Dynamilk: a farming system model to explore the balance between forage and milk production in grassland based systems

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Abstract

Dairy systems based on grasslands are sensitive towards environmental variations (climatic events) and production constraints changes. Modeling approach enables to study the trade-offs between animal performances, herbage utilization and feed self-sufficiency. The use of a dynamic model enables to study several situations with contrasted strategies of biotechnical subsystems management in order to test different calving distributions, cattle and grasslands characteristics, or practices on pastures and meadows. A dynamic model at the farm-scale can also show the impacts of changes on the whole production systems over many years. In particular, such a dynamic model, called Dynamilk, has been created and implemented. Dynamilk is focused on relationships among dairy cattle, management and resources. This model is based on a bio-technical approach focused on grassland use by animals. Dynamilk is made up with three sub systems: ressources with grasslands and forages, dairy cattle and farmer's management. Validation of Dynamilk has been conducted by parts (grass growth sub model and dairy cattle sub model) and on the whole model's behavior.

Introduction

Dairy farming systems located in mountain areas undergoes geographical, soil and weather conditions constraints which minimize their competitiveness on domestic market. Maintaining cost production at a low level, developing and promoting quality products to diversify dairy production from average standard milk are both ways to compensate their lack of competitiveness (Poetsch, 2007; Bernuès et al., 2011). Subscribing to Protected Geographical Status (PGS) specifications enables to promote a quality production and the special link between farming practices, milk production and soil ("terroir") (Barjolle & Sylvander, 2003).In order to reinforce this link, cheese PGS specifications require that forage systems are based on grassland utilization through production constraints such as a better forage self-sufficiency, limits on feed concentrates. Maintaining cost production at a low level and abiding by the PGS specification demands can be achieved by optimizing the use of grasslands, forage and dairy cattle management. Nevertheless, these possible ways to improve forage and feed self-sufficiency should not be carried out at the expense of environment (grassland floristic diversity), milk quality and production, or impair the ability of dairy farms to cope with climatic events or production constraints changes. Indeed, dairy farming systems located in mountain areas are based on grasslands with a predominance of permanent pastures managed with low chemical inputs. Thus, these systems are very sensitive to environmental variations, climatic events and production constraints changes (Blanc et al., 2010).

In this context, our aim by using a model at farm-scale is to explore different dairy systems under geographical and production constraints with contrasting production strategies in order to understand what are the possible trade-offs between animal production, feed and forage self-sufficiency and sustainaible grasslands use. Contrasting production strategies rely on i) dynamic of dairy cattle needs depends on dairy cattle specifics such as breed characteristics, potential milk production and cattle management with calving distribution, calving age, culling and replacement rates; ii) herbage supply dynamics depend on grasslands characteristics through grass composition, pastures and meadows management and weather conditions.

This paper is focused on Dynamilk model development, its design and its functioning. One fundamental step of a model establishment process is its validation to check the adequacy of model behavior and predicted results with real data (Peck, 2004; Tedeschi, 2006). Therefore, validation results about the whole model and the sub-models are presented in this present paper.

