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Development and evaluation of the pasture-based herd dynamic milk (PBHDM) model for dairy systems.

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PBHDM: Pasture-Based Herd Dynamic Milk
HDM: Herd Dynamic Milk
PostGH: Post grazing height, PreGH: Pre grazing height
UFL: unité fouragère lait, PDI: protéine digestible dans l'intestin, FV: Fill Value
LSR: Low Stocking Rate, MSR : Mean Stocking Rate, HSR : High Stocking Rate

Abstract

Modelling pasture-based systems is a challenge for modellers worldwide. However, models can play a vital role as grazing management tools and help the decision making process at farm level. The objective of this paper is to describe and evaluate the Pasture-Based Herd Dynamic Milk (**PBHDM**) model. The PBHDM model comprises the Herd Dynamic Milk (**HDM**) model and integrates it with a grazing management and a paddock sub-model. Animal intake at grazing is dependent on the animal characteristics but also on grass availability and quality. It also depends on the interactions between the animal and the grass during the defoliation process. Management of grass on farm can be regulated through different rules during the grazing season including the decision to cut some paddocks in the case of a grass surplus and to allocate supplementation in the case of a grass deficit. The PBHDM was evaluated by comparing model outputs with two grazing systems one in France and one in Ireland. For both farms the grazing season is longer than 7 months. Model outputs that were compared to the actual experimental data included milk production, pre- and post-grazing height and feed supplementation levels. These outputs were all compared on a weekly basis while paddock residence time and total grass harvested as conserved grass silage was evaluated over the grazing season as a whole. The model was capable of reproducing the two grazing systems with acceptable accuracy. It simulated the pre- and post-grazing height with a maximal difference between the actual and the simulated average height through the year of 0.4 cm. The model has a tendency to slightly over-estimate the milk production especially in autumn. However in general the model is relatively accurate with a root mean square error less than 20% for the simulated farms.

Keywords: Grazing management, modelling, dairy cow, grass intake, milk production

1. Introduction

As a result of the abolition of EU milk quotas in 2015, EU farmers will have options to expand their dairy farming businesses for the first time in a generation. However, making major changes in any dairy farm creates increased risk for the overall business. Modelling farm systems allows different stakeholders to evaluate options, for example the impact of farm expansion or a change in genetic potential of the herd without the completion of expensive experiments. Furthermore, a model can provide more precise information for a specific farm than a non-tailored global study due to the potential to parameterize the model for individual farm situations.

The optimum management of grazing dairy systems is characterised by making the right decisions in a timely fashion. Those decisions can be for example about moving the cattle from one paddock to another, harvesting paddocks when in surplus, feeding supplement when in deficit, etc. Being capable of simulating these potential decisions which could be made on a daily basis is a requirement for any model if it is going to reproduce grazing systems accurately. The model needs to be able to take into account the impact of the individual paddock on the intake of the animals and the subsequent consequences on the performance as well as being capable of evaluating targets for the farm. To permit an accurate representation of an existing dairy farm, the individual representation of each animal and paddock is important to permit the model to take into account the variability between animal and paddock. Individual based modelling permits the simulation of all of these parameters depending on the pertinent question.

The simulation of the impact of the defoliation process on intake is a necessity for a grazing model to predict the impact of the management rules (different pastures allowance and/or grazing residuals). Several grass intake models have been developed but they are not capable of taking into account every component of grazing. For example the GrazeIn (Delagarde et al., 2011) model is a static model of grazing for the dairy herd. It takes into account the herbage allowance, the daily time at pasture and the sward surface height (as described in (Delagarde et al., 2011). However, the model is not capable of simulating the decrease in grass height in a paddock over time and therefore the model is not capable of simulating the impact of post-grazing height (**postGH**). Furthermore the GrazeIn model does not simulate the grazing process as it is only able to model one paddock and not a whole grazing season across a farm with movement of the cattle from one paddock to another. An animal intake model developed by Baudracco et al (2010) and used in E-cow (Baudracco et al., 2012) and E-dairy (Baudracco et al., 2013), has been developed for the grazing animals but although the model is able to take into account the effect of herbage allowance it is not able to take into account the impact of grass height and the defoliation process on animal performance.

