FACCE-MACSUR

D-L1.3 Bringing together grassland and farm scale modelling. Part 1. Characterizing grasslands in farm scale modelling

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Abstract/Executive summary

This report provides an overview of how grasslands are represented in six different farm-scale models represented in MACSUR. A survey was conducted, followed by a workshop in which modellers discussed the results of the survey, and identified research challenges and knowledge gaps. The workshop was attended by grassland as well as livestock specialists. The investigated models differed largely with respect to how grasslands were represented, e.g. as regards weather and management factors accounted for, spatial and temporal resolution, and output variables. All models had grassland modules that simulate DM yield and herbage N content (or crude protein (CP) content = N content x 6.25). Many models also simulate P content, whereas only one simulate K content. About half of the model simulate herbage energy value and/or herbage fibre content and fibre and/or dry matter digestibility. Critical input data required from grassland models to simulate ruminant productivity and GHG emissions at farm scale was identified by the workshop participants. The different types of input data required were ranked in order of importance as regards their influence on important system outputs. For simulation of ruminant productivity and GHG emissions, herbage DM yield was ranked as the most important input variable from grassland models, followed by CP content together with at least one variable describing herbage fibre characteristics. These findings suggest that work on improving the ability of the current grassland models with respect to simulation of fibre/energy should be prioritized in farm-scale modelling aiming at quantifying livestock production and GHG emissions under different management regimes and climate conditions. More work is also needed on model evaluation, a task that has not been prioritized yet for some models.

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Introduction

Ruminant production systems are important producers of food, support rural communities and culture, and help to maintain a range of ecosystem services including the sequestering of carbon in grassland soils. However, these systems also contribute significantly to climate change through greenhouse gas (GHG) emissions, while intensification of production has driven biodiversity and nutrient loss, and soil degradation (Kipling et al, 2016a). With supplementary feeds representing major economic and environmental costs in farming, understanding better how the quantity and quality of grass available to farmers is likely to change under climate change (CC) is a vital element to risk assessments of the impact of climate change on agriculture at the European and farm scales. Many farm-scale models include characterisations of grassland systems. Developing the capacity of these components through work with grassland modellers is of great importance in ensuring that grassland processes are accurately incorporated into farm-scale modelling of the economic and environmental outputs from livestock production systems of which greenhouse gas (GHG) emissions is of special concern in relation to CC.

The objectives of task L 1.3 are: 1) to explore the state of art in characterizing grasslands in farm scale modelling and produce a work plan for future development within the task (D -L 1.3.1), and 2) to develop and report on activities in the focus topics developed based on D-L 1.3.1 (D-L 1.3.2). This report constitutes D-L 1.3.1.

Methods

As a first step, a model survey was carried out focussing on how grasslands are represented in farm scale models used in MACSUR. An invitation to participate in the survey was sent to all participants in MACSUR tasks L 1.3 and L 1.4. The survey questions are presented in Appendix 1. Six model representatives responded to the survey.

As a second step, a workshop was held in Braunschweig, Germany, 29-30 October 2015, with the aim to explore the state of art in characterizing grasslands in farm scale modelling and produce a work plan for future development within task, based on the results of the survey and subsequent discussions. The workshop was co-organized by L 1.3 and L 1.4. The workshop was attended by grassland as well as livestock specialists.

Critical input data required from grassland models to simulate ruminant productivity and GHG emissions at farm scale was identified and ranked in order of importance as dependent on the type of output data requested from the livestock model.

Result

Model survey on how grasslands are represented in farm scale models

The survey generated information on how grasslands are represented in six farm scale models represented in MACSUR 2, together with additional information on modelling approaches used. The complete survey with questions and responses is presented in Appendix 1. The most important information is summarized below.

Four of the farm-scale models had also been used in MACSUR 1, while two were introduced to MACSUR in MACUR 2. The survey revealed a wide span of models with respect to how grasslands are represented, as regards e.g. weather dependency, management factors accounted for, spatial and temporal resolution of simulations, and output variables.

Four of the farm-scale models had internal grassland model components, whereas two relied on external grassland models for generation of grassland data. In two of the farm-scale models, the grassland model component was classified as process-based, whereas in three of the models it was classified as empirical and in one model as semi-empirical.