Dynamilk: a model at farm level

Whole model description

Dynamilk is a dynamic model which mimics the farming system functioning of a grassland dairy farm. It is a deterministic model with a daily time step. Dynamilk is based on a bio-technical approach focused on grassland, feed and forage use by animals. The model is focused on relationships among farmer management and production system components such as dairy cattle, grasslands and feed resources. Dynamilk is designed to consider: i) dynamic animal needs and production determined by dairy cattle caracteristics and farmer management; ii) dynamic grassland production depending on botanical and agronomical caracteristics, forage management and weather conditions. The architecture of Dynamilk is described on *Figure 1*.
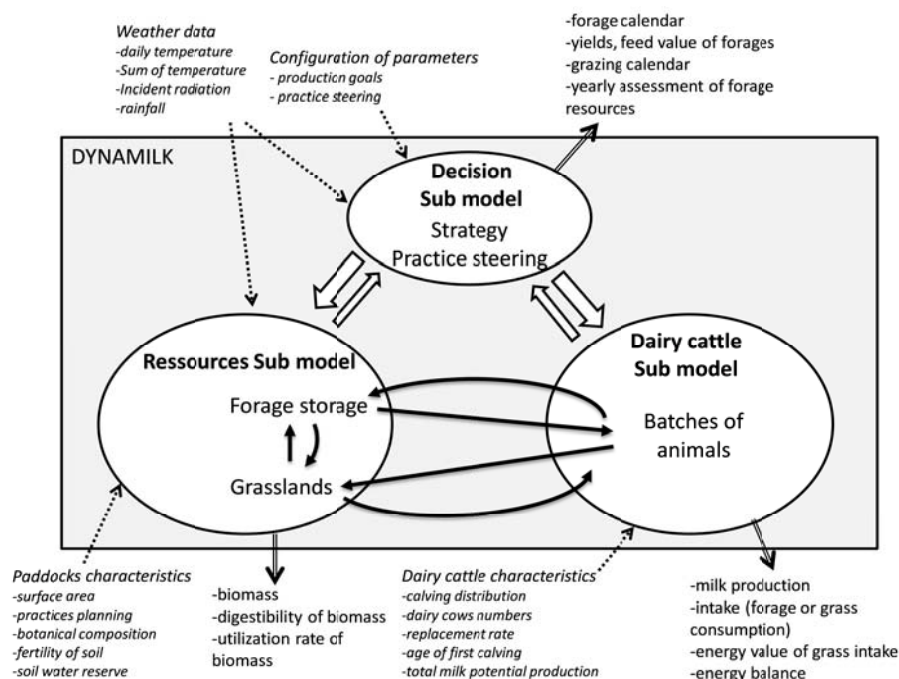
Figure 1: Dynamilk architecture with three interrelated sub models (meanings of different arrows: ⇨ represent information flows and ➡ biomass and matter flows; ┈➤ inputs and ➡ outputs of the model)

The production system components are monitored by the management system which represents farmer decisions. Management or decision sub-system is made up of farm management strategy with production goals and a set of rules to steer the bio-technical components towards the definied production goals.

The main inputs of Dynamilk are weather data, a description of the case to simulate with paddock and herd characteristics. Farm management strategy and parameters of management practices are defined in a simulation script called "scenario". These inputs enable to simulate either real dairy farms or artificial ones.

Dynamilk main output is milk yield in relation with herbage, forage and concentrate offers. As a matter of fact, energy supply by winter diet or pasture does not always match with animal requirements, defined by their physiological status (lactation, growth, pregnancy and potential milk production). The other outputs of Dynamilk are annual herbage yields and energy values of different kind of forages, annual biomass utilization rates of grasslands, daily biomass intakes, bodyscore and weight daily variations of dairy cows. Besides, Dynamilk enables to indicate farming system evolution over many years about forage self-sufficiency rates, milk production annual variations.

Decision sub model

The main practices implemented inside Dynamilk to rule the production system are forage system management with mowing practices, forage stores, winter diet, concentrate distribution and grazing management. Mowing practices are triggered by a set of rules depending on a minimum sward biomass, plant development stage, kind of planed cuts (silage or field-dried hay) and weather conditions. After forage harvested, they are stored and classified in relation to their kind and feed value. The different forages are allocated to the different feedlots according to their feed value. Daily concentrate supply depends on the defined total amount of concentrate per year. This amount is indexed to cow lactating status (beginning or end of lactation) and daily potential milk yield. Winter diets of all the batches can be elaborated knowing the allocated forages and concentrate supply per day. For instance, lactating cows are fed with concentrates and a defined mix of good quality first cut forage (grass silage) and regrowth hay. Pasture practices are ruled as simplified rotational grazing management (Hoden et al., 1991; Delaby et al., 2001). Thereby, batch moving from one paddock to another is triggered by a drop of 10% of the maximum milk yield achieved on the paddock. This rule is permitted by a calculation on grass height: in relation to the height at the entrance of the paddock, the objective height at which the batch must move out can be known (Delaby et al., 2001). The same calculation is applied to dry-cow and heifer batches. Turn-out and wintering are initiated by a minimum average temperature and a sward biomass on the paddocks, all these parameters are chosen and defined in the "scenario". For instance, turn-out is triggered by an average temperature calculated on 4 consecutive days above 4°C, if the conditions on sward biomass and height of paddocks are met. These conditions are a sward biomass above 1 t dry matter per ha (t DM.ha^{-1}) and a height above 8 cm at least.