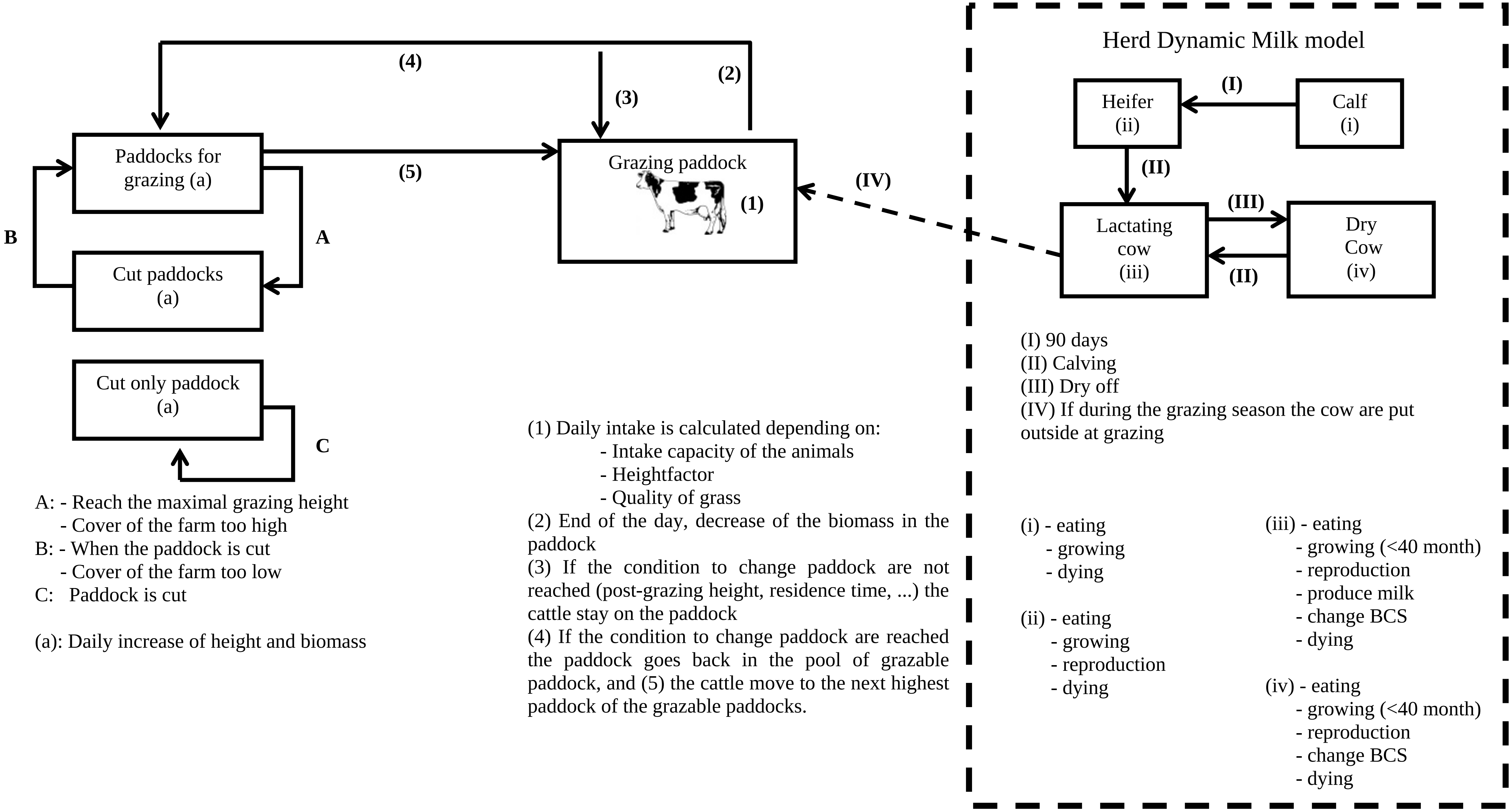
Several whole farm models are published in the literature but few exist that allow a full simulation of grazing systems at both individual animal and paddock level. The SEPATOU model (Cross et al., 2003) is a whole farm model for grazing systems which takes into account the interaction between the sward and the animals, both pasture and animal performance are simulated. The model takes into account the impact of stocking rate (**SR**), the daily access to a paddock and the profile of digestibility change as animals graze through the grass height profiles (i.e. the actual grass available to the animals). However, on the cow side, the model only predicts the milk production without any variation of body weight (**BW**) or body condition score (**BCS**) through lactation. Furthermore, no explicit grassland management system has been included (e.g. rules to move the animals from one paddock to another or to add supplementation to the diet due at an insufficient farm cover), which makes it impossible to recreate actual farms and systems. The DairyWise model (Schils et al., 2007) is a whole dairy farm model which describes technical, environmental and financial processes. However, although each paddock is represented independently in the model, the process of grazing is not simulated with precision and does not take into account the effect of herbage allowance or grass height on intake and animal performance.

The objective of the Pasture-Based Herd Dynamic Milk (**PBHDM**) model presented in this paper is to demonstrate a model capable of simulating management, taking into account the individual animal (through the Herd Dynamic Milk (**HDM**) model), the paddocks and their interaction considering the management policy applied throughout the grazing season. A key focus of the model is to be capable of taking into account the impact of grazing management and the subsequent consequence on postGH, simulating the effect on intake and ultimately performance. The key focus of this study is to describe and evaluate the PBHDM model.

2. Materials and Methods

The model described in this paper is an individual based dynamic model of a dairy farm. It is developed in the programming language C++. The model allows the simulation of animal intake, milk production, body condition and body condition change of animals, while grazing is simulated by individual animals interacting with individual paddocks on the farm. The length of the simulation is not fixed and can go from 1 month to theoretically infinity. PBHDM combines two sub models the HDM model and a paddock sub model. The HDM model has been described and evaluated by Ruelle et al. (under review). In the paddock sub model, each paddock is simulated individually allowing a precise description of grazing in terms of the progression of intake as well as simulating the interaction between pre- and postGH. Each paddock is described by its area and every day by its actual grass height and biomass. The paddock can be either grazed or cut depending on the management rules and the grass available on farm. The herd and paddock sub model interact through the individual grazing of each animal. A conceptual diagram of the model is provided in Figure 1.

Figure 1: Flow diagram representing the function of the Pasture-Based Herd Dynamic Milk model.



