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Development of a model to predict pasture intake for grazing dairy cows in Argentina

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ABSTRACT

Milk production in Argentina is based on grazed pastures and supplementary feeds. Pasture dry matter intake affects markedly the performance of grazing dairy systems. The objective of this study was to develop a simple model to predict daily pasture dry matter intake (DMI) of grazing dairy cows in Argentina, which in turn, would enable the effects of stocking rate on pasture DMI, farm productivity and profitability to be explored. The model assumed that potential DMI of cows fed only pasture is initially limited by either rumen fill or energy demand. Cow live weight, stage of lactation, and concentration of neutral detergent fibre in the pasture account for the rumen fill effect, while requirements for maintenance, pregnancy, and potential milk production influence the cow's energy demand. Potential pasture intake is then estimated from the potential DMI, by taking into account the reduction in potential intake that occurs when supplements are consumed. Finally, actual pasture intake is estimated as a function of pasture allowance and potential pasture intake, based on an empirical equation derived from grazing experiments in Argentina, mainly with lucerne pastures. The fitness of the model was evaluated by the square root of the mean-square prediction error (RMSPE), expressed as a percentage of the mean actual pasture intake. The accuracy of the model was satisfactory, with RMSPE of 9.6% and 7.3% for two Argentine datasets (lucerne pastures), and 8.1% for one Irish dataset (ryegrass-clover pastures). The model can be used as a part of a whole-farm model to predict the effects of stocking rate on farm productivity and profitability.

Keywords: pasture intake, prediction, grazing, dairy cow

INTRODUCTION

Dairy production in Argentina is based on grazed pastures, with conserved forages and concentrates comprising approximately 33% of the cow's diet. Productivity and profitability of grazing dairy systems are highly dependant on cows' pasture dry matter intake (DMI). Herbage allowance (kg DM offered/cow/day) is the factor exerting the greatest effect on pasture DMI in grazing dairy systems (Hodgson *et al.*, 1994; Holmes, 1987; Leaver, 1985).

Factors affecting herbage intake by grazing animals can be broadly classified as nutritional and non-nutritional. Nutritional factors include physical satiety and physiological energy demand of the animal, and these limit pasture intake at high herbage allowances. Non-nutritional factors constrain grazing activities and the rate of intake, basically through their effects on bite weight and grazing time, and these limit pasture intake at low herbage allowances (Poppi *et al.*, 1987).

Neutral detergent fibre (NDF) is an important nutritional factor through its effects on digestion and rumen fill, but NDF can indirectly reflect non-nutritional factors such as the amount of green or dead material, and the breaking strength of plant material, which usually increases with the stage of maturity of plants. Mechanical properties of herbage may influence the rate of intake. Mechanical properties of the herbage could be predicted by an index of fibrosity such as NDF (Prache & Peyraud, 2001).

The animal can be regarded as having an upper limit to intake, or 'potential intake'. Physiological demand for energy and physical limitation of the rumen capacity have been described as the two basic mechanisms explaining intake regulation when animals have unlimited access to feed (Forbes, 1995). With diets containing high concentrations of NDF, intake is limited by the physical capacity of the animal, and becomes a function primarily of dietary characteristics. With diets containing low concentrations of NDF, intake is controlled by the physiological energy demand of the animal, and is principally a function of animal characteristics (Mertens, 1987). Simple mathematical equations describing intake regulation were derived by Mertens (1987). His model, the NDF-energy system, is based on the concept that, in animals with unlimited access to feed, feed intake is regulated by metabolic and physical control. This theoretical approach was used in the present model to predict potential DMI.

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The objective of this study was to develop a model to predict daily pasture DMI for grazing dairy cows in Argentina. The model integrated nutritional and non-nutritional factors, and was based on sward and animal parameters usually measured in Argentine grazing studies. There are no similar models to predict intake of grazing dairy cows in Argentina.

METHODS

Description of the model

A theoretical-mechanistic framework combined with an empirical equation was used in the present model to predict daily pasture DMI. Potential DMI (PotDMI) is initially predicted, assuming that cows have access to unlimited amounts of pasture as a sole feed. Potential pasture DMI (PPI) is then estimated from the potential DMI, by taking into account the reduction in potential DMI that occurs when supplements are consumed. Two possible values for both PotDMI and PPI are calculated, assuming that intake is limited by either physiological energy demand ($PotDMI_e$ and PPI_e), or by rumen fill ($PotDMI_r$ and PPI_r). The lowest value of PPI_e and PPI_r is then selected as the predicted PPI of the cow. Finally, actual pasture intake is estimated as a function of the actual pasture allowance and PPI, based on an empirical equation derived from data from grazing experiments in Argentina.

Sward structure, herbage mass and botanical composition, although known to be important, were not included in the present model for the sake of simplicity.