Resources sub model description

The resources sub model is made up of field pattern with paddocks and forage storages. Each paddock is made up of sward model which predicts dynamics of biomass, structure and digestibility of herbage. This model was developped and evaluated by Jouven et al., (2006a; 2006b). This sward model is designed to respond to various defloliation regimes (cut or pasture),

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perform multiple-year simulations. Each paddock is discribed by its grassland community, defined by its composition in functional types of grasses (Cruz et al., 2002).

In relation to management sub system and farm's strategy, each paddock is described by practices seasonal planning: mowing or pasture as it is shown on *Figure 2*. This planning allows decision sub system to implement defined set of rules to trigger different practices.
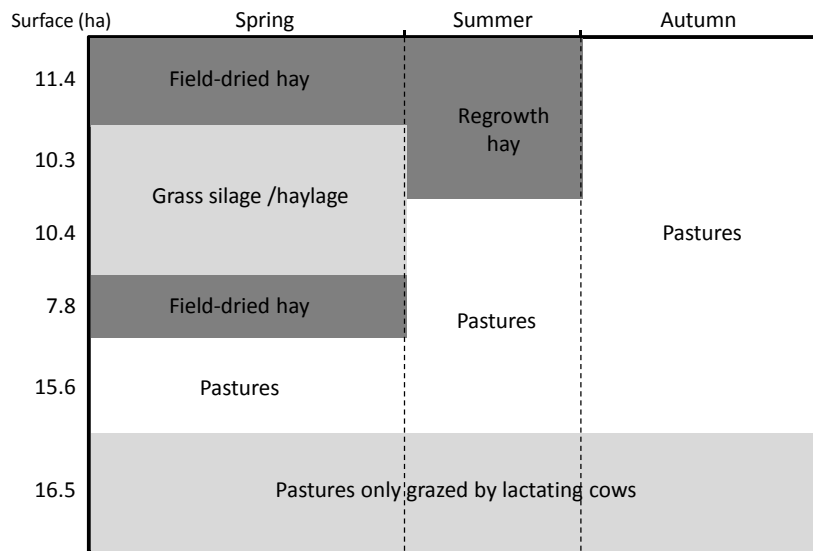
Figure 2 : A description of a field pattern and the different uses of the paddocks over the year (example of the case-study)

The other component of resources sub model is forage storage. There are three kinds of forages described by their quantity and their energy value: "good quality" first cuts which corresponds to silage and haylage, "poor quality" hay first cuts and regrowth second and third cuts.

Dairy cattle sub model description

Dairy cattle sub model is made up of two units: demographic structure model and, intake and production model. The demographic model enables to generate the demographic structure of the herd with five inputs parameters: numbers of dairy cows, replacement rate, age of the first calving, calving distribution all over the year, and total milk potential production. They enable to calculate each number of animals among their batch with a weekly time step. There are 5 batches: lactating dairy cows, dry cows, young heifers (0 to 1 year-old), middle-age heifers (1 to 2 year-old) and if the age of the first calving is 3 year-old, old heifers (2 to 3 year-old). Lactating dairy cow batch is subdivided into four groups to discriminate on the one side, primiparous and multiparous animals and on the other side, the beginning of lactation (1 to 12 weeks) and the second part of lactation (13 to 44 weeks). Furthermore, these simple input parameters allow establishing physiological states (week of lactation, pregnancy state, age, growth…) of each animal related to calving distribution. The data are combined to one "pilot animal" per batch or per group for lactating cow batch. Thereby, this pilot animal is representative of all the animals of a batch through a weighted mean of every variable according to animal physiological status.

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Intake and milk production model is designed to be focused on the sensitivity of milk production in relation to feed and herbage offer variation. Milk production is modeled as a result of the energy requirements defined by potential milk production, the variation of energy supply by diet and, the ability of dairy cows to mobilize or store body reserves (Coulon & Remond, 1991; Friggens & Newbold, 2007; Martin & Sauvant, 2010a; , 2010b). Intake and milk production model is built according to a mathematical description of major mechanisms of intake, body reserve mobilization and storage developed by INRA (Faverdin et al., 2011).

