ha^{-1} yr^{-1})**	**Emission factor simulated- N_2O**	**Emission factor simulated- CH_4**	**Ammonia**
Baseline: 2.9 LU ha^{-1}, 226 kg N ha-1, total N input = 458 kg N ha^{-1}	N_2O: 2% (PPR) 1 % organic manure 1% mineral fertiliser soil C: 0.14 t C ha^{-1} yr^{-1}	0.18 - 6% (PPR), 0.5 - 4.5% organic manure, 0.4% - 4% mineral fertiliser	N_2O : soil moisture (precipitation x soil texture) CO_2 : climate (temp x precipitation)	Proportion of N_2/N_2O for N_2O: land-use history for CO_2	3.05 - 4.1 t C ha^{-1} yr^{-1} (net ecosystem exchange)	0.97% - 1.7% (global emission factor)	Sink 1.25 kg CH_4-C ha^{-1} yr^{-1}	39.8-48.4 kg NH_3-N ha^{-1} yr^{-1}
Reduction in stocking rate (by 1 LU ha^{-1}) fertiliser input 156 kg N ha^{-1}. Total N input per hectare = 308 kg N ha^{-1}	N_2O: 2% (PPR) 1 % organic manure 1% mineral fertiliser	0.18 - 6% (PPR), 0.5 - 4.5% organic manure, 0.4% - 4% mineral fertiliser	Urine deposition rate and urine composition for N_2O	C offtake during grazing and C deposition in faeces	Decrease in NEE BY 0.2 - 0.4 t C ha^{-1} yr^{-1}	0.8% - 1.4%	Increase in sink capacity 0.13 kg CH_4-C ha^{-1} yr^{-1}	Decrease 10 - 14 kg NH_3-N ha^{-1} yr^{-1}
Clover addition, slurry (30 t ha^{-1}) no additional fertiliser 1.9 LU ha^{-1} total N input 305 kg N ha^{-1} = 66 kg N slurry (39 kg TAN), 80 kg N from fixation,	0% (N_2O)	0.0 - 0.05% N_2O	Clover proportion in sward	N fixation rate	No change (if oversown)	0.6- 1.1%	sink 1.18 kg CH_4-C ha^{-1} yr^{-1}	Decrease of 15.4 - 19.2 kg NH_3-N ha^{-1} if 60 kg urea is not spread
Addition of extra 60t slurry (90 kg TAN) Note: mineral fertiliser reduced	1% (N_2O)		Slurry Dry Matter and total ammoniacal N content	Mineralisation rate of slurry C, mineralisation of organic N	Increase by 0.31 t C ha^{-1}	0.54% - 1.1%	CH_4 Source 0.21 kg CH_4-C ha^{-1} yr^{-1}	Increase of 24.3-41.8 kg NH_3-N ha^{-1} yr^{-1}
Nitrification inhibitors	Not in IPCC inventories - 40% reduction in direct/indirect emissions in NZ inventory	30% - 70% reduction in N_2O	Rate of nitrification inhibition	Breakdown rate of DCD in soil	No change	0.3% - 0.7% (approx. 50% reduction)	No change	No change

3. Animal level

3.1. The enteric fermentation model (Dutch Tier 3)

3.1.1. Model description

3.1.1.1. Modelling aim and use

The basal part of the current Dutch Tier 3 model for enteric CH_4 emission in dairy cattle was constructed to represent the dynamical aspects of the interaction between feed substrates and micro-organisms in the rumen (Dijkstra *et al*., 1992). Most important factors known to affect microbial activity and feed substrate degradation were included. The model aims to obtain an improved understanding of how feed and animal characteristics and rumen fermentation conditions affect feed degradation and microbial activity, and the end-products of microbial activity that are absorbed (ammonium, volatile fatty acids) from rumen or flow out to the small intestine (microbial matter and undegraded substrates).

Later versions of the model were made more specific for lactating dairy cows by including a representation of the stoichiometry of volatile fatty acid production (Bannink *et al*., 2006; 2008) and rumen hydrogen balance (Mills *et al*., 2001; Figure 7) that was derived from in vivo data of rumen digestion in lactating cows only. Based on this hydrogen balance, after inclusion of a representation of fermentation processes in the large intestine comparable to that of the rumen, and under assumption of total conversion of net hydrogen surplus into CH_4, calculations of enteric CH_4 emission were added to the model. Empirical equations were added to represent the digestive processes in the small intestine and the outflow of substrate into the large intestine.