The temporal resolution of the grassland model component varied from one day (three models) to two weeks (one model) or one month (two models), and the spatial resolution from field (four models; one also considering within field-variation in the form of patches in pastures) to farm scale (two models; one of which also works at catchment scale).

The sensitivity to environmental factors differed largely between the grassland model components. While the two process based models and the semi-empirical model accounted for the major environmental variables normally accounted for in process-based crop models, i.e. air temperature, precipitation, solar radiation, and CO_2 concentration, some of the other empirical models were only sensitive to water availability.

The models also differ largely with respect to management factors accounted for and how plants and animal components are linked and feedbacks between the two system components. All models accounts for fertilization (e.g. timing, amount and type of fertilizer) and harvesting management factors (e.g. timing of harvest, defoliation intensity). Several of the models also account for soil management (e.g. plowing, mulching) and grazing management (e.g. timing of grazing). Example of feedbacks that are included in some models are nutrient cycling pathways, and effects of treading on plants.

All grassland model components simulate DM yield and herbage N content (or crude protein (CP) content, which normally is calculated as 6.25 x N content). Many models also simulate P content, whereas only one simulate K content. About half of the model simulate the energy value of the herbage and/or the fibre content and fibre or DM digestibility, from which the energy value can be estimated, whereas the other half of the models does not.

The question if the grassland model component had been validated was answered by a “yes” for two models, of which one was an internal model and the other was the external model STICS. For two of the other four internal grassland models, the answer was “no”, whereas for the remaining two models the answer was that it had been validated “partly” (for a specific production system and region) or for “some components” (grass growth). Only the external model seems to have been validated for output variables reflecting the nutritive value of the herbage in ruminant feeding such as fibre content and digestibility.

Identification and prioritisation of input data required from grassland models in farm scale modelling of livestock production and GHG emissions

The most important information input data required from grassland models in order to simulate livestock production and GHG emission at farm scale was found to be, as agreed upon by the workshop participants, in priority order: 1) herbage DM yield or biomass per ha, 2) herbage crude protein content plus one fibre variable (eg. content of NDF fibres), 3) more fibre variables (content of additional fibre fractions and their digestibility) (Table 1). For simulation of product quality, information from grassland models on herbage fatty acid content and composition of may be required in addition to the variables described above.

For simulation of excreta production, an important system component in simulation of N leaching from farms or emission of GHG gasses associated with storage and application of manure on agricultural land, the three sets of variables mentioned first above are most important, while the content of P may be important in addition to these three in some situations, such as for simulations of P losses to the environment.

Table 1. Input required from grassland models in farm scale modelling of livestock production in priority order as according to the participants in the MACSUR Live M workshop on Task L 1.3, Braunschweig, Germany, 29-30 October 2015.

Output of livestock model	**Required input from grassland model by current models**	**Order of importance**
Product quantity (kg milk and meat per animal, farm or ha)	DM yield, crude protein content (from N content), fibre content (e.g. NDF, ADF), fiber digestibility (e.g. iNDF) and ash content of the DM yield (cut swards) or of the total DM aboveground (which all contribute to DM digestibility from which the energy value can be estimated)	1. DM yield (what taken from field) or total DM aboveground 2. Crude protein plus one fibre variable 3. More fibre variables plus ash content[1]
GHG emissions from livestock production systems (e.g. kg GHG per animal or ha)	Same as above	Same as above
Product quality (nutritive value of milk and meat)	Fatty acid content and composition of herbage	First three above, then this (4)
Excreta quantity and composition (P content)	P content of herbage (N content can be used as a proxy)	1, 2, 3, then this one (5)
Water in excreta	K and Na content of herbage (N content can be used as a proxy)	1,2,3, then this one (6)

[1]Depending on type of system and focus of study, information about plant species composition can also be important input from grassland models (multi-species sward modelling)

Depending on type of system and focus of study, information about the plant species composition of the herbage can also be important, as plant species may affect feed intake, milk and meat production in ways not fully explained by protein and fibre content.

The farm scale models in the survey do not simulate effects of feed quality on animal health. If functions for health aspects of feeding are to be implemented in farm scale models, information on the content of mycotoxins and heavy metals in the herbage or conserved forage may be required from grassland models.

