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Prediction of herbage dry matter intake for dairy cows grazing ryegrass-based pastures

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ABSTRACT

A model that combines theoretical and empirical equations was developed to predict daily dry matter intake (DMI) for Holstein-Friesian (HF) cows grazing ryegrass-based swards and offered differing levels of concentrate supplementation. An upper limit to potential herbage dry matter (DM) intake at grazing was set, which is the lower of three limits set by either physical (rumen fill), metabolic (energy demand) or grazing restrictions. Potential herbage DMI at grazing and the herbage allowance were then used to predict herbage DMI, of cows fed only pasture, using an empirical algorithm. If supplements are fed, substitution rate was predicted to calculate actual herbage DMI. An independent dataset, with individual herbage DMI measurements (n = 1,147) of three strains of lactating HF cows, was used to validate the model. Data within strains were averaged for every month of lactation, allowing 27 data points for validation. The fitness of the model was satisfactory, with a relative prediction error (RPE) of 0.083 and a concordance correlation coefficient (CCC) of 0.74. Herbage DMI was simulated for HF cows of different genotypes fed different levels of concentrate supplementation at different herbage allowances. The model successfully predicted herbage DMI of grazing cows under different combinations of nutritional, physiological and genetic variables.

Keywords: prediction**;** herbage intake; grazing; dairy cow; ryegrass.

INTRODUCTION

Livestock production is highly correlated with dry matter intake (DMI). In grassland grazing systems, low and variable herbage intake has been reported as a strong constraint of milk production in high genetic merit dairy cows (Boudon *et al.*, 2009). Accurate prediction of herbage dry matter (DM) intake can improve herbage allocation and herbage intake in grazing dairy systems (Woodward *et al.*, 2001).

Different approaches have been used to predict herbage intake of grazing cattle. Among them, mechanistic and empirical models have been developed, focusing on ingestive behaviour (Woodward *et al.*, 2008), rumen digestion (Chilibroste *et al.*, 1997), sward characteristics (Heard *et al.*, 2004), animal characteristics (Caird & Holmes, 1986) or animal internal state (Gregorini *et al.,* 2009).

The set of inputs required by a model to predict herbage DMI could be complex, because of the characteristics of swards and animals, and of the biological processes involved in food selection, ingestion and digestion. Researchers are challenged by the need to develop models that account for an increased amount of information while maintaining simplicity. An easy-to-obtain set of inputs will increase the practical usefulness of the model (Gregorini *et al.*, 2009). The model proposed in this study combines theoretical and empirical equations to predict herbage DMI, requires an easy-to-obtain set of inputs and is sensitive to nutritional, physiological and genetic factors of the cows.

The objectives of this study were to develop a model to predict daily DMI of ryegrass (*Lolium perenne* L.*)* pastures for grazing Holstein Friesian (H-F) cows, and to simulate herbage DMI of two different genotypes of H-F cows under different levels of concentrate supplementation and herbage allowance.

MATERIALS AND METHODS

Model overview

A model initially developed to predict herbage DMI of cows grazing lucerne (*Medicago sativa* L.) pastures (Baudracco *et al.*, 2006), was adapted and improved to predict daily herbage DMI of lactating HF dairy cows grazing ryegrass-based pastures. The model sets an upper limit to potential herbage DMI at grazing (*PotDMI*) for cows fed only pasture, which is the minimum out of three limits:

i) Physical limitation to rumen fill (*PotDMIr*),
ii) Metabolic limitation to energy demand ($PotDMI_e$) and
iii) A 'grazing limit' of 37.5 g herbage DMI per kg LW ($PotDMI_g$).

The minimum *PotDMI* and the herbage allowance (kg DM/cow/d) are used to predict herbage DMI of cows fed only pasture ($HerbDMI_o$) by using an empirical algorithm. When supplements are used, an algorithm that predicts substitution rate is used to predict actual herbage DMI. The model requires the following inputs: liveweight (LW), days in milk, days pregnant, potential milk yield, herbage allowance, pasture neutral detergent fibre (NDF) content, pasture ME content and kg DM supplements consumed.

Potential herbage DM intake at grazing

Potential herbage DMI at grazing (*PotDMI*) expresses the maximum intake possible for cows fed only pasture. It is calculated as the minimum of metabolic ($PotDMI_e$), physical ($PotDMI_r$) and grazing ($PotDMI_g$) limits.