The current model version is used to investigate how feed and animal characteristics affect enteric fermentation and digestive processes, and what consequences are to be expected for the amount and profile of nutrients absorbed from the gastrointestinal tract, for excretion and composition of urine and faeces (to be related to TAN and ammonia emission), for the production of milk (given its composition), and for emission of enteric CH_4.

3.1.1.2. Model structure

The model is a process-oriented model and hence consists of a set of ordinary differential equations that describe the change in time of pools of substrate, micro-organisms and microbial end-product present in the rumen and large intestine. The inflows and outflows from these pools are described and parameterized as much as possible from reports of in vivo trials. The model identifies several types and forms of substrates. It makes a distinction between soluble or degraded substrate, potentially degradable but still undegraded substrate, and undegradable substrate. It distinguishes between sugars and starch as amylolytic carbohydrates used by amylolytic micro-organisms, and cell wall material as a fibrolytic carbohydrate source for fibrolytic micro-organisms. The model distinguishes three types of micro-organisms; amylolytic bacteria and fibrolytic bacteria utilizing the carbohydrate sources named accordingly with retention times related to fluid and particulate substrate, respectively, and protozoa that predate on bacteria having a much longer retention time in the rumen.

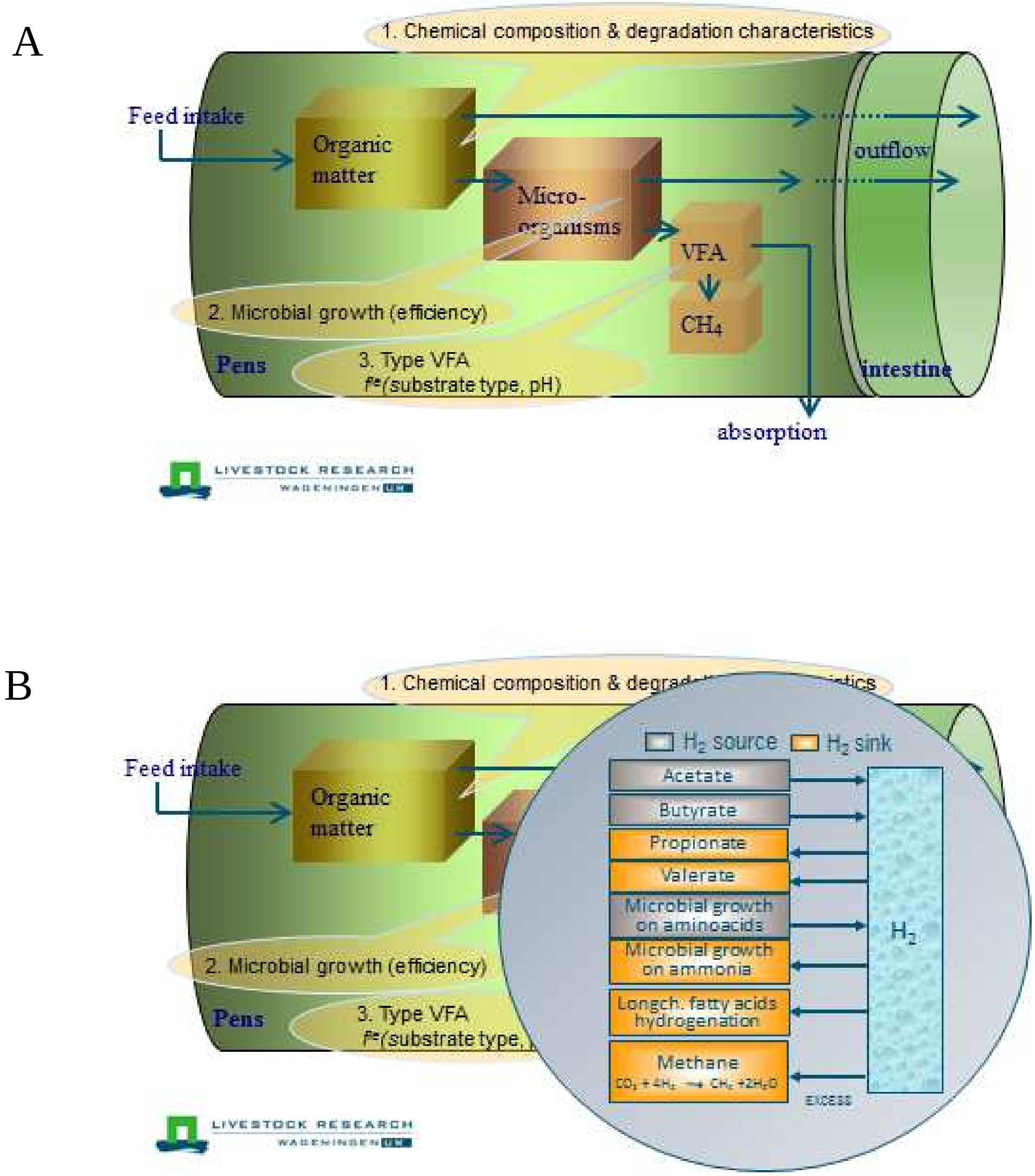


Figure 7. Diagram of model structure including three causal factors to explain variation in A) microbial fermentation of feed substrate, microbial growth, production of volatile fatty acids and methane as end-products of fermentation, B) the effect of the profile of volatile fatty acids, microbial growth and long-chain fatty acid bio-hydrogenation on hydrogen excess and methanogenesis.

3.1.1.3. Model inputs and outputs

The model is driven on inputs related to nutrition, including dry matter (DM) intake rate and the chemical composition of feed DM (in principle possible to give individual and different meals as an input as well), and intrinsic degradation characteristics of the starch, crude protein and cell wall material (structural carbohydrates) in feed DM. Besides these degradable fractions, the model also requires input on dietary content of crude sugars, fat content (including the degree of saturation of dietary fat), organic acids, ash and ammonia.

In addition to feed related model inputs, the model requires some parameter values which are estimated by empirical equations already included in the model when used as a Tier 3 approach, but which can also be given as an input by the model user. These parameters involve the volume of the rumen and of the large intestine, the fractional passage rates of fluid and particulate matter in rumen and large intestine, and three pH parameters (average, minimum and time period below 6.3) as a reflection of daily pH dynamics.

Finally, for prediction of milk production, the model requires protein, fat and lactose content in milk be given as an input (or simply assuming the reference values for calculation of fat and protein corrected milk).

3.1.2. Options tested

