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Using an existing intake model to demonstrate relationships between herbage allowance, hunger drive, days in milk and actual intake in grazing dairy cows

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ABSTRACT

A sheep intake model was adjusted for dairy cows and used to illustrate intake in relation to inherent hunger, days in milk (DIM), and herbage allowance. Intake is predicted by an exponential function of pre-grazing herbage mass, stocking density and hunger drive (k). In adjusting the model, k was re-parameterised using a data set of n = 1,198; it was then adjusted to represent intake decline from peak to end of lactation. This adjustment resulted in splitting k into a and b. Parameter a represented inherent hunger and b its persistence during lactation. The re-parameterised model was tested against an independent data set (n = 287). The square root of mean prediction error was 1.57, indicating good prediction accuracy. Data from three different cow strains, New Zealand-70 and -90 and North American-90 (n = 210, 293 and 271, respectively) were used to re-estimate a and b, and to illustrate inherent hunger drive. a and b differed (P <0.01) between strains. Then, with the adjusted and re-parameterized models, the interaction effect of herbage allowance, strain, and DIM on intake were simulated. The adjusted model offers an easy-to-use tool to compare, interpret and illustrate feeding scenarios.

Keywords: herbage intake; modelling; hunger drive; herbage allowance.

INTRODUCTION

Intake regulation factors and the ability to predict changes in intake are of particular interest as they facilitate the development of management tools to allocate feed resources better.

Pasture intake has been described as a series of complex interactions, including ingestive and digestive behaviours (Allden & Whittaker, 1970) and hormonal and metabolic stimuli to eat (Illius & Jessop, 1996; Roche *et al*., 2008). Several mechanistic models have been developed to study the complexity of these functional interactions such as, Woodward (1997), Baumont *et al.* (2004) and Chilibroste *et al.* (2008). However, most of these models often fall short in prediction accuracy, due to the ‘hard to get’ set of inputs needed and the significant error in measuring such input variables. Although predictive empirical models are simpler, criticism is based on their empirical elements and the range and the size of data used in the equation building process (Vazquez & Smith, 1999; Delagarde & O’Donovan, 2005). Meanwhile farmers still face the seemingly simple yet intractable question: how many kilograms of pasture a dairy cow is going to consume per unit of time? Existing simple algorithms with strong biological bases have been developed that address these questions and help to understand, condense and interpret information collected from pasture intake measurements or farm generated data. The objective of this work was to use an existent, simple and theoretical intake model developed for sheep (McCall *et al.*, 1986), adjust it for dairy cows, and use it to assist in a comparative analysis of the relationship between herbage allowance, inherent hunger drive, days in milk (DIM) and intake from the peak towards the end of lactation.

MATERIALS AND METHODS

The model

The model used in this exercise was a simple intake model described by McCall *et al.* (1986). Intake (kg dry matter (DM)/d) of an individual animal was predicted as follows:

$$I = \frac{y_0}{n \times t} \times \left(1 - e^{-k \times n \times t}\right)$$

where:

y_0 = Pre-grazing herbage mass (kg DM/ha)
n = Instant stocking rate on the grazing break (animals/ha)
t = Total time in the grazing break (d)
k = Constant determining the shape of the response function (animals/ha x d)
$\frac{y_0}{n \times t}$ = herbage allowance (kg DM/cow/d)

In the present work k is taken as a “proxy” of hunger drive. McCall *et al.* (1986) stated that k varies with the stock class involved, its physiological stage and live weight.

Model adaptation and validation

Although the model was originally developed for sheep, it is intrinsically generic allowing parameterisation for other species. The model was re-parameterised for dairy cows from the peak towards the end of lactation. The data for model re-

TABLE 1: Mean ± standard deviation of variables used in the adaptation and validation of the general model, and model parameter estimations for different cows strain. Data utilised in the present work only considered non-supplemented cows. DM = Dry matter.