2.1 Animal component

2.1.1 Brief description of the HDM model

The HDM model has been previously fully described (Ruelle et al., under review). Briefly, the model allows differentiated management of different groups of animals (mainly through feeding). The groups included are calves (0 - 90days), three groups of heifers (90 days to 365 days, 12 to 24 months and over 24 months), the lactating cows and the dry cows. Each animal is simulated individually permitting a precise representation of each animal on the farm. At calving, the dam (heifer or cow) is transferred from the heifer or dry cow group to the lactating cow group and one or two calves are added to the calf groups depending on the prolificacy (adjusting for mortality). The heifers' growth and intake are modelled using the French model of Garcia et al. (2010) and Agabriel and Meschy (2010). Reproductive events are modelled using data from the literature for: conception rate (Buckley et al., 2003, Dillon et al., 2003, Inchaisri et al., 2010, McDougall et al., 2012), abortion and late embryonic death (Cutullic et al., 2011), calving ease (Lombard et al., 2007, Mee et al., 2011) and twinning events (Del Río et al., 2007). The mortality during the year and at calving is simulated based on Ettema and Santos (2004) and Miller et al. (2008). The model is dynamic in nature allowing it to react to changing conditions at farm level. For example, events happening at calving will have a subsequent impact on the fertility of the animal, or a reduction in feed supply in early lactation will lead to a reduction in BCS, which will have an impact later. Each individual cow's intake is simulated following the French intake and energy systems (Delagarde et al., 2011, Faverdin et al., 2011). The cow's dry matter intake is dependent on both animal and feedstuff characteristics. The simulation of the milk production per day is calculated based on an interaction between the energy intake by the cow, BCS change and the individual animal's theoretical milk yield. The theoretical milk yield is the milk which would be produced if the cow was in an energy balance equal to 0 without any change in body condition. If the energy intake allows a lower production than her theoretical potential, the cow will mobilize reserves (BCS loss), which will allow her to produce more milk than possible through the feed alone. If the energy intake allows a higher milk production than the cow's theoretical potential, part of this energy is used to increase the body reserve of the cow (BCS gain) and part will produce additional milk production. Each cow has a pool of BCS that can be mobilized during the lactation. This pool is dependent on the parity of the animal, her theoretical maximal milk production and her BCS at calving (Delaby et al., 2010). The utilisation of the pool during the lactation will depend on the feed intake and energy demand (the cow can't lose more than the total available pool which is calculated at calving). The model predicts the production of standard milk at 4.0% fat and 3.1% protein (Faverdin et al., 2010) (Equation 1). In this paper all milk production is expressed in kg of standard milk (Faverdin et al., 2010). The equation is used to transform actual milk data to standard milk for comparison purposes based on the following equation (Faverdin et al., 2010):

$$StandardMY = \frac{MY \times (0.44 + 0.0055 \times (FC - 40) + 0.0033 \times (PC - 31))}{0.44}. \quad (1)$$

With MY the milk yield (kg), FC the fat content of the milk (g/kg) and PC the protein content of the milk (g/kg).

2.1.2 Intake of the animal at grazing

Intake at grazing is calculated based on several equations which are previously published. The intake at grazing is based on the French system described in several publications (Faverdin et al., 2010, Delagarde et al., 2011, Faverdin et al., 2011). Basically, in the French system, the intake at grazing is calculated depending on the possible intake of the animal indoor corrected for herbage allowance and time at pasture. The indoor intake of the animal is dependent on the quality of the feed offered. The quality of the forage is characterised by its energy value ((**UFL** "unité fouragère lait"), protein (**PDI** "protéine digestible dans l'intestin) and FV (Fill Value). The FV of a forage reflects an inverse function of its ingestibility and is calculated by the ratio of intake of the reference forage to voluntary dry matter intake of the considered forage (Faverdin et al., 2011). The quality of the concentrate is determined by its UFL and PDI. The concentrate has no fixed FV, its FV is calculated dependent on the substitution rate between concentrate and forage which represents the metabolic regulation of intake (Faverdin et al., 2011).

In the PBHDM model, when a paddock is being grazed, grass intake is modelled taking into account the impact of the grass height (Delaby et al., 2001), thus grass height change as the paddock is being grazed. The Height-Factor component replaces the herbage allowance component in the GrazIn model (Delagarde et al., 2011) to permit the simulation of the impact of the defoliation process on the intake of the individual animal. The Height-Factor (equation 2) is dependent on the minimal postGH (minPGH), the actual height of the paddock and the preGH (Delaby et al., 2001).

$$HeightFactor = 1 - e^{-6 \times \frac{actGH - min\,PGH}{preGH - min\,PGH}} \qquad (2)$$

With:

actGH: the actual grass height in cm,

minPGH: the minimal possible postGH in cm,

preGH: the preGH in cm.

The minPGH (equation 3) is estimated depending on the preGH knowing that the higher the preGH, the more difficult it will be to graze to a low postGH (Wade, 1991, Delaby et al., 2001).

$$min\,PGH = 2 - 0.1 \times preGH + 0.015 \times preGH^2 \qquad (3)$$

The Height-Factor is used to simulate the change in grass FV as animals graze through the grass profile and results in an increase in FV with the decrease of the GH. This component of the model permits the simulation of the negative effect of the decrease of the GH on grass intake. To be able to accurately simulate the impact of the defoliation process within a 24 hour period, the intake of the animal and the actual GH are recalculated every two hours. During each calculation period, the intake of every cow is calculated and summed in order to obtain the global intake of the herd. The grass intake during that period is then subtracted from the biomass of the paddock leading to a new height for each 2 hour period. The Height-Factor is then recalculated leading to the intake of the animals for the next 2 hours. This Height-Factor allows the model to simulate the decrease of intake during the day as well as when a paddock is grazed over a number of days.