The following mitigation options were studied with the enteric fermentation model, in accordance with the outcome of initial discussions with representatives of several work packages in AnimalChange, which relate to various options for farms to adapt to climatic changes:

- Improving forage quality
    - Grass silage diet (in relation to N fertilization rate and sward weight or stage of grass maturity at moment of cutting)
    - Maize / grass silage diet (in relation to stage of ripening, moment of harvest of maize silage)
- Exchange of forages (grass silage versus maize silage)
- Varying carbohydrates as supplement of grass silage based diet (sugar-rich and starch-rich products, and maize silage)
- Protein supplementation:
    - (Low N) grass silage based diet (formaldehyde treated soybean meal, untreated soybean meal, high N grass silage, high N grass herbage)
    - Maize silage based diet (low N grass silage with urea, low N grass silage without urea, untreated soybean meal, high N grass silage)

For all these options, effects of DM intake and effects on milk production were included. Furthermore, two additional options are indicated based on results published in literature:

- Fat supplementation
- Nitrate as CH_4 reducing additive

3.1.3. Results and discussion

Results are presented in Table 4.

3.1.3.1. Varying quality of grass silage

An extreme range of N fertilization rates of grassland and moment of first cut was simulated to have a strong impact on the amount of CH_4 emitted per kg of DM of grass silage, but in particular per kg of milk produced (from hereon, milk is considered to be fat- and protein-corrected milk). For the latter, differences mounted up to 15% with the lowest CH_4 emission realized for a highly fertilized grassland and early cut grass, whereas they stayed within 5% difference when expressed per kg grass DM. These simulation results demonstrate the principal of the effect of changes in chemical composition and rumen degradability of grass on the direction of changes in CH_4 emission. For practical conditions probably only far less extreme changes in N fertilization rate and moment of cutting are feasible. Nevertheless, just a quarter of the size of these measures tested here (75 kg N ha^{-1} higher fertilization rate; 375 kg DM ha^{-1} lower grass harvest for the first cut) still results in an expected 5% lower CH_4 emission.

3.1.3.2. Varying quality of maize silage

Extremes in the moment of cutting of maize silage resulted in only a 5% difference in the amount of CH_4 produced per kg of dietary DM, and a 3 to 10% difference per kg of milk produced depending on whether aminogenic nutrients are protein deficient for optimal rumen microbial activity and or for milk protein synthesis.

3.1.3.3. Exchange of grass and maize silage

Small effects on CH_4 production per kg dietary DM were simulated for the exchange of maize silage for grass silage. When expressed per kg of milk simulated, there was a substantial reduction of 10% in the amount of CH_4 with an increase of the proportion of maize silage up to 30% of dietary DM. A further increase of the proportion of maize silage did not show such a decreased CH_4 yield. In the simulations performed the diet was not supplemented with crude protein and with the further increase in the proportion of maize silage above 30% of dietary DM the supply of aminogenic nutrients became limiting for milk production. This limitation reduced milk production and hence increased CH_4 emission per kg of milk again compared to proportional inclusions below 30%.