Metabolic limit to intake

The metabolic limit to intake ($PotDMI_e$) is calculated as total metabolisable energy (ME) requirements (*MEReq*) divided by ME concentration of pasture (*PastME*), as shown in the following equations:

$$PotDMI_e\ (kg\ DM/cow/d) = MEReq\ /\ PastME \qquad \text{Equation 1}$$

$$MEReq\ (MJ\ ME/cow/d) = ME_m + ME_p + (ME_l\ Y) \qquad \text{Equation 2}$$

where ME_m and ME_p are the ME required for maintenance and pregnancy, respectively. ME_l is the ME required to synthesize one litre of milk, and Y is the potential milk yield per cow (L/d). Requirements for ME_m, ME_p and ME_l are calculated according to Freer *et al.* (2007).

Potential milk yield is calculated on the basis of a mathematical mammary gland model (Vetharaniam *et al.*, 2003) based on the interaction of two pools of alveoli (groups of secretory cells), one active pool and one quiescent pool. The equation to predict milk production, *Y*, proposed in this mammary gland model is:

$$Y\left(\frac{kg}{d}\right) = SE^{\mathrm{L}}\left(\mathrm{d}e^{-\mathrm{k}2\ \mathrm{t}} + l6\ \mathrm{e}^{\mathrm{w}6\ \mathrm{t}} + l7\ e^{w7\ t}\right) \qquad \text{Equation 3}$$

Where *S* is the maximum milk secretion rate of active alveoli, *t* is the time after parturition (days), *E* is the energy status at day *t*, *L* is a parameter that governs the response of milk yield to nutrition, and *d*, k_2, *l*6, *w*6, *l*7, *w*7, are parameters related to the alveolar dynamics, in terms of the number of active, quiescent and senescent alveoli. Detailed explanation about the latter parameters can be found in Vetharaniam *et al.*, 2003. The energy status, *E*, was set to 1 because *Y* represents potential milk yield with no nutritional limitations in the present model.

Potential milk yield is estimated using the parameters reported by Vetharaniam *et al.* (2003) for first lactation cows of both New Zealand H-F and North American H-F strains fed TMR diets with no nutritional limitations. The constant *S* was re-parameterised for herds with 79% multiparous cows and lactation yields of either 10,097 and 7,304 kg milk per cow for North American and New Zealand strains (Kolver *et al.*, 2002), respectively.

Physical limit to intake

The physical limitation model developed by Mertens (1987) states that, when the fill effect of the diet is high, daily potential intake ($PotDMI_r$) can be expressed as a constant rumen capacity (*C*) divided by the fill effect (*F*) of the diet:

$$PotDMI_r\ (kg\ DM/d) = \frac{C}{F} \qquad \text{Equation 4}$$

In the model, it was assumed that the animal has a potential neutral detergent fibre (NDF) rumen capacity, and that the feeds have a given capacity to occupy space determined by its NDF content. Given that ruminal volume is a function of body weight, rumen capacity is expressed in the model in terms of kg of NDF as percentage of the body weight. Therefore, Equation 4 can be re-arranged as follows:

$$PotDMI_r = \frac{0.0165\ \mathrm{LW}}{\%\ Pasture\ NDF}\ SOL \qquad \text{Equation 5}$$

The term 0.0165 times LW is supported by data from Vazquez and Smith (2000), which show that, at high herbage allowance (HA), the average daily intake of NDF was 1.65% of LW. The *SOL* is a coefficient accounting for the effect of stage of lactation on rumen capacity, which is defined in Equation 6, as proposed by Hulme *et al.* (1986):

$$SOL = 0.67 + (4.0401\ \mathrm{Log(w)} - 0.095\ w + 0.095)\ 0.0972 \qquad \text{Equation 6}$$

where *w* is the week of lactation.

Grazing limit to intake

A "grazing limit" ($PotDMI_g$) was defined as follows:

$$PotDMI_g = \mathrm{LW} \times 0.0375 \times \mathrm{SOL} \qquad \text{Equation 7}$$

This value of 3.75% of LW is based on maximum intakes measured for high yielding HF cows grazing with no pasture quality or quantity restrictions (Kolver & Muller, 1998). The $PotDMI_g$ sets an upper limit to maximum herbage DMI in cases of high yielding cows consuming pastures with low NDF, in which case the physical ($PotDMI_r$) and metabolic ($PotDMI_e$) limits set unrealistically high values to herbage DMI at grazing.