2.2 Grass

Paddocks are individually described by their area, biomass, and height. As proposed by Delagarde et al. (2000) the biomass per hectare (ha) of the paddock is directly related to the grass height of the paddock with different densities by layers. Four height profiles are defined with a density of 650 kg/DM per ha per cm between 0 to 2 cm, 500 kg/DM per ha per cm between 2 to 4 cm, 350 kg/DM per ha per cm between 4 and 6 cm and 250 kg/DM per ha per cm over 6 cm all of which can also be parameterised by the user. The model includes daily grass growth for each paddock per week of year. The model currently uses fixed daily grass growth rates generated each week from historical grass growth records carried out in Moorepark (52.17N; -8.27W). The grass height for every paddock is calculated daily depending on the corresponding daily grass growth. As proposed by Delaby and Peyraud (1998), when a paddock is being grazed, its grass growth estimate is divided by two to integrate the effect of the leaf area index diminishing with the defoliation process.

2.3 Management decision rules

The model allows significant flexibility around grazing management rules and thus facilitates simulation of a range of different grazing management systems and practices. The cattle management is simulated by the HDM model (Ruelle *et al*, under review), and includes information regarding the number of animals, the insemination period, the drying rules and the culling rules.

2.3.1 Feed allocation

The feed allocated to the cattle is separated into different subsections which can be described weekly. For each week the principal forage (which can be fed either *ad libitum* or as a fixed quantity) is defined. In the case of grazing, the main forage is grazed grass. For each additional feed fed, the quantity (fixed amount or *ad libitum*), type (forage and/or concentrate) and quality (weekly in terms of energy, protein and fill value) are required as inputs. Supplementation with either forage or concentrate can be included in the model based on a number of different criteria which include: compulsory supplementation all year round, calendar based supplementation as well as supplementation based on feed deficit situations. The model assumes that the cow will consume all the supplement offered.

2.3.2 Location and paddock change rules

The start of the grazing season can either be a fixed date for the herd or each animal is put out to graze as soon as they calve, for example. The end of the grazing season can either be at a fixed date or individually. The daily access time at grazing is set at 20 h by default (taking into account 4 hours for two milking's in each 24 hour periods), this time can be changed in the management parameters and if lower than 20 h, this will have an impact on the intake of the cattle as has been previously described by Delagarde et al (2011). Different rules to move the cattle from one paddock to another can be applied. Animals are moved when the target postGH has been reached if the height of the paddock at the end of the day or half way through the day is within 5% of target postGH (this value can be changed in the management rules). The cattle can be moved either after the milkings or half way through the day. The postGH can either be fixed or, as suggested by Delaby et al (2001) be dependent on the preGH fixed within the management rules (very severe, severe, normal or lax grazing equation 4 to 7):

$$\text{Lax: } obj\_postGH=6-0.1x\ preGH+0.015x\ preGH^2 \quad (4)$$

$$\text{Normal: } obj\_postGH=5-0.1x\ preGH+0.015x\ preGH^2 \quad (5)$$

$$\text{Severe: } obj\_postGH=4-0.1x\ preGH+0.015x\ preGH^2 \quad (6)$$

$$\text{Very severe: } obj\_postGH=3.5-0.1x\ preGH+0.015x\ preGH^2 \quad (7)$$

The model can also be parameterized to allocate a certain daily herbage allowance per cow. In that case paddocks will be divided in sub paddock to permit an allocation of the objective grass allowance and the cattle will stay in the sub paddock only for a day (20 hours of grazing). In each case the cattle are moved to the next highest paddock available for grazing.

2.3.3 Management of the grass area at paddock level

Two groups of paddocks are defined in the model: paddocks which are going to be grazed and those which will be cut for silage, hay or haylage. Paddocks can be moved from one group to another depending on rules applied in the model. A maximal grazing height is set in the management rules. If a paddock reaches this maximal height it will automatically be moved to the cut paddock group and won't be grazed during that rotation.

Harvesting the grass will happen as soon as there is one paddock reaching the maximal height for harvest (this value is parameterised in the management rules). At the same time, every paddock which has exceeded the maximal height for grazing will be also cut as is the general management policy at farm level. The post-cutting height is set at 5 cm by default. This value can be changed in the management rules. Every paddock which is cut at that time will go back in the grazing paddock groups unless the paddock is an only-cut paddock (defined in the management rules at the start of the simulation).

2.3.4 Management of the grass area at farm level

Within the management rules, the model is parameterised to evaluate the grass available on farm. As suggested in the Melodie model (Chardon et al., 2012), the grass available is defined as the grass that will be available for grazing within 10 days, including the grass growth. Specifically, paddocks included in this calculation are those which within 10 days will have a grass height higher than the lower objective minimal preGH and which are in the grazing group. The lower objective minimal preGH is set in the management rules and represents an imaginary lowest grass height bound below which the user does not wish the cattle to enter a paddock. The grass available will then be the sum of the biomass over 4 cm in those paddocks. The demand of the herd is calculated as an estimate of the 10 days intake requirement.

If there is too much grass on the farm, the model will decrease the supplementation if possible based on the management rules and/or will allocate paddocks to be directly cut without being grazed. If there is not enough grass on farm, the model will bring back paddocks allocated to cutting (if available and grass height is not too high) and/or will add supplementation in the diet (if permitted in the management rules). The supplementation allowed can be either forage and/or concentrate. The supplementation in terms of forage can be allocated by steps of 4 kg DM/animal, the supplementation in terms of concentrate can be allocated by steps of 1 kg DM/animal.

In the model, even if the requirement of the cattle and the farm cover is calculated daily, the management rules are applied for a full week once applied. Concentrate and silage are always supplemented for at least a week to better represent real life management, as a farmer would never feed silage for a single day.