3.1.3.4. Supplementing with various carbohydrate sources

Simulated CH_4 per kg of dietary DM was highest when a low N, early cut grass silage was supplemented with molasses and wheat, and lowest when supplemented with maize and maize silage. The supplement composed a 30% of dietary DM and the predicted CH_4 production differed by 5%. When expressed per kg of milk produced the supplementation with molasses showed about an 8% higher CH_4 emission compared to the other carbohydrate sources, whereas the most glucogenic nutrients delivering carbohydrates (wheat and maize) showed the lowest values.

3.1.3.5. Protein supplementation of grass silage based diets

Simulation of supplementing a low N, early cut grass silage with various protein sources for 20% of dietary DM revealed that a higher CH_4 emission per kg DM was predicted with untreated soybean meal (highly digestible in the rumen) as a protein supplement compared to protein supplementation by treated soybean meal and high N grass silage. Differences remained small however, less than 3%.

When expressed per kg of milk produced the lowest CH_4 emission was predicted for treated and untreated soybean meal and the highest for high N grass silage or grass herbage as protein supplement, with a maximum difference of 20%. Formaldehyde-treated soybean meal demonstrated a 5% lower CH_4 emission per kg of milk compared to untreated soybean meal reflecting its resistance against rumen degradation and lower contribution to rumen fermentable substrate.

3.1.3.6. Protein supplementation of maize silage based diets

Supplementation of a maize silage diet with a protein source diet for 20% of dietary DM was simulated to deliver the highest CH_4 emission per kg DM with untreated soybean meal and high N grass herbage as a supplement because of their higher rumen degradability. Differences with high N grass silage (with or without urea) and maize, and with soybean meal as supplement remained small and within 3%.

When expressed in CH_4 per kg of milk produced, soybean meal, maize and soybean meal and low N grass silage with urea as protein supplement showed about 15% lower CH_4 emission than for high N grass herbage, high N grass silage, and low N grass silage without urea.

3.1.3.7. Fat supplementation and nitrate as methane-reducing additive

Supplementing fat is a very potent measure to reduce CH_4 emission in cows, if dietary levels are kept below threshold levels. With every 1% of increase of the fat content of dietary DM the CH_4 emission reduces with 1 g CH_4 kg DM^{-1} which is roughly 5% when the basal diet (excluding the fat source) would deliver 20 g CH_4 kg DM^{-1}. This means that a 4% of dietary DM being supplemented fat would reduce CH_4 emission by 20%. Although fat supplementation is a very potent measure to reduce CH_4, this measure may not feasible during the whole lactation cycle.

Another potent measure to mitigate CH_4 is the addition of nitrate. Addition of nitrate at 0.5% of dietary DM reduces CH_4 emission by 0.8 g kg DM^{-1} which is 4% when the basal diet would deliver 20 g CH_4 kg DM^{-1}. This means that an addition of nitrate at a level of 1% of dietary DM would reduce CH_4 emission by 10%. With a nitrate level of 2% of dietary DM a persistent reduction in CH_4 emission by 16% has been measured in dairy cows by Van Zijderveld *et al*. (2011).

3.1.3.8. Additional factors to consider when comparing feeding measures

3.1.3.8.1 Effect of feeding measures on feed intake

The relative differences between individual feeding measures in their effect on CH_4 emission remained rather consistent across a level of feed intake ranging from 14 to 20 kg DM d^{-1}, which would cover average feed intake established by the average dairy cow in various production conditions. Feed intake level in itself had a higher impact on CH_4 emission per kg of dietary DM ingested or per kg of milk produced than the feeding measures evaluated. Feed intake ranging from 14 to 20 kg DM intake per day caused roughly 20% differences for most of the diets and measures simulated. This means that not only the effect of a feeding measure in itself on enteric fermentation needs to be evaluated, but also the accompanying effect of that measure on feed intake level achieved.

The present study does not give an indication of such effects on feed intake however. The process-oriented model does not include predictions of (changes in) feed intake, but this is given as an input. It is difficult to predict effects on feed intake, but estimates may be derived from trials reported in literature, or from on-farm insights in practice or from models that have been developed to evaluate feed intake effects.

3.1.3.8.2 Effect of feeding measures on milk yield

Effects on milk yield may be calculated from the intake of metabolizable energy or net energy of lactation. However, model calculations show for several feeding scenarios that predicted milk yield may be limited by the supply of aminogenic or glucogenic nutrients, and not by energy supply. A lower milk yield than the potential yield expected based on energy supply occurred in particular with 1) low N grass silage diets with a limiting glucogenic nutrient supply when starch-rich carbohydrates or maize silage is lacking, 2) maize silage diets which lack a protein supplementation.