Results and discussion:

Among all the existing methods and steps to validate a model (Rykiel, 1996; Tedeschi, 2006), we only present results demonstrating that Dynamilk possesses an appropriate behavior and a satisfactory range of accuracy. Validation has been carried out by parts: firstly, bio-technical sub-models with grass growth and dairy cattle models and secondly, Dynamilk as a whole.

Validation of bio-technical sub-models

Grass growth model has been validated by a comparison against experimental data (Jouven et al., 2006b). Thanks to the Root Mean Square Deviation (RMSD), its prediction has been evaluated to 0.7 t DM.ha^{-1} for biomass production and 0.04 g.g-1 for biomass digestibility.

Dairy cattle sub-model has been validated by a comparison of its milk production prediction against experimental data. The means of predicted values are very close to the observed values and the RMSD is between 1.8 and 2.1 kg of milk for indoor trials and 1.4 kg of milk for grazing trial (Table 1). RMSD values represent 5.7 to 6.9 % of the observed milk production that is comparable to the order-of-magnitude of predictions of the models developed by Bryant et al.(2008) or Faverdin et al. (2011) for example.

Table 1: Statistical analysis to assess the accuracy of dairy cattle sub-model prediction (P: predicted data, O: observed data).

Values (kg per cow and day)	Indoor trial n°1	Indoor trial n°2	Grazing trial
RMSD	1.8	2.1	1.4
MSD	3.1	4.4	2.0
P	31.9	30.7	21.8
O	31.4	30.6	21.5

Validation of Dynamilk

Thereby, we compared Dynamilk predicted results against real data. We used a farming data case-study carried out by livestock research and extension institute "Institut de l'Elevage", (Reuillon, 2008). This case-study is typical of dairy farms based on permanent grasslands located in medium-altitude mountain area (Massif Central, France). The case-study is developed from monitoring of farm operation and business over several years; it is regularly updated. We based the comparison on 2010 updated version of case-study.

Thanks to this case-study data about forage system and dairy cattle characteristics, we define the input parameters of the dairy cattle, forage system and paddocks, and management sub system. In other ways, we recreate the farming system of the case-study in order to simulate it.

Description of field pattern, forage system management and dairy cattle parameters
The case-study farm is characterized by a usable agricultural area of 72 hectares (ha) with 29% devoted to grass silage or haylage and 27% to field-dried hay. 54% of these areas are afterwards mowed for regrowth hay during summer time. The remaining areas are dedicated to pastures with 23% of usable agricultural area for lactating cows and 21% to dry cows and heifers. This field pattern is the same than the one depicted on *Figure 2*.

We settled dairy cattle parameters with the dairy herd made up of 47 dairy cows with replacement heifers. The replacement rate is 31% of the dairy cow numbers and the average first calving age is 30 month-old, established to 3 year-old for Dynamilk. Dairy herd is characterized by a pure breed Prim' Holstein animals with 6600 liters per lactation of milk yield. Annual milk quota is 300 000 liters. Calving distribution is mainly spread from August to December with few calving all over the year. We set calving spreading out from August to February with a peak from September to late November. Winter diet consists in a mix of grass silage, field-dried hay and regrowth hay. Total amount of concentrates is valued to 210g per liter of milk, i.e. 1300 kg per animal and per year.

Comparison of predicted results against case-study data
We carried out two simulations over two time series: from 1993 to 1997 and from 2005 to 2010. These two periods have been chosen for being contrasted: time series from 1993 to 1997 does not show any particular climatic events and, at the opposite, time series from 2005 to 2010 includes heat waves and/or major water deficits like 2005, 2006 and 2009 years. These weather data come from a weather station located in Marcenat (1060 masl) in Massif Central (France).
Milk production