Data set and variables	Peak of lactation	End of lactation
Adaptation		
Herbage allowance (kg DM/cow/d)	43.0 ± 9.4	35.2 ± 16.1
Days in milk	60 ± 16	260 ± 21
Live weight (kg)	450 ± 64	490 ± 56
Milk yield (kg/d)	23.2 ± 4.8	9.2 ± 2.7
Pasture intake (kg DM/d)	13.9 ± 2.4	9.5 ± 2.5
Validation		
Herbage allowance (kg DM/cow/d)	61.2 ± 8.4	56.2 ± 18.3
Days in milk	56 ± 18	253 ± 27
Live weight (kg)	470 ± 66	480 ± 61
Milk yield (kg/d)	24.6 ± 4.7	10.0 ± 3.4
Pasture intake (kg DM/d)	13.7 ± 3.2	10.3 ± 1.9
New Zealand-70 strain		
Herbage allowance (kg DM/cow/d)	34.5 ± 6.5	37.8 ± 3.2
Days in milk	62 ± 24	241 ± 23
Live weight (kg)	422 ± 53	469 ± 38
Milk yield (kg/d)	22.0 ± 4.5	12.5 ± 3.7
Pasture intake (kg DM/d)	13.9 ± 2.2	13.3 ± 1.8
New Zealand-90 strain		
Herbage allowance (kg DM/cow/d)	32.3 ± 7.5	41.9 ± 5.5
Days in milk	61 ± 22	240 ± 26
Live weight (kg)	431 ± 47	468 ± 44
Milk yield (kg/d)	25.8 ± 4.2	12.7 ± 2.8
Pasture intake (kg DM/d)	16.8 ± 2.3	15.7 ± 2.6
North American-90 strain		
Herbage allowance (kg DM/cow/d)	36.5 ± 6.6	38.6 ± 4.0
Days in milk	57 ± 18	236 ± 20
Live weight (kg)	455 ± 45	482 ± 36
Milk yield (kg/d)	27.5 ± 3.8	12.1 ± 2.9
Pasture intake (kg DM/d)	14.9 ± 2.2	15.8 ± 2.0

parameterisation were taken from Macdonald *et al.* (2008a) (Table 1) and consisted of individual herbage intakes, measured by the alkanes technique, of 1,198 lactating dairy cows from five herds over three consecutive lactations. The model validation was conducted with an independent data set of individual herbage intakes, also measured with the alkanes technique, of 287 lactating dairy cows from five herds, over one lactation (Table 1). There were three sampling points per lactation (59 ± 15, 179 ± 5 and 259 ± 21 DIM). The data were averaged for each herd giving 60 data points for calibration and 15 for validation.

The model was first fitted separately for 60, 180 and 260 DIM. As k diminished with increasing DIM (Figure 1), k was then replaced by a function representing such a reduction:

$$k = a \times e^{(-b \times \mathrm{DIM})}$$

where

a: defines the inherent hunger drive (animals/ha x d)$^{-1}$

b: defines persistency of hunger drive as lactation progresses (d^{-1}). A value of zero would mean no effect of DIM on k

The parameter fitting was completed using Microsoft Excel 2000 Solver add-in (Microsoft Corp., Seattle, Washington, USA).

Estimation of model constants *a* and *b* for different cow strains

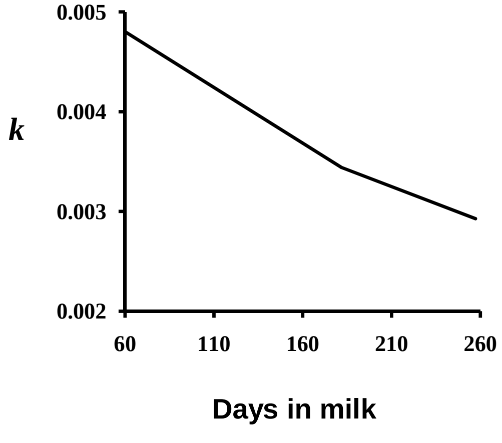
Once the model was adapted and validated; it was fitted to a third and independent set of data (Macdonald *et al.*, 2008b) (Table 1). The data consisted of individual herbage intakes, measured with the alkanes technique, of 774 lactating dairy cows of three cow strains: New Zealand-70 (Average of ≤7% North American-Holstein Frisian genetics and a Breeding Worth of -\$10), New Zealand-90 (Average of ≤24% North American genetics and a Breeding Worth of +\$86) and North American-90 (Average of ≥91% North American genetics and a Breeding Worth of +\$84). The constants *a* and *b* of the model were estimated for three individual herds (replicates) from each strain separately and analysed by ANOVA with strain as treatment in GenStat 11.1. Multiple comparison of *a* and *b* means were done by Bonferroni analysis (Payne et al., 2008).