Nutrient limitation of milk yield may hence strongly affect the effect of a feeding measure on CH_4 per kg of milk produced. Simulation results indicate that in some cases such effects on milk production were of a similar magnitude than the simulated effect of the feeding measures itself. Results of the present study show that, next to the effect of a feeding measure on the level of feed intake, the supply of aminogenic and glucogenic nutrients and their potential limitation of milk production is a further aspect to be taken into account when evaluating effects of feeding measures on CH_4 emission per kg of milk.

Table 4. Summary of results obtained for dairy cattle with the enteric fermentation model, added with results from literature

Description of the dietary options ***(given in % DM)***	**IPCC emission factor** ***(CH_4 energy as % of GE intake)***	**Range within literature** ***(CH_4 energy as % of GE intake)***	**Main source of variability**	**Main source of uncertainty**	**Change of C seques-tration** ***(t C ha^{-1} yr^{-1})***	**Emission factor simulated N_2O**	**Emission factor simulated CH_4** ***(CH_4 energy as % of GE intake)***	**Urine N simulated as source of ammonia** ***(g d^{-1})***	**Model used**
Changing quality of grass silage with 90% grass silage 10% concentrate *(N fertilization rate and sward weight at cutting)*	6.5% default; measure not in IPCC inventories	5.5 – 7.0%	DM intake, grass composition (protein, sugar, NDF), rumen digestion	Rumen degradability NDF, rumen fermentation profile			5.4 - 6.3% of GE intake	133-455 g urine N d^{-1}	Dutch Tier 3
Changing quality maize silage with 60% maize silage 30% grass silage 10% concentrate *(early vs. late cutting)*	6.5% default; measure not in IPCC inventories	5.5 – 6.5%	DM intake, starch content, rumen (& large intestinal) digestion NDF & starch	Rumen degradability NDF and starch, rumen fermentation profile			5.4 - 6.2% of GE intake	139-177 g urine N d^{-1}	Dutch Tier 3
Exchange of forage type with 90% forage 10% concentrate *(exchange of maize silage for grass silage)*	6.5% default; measure not in IPCC inventories	5.9 – 7.0%	DM intake, rumen and total digestion NDF & starch	Rumen degradability starch, NDF and CP, rumen fermentation profile			5.4 - 6.2% of GE intake	71-160 g urine N d^{-1}	Dutch Tier 3
Carbohydrates supplement with 70% grass silage, 30% supplement *(molasses, general compound feed, wheat, maize, maize silage)*	6.5% default; measure not in IPCC inventories	5.7 – 7.0 %	DM intake, rumen digestion NDF & starch	Rumen degradability (part. NDF), rumen fermentation profile			5.6– 6.8% of GE intake		Dutch Tier 3
Protein supplemented with 70% grass silage 10% concentrate 20% supplement *(soybean meal treated or untreated, high N grass silage & soybean meal, high N grass silage or grass herbage)*	6.5% default; measure not in IPCC inventories	5.6 – 6.8%	DM intake, rumen digestion & microbial activity	Rumen degradability NDF, rumen fermentation profile			5.7- 6.3% of GE intake		Dutch Tier 3

Protein supplement with 70% maize silage 10% concentrate 20% supplement *(low N grass silage, urea, maize silage & soybean meal, soybean meal, high N grass silage or herbage)*	6.5% default; measure not in IPCC inventories		DM intake, rumen digestion & microbial activity	Rumen degradability NDF & starch, rumen fermentation profile			5.5- 6.3% of GE intake		Dutch Tier 3
Fat supplementation	6.5% default; measure not in IPCC inventories	6% reduction of default of 6.5% GE intake per 1% increase of fat in dietary DM (up to max fat content of 10% DM)	Negative effects on DM intake & rumen digestion, level of protection to prevent effects on rumen fermentation	Rumen NDF degradability, (rumen fermentation profile)				Reduced by fat dilution of dietary N	(partly) in Dutch Tier 3 WP6-Animal Change Literature
Nitrate supplementation	6.5% default; measure not in IPCC inventories	6% reduction of default of 6.5% GE intake per 0.5% of nitrate in dietary DM (depends on DM intake; efficacy of 80% assumed; max. 2% nitrate in dietary DM)	Dosage & efficacy rumen nitrate reduction	Rate of nitrate reduction & nitrate/nitrite absorption or outflow, rumen fermentation profile, (health issues DM intake around max dosage)				Neutral with dietary urea exchanged, increased when added to diet without urea exchange	Literature WP6-Animal Change