Monthly predicted milk yields are in accordance with the ones of the case-study, as it is shown on *Figure 3*. Average milk production of the case-study is 6600 kg per cow and year (Reuillon, 2011) compared to respectively 6663 and 6636 kg per cow and year for time series 1993-1997 and 2005-2010. Seasonality of milk production is not exactly identical to the case-study. It's mainly due to the slightly different calving distribution. Indeed, we defined calving spreading out from August to February whereas few calving happens all over the year in the case-study reality. This adaptation in order to set parameters for the simulation is due to dairy cattle sub-model building constraints. Thereby, predicted milk production during summer time is lower than reality since dry cow numbers are larger than expected over this period. Between the two simulated periods, there is almost no variation of milk production, except during the grazing period. Indeed, milk production is related to grass growth, depending on weather data.
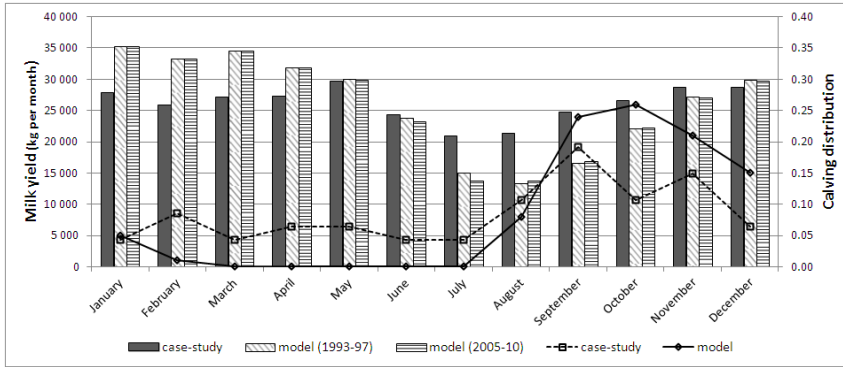
Figure 3 : Comparison on monthly milk yields between the case-study and predicted results by Dynamilk on two time series: 1993 to 1997 and 2005 to 2010 considering the two calving distributions (inputs)

Forage system and feeding management

We compared data concerning forage yields and values, forage system management, dairy cattle production. Table 2 shows average numbers carried out on the two studied time series. All the practices (cuts and grazing) on grasslands of 1995 are recorded on *Figure 4*, as an example.
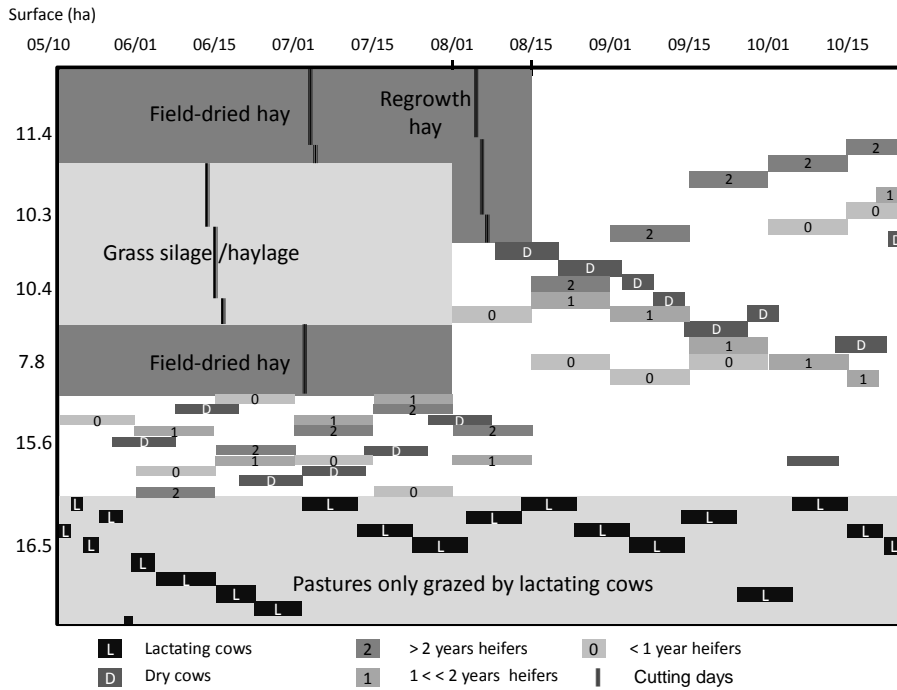
Figure 4: Example of forage and grazing calendar of the simulated field pattern (1995). This calendar was made from Dynamilk's results (black lines represent cuts; paddock occupied by the different batches of the dairy cattle are symbolized by a square and a symbol specific for every batch (letter or number)