2.4 Model outputs

As all parameters are calculated daily in the model a detailed set of outputs are available. Information about intakes, BCS, BW, milk production, fertility status are available daily for each cow. Information about GH, biomass, grazing events, preGH, postGH are available daily for each paddock. For this study the model has been parameterized to generate summary outputs for the year as well as total milk production for the farm, per ha and per cow, the total forage harvested and fed, the number of animals (pregnant or not) at the end of the year and the average pre- and postGH. Other outputs can be calculated as required.

2.5 Model Evaluation

The PBHDM model was evaluated by parameterising the model and comparing model outputs against two contrasting dairy farming systems operated in France and Ireland for two years (2009 and 2010 for France, 2010 and 2011 for Ireland).

2.5.1 Description of the French experiment

The first experiment was conducted at the INRA experimental farm of Le Pin-au-Haras in France (Normandy region - 48.448N, 0.098E). This experiment has previously been fully described by Cutullic et al. (2011) and Delaby et al. (2013). The aim of the experiment was to evaluate the adaptation ability of different types of cows across different dairy systems. Since 2006, two groups of dairy cows from the Holstein and Normande breeds were evaluated under two feeding strategies. The first strategy involved a scenario with low inputs and where the animal adapts to the local feed available (low feeding group) and the second scenario was where the feeding level was adapted to satisfy the animal requirements and to allow her to express the genetic potential (high feeding group). Both groups were composed of a total of 36 cows and each cow was assigned to one feeding group for the full period of the study. A compact calving period occurred over 3 months between January and March.

Cows were at grazing from the 1st of April. The end of the grazing season was around the 25th of November for both years and depended on the farm cover. In early lactation during the indoor feeding period (average of 90 days), animals of the high feeding group received an *ad libitum* total mixed ration with maize silage (55%), dehydrated alfalfa pellets (15%) and 30% of concentrate (average concentrate 1.1 UFL and 165 PDI per kg DM). During the same period animals of the low feeding group were fed *ad libitum* with a total mixed ration composed of grass silage (50%) and haylage (50%) without any concentrate.

At grazing and until the end of the lactation, the high feeding group received 4 kg of concentrate per cow per day (average of 1.11 UFL and 136g PDI), when there was a pasture deficit, usually around the first of July (depending on the farm cover), 5 kg of maize silage was added to the diet. The high feeding group utilised a grazing area of 12.3 ha in 6 paddocks; the low feeding group utilised a grazing area of 21.1 ha in 7 paddocks (fed with grass only). The simplified rotational grazing system described by Hoden et al (1991) and characterised by a long residency period in a paddock is applied in this experimental farm (6 to 12 days according the biomass per ha and the paddock area). When cows were housed after the autumn period, the grazed grass was replaced by grass silage. During the grazing period, for both feeding groups, grass silage could be added to the diet in case of a grass deficit on farm. The milk yield was recorded every day; the milk composition (fat and protein content) was evaluated for 6 milkings every week. The BW of each cow was measured weekly and the BCS was estimated monthly. The biomass and grass height of the paddock were measured before and after each grazing event by cutting and using a plate meter(Delaby and Peyraud, 1998).

2.5.2 Description of the Irish experiment

The second experiment was conducted at the Curtins farm (52.17N; -8.27W) of the Animal and Grassland Research and Innovation Centre, Teagasc, Moorepark, in Ireland. This experiment has been fully described in McCarthy et al. (2013). The aim of the experiment was to determine the impact of different stocking rates (**SR**) and calving dates on key physical, biological and economic performance. In each year, 6 treatments were evaluated, 3 different SR (**HSR**: 3.28 cow/ha, **MR2**: 2.91 cow/ha and **LSR**: 2.51 cow/ha) and two calving dates (12 February and 25 February). For the model evaluation the groups of the HSR and the LSR have been simulated for both calving dates. Each group was composed of 46 cows and 18 paddocks with a total area of 18.3 ha and 14.0 ha for the low and high SR's, respectively. Once assigned to one SR each cow remained in that group for the whole study. The breeding season was conducted between April and July leading to an average calving date of mid-February.

The grazing season ran from calving to the 20th of November. During periods of grass deficit on the farm, concentrate was added (maximum of 3 kg) to the diet with additional grass silage added if the feed deficit was larger than 3kg. Grass growth was evaluated by visual assessment following the method of O'Donovan et al. (2002), the biomass and grass height of the paddock were measured before and after each grazing event by cutting as well as with the rising plate matter (Jenquip, Fielding, New Zealand). For the remaining cows still lactating after the grazing season, the indoor feed comprised of grass silage accompanied by 3.5 kg of concentrate (quality of 1.09 UFL and 103 PDI).

For each farm, the initialization of the simulation was set based on the state of the farm on the 1st of January for both years. The main model inputs on January 1st were:

- The description of each animal in terms of BCS, BW, day in lactation (set as 0 when cows were not lactating), day in gestation and age;
- The description of each paddock in terms of area and biomass.

The information regarding the grass growth and quality are deterministic and based on measured data. For each farm and for each year, an average value of the grass growth and the quality of grass per week of the specific year and farm has been used to permit a more precise simulation. The information about compulsory forage and concentrate supplementation has also been entered on a weekly basis. Management rules in terms of drying off cows, insemination period, supplementation and feed allocation are described in the inputs. For the Irish farm the decision to move from one paddock to another is dependent on an objective postGH set up in the management rules of the experiment (3.75 cm for the HSR for both years; 4.75 cm for the LSR in 2009, 4.25 cm for the LSR in 2010). For the French farm, the grazing severity has been defined as normal (Equation 5).