Herbage DM intake of cows fed only pasture ($HerbDMI_o$)

The minimum between $PotDMI_r$, $PotDMI_e$ and $PotDMI_g$ is selected as the final potential herbage DMI at grazing (*PotDMI*). The extent to which the cow achieves her *PotDMI* depends on HA. The ratio of HA to *PotDMI* (*HA*/*PotDMI*) is a measure of the pasture offered relative to the cow's demand for pasture at grazing, and it is used to predict actual herbage DMI in the present model. For instance, assuming a HA of 40 kg DM/cow/d and a *PotDMI* of 20 kg DM/cow/d, the ratio of HA to *PotDMI* will be two.

This theoretical framework was used to calculate the *PotDMI* and the ratio *HA*/*PotDMI* for un-supplemented treatments of nine experiments with cows grazing ryegrass-based pastures, and in which HA was measured to ground level. In Figure 1, the calculated ratio *HA*/*PotDMI* and the measured harvesting efficiency of those experiments are regressed, and the empirical equation obtained from Figure 1 is used to predict harvesting efficiency and actual herbage DMI of cows fed only pasture. Using the example given (*HA*/*PotDMI* = 2), harvesting efficiency (*HE*; herbage consumed:HA x 100) and pasture DMI ($HerbDMI_o$) can be predicted as follows:

$$HE\ (\%) = 57.676\ \left(\frac{HA}{PotDMI}\right)^{-0.536} = 39.8$$

Equation 8

$$HerbDMI_o\ (kg\ DM/d) = HA\ (HE) = 40\ (39.78\ \frac{1}{100}) = 15.9$$

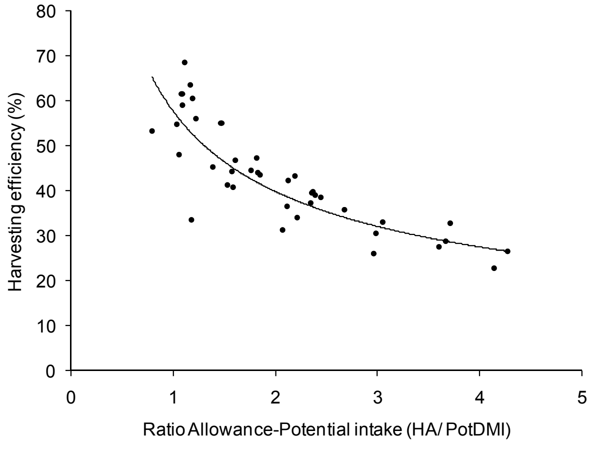
Equation 9

Thus, the *PotDMI* is both a limit and a driver for herbage DM intake (see Figure 1).

Herbage DM intake of cow fed supplements (*$HerbDMI_s$*)

The predicted herbage DMI of cows fed supplements (*$HerbDMI_s$*) is calculated with Equation 10:

FIGURE 1: Harvesting efficiency (HE, herbage consumed: herbage allowance x 100) as a function of the ratio herbage allowance: *PotDMI* (PA/*PotDMI*), using data from un-supplemented treatments of nine short-term grazing experiments with ryegrass-based pastures (Robaina *et al.*, 1998; Wales *et al.*, 1998; Dalley *et al.*, 1999; Stockdale, 1999; Wales *et al.*, 1999; Dalley *et al.*, 2001; Wales *et al.*, 2001; Ribeiro *et al.*, 2005; Lee *et al.*, 2008). Herbage allowance was measured to ground level in all the studies. HE = 57.676 $(PA/PotDMI)^{-0.536}$ (R^2 =0.749).



$$HerbDMI_S = HerbDMI_o - (SR)SupplDMI$$

Equation 10

Substitution rate (SR) expresses the decrease in kg DMI of herbage per kg DMI of supplement (SuppDMI), and it is calculated as follows:

$SR = 0.21\ HDMI - 0.18$; (Stockdale, 2000)