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At a first sight, implemented rules to steer mowing process allow to perform cuts in right time. Nonetheless, regrowth hay harvests happened earlier than the case-study ones for 1993 – 1997. First cut yields of grass silage – haylage with respectively 3.8 and 3.7 t dry matter per ha (t DM.ha^{-1}) for 1993 - 1997 and 2005 - 2010 and yields of field-dried hay with 4.5 and 3.5 are comparable to the case-study data. On the period of 2005 to 2010, field-dried hay yields are lower than the reality (3.5 t DM.ha^{-1} against 3.6). Regrowth hay yields are lower than the case-study with 1.7 and 1.5 t DM.ha^{-1} against 2.5. This fact implies that the average stored amount and the assessment of forage balance at the turnout date on the period from 2005 to 2010 is lower than the case-study or the period from 1993 to 1997. At the opposite of 1993 to 1997 period, regrowth hay yields have not been offset by better yields of field-dried hay in this case. These differences of yields are due to the sensitivity of grass growth model to water deficits (Baumont et al., 2008) and 2005-2010 time period includes water deficits during spring or beginning of summer at harvesting moment.

Feed values of harvested forages are characterized by a same order-of-magnitude of feed values presented by the case study. Harvested forages on 1993 – 1997 have nearly the same values than case-study. The average values of first cut forages (grass silage and field-dried hay) on time period of 2005 – 2011 are slightly lower than the two others with 0.80 UFL (feed unit for lactation) against 0.82 and 0.69 against 0.72 or 0.73. On the contrary, average feed values of regrowth hay are better with 0.80 than case-study value (0.75). This value is close to the value (0.83) of regrowth hay on a permanent grassland in medium-altitude mountainous area such as Massif Central proposed by INRA Feed tables for ruminants (Baumont et al., 2007).

The case-study assesses total amount of consumed forages by the dairy cattle at 2.67 t dry matter per livestock unit (t DM.LU^{-1}). This estimate is close to the predicted amount by Dynamilk with respectively 2.69 and 2.62 t DM.LU^{-1}. On the time series 2005 – 2010, the average total stored amount is inferior to the average total amount of consumed forages. This can be explained by lower forage yields than the ones of 1993-1997 due to some dry years. This simulation indicates that this forage system can be sensitive to high water deficit and impair self-sufficiency rate. In fact, the average forage balance at turn-out is nearly positive (0.07 t DM.LU^{-1}) with two negative years (-0.44 t DM.LU^{-1}).

The case-study data does not include certain data on pasture management data such as daily grass intake or feed values of grass intake. This information is difficult to accurately obtain within a none-research context. Average feed values of grass intake are similar to table data developed by INRA in a rotational grazing system management considering concentrates and substitution rates (Delaby et al., 2001; Faverdin et al., 2007; Delagarde et al., 2011; Faverdin et al., 2011).
As it is shown on *Figure 4*, some paddocks are under grazed. Indeed, few paddocks are only grazed one time per pasture season, even paddocks devoted to lactating cows and, some grassland are not grazed after being mowed whereas they were available to be grazed. This fact indicates that there is an under-utilization of grazing resources. The grassland use could be optimized through a higher surface devoted to forage harvesting to improve the self-sufficiency rate and to cope with dry year, through an increase of stocking rate, or through a decrease of concentrates at grazing.

Table 2: Comparison of predicted results with Dynamilk (mean, minimum and maximum values between years) against case-study data on forage yields, forage system management and dairy cattle production