Utilising the means of the constants *a* and *b* for each cow strain, different scenarios differing in herbage allowance and DIM were simulated to compare any potential difference in pasture intake between cow strains.

Statistical criteria for model validation, evaluation and comparison

To evaluate model accuracy, commonly used deviance measures were utilised following similar criteria to Shah and Murphy (2004). The measures utilised were: mean absolute error (MAE) (%), mean square prediction error (MSPE) (kg/d), and square root of MSPE (RMSPE) (kg^2/d^2). The MSPE is often used in intake prediction comparison studies (Rook *et al.*, 1991; Fuentes-Pila *et al.*, 1996; Roseler *et al.*, 1997a) and to validate equations for intake prediction (Vadiveloo & Holmes, 1979; Rook *et al.,* 1991; Roseler *et al.*, 1997b). The MSPE is defined as Σ (Oi − Pi)^2/n, where n = number of pairs of observed (O) and predicted (P) DMI values being compared. The MAE is defined as (Σ|Oi − Pi|)/n. The relative prediction error (RPE, MAE as a percentage of observed mean values) was used to determine precision and reproducibility of prediction.

FIGURE 1: Constant *k*, a "proxy" of hunger drive, as affected by days in milk.



RESULTS

Calibration

The values of the constants *a* and *b* for the calibrated model were 0.00541 and 0.00187, respectively.

Evaluation and validation of the adapted model

The MSPE, MAE and RPE were 2.49, 1.3 and 10.8 respectively.

Estimation of model constants *a* and *b* for different strains.

Constant *a* differed (P <0.01; standard error of mean (SEM), 0.000124) among cow strains. New Zealand-70 had the lowest *a* (0.00768); while New Zealand-90 and North American-90 had similar *a* values, 0.00851 and 0.00864, respectively. Constant *b* did not differ (P >0.05; SEM, 0.000165) among cow strains (Average 0.00228). The values of MSPE, MAE and RPE for New Zealand-70 were 0.48, 0.68 and 5.20 respectively. For New Zealand-90 the values of MSPE, MAE and RPE were 2.26, 1.47 and 9.36 respectively. The values of MSPE, MAE and RPE for North American-90 were 0.42, 0.42 and 3.70 respectively.

Simulations

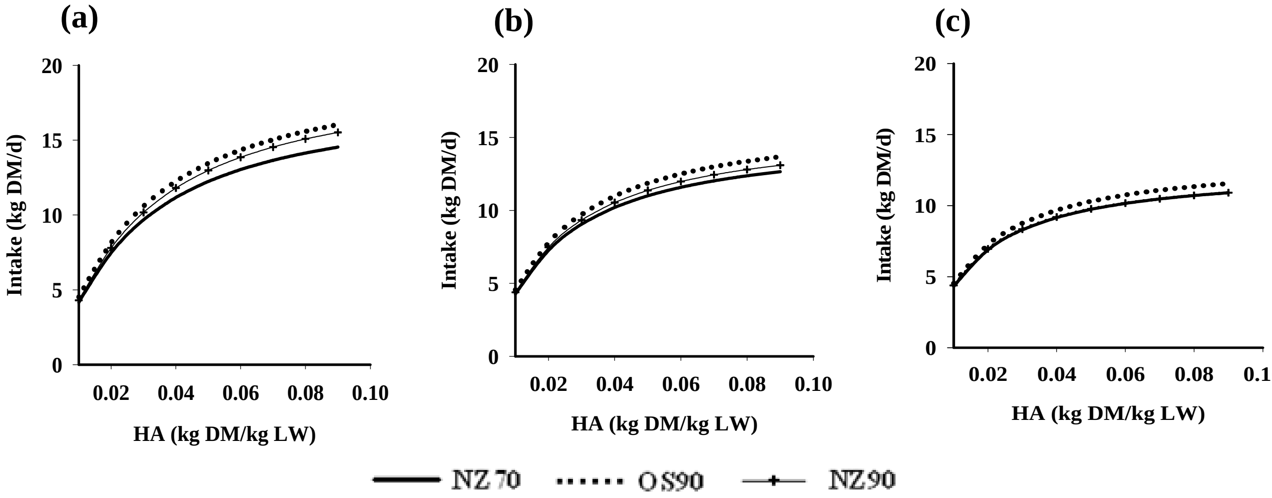
The results of the simulations presenting feeding scenarios differing in herbage allowance for the three strains from the peak to the end of lactation are presented in Figure 2.