Equation 11

where *HDMI* is herbage DMI before supplementation, expressed as kg DM/100 kg LW. In the present model, the value for *HDMI* is calculated as:

$$HDMI = \frac{HerbDMIo}{LW}100$$

Equation 12

Model validation

An independent dataset was obtained from a trial with three strains of H-F cows grazing ryegrass-clover pasture in New Zealand (Macdonald *et al.*, 2008). The strains were North American H-F 90s (NA90; ≥ 91% North American genetics), New Zealand H-F 90s (NZ90; ≤ 24% North American genetics) and New Zealand H-F 70s (NZ70; ≤ 7% North American genetics). The dataset comprised individual herbage DMI measurements (n = 1,147) estimated using the n-alkanes technique for lactating cows over two lactations. Data were grouped by strain and month of lactation, resulting in 27 data points for validation of the whole dataset and nine points for validation within each strain. Mean values in the dataset were: 505 kg LW (range 352 to 750 kg), 43.7 kg DM/cow/d HA (range 30.2 to 69.0 kg), 37.9% pasture NDF (range 30.7 to 48.0%) and 14.6 kg DM/cow/d herbage DMI (range 7.5 to 24.0 kg). Herbage allowance was measured to ground level.

Predicted herbage DMI values (P) were compared against actual observed herbage DMI values (A) using the mean square prediction error (MSPE) defined by Fuentes-Pila *et al.* (1996) as:

$$\text{MSPE} = \frac{1}{n}\sum(A-P)^2$$

where *n* is the number of pairs of values of *A* and *P* being compared.

The fitness of the model was evaluated by the relative prediction error (RPE) defined as the ratio between the positive root square of the MSPE and the mean of the actual intake values (Fuentes-Pila *et al.*, 2003) and by the concordance correlation coefficient (CCC) (Lin, 1989). The accuracy of the prediction was considered satisfactory when the RPE was lower than 0.10 (Fuentes-Pila *et al.*, 1996). Additionally, the mean bias (kg/d) was calculated, which is defined as the difference between the mean of the actual intake values and the mean of the predicted intake values (Fuentes-Pila *et al.*, 2003).

RESULTS

Model validation

For the whole dataset taken from Macdonald *et al.* (2008), the MSPE was 1.40, the RPE 0.083, the CCC 0.74 and the mean bias +0.03 kg DM. Per strain, the RPE were 0.084, 0.087 and 0.060, the CCC 0.67, 0.72 and 0.75, and the mean bias were -0.82, +0.95 and -0.18 kg DM/d for NA90, NZ90 and NZ70 strains, respectively. Figure 2 shows the relationship between predicted and actual intake values per month of lactation for each strain.

FIGURE 2: Actual versus predicted herbage intake (kg DM/cow/d) for the three strains of Holstein-Friesian: NA90 (○), NZ90 (■) and NZ70 (▲). One data point plotted per month of lactation for each strain. The solid line (Y = X) indicates the position of the perfect fit between actual and model predicted values.

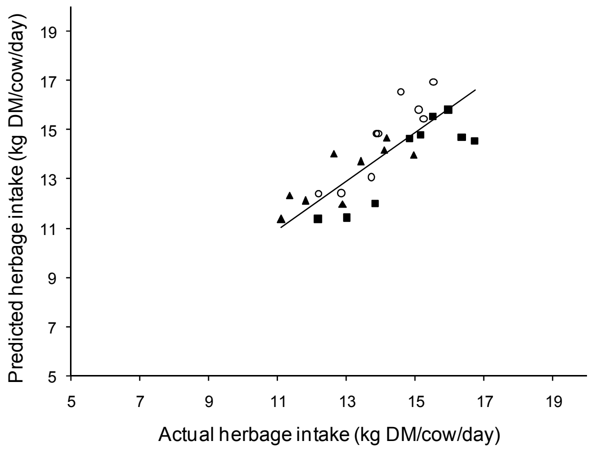
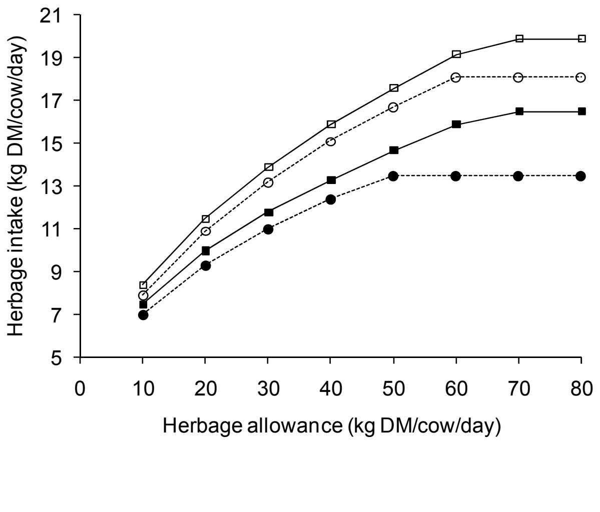