	Case-study	Dynamilk's results 1993 - 1997	Dynamilk's results 2005 - 2010
Harvesting dates (month/day)			
Grass silage - haylage	4/10 to 7/01	5/10 *(5/25–6/10)*	6/04 *(5/19–6/12)*
Field-dried hay	7/01 to 8/20	7/4 *(6/30–7/7)*	6/27 *(6/11–7/5)*
Regrowth hay	8/20 to 9/10	8/9 *(8/2–8/25)*	8/22 *(8/2–9/10)*
Yields (t DM.ha^{-1})			
Grass silage - haylage	3.6	3.8 *(3.6 – 4.4)*	3.7 *(3 – 4.4)*
Field-dried hay (first cut)	4	4.5 *(4.1 – 5)*	3.5 *(2.3 – 4.7)*
Regrowth hay (second cut)	2.5	1.7 *(1.4 – 2)*	1.5 *(0.7 – 2)*
Stored forages (t DM.LU^{1})			
Total stored amount	2.9	2.9 *(2.8 – 3.1)*	2.5 *(1.9 – 3.1)*
Forage balance at turnout	na[1]	0.35 (0.03 – 0.57)	0.07 (-0.44 – 0.62)
Feed values of forages and grass (UFL^{2})			
Grass silage - haylage	0.82	0.82 *(0.81 – 0.83)*	0.80 *(0.76 – 0.83)*
Field-dried hay	0.72	0.73 *(0.72 – 0.73)*	0.69 *(0.68 – 0.69)*
Regrowth hay	0.75	0.77 *(0.73 – 0.82)*	0.80 *(0.75 – 0.83)*
Ingested grass	na	0.84 *(0.83 – 0.86)*	0.83 *(0.78 – 0.86)*
Forages and grass intake			
Total amount (t DM.LU^{-1})	2.67	2.69 *(2.57 – 3.02)*	2.62 *(2.50 – 2.74)*
Winter diet intake (kg DM.d^{-1})	15	15.5 *(15.4 – 15.6)*	15.5 *(15.3 – 15.8)*
Grass intake at pasture (kg DM.d^{-1})	na	13.3 *(12.9 – 13.7)*	12.9 *(11.6 – 13.3)*

[1] na = none available; [2] : 1 UFL = 1700 kcal net energy for lactation

Conclusion

Dynamilk is a dynamic model which mimics the functioning of dairy farms based on grasslands located in mountain areas. Dynamilk has been validated by parts. The validation of the two biotechnical sub-models has shown that Dynamilk accurately simulates grass growth of permanent pastures and milk yields of dairy cows during indoor and grazing periods. Furthermore, the validation of the whole model by a comparison with a case-study data has displayed that Dynamilk possesses a right and satisfactory behavior and results, in terms of both forage system management (yields, feed values of harvested forages) and animal production (intake and milk production). Even if this validation test is carried out on one single situation, Dynamilk can be used to simulate grassland based dairy systems.

The original design and construction of Dynamilk enable to i) collect precise data about the evolution of different components of the studied farming system, especially the variation from a year to another; ii) use different time series with different weather data (real or artificial ones with repetition of climatic events) to assess the resilience of farming system to cope with climatic events; iii) test different contrasted production systems with a wide-ranging of possibilities on dairy cattle (performance and demographic characteristics), grasslands and forage system management, feeding strategies… For instance, Dynamilk will be afterwards used to investigate if a production system based on spring calving enable to lean towards a better self-sufficiency rate

than an autumn and winter calving system considering a better match between animal needs and biomass offer by grasslands at pasture.

Acknowledgments

References

Barjolle, D. & Sylvander, B. (2003). Facteurs de succès des produits d'origine certifiée dans les filières agro-alimentaires en Europe : marché, ressources et institutions. Inra Prod.Anim. 16(4): 289-293.

Baumont, R., Dulphy, J.-P., Sauvant, D., Meschy, F., Aufrère, J. & Peyraud, J.-L. (2007). Valeur alimentaire des fourrages et des matières premières: tables et prévision. In Alimentation des bovins, ovins et caprins - Besoins des animaux - Valeur des aliments. T. I. 2007, Quae**: 307.

Baumont, R., Jouven, M., Deux, N. & Farruggia, A. (2008). How can farms with beef cattle systems based on permanent pasture cope with extreme climatic years? Results of a study using the whole-farm simulator SEBIEN. In Empowerment of the rural actors: a renewal of farming systems perspectives: 8th European IFSA Symposium, Clermont-Ferrand, France, 6-10 July 2008**: 435-444.

Bernuès, A., Ruiz, R., Olaizola, A., Villalba, D. & Casasus, I. (2011). Sustainability of pasture-based livestock farming systems in the European Mediterranean context: Synergies and trade-offs. Livestock Science 139(139): 44-57.

Blanc, F., Dumont, B., Brunschwig, G., Bocquier, F. & Agabriel, J. (2010). Extensive ruminant farming systems highlight animal coping processes based on robustness, flexibility and plasticity. INRA Productions Animales 23(1): 65-80.