2.5.3 Model evaluation

The model has been evaluated at different levels linked to the grazing season:

- the milk yield per ha (which corresponds to the milk produced during the grazing period only),
- the weekly milk yield per cow during the grazing season,
- the average silage and concentrate fed per cow,
- the quantity of grass harvested during the grazing season as grass silage,
- the average pre- and postGH,
- the average residence time in each paddock.

The model has been compared to the actual data for each farmlet.

To evaluate the accuracy of the model on a weekly basis the Root Mean Square Error (**RMSE**) and the Relative Prediction Error (**RPE**) were used.

The RMSE is calculated as (Bibby and Toutenburg, 1977):

$$RMSE = \sqrt{\frac{1}{n}\sum(A-P)^2} \quad (8)$$

with *A* the actual data and *P* the corresponding predicted data.

The RMSE provides information on the accuracy of the simulation by comparing term by term the actual and predicted data. The lower is the RMSE the more accurate, the simulation.

The RPE is calculated as (Fuentes-Pila et al., 1996):

$$RPE = \left(\frac{RMSE}{Am}\right) \times 100 \qquad (9)$$

with *Am* the average value of the actual data.

The RPE is an expression of the RMSE as a percentage of the actual data. According to Fuentes-Pila et al. (1996), a RPE lower than 10% indicates a satisfactory prediction, between 10% and 20% relatively acceptable prediction, and an RPE greater than 20% suggest a poor model prediction.

3. Results

3.1 Model comparison using French data

The results of the comparison between model output and experimental are summarised in Tables 1 and 2.

3.1.1 Milk production

The average experimental milk production per ha by the high feeding group was 15,087 kg while the model simulated milk production of 16,029 kg leading to a difference of 6.2% (Table 1). The average experimental milk production per ha by the low feeding group was 7,010 kg while the model simulated milk production of 7,789 kg leading to a difference of 11.1%. Therefore the model simulated a milk production difference of 8,240 kg of milk per ha between feeding levels while the experimental farm difference was 8,777 kg per ha.

On a weekly basis the model was acceptable with a RPE of consistency less than 16% across year and season (Table 2). The model accuracy for the high and low feeding group in 2009 had an RPE of 8.0% and 13.7%, with the corresponding figures for 2010 of 10.8% and 12.0%.

3.1.2 Pre- and postGH

In terms of the average pre- and postGH, in the experiment, the average preGH and postGH was respectively 9.3 cm and 5.1 cm for the low feeding group. The simulation had a corresponding preGH and postGH of 9.3 cm and 5.0. For the high feeding group, the experiment had an average preGH of 9.8 cm and an average postGH of 5.3cm compare to 9.1 cm and 5.1 cm in the simulation.

3.1.3 Residence time

In the experiment, the residence time in paddocks was on average 9.2 days for the high feeding group compared to 9.4 days in the simulation. The low feeding group had an average residence time of 8.1 days which was obtained from the model and the experimental data.

Table 1: Comparision of the actual (A) and simulated (S) result on the French farm during the grazing season.

		2009				2010			
		A	S	A-S	%diff*	A	S	A-S	%diff*
Low Feeding	silage distributed per cow (kg DM)	692	520	172	24.86	891	926	-35	-3.93
	MYper ha (kg)	6794	7270	-476	-7.01	7226	8303	-1077	-14.90
	grass harvested per ha (kg DM)	3246	4114	-868	-26.75	2633	2800	-167	-6.36
	average preGH (cm)	5.3	5.1	0.2	3.77	4.9	4.8	0.1	2.04
	average postGH (cm)	10	9.8	0.2	2.00	8.6	8.7	-0.1	-1.16
	average residence time (days)	8.1	8.6	-0.5	-6.17	8	7.5	0.5	6.25
High Feeding	silage distributed per cow (kg DM)	1141	1058	83	7.26	1088	1455	-367	-33.71
	MYper ha (kg)	14988	15314	-326	-2.17	15187	16744	-1557	-10.25
	grass harvested per ha (kg DM)	2181	2526	-345	-15.80	1534	1302	232	15.10
	Average pre-GH (cm)	5.5	5.1	0.4	7.27	5.1	5	0.1	1.96
	average postGH (cm)	10	9.9	0.1	1.00	9.5	9.2	0.3	3.16
	average residence time (days)	9.4	9.6	-0.2	-2.13	8.9	9.1	-0.2	-2.25

*percentage of difference: (A-S)/A*100

Table 2: comparison of the average weekly milk production (kg) per cow during the grazing season in the French farm

		Actual (kg)	Simulated (kg)	RMSE (kg)	RPE (%)	Actual (kg)	Simulated (kg)	RMSE (kg)	RPE (%)
		2009				2010			
Low Feeding	all season	17.0	18.3	2.3	13.7	19.7	21.2	2.4	12.0
	summer	19.8	21.3	2.5	12.9	21.5	24.0	3.1	14.3
	autumn	13.9	15.2	2.1	15.3	17.8	18.2	1.2	6.4
High Feeding	all season	22.5	22.6	1.8	8.0	22.4	24.4	2.4	10.8
	summer	25.6	25.6	2.2	8.4	25.4	27.3	2.5	8.9
	autumn	19.2	19.4	1.2	6.2	19.1	21.2	2.2	11.5

3.2 Model comparison using the Irish experimental data

The results of the comparison between model output and experiment are summarised in Tables 3 and 4.