Input data required by grassland models from livestock models

Grassland model components may also require input from livestock model components. All the surveyed grassland models account for effects of macro nutrient supply on grass growth. Thus, they require information about the amount and chemical composition of dung and urine deposited by grazers or collected from housed animals for application to grass fields as slurry or solid manure. The livestock component in several of the surveyed farm scale models provide information on one or more of the following variables: the content of N, organic matter, P and K in dung and urine excreted by animals (Appendix 1).

Additional information from livestock models that might be required for simulations of plant growth and nutrient dynamics in farm scale modelling of grazers, include grazing preferences (selection by grazers of sward components according to plant development stage and plant species), grazing offtake, duration and intensity of grazing, duration, intensity and spatial distribution of trampling, and spatial distribution of excreta. A few models include one or more of these aspects (Appendix 1).

Discussion

The six farm scale models surveyed showed similarities as well as differences. While some of models had internal grassland modules, others used external grassland models. Among the internal grassland modules, both process-based and empirical models were represented. The grassland models were also heterogeneous as regards temporal and spatial resolution. Thus, while the majority of models operated with daily time steps and field as the minimum area unit, there were also models with longer (up to month) time-steps and coarser or finer spatial resolution. These differences reflect differences in the purpose for which the farm scale models were built, differences in resource availability for model development including data availability, and differences in modelling preferences as regards e g. model complexity (e.g. Del Prado et al. 2013, Snow et al. 2013).

The workshop participants discussed the different requirements identified critical input data required by livestock models from grassland models as dependent of the type of process simulated by the livestock model. The type of input data required by a livestock model module from a grassland model module will vary depending on the type of farm scale model and focus of the modelling study. The different types of data required were ranked in order of importance as regards their influence on important livestock farming system outputs. For simulation of livestock product quantity (kg milk or meat), DM yield was ranked as the most important input variable from grassland models, followed by herbage CP content together with at least one variable describing the fibre content of the herbage. Additional variables describing the fibre content or its digestibility was ranked third together with herbage ash content. For simulation of GHG emissions, the list of variables and their ranking order was identical to that for simulation of biomass, i.e. DM yield ranked first, followed by CP and fibre characteristics. The CP, fibre content and fibre digestibility may in turn be used to estimate the energy value of the herbage, which may be important for composing feed ratios and calculating animal responses to feeding.

The list of prioritized input variables should be compared with the list of output provided by the investigated grassland model modules. A common feature of all the grassland models investigated is that they simulate DM yield and herbage N content. However, only half of the models simulate herbage fibre characteristics and/or energy value. Against this background, work on improving the ability of the current grassland models with respect to simulation of fibre/energy should be prioritized in farm-scale modelling aiming at quantifying livestock production and GHG emissions under different management regimes and climates. A recent review also points out that relatively few grassland models include functions for simulation of nutritive value, and that development in the capacity of models to simulate these aspects should be prioritized (Kipling et al, 2016b).

In MACSUR Live M, task L1.2 “Modelling grassland quality under climate change” is specifically aimed at knowledge exchange and development activities related to the modelling of the nutritive value of forages. A main activity is to review and compare different approaches for simulation of forage nutritive value (Virkajärvi et al., 2016; Virkajävi et al., 2017). The anticipated review paper will provide a valuable basis for extending current farm-scale models with new or improved functions for simulating important forage quality characteristics, such as fibre content and fibre digestibility. Another related, current activity in MACSUR is the recently initiated comparison of three grassland models with respect to simulation of nutritive value of timothy grass (Persson et al., 2017). This model comparison will provide further information on strength and weaknesses of different approaches, as basis for improvements concerning the representation of grasslands in farm scale models

Many farm scale models do not only simulate GHG emissions, which deals with N and C losses from farms, but also other losses such as run-off and leaching of macronutrients. For such models, input data from grassland models on macronutrient content is needed. While many of the investigated models simulate herbage P content, only a few simuate K or other macronutrients. Such information may be required to simulate excreta production by livestock, an important component of the nutrient cycle of the farm as well as a source of nutrient losses to the environment (Del Prado et al., 2013).