FIGURE 3: Simulated herbage DM intake for cows fed either pasture or pasture plus 6 kg DM/cow/d supplements. North American 90s fed solely pasture (-□-), New Zealand 90s fed solely pasture (┄○┄), North American 90s fed 6 kg DM supplement (-■-), New Zealand 90s fed 6 kg DM supplement (┄●┄). Simulations for cows of 550 kg LW (NA90) and 500 kg LW (NZ90), 80 days in milk, fed pasture with 45% NDF and daily potential milksolid yields of 2.1 kg (NZ90) and 2.5 kg (NA90).



Model simulations

Herbage DMI was simulated for both NA90 and NZ90 H-F strains, for eight levels of herbage allowance and two levels of concentrate supplementation (Figure 3).

DISCUSSION

The RPEs lower than 0.10, obtained in the validation of the model, indicate that the model had a satisfactory level of accuracy for both the complete dataset and data within strains, based on the study of Fuentes-Pila *et al.* (1996). Measured herbage intakes were close to predicted herbage intakes, with a mean bias (actual – predicted) of -0.82 (NA90), +0.95 (NZ90) and -0.18 (NZ70) kg DM/cow/d. These deviations from actual intake are less than or equal to those of similar studies (Delagarde & O'Donovan, 2005; Gregorini *et al.*, 2009).

Predicted intakes may deviate from actual intakes due to short-term changes in body reserves (Caird & Holmes, 1986), not accounted for in the current model. Also, deviations from model prediction suggest that there are some strain-related factors not accounted for in the model, which caused greater than predicted herbage DMI for NZ90 and lower than predicted herbage DMI for NA90. One of these unaccounted factors could be related to the "grazing ability" of the cow. Lower ability to achieve high levels of herbage DMI at grazing, expressed as % LW, was reported for North American HF than for New Zealand H-F cows (Kolver *et al.*, 2002; Kolver *et al.*, 2005).

In a trial comparing grazing behaviour of H-F strains, the NZ H-F strain had a longer grazing time per day than two NA H-F strains (McCarthy *et al.*, 2007) when fed on pasture only. This was unexpected based on the lower potential milk yield of the NZ H-F than the NA H-F strains, suggesting a greater inherent grazing drive for NZ H-F. This is supported by the historical long-term selection of NZ H-F cows, based on milk fat and protein production, feed efficiency and longevity on a predominantly grass-based diet.

The typical asymptotic relationship between HA and herbage DMI for cows fed solely pasture is also observed in the current model simulations depicted in Figure 3. Thus, herbage DMI increased as HA increased up to a maximum of 18.1 (NZ90) and 19.9 kg DM/cow/d (NA90).

Predicted substitution rates also increased as PA increased, from 0.45 to 0.77 kg DM/kg DM (NZ90) and from 0.43 to 0.57 kg DM/kg DM (NA90) as PA increased from 40 to 70 kg DM/cow/d (Figure 3). The increase in substitution rate as PA increased agrees with previous studies (Robaina *et al.*, 1998; Wales *et al.*, 1999). The difference in substitution rate between H-F strains agrees with results from Kolver *et al.* (2005), who found substitution rates of 0.75 and 0.67 kg DM/kg DM for New Zealand H-F (<13% NA genetics) and North American H-F (>87% NA genetics) cows, respectively, when fed generously on pasture (HA range 50 to 70 kg DM/cow/d) and supplemented with 6 kg DM concentrates. The lower substitution rates predicted for NA H-F cows occurred because the model set a greater metabolic limit to intake for NA H-F than NZ H-F cows ($PotDMI_e$), given the higher potential milk yield of the former.

The current model predicted herbage DMI with acceptable accuracy for cows of H-F strains and can simulate different feeding scenarios by changing herbage allowance and the level of supplementation. The model could be improved by accounting for the different abilities of grazing of different HF strains, for example by using different values for maximum intake as percentage of LW in potential DMI calculations (PotDIMg). The present model combines a simple approach to predict herbage DMI, using a set of inputs that are relatively easy-to-obtain, while accounting for nutritional, physiological and genetic variables.

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