3.2.1 Milk production

In the experiment, the LSR produced a total of 14,985 kg milk per ha while the model simulated a milk production of 15,758 kg leading to a difference of 5.3%. The HSR produced 18,133 kg of milk per ha in the experiment compared to 18,715 kg of milk per ha in the simulation leading to a difference of 3.2% (Table 3). The difference in production per ha between the HSR and LSR was on average 3,148 kg of milk in the experiment compared to 2,957 kg in the model.

On a weekly basis (Table 4) the model is relatively accurate with a RPE over the year of 11.7% and 10.2% for the LSR in 2010 and 2011, respectively and a RPE of 13.7% and 11.7% for the HSR in 2010 and 2011, respectively. All seasonal RPE values were less than 15% except for the HSR in autumn 2010 (19%). In general RPE values tended to be higher in the autumn with a constant overestimation of the weekly milk production per cow.

3.2.2 Pre- and post-grazing height

For the LSR, the preGH and postGH was on average at 8.2 cm and 4.2 cm for both the experiment and the simulation. For the HSR, the preGH was on average 8.4cm in the experiment and 8.7 cm in the simulation while the postGH was on average 3.4 cm for both the experiment and the simulation.

Table 3: Comparision of the actual (A) and simulated (S) result on the Irish farm during the grazing season for the low SR (2.51 cow/ha) and the high SR (2.51 cow/ha).

		A	S	A-S	% diff*	A	S	A-S	% diff*
Low SR	silage distributed per cow (kg DM)	104	156	-52	-50.31	156	107	49	31.45
	concentrate distributed per cow (kg DM)	603	507	96	15.89	275	273	2	0.61
	MYper ha (kg)	15029	16625	-1596	-10.62	14942	14891	52	0.35
	grass harvested per ha (kg DM)	6644	5131	1513	22.77	5654	6217	-563	-9.96
	average preGH (cm)	8.1	8.0	0.1	0.84	8.3	8.3	0.0	-0.45
	average postGH (cm)	4.4	4.4	0.0	-0.90	4.0	4.0	0.0	-0.47
	average residence time (days)	1.9	1.7	0.2	10.53	2.1	2.0	0.1	3.12
High SR	silage distributed per cow (kg DM)	149	91	58	38.90	296	59	237	80.02
	concentrate distributed per cow (kg DM)	578	520	58	10.08	250	278	-28	-11.12
	MYper ha (kg)	18141	19450	-1309	-7.22	18126	17979	147	0.81
	grass harvested per ha (kg DM)	5775	2758	3017	52.24	5871	5000	871.2	14.84
	average preGH (cm)	7.9	8.3	-0.4	-4.91	8.9	9.0	-0.1	-1.51
	average postGH (cm)	3.4	3.5	-0.1	-2.87	3.4	3.3	0.0	1.45
	average residence time (days)	1.9	1.9	0	0.00	2.0	2.3	-0.3	-15.00

*percentage of difference: (A-S)/A*100

Table 4: comparison of the average weekly milk production (kg) per cow during the grazing season in the Irish for the low SR (2.51 cow/ha) and the high SR (2.51 cow/ha)

		Actual (kg)	Simulated (kg)	RMSE (kg)	RPE (%)	Actual (kg)	Simulated (kg)	RMSE (kg)	RPE (%)
		2010				2011			
Low SR	all season	21.6	23.2	2.6	11.7	21.5	22.2	2.2	10.2
	spring	22.9	25.8	3.2	14.0	24.2	24.8	1.5	6.2
	summer	24.6	26.5	2.9	11.9	24.9	25.3	1.7	6.7
	autumn	19.4	20.4	1.7	8.9	19.1	19.5	2.7	14.3
High SR	all season	20.6	22.2	2.9	13.7	20.0	21.3	2.4	11.8
	spring	23.1	25.0	2.4	10.6	23.7	24.1	2.5	10.4
	summer	23.4	24.6	2.9	12.3	23.2	24.1	2.0	8.7
	autumn	17.6	20.1	3.3	18.6	17.1	18.5	2.3	13.7

3.2.3 Residence time

In the experiment, the average residence time for the LSR was 2 days compared to 1.9 days for the model. The HSR has an average residence time of 2 days in the experiment and 2.1 days in the simulation.

4. Discussion

4.1 Modelling choices

In order to be able to simulate different management and grazing practices and to take into account the impact of the pre- and postGH, the model must be able to describe the defoliation process as the animal grazes through the sward. In this model this is simulated through the inclusion of a Grass-Height factor. The addition of this factor permits the simulation of the impact on the grass intake and animal performance as a result of a decrease of the postGH all simulated by the model representing each animal and paddock individually. The inclusion of the agent based choices allows the user to accurately represent the effect of different management practices associated with the grazing process.

4.2 Evaluation of the model

Whole farm models are often very complex to evaluate and a comparison against actual experimentation is often difficult. Consequently, the evaluation can sometimes only be completed by evaluating the model outputs through a panel of experts (Cross et al., 2003). Statistical analyses are used when the model outputs can be compared with actual experimental outputs. However, for whole farm models the ability of the model to respond in a sensible manner to different scenarios is often the most important factor in the model evaluation.