Bryant, J., Lopez-Villalobos, N., Holmes, C., Pryce, J., Rossi, J. & Macdonald, K. (2008). Development and evaluation of a pastoral simulation model that predicts dairy cattle performance based on animal genotype and environmental sensitivity information. Agricultural Systems 97: 13–25.

Coulon, J. B. & Remond, B. (1991). Variations in Milk Output and Milk Protein-Content in Response to the Level of Energy Supply to the Dairy-Cow - a Review. Livestock Production Science 29(1): 31-47.

Cruz, P., Duru, M., Therond, O., Theau, J. P., Ducourtieux, C., Jouany, C., Al Haj Khaled, R. & Ansquer, P. (2002). Une nouvelle approche pour caractériser les prairies naturelles et leur valeur d'usage. Fourrages(172): 335-354.

Delaby, L., Peyraud J.L. & P., F. (2001). Pâtur'IN: le pâturage das vaches laitières assistés par ordinateur. Fourrages 167: 385-398.

Delagarde, R., Faverdin, P., Baratte, C. & Peyraud, J. L. (2011). GrazeIn: a model of herbage intake and milk production for grazing dairy cows. 2. Prediction of intake under rotational and continuously stocked grazing management. Grass and Forage Science 66(1): 45-60.

Faverdin, P., Baratte, C., Delagarde, R. & Peyraud, J. L. (2011). GrazeIn: a model of herbage intake and milk production for grazing dairy cows. 1. Prediction of intake capacity, voluntary intake and milk production during lactation. Grass and Forage Science 66(1): 29-44.

Faverdin, P., Delagarde R., Delaby L. & Meschy F. (2007). Alimentation des vaches laitières. In Alimentation des bovins, ovins et caprins - Besoins des animaux - Valeur des aliments. t. I. 2007, Quae**: 307.

Friggens, N. C. & Newbold, J. R. (2007). Towards a biological basis for predicting nutrient partitioning: the dairy cow as an example. animal 1(01): 87-97.

Hoden, A., Peyraud, J. L., Muller, A., Delaby, L. & Faverdin, P. (1991). Simplified Rotational Grazing Management of Dairy-Cows - Effects of Rates of Stocking and Concentrate. Journal of Agricultural Science 116: 417-428.

Jouven, M., Carrere, P. & Baumont, R. (2006a). Model predicting dynamics of biomass, structure and digestibility of herbage in managed permanent pastures. 1. Model description. Grass and Forage Science 61(2): 112-124.

Jouven, M., Carrere, P. & Baumont, R. (2006b). Model predicting dynamics of biomass, structure and digestibility of herbage in managed permanent pastures. 2. Model evaluation. Grass and Forage Science 61(2): 125-133.

Martin, O. & Sauvant, D. (2010a). A teleonomic model describing performance (body, milk and intake) during growth and over repeated reproductive cycles throughout the lifespan of dairy cattle. 1. Trajectories of life function priorities and genetic scaling. animal 4(12): 2030-2047.

Martin, O. & Sauvant, D. (2010b). A teleonomic model describing performance (body, milk and intake) during growth and over repeated reproductive cycles throughout the lifespan of dairy cattle. 2. Voluntary intake and energy partitioning. animal 4(12): 2048-2056.

Peck, S. L. (2004). Simulation as experiment: a philosophical reassessment for biological modeling. Trends in Ecology & Evolution 19(10): 530-534.

Poetsch, E. M. (2007). Low inputs farming systems and livestock production – Grassland and dairy farming in Austria Low inputs Farming Systems: an opportunity to develop sustainable agriculture, JRC European Commission.

Reuillon, J. L. (2008). Références systèmes Bovins Lait des réseaux d'élevage d'Auvergne et Lozère. Clermont-Fd, Institut de l'Elevage.

Reuillon, J. L. (2011). REFERENTIEL 2011 des réseaux d'élevage Auvergne, Lozère, Aveyron - Conjoncture 2010. Clermont-Ferrand, Institut de l'Elevage.

Rykiel, E. J. J. (1996). Testing ecological models: the meaning of validation. Ecological Modelling 90(3): 229-244.

Tedeschi, L. O. (2006). Assessment of the adequacy of mathematical models. Agricultural Systems 89(2-3): 225-247.