DISCUSSION

Fuentes-Pila *et al.* (1996) considered feed intake prediction models robust and satisfactory for the prediction of DMI if RPE <10%. The RPE of the present model was close to such a threshold; thus, it can acceptably predict pasture DMI from the peak towards the end of lactation. The prediction accuracy of the model was also measured through MSPE, MAE and RMSE. The present model had a value of MSPE (2.49 kg^2/d^2), smaller than that presented by Shah and Murphy (2004) for a similar model (5.06 kg^2/d^2). These authors argued that their model's value of MSPE, and in consequence the present model, suggest considerably good prediction accuracy. Although the model seems to be accurate and robust, the agro-ecological context of New Zealand best practice grazing management, in which the model was created, adapted and re-parameterized, may set some boundaries to its applicability.

The values of *a* and *b* for the three cow strains, genetically differing in potential milk yield, indicated that modern strains like New Zealand-90 and North American-90, have greater hunger drive in comparison with the older strain, New Zealand-70, as suggested by Roche *et al.* (2006). Increments

FIGURE 2: Effect of herbage allowance (HA) for (a) 60 days in milk, (b) 150 days in milk and (c) 240 days in milk on pasture intake from the peak towards the end of lactation of grazing dairy cows with different genetic merit New Zealand-70 (NZ70), New Zealand-90 (NZ90) and North American-90 (NA90).



in DMI come with genetic improvements for milk production (Linnane *et al.*, 2004; Kolver *et al.*, 2005). The driver to produce milk also drives cows to eat more (Roche *et al.*, 2006). The results of the simulations presented in Figure 2 support such a premise. The strains with greater potential for milk yield achieved greater pasture DMI during the time period considered in this work; especially for the North American-90. As expected, all strains responded positively to increasing herbage allowance. However, this effect was more pronounced in the New Zealand-90 and North American-90 strains. This implies that cows with a greater drive to eat, may find restrictions to pasture DMI at low levels of pasture availability, and not be able to adopt compensatory foraging behaviours (Chilibroste *et al.,* 2004). Although the latter may imply that possibly reduced milk production by high genetic merit cows can be overcome by increasing herbage allowance, this may not be the optimal solution. Even allocating very high herbage allowances, none of the strains could reach their potential pasture DMI.

These results demonstrate the capability of the model not only to simulate differential responses in pasture DMI to variations in inherent hunger, but also the interaction with external factors regulating pasture DMI as herbage allowance. The control and prediction of DMI has received attention since the pioneer works of Wolff (1874). Efforts to predict pasture intake by grazing dairy cows have attracted several decades of study. This effort has been translated into several predictive models varying in complexity, which does not necessary mean accuracy of prediction (See Delagarde and O'Donovan (2005)). The model proposed by McCall *et al.* (1986), adapted in the present work for grazing dairy cows, is characterised for its simplicity and the strong biological meaning of its few components. This offers an easy-to-use tool to compare, interpret and illustrate similar feeding scenarios.

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