The model described in this paper is capable of simulating two completely different grazing systems; a French grazing system with a paddock residence time of approximately 9 days in each rotation and the Irish grazing system with a shorter residence time, daily grass allocations and ultimately smaller paddocks. For the Irish experiment the model has been capable of representing the impact of SR and postGH on animal performance. Indeed, the model predicted a higher milk production per ha for the HSR (2,957 kg milk more per ha), but was also capable of simulating the effect of stocking rate on sward residuals and ultimately the effect of residual on milk yield per cow and per ha. This is in accordance with the results of McCarthy et al. (2013) which showed that an increase in SR will result in a decrease in the milk production per cow but an increase in the milk production per ha. The model showed an acceptable prediction of the requirement for and the effect of concentrate supplementation throughout the year, however it had a tendency to underestimate the silage supplementation requirements.

The model has been relatively accurate in predicting the pre- and postGH of the Irish experiment with a maximum difference between the actual and simulated data of 0.4 cm. This ability to accurately simulate the postGH and its impact on performance is extremely important and complex. It allows the interaction between stocking rate, animal performance and farm performance to be simulated accurately. Within the French simulation, the model has been capable of taking into account the impact of the different feeding levels. However it had a tendency to overestimate the milk production. It has been well able to simulate the pre- and postGH (maximal difference of 0.4 cm) and the average residence time in the paddock (maximal difference of 0.5 days).

On the weekly comparison for both studies the model showed an acceptable prediction (Fuentes-Pila et al., 1996) with all RPE values lower than 20% (Table 2 and 4).The consequence of different feeding system was demonstrated by the model. Using the Irish simulations the LSR group of cows produced on average 0.92 kg more milk per cow per day than the cows of the HSR. Using the French simulation, the cows in the high feeding group produced on average 3.73 kg more milk per day. For the Irish simulation the higher RMSEs are during the autumn time when the largest amounts of supplements were fed. Simulating on a weekly time interval creates a situation where timing of model events may not fully concord (deviation of a few days) with the actual experimental conditions. Examples include calving date differences, timing of supplementation and paddock date changes in the French simulation. Those differences may suggest that the model is less accurate than in reality.

Comparing the accuracy of different whole farm models is never easy as generally studies are never developed specifically to evaluate a model. Whole farm models which are simulating grazing are not always evaluated against actual experiments (Cross et al., 2003, Chardon et al., 2012) and the evaluation of the accuracy in terms of pre- and postGH or pre- and post-grazing biomass is absent. Furthermore models are not developed with the same purpose, leading to different variables being evaluated for each model. For example, the whole farm model (Beukes et al., 2008) was evaluated on its accuracy in predicting milk solids output and pasture production. Their model showed a 31% difference between the predicted and actual milk solids production. It was however accurate in terms of pasture production with a difference of 14% in pasture cover and 11% in pasture production. The E-dairy model (Baudracco et al., 2013) had an average difference of 4% of the milk production and 6% for the milk solids between the observed and simulated data over 2 data sets of 2 and 3 years. However, no information about the accuracy in terms of grazing management is available. McCall et al. (1999) compared the output of a model with the actual data of 9 different farmlets with the model parameterized to optimize the milk production per ha. On average the difference between the simulation and the observed data was 3% for the fat corrected milk. But once again the model only gives information on the livestock evaluation and not on the grazing management.

4.2 Future use of the PBHDM model

There are two main types of models developed in agronomy; models which are used for research (Chardon et al., 2012) and models which are used as decision support tools (Donnelly et al., 1997). The PBHDM model was developed to be both useful at a research level as well as the foundation for a future decision support tool. Most models are designed to be used in the country for which they were developed and are built in order to take into account the main factors of variation which are important for systems in that country. One of the main goals in developing the PBHDM model is to have a model able to reproduce an Irish pasture-based dairy system but also to create a management model which is flexible and can respond to different management practices in a sensible manner. The novelty of this model is to be able to take into account the management rules at the scale of the individual animal, individual paddock and at the farm level permitting significantly robust simulations as well as being able to represent the defoliation process. The ability of the PBHDM model to take into account the impact of pre- and postGH and the stocking rate on the milk production performance is important for the accurate simulation of pasture-based systems. Furthermore the ability of the model to account for a reduction in intake through the incorporation of the defoliation process gives the model the ability to simulate various grazing systems from rotational grazing to set stocking as well as different management practices within rotational grazing systems.

The model, when implemented as a decision support tool, will be used to support the decision making process regarding SR, preGH, postGH and concentrate supplementation. The ability of the model to accurately simulate these different impacts will be important to help farmers' decision making processes. For example, the PBHDM will allow dairy farmers to make informed decisions when combined with price information around the expected economic returns for various concentrate feeding strategies at farm level. The development of a grass growth model is on-going in Moorepark; as soon as it is completed the grass growth model will be merged with the PBHDM model to permit simulations across wider geographical areas. Long term management strategies can already be devised at research level through combining the PBHDM with the MDSM (Shalloo et al., 2004) thus allowing economic appraisals of various management strategies to be developed. For example, the agronomic and economic impact of the supplementation of different amounts of concentrate at different SR's can be studied, to determine the optimum systems under various conditions.

5. Conclusion

The PBHDM model is a dynamic model of a dairy farm developed in C++ capable of simulating the impact of different on-farm management practices on animal and paddock related characteristics. Individual animal and individual paddocks are described on a daily basis. Management practices are applied at both the individual animal and the paddock level. The decision support functions of the model have been developed to simulate various grazing systems with flexibility to incorporate a wide range of management rules. Model evaluation indicates a relatively high level of accuracy in the simulation of the main components of grazing such as the pre- and postGH or the grazing severity and their impact on the performance of the herd.

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