4. Manure (storage) level

A process-oriented model is constructed which describes the conversions of C, N and S in stored manure (Hutchings *et al*., unpublished; Figure 8). The model requires the amount and composition of animal excreta (or manure quality) as an input, and predicts emissions of CH_4, CO_2, NH_3, N_2O, N_2, H_2S from stored manure, and a distribution of C between fractions with a distinct degradability and a distinction between ammoniacal and organic N. The model calculates at an hourly or daily time step. Only a preliminary parameterization of the model has been used however, and further development is needed before any conclusive results can be shown. Besides parameterization also further attention is needed to modelling slurry temperature and the transformations taking place in the crust on top of stored manure.

Based on earlier work of Reijs (2007) and Ellis *et al*. (2011) equations were added to the model of enteric fermentation to quantify quantity and composition of excreta and these model outputs were made compatible with the inputs required by this manure storage model. Some initial simulations have been performed with a combination of both models. The consequences of the diets on the excreta quality are shown in Figure 9. As the proportion of grass silage increases, the amount of cellulose and hemicellulose (CHO) decreases whilst the crude protein (CP) increases. The net effect on the cellulose/ hemicellulose + crude protein (+CP) is much less pronounced.

The quality of the slurry has a marked effect on the simulated CH_4 emission from the stored slurry. This is illustrated in Figure 10, where the CH_4 emissions from slurry resulting from diets containing different types of grass silage are shown.

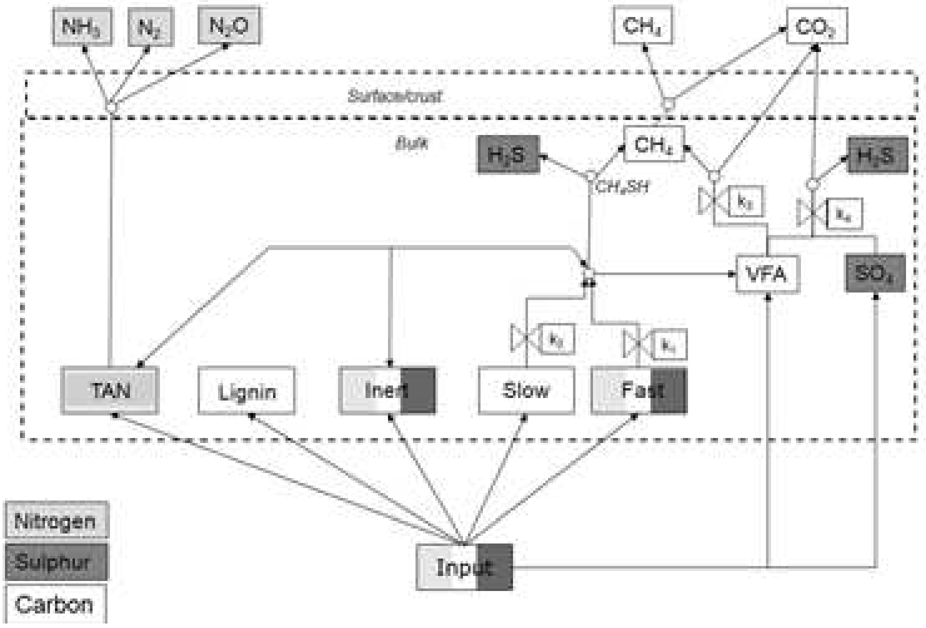


Figure 8. Diagram of a model of manure storage (Hutchings et al., under development)