For modelling of livestock product quality such as the fatty acid composition of milk and meat, grassland models simulating the fatty acid composition of the herbage would be beneficial according to the workshop participants. However, none of the models in the current survey simulates fatty acids, and based on the review (Virkajärvi et al., 2017) fatty acids appears not to be prioritized in current grassland modelling.

Grassland models may also require information from livestock models, especially for simulation of systems involving grazers in which many plant-animal interactions occur. This includes information on grazing preferences, grazing offtake and amount and composition of excreta falling on the grassland. The surveyed models differed largely with respect to representation of grazing processes and feedbacks from the livestock to the grassland model component, reflecting the variety of systems studied and modelling focus. In a review of six farming-system models, including FASSET, Snow et al. (2014) discuss challenges in simulating animal-plant interactions in pastures, and strength and weaknesses of different modelling approaches represented by the models reviewed.

One important finding that should be highlighted is that two of the farm-scale models in the survey included internal grassland modules that, so far had only been partly validated against independent observations, and two of the models had not been validated at all. This contrasts to STICS (Jégo et al. 2013) and many other freestanding grassland model (e.g. Graux et al., 2011; Jing et al., 2013; Persson et al., 2014) which have been validated against independent field data. Model validation (also referred to as evaluation) provides information about the level of accuracy of the model in reproducing the system and is an essential part of any modelling study (Sinclair & Seligman, 2000).

A formal validation is rarely possible for farm-scale models since measures datasets are rarely available to evaluate even the most important aspects of the model (Del Prado et al., 2013). Model evaluation is still very important and necessary, and individual model components could be evaluated separately (Del Prado et al., 2013). For example, the grassland component of a farm scale model could be evaluated by comparing simulations and observations on yield and forage quality from plot-scale field trials, and by comparing its performance with that of other grassland models using the same observation data.

Next steps

This report could form the basis for a state-of-art paper on the representation of grasslands in farm-scale modelling identifying needs of further development, with especial focus on the priority areas identified here. However, before extending the report to a review paper, the potential overlaps with the state-of-art papers that are underway from L 1.2 and L 1.4, has to be discussed. In L.1.2, a review paper is underway on approaches for simulating nutritive value in grasslands (Virkajärvi et al, 2017), whereas in L1.4, a paper is underway on model linkage (Hutchings et al., in prep). The latter paper includes an overview of information flows between different farm components, such as fields and livestock, and how they are represented in farm-scale models represented in MACSUR.

When considering extending this report to a state-of-art paper, possible overlaps with previous reviews including aspects of plant-animal interactions in farm-scale models (eg. Del Prado et al., 2013; Snow et al., 2013) should also be considered and minimized. To increase the value of the potential review paper, it would probably be an advantage if a few more farm-scale models were included in the review paper than those surveyed here. An apparent candidate is the farm-scale model HOLOS-NOR which also is represented in MACSUR and has been used in several studies by MACSUR partners (eg. Özkan et al. 2016).

To make a new state-of art paper that stands out from those mentioned above, in spite of partly overlapping focus areas, one possibility could be to include a section on model validation. This section could address the need of validating the current farm-scale models against field observations, and suggest how such validation could be organized taking into account the specific challenges related to farm-scale modelling as discussed above.

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Appendix 1.

Overview of how grassland is represented in six farm-scale models

Model or model combination	SFARMOD	Mountain grasslands in the Western Carpathians	FASSET	MELODIE (whole farm) + STICS (grassland)	SIMSDAIRY	DairyWise
Institute	Cranfield University	Inst. of Technology and Life Sciences at Falenty; Malopolska Research Centre in Krakow	Aarhus University	INRA	Basque Centre For Climate Change	Wageningen UR Livestock Research
Contact (name)	Sandars, D.	Twardy, S.	Hutchings, N.	Graux, A.-I.	del Prado, A.	van Middelkoop, J.
Contact (e-mail)						
Was the model used in MACSUR1?	Yes: Live M Model Comparisons	No	Yes: L1.3	MELODIE: no STICS : yes		Yes
Internal or external grassland model component?	Internal	Internal	Internal	External	Internal	External
Process based or empirical grassland model component?	Empirical mostly but grass growth curves are a function over time and other variables	Empirical	Process based	Process based	Semi-empirical	Empirical
Temporal resolution of the grassland model component?	14 days	Month	Day	Day	Month	Day
Spatial resolution of the grassland model component?	Farm	Small mountain catchment and farms	Field and patch	Field	Farm represented by 4 types of homogeneous fields	Field
Drivers of the grassland model component? (weather variables, N, C02 etc.)	30-year mean annual rainfall	Weather, nutrient supply as effected by management	Temperature, rainfall, solar radiation, CO2, inputs of N and water	Weather, CO2, nutrient supply including from organic residues as affected by management	Temperature, rainfall, N supply as affected by management	N, soil type, groundwater table