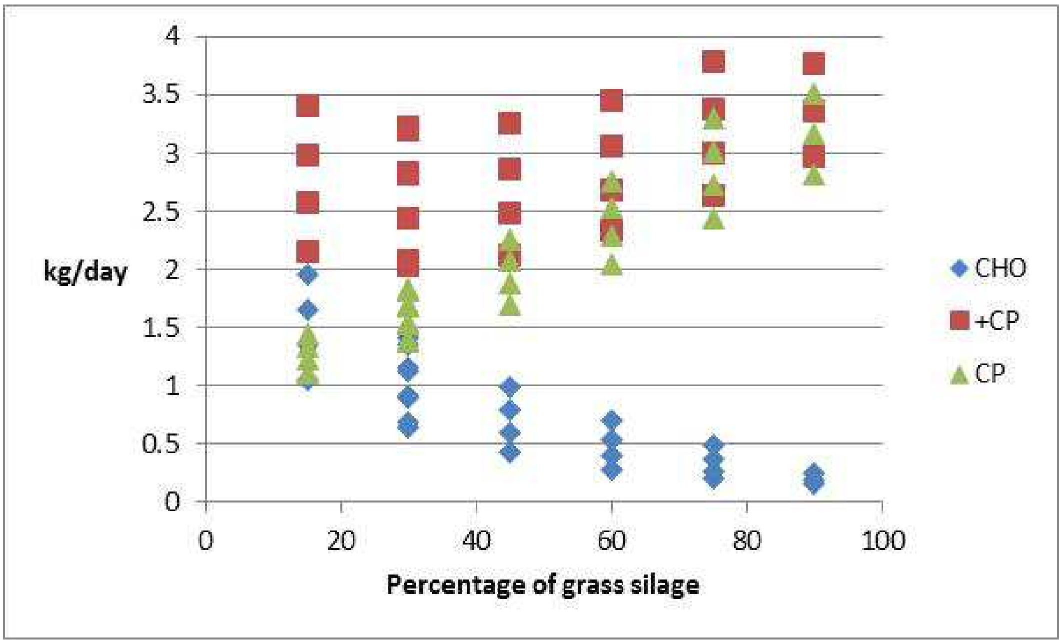


Figure 9 *Effect of percentage of grass silage in the diet on excretion of hemi-cellulose/cellulose (CHO), crude protein (CP), and hemi-cellulose/cellulose plus crude protein (+CP).*

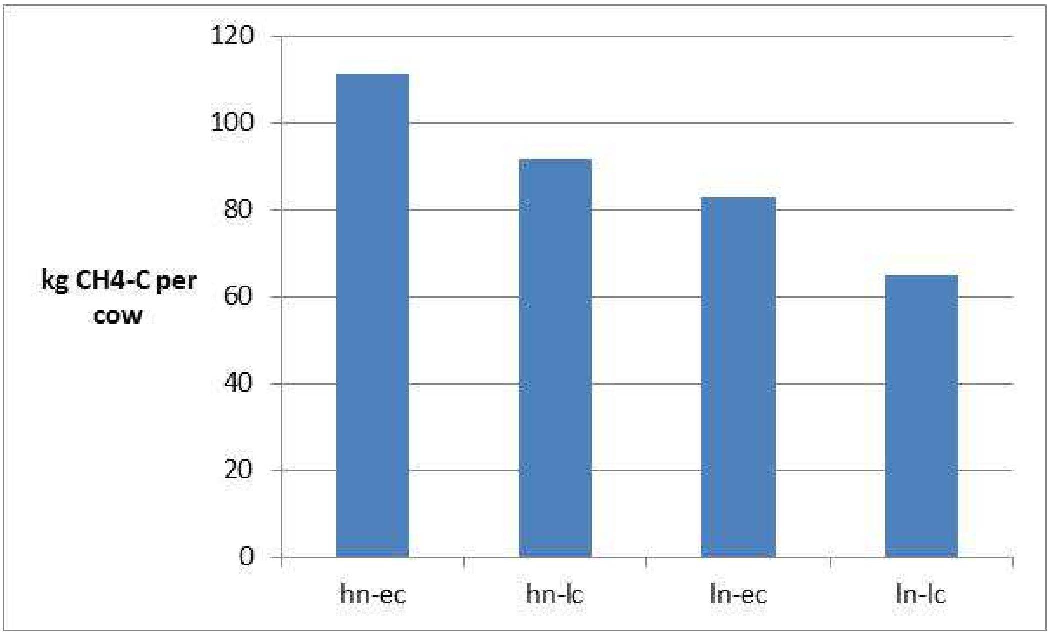


Figure 10 *The methane emissions per cow for slurry from diets of high-nitrogen, early-cut silage (hn-ec), high-nitrogen, late-cut silage (hn-lc), low-nitrogen, early-cut silage (ln-ec) and low-nitrogen, late-cut silage (ln-lc).*

Figure 11 shows how the emissions of CH_4 during storage were affected by the percentage of silage in the diet. Here we see that an increase in the proportion of grass silage in the diet leads to an increase in CH_4 emissions. This occurs because the cellulose and hemicellulose is assumed to have a slower degradation rate than the crude protein. The range for the Western Europe IPCC (2006) Tier 1 emission factors for CH_4 for dairy cattle slurry in temperate conditions (34 to 75 kg cow^{-1} yr^{-1}) is lower than the simulated values but similar to those for North America. The basis for these difference in Tier 1 values between the two continents is unclear.

More work (and in particular, a more thorough parameterisation) is required before making firmer conclusions.

Work is continuing on how to make the outputs of the manure storage model compatible with the inputs required by the DNDC model (Chapter 2). Making the model inputs/outputs compatible to each other enables a combined simulation approach with the enteric fermentation model, the manure storage model and the DNDC model. This is planned for the Deliverable 8.3.

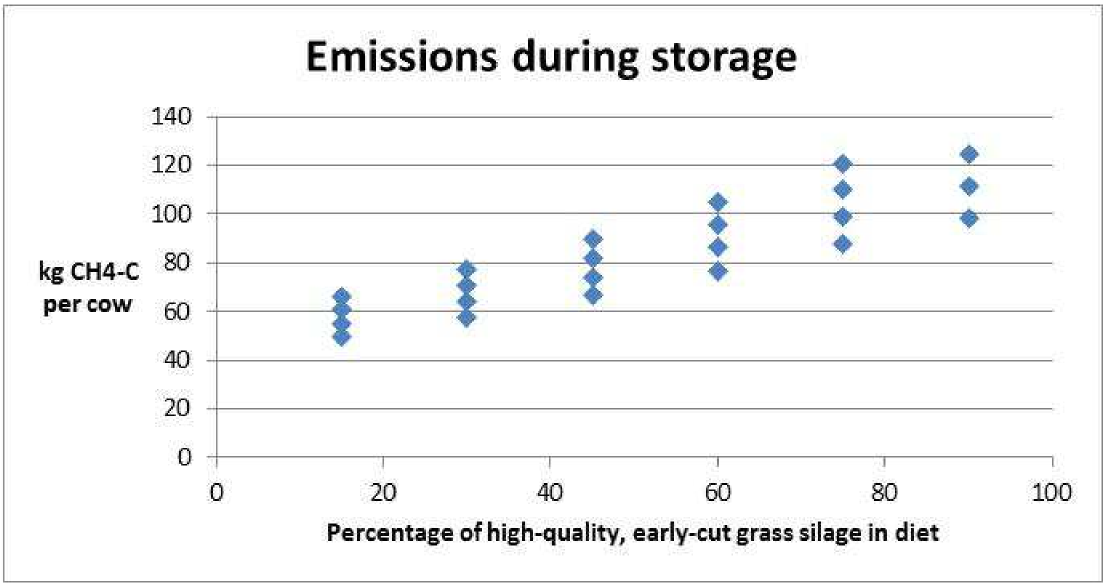


Figure 11. Methane emissions during storage with different proportions of silage in the diet. At a given percentage of silage contribution, the lowest point represents the lowest assumed dry matter intake and the highest, the highest assumed intake.

5. Concluding remarks / integrative approach

Gathering evidence of the mitigation options and the effects of adaptation should not be limited to empirical approaches (like in WP6 and WP7 of AnimalChange). Interactions occur between various aspects of farm management and between various emission sources. Gathering information on a more theoretical basis is essential to provide an understanding of the mechanisms involved and a realistic view of how various emission sources are related to some key farm parameters (*e.g.* level of fertilization, crop yield, and animal feed intake and productivity), how they are interrelated to be able to quantify trade-offs, and to quantify how they are related to mitigation and adaptation options.

This report provides the first version of process based estimates of mitigation and adaptation options calculated with PaSim, DNDC and the Dutch Tier 3 enteric fermentation model (Deliverable 8.2, milestone 29.). The results of this Deliverable/milestone will be used in the whole farm modelling of Component 3 of AnimalChange.

In evaluating effects on GHG emissions from farms, sufficient detail and accuracy is required for the emission factors that are adopted for the individual sources and sinks. Moreover, sources and sinks have to be quantified in an integrated manner, meaning that they cannot be treated to be independent from each other for reasons of convenience, but that they have to be estimated taking the underlying processes and mechanisms into account.

A combined use of the enteric fermentation, manure storage and soil model is planned for this year. Currently, model inputs and outputs have already been made compatible among the models, and hence this major limitation for a combined modelling effort has been taken away. In Deliverable 8.3 results will be presented of a combined use of these three models. The results will identify the interrelationship between emission from enteric fermentation, from manure and from soils for a selection of specific farming conditions and management options. This selection will be tuned with outcomes of previous workshops, deliverables and on-going work in AnimalChange in Component 2 and Component 3.

The options described in this report are options at the *field* and the *animal* scale. It is important to have a clear understanding of the effects of possible options at that scale, since it is this 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 this reason, it is important that the present simulation results become upgraded to a higher level. This can only be done by taking into account the precise background and causes of the variation in emission factors in a realistic manner instead of using rather generic IPCC values which have, in principle, not been generated for such specific use.

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