Which management factors are accounted for in the model? (cutting date, N fertilizer level etc.) **(Soil factors are also included here although not asked for in the original survey)**	Soil: Soil type	Management: Fertilization, NPK fertilizer factors, organizational factors including date of mowing), technology related to the harvesting and preservation of yields. Soil: relief of terrain (slope exposure, altitude a.s.l.)		Management: soil tillage, sowing, fertilization, irrigation, harvesting, soil modification by different techniques: cutting, mulching, topping; thinning, pruning, trellis system etc.; initial (plant and soil) and permanent conditions. Soil: soil description	Management: fertilisation (type, rate, timing), manuring (type, rate, application method), grazing (time, type of animal), history of fields, sward age, ploughing, seeding date (for arable fields), use of inhibitors, plant traits, for testing new cultivars (e.g. N use efficiency), plant residue recycling (arable fields), irrigation, mixed clover vs non-legume swards. Soil: soil texture, soil drainage	Management: grassland use
Output variables from the grassland model component? (plant DM, C/N, herbage quality etc.)	Plant DM, N and P offtake as a function of yield produced	Plant DM, botanical composition, ratio of proteins to crude fibers and sugars in herbage, Utility Value Number	Plant DM, N, C, P, herbage height and digestibility		Plant DM, herbage N and C, plant residue N, and N fixation	Plant DM, herbage CP, N, P, K, energy and digestibility
How are grassland and animal processes linked in the model?	Grassland output is optimized for livestock needs and timing. Methods of manure application are optimised for all land including grassland	Direct links between grassland and animal processes are observed in mountain pastures. They can be parameterized by the weight gain per animal, milk production, meat, leather and wool quality	Pasture generates feed items that are part of feed choices of livestock	The animal grass intake removes grass biomass. Grassland is fertilized through animal returns. Grass growth is	Numerous feedback loops: Animal energy and protein requirements must be met and balanced through diet. Part of this diet is homegrown (pasture or other grazed or cut forages). Animal excretion contributes to soil fertility and thereby herbage growth and N composition. This affects excreted N	Animals graze (if user indicates that), manure and urine are deposited in grassland, treading losses are taken into account.

					both at grazing or housing. The model runs in an iterative way through several calculation cycles until it gets to a balance.	
Has the grassland model component been validated?	Yes	No. Modeling is in progress; supposed to be implemented during MACSUR 2.	No (for grazed situations)	Yes	Partly: only for productivity of intensive grassland systems in the UK	Some components
If yes, how was it validated?	Sense tested against representative data under diverse conditions			See Coucheney et al. (2015)	Using historical data of grasslands responses to N fertiliser inputs.	Grass growth was compared to an independent dataset (not yet published).
Please share any other important characteristics of the grassland model not covered above	Cutting dates form part of the optimisation and vary due to climate and location. We can model both permanent pasture and rotational grazing of any length including rotational transfers of fertility. We include all N loss pathways and N and P are balanced across Sfarmmod to zero sum over the rotations.	There is also important the natural potential of grasslands occurring in low-input conditions, without the fertilizer-based production of grass biomass. The non-production role of grasslands, which is important in mountain areas, requires to be emphasized as well.		It does not simulate grass-legume mixtures; Alfafa is currently the only available legume. The model allows long-term simulations and intercropping simulation.	It can test new plant and animal breeds, optimises N fertilisation based on different criteria, e.g. to maximise N herbage over N losses. Nutrient cycling and N losses (N2O, N2, NOx, NO3-leaching) are sensitive to soil, weather and management conditions (e.g soil-plant-animal interactions)	It is developed specifically for Dutch circumstances.