Physiological limit

The model of Mertens (1987) proposed that when intake is limited by physiological energy demand, daily $PotDMI_e$ (kg DM/day) multiplied by the metabolisable energy (ME) content of the diet (EC) equals the animal's daily ME requirements (R):

$$R = PotDMI_e \times EC \quad (1)$$

For grazing cows fed supplements, Equation 1 can be disaggregated, and expressed as:

$$R = (DMI_s \times EC_s) + (PPI_e \times EC_p) \quad (2)$$

Where DMI_s and EC_s are DMI and ME concentration of supplements, PPI_e is the potential pasture intake when energy demand limits intake, and EC_p is the ME concentration of pastures. This can be re-arranged to calculate potential pasture intake as follows:

$$PPI_e = \frac{R - (DMI_s \times EC_s)}{EC_p} \quad (3)$$

Prediction of total requirements of metabolisable energy

Total requirements of metabolisable energy are estimated using Equation 4:

$$R = ME_m + ME_p + (ME_L \times Y) \quad (4)$$

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 (litres/day). Requirements for ME_m, ME_p and ME_L are calculated according to recommendations of SCA (1990). The exponential model proposed by Wilmink (1987) is used to predict potential milk yield at any day of the lactation period (Equation 5).

$$Y_t = a + be^{-0.05t} + ct \quad (5)$$

Where Y_t is the potential yield of milk in the t^{th} day of lactation. Parameters a, b, and c determine the overall shape of the curve. The values for parameters a, b, and c used in this model were extracted from the results of a study investigating the effects of strain of Holstein-Friesian cows, feeding system and parity on lactation curves of dairy cows in Ireland (Horan *et al.*, 2005a). Parameters used in this model were those corresponding to the treatment with high productivity cows offered a high concentrate diet. Parameter a was increased arbitrarily by 5% in order to represent a curve of potential milk yield for high-yielding Holstein cows. The values for parameters a, b, and c used in this model were 43.26, -22.9, and -0.0889 for a, b and c, respectively. These values give a milk yield of 8,599 litres per cow (4% fat corrected) in 305 days of lactation.

Physical limit

Mathematically, the physical limitation theory of Mertens (1987) states that daily potential intake ($PotDMI_r$) times the fill effect (F) of the diet equals a constant daily intake capacity (C):

$$C = PotDMI_r \times F \quad (6)$$

This equation can be re-arranged to obtain potential DMI intake:

$$PotDMI_r = C/F \quad (7)$$

Based on equation 7, a theoretical equation is proposed to predict the potential DMI (kg DM/day) when intake is controlled physically in grazing dairy cows, with unlimited access to pasture as sole feed.

$$\text{PotDMIr} = \frac{1.65\% \times \text{Liveweight}}{\%\ \text{pasture NDF}} \times \text{SOL} \qquad (8)$$

The term 1.65% x live weight (Lwt) accounts for the filling capacity of the animal (C) and the % pasture NDF for the filling effect of the ration (F) when only pasture is fed. Vazquez and Smith (2000) found that, at high pasture allowance, the average daily intake of NDF was: 1.65% x Lwt. SOL is a coefficient accounting for the effect of stage of lactation on rumen capacity, which is defined in Equation 9, as proposed by Hulme *et al.* (1986):

$$\text{SOL} = 0.67 + (4.0401 \times \text{Log}(w) - 0.095 \times w) \times 0.0972 \qquad (9)$$

where w is the week of lactation.

Equation 10 enables the calculation of potential pasture intake (PPI_r) when rumen fill limits intake, accounting for the reduction in the animal's capacity when supplements are consumed.

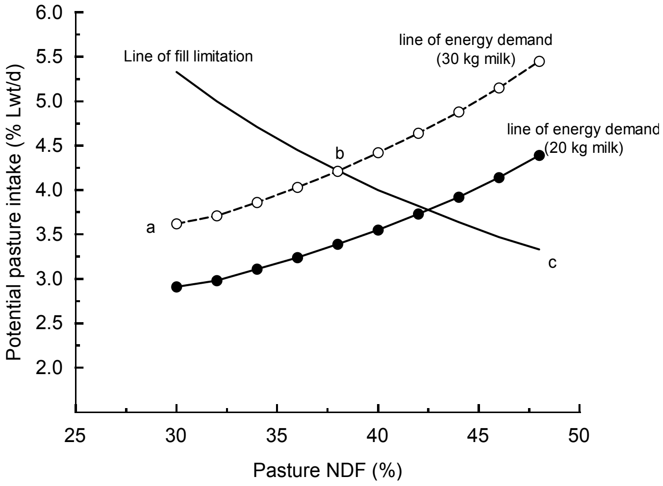
$$\text{PPI}_r = \text{PotDMI}_r\ (\text{kg DM/d}) - \text{Supplements eaten (kg DM/d)} \qquad (10)$$

It should be noted that 1 kg DM consumed as supplement reduces potential pasture intake (PPI_r) by 1 kg, but actual intake is not necessarily reduced by 1 kg, as shown in the results below.

Integration of physiological and physical intake control

Because NDF is related to both the filling effect and the energy density of feeds, it can be used to relate the two mechanisms of intake regulation on a common scale, as shown in Figure 1. In the example shown in Figure 1, the intercept point between the two mechanisms of intake regulation is approximately 38% NDF for a cow with a potential milk production of 30 kg/day. At this point, PPI_e equals PPI_r. At higher NDF concentrations, intake would be limited by rumen fill, while at lower pasture NDFs intake would be limited by energy demand, for a cow with a potential milk yield of 30 kg per day. Therefore, PPI= min (PPI_e, PPI_r).

FIGURE 1: Predictions of potential pasture intake according to the current model, adapted from the NDF-energy system proposed by Mertens (1987). Example for a cow of 550 kg Lwt, in the 2nd month of lactation, fed only pasture. Theoretical intake limitation by rumen fill (——). Theoretical intake limitation by energy demand for a cow with potential of 30 kg milk (- -○- -), and 20 kg milk of 4% fat corrected (—●—). Line a to b represents potential intake limited by energy demand of the animal. Line b to c represents potential intake limited by the fill effect of the diet. Section above the point b in both lines represent unattainable intake, as predicted by the theoretical equations.



Prediction of actual pasture intake and harvesting efficiency

The extent to which the cow achieves her PPI depends on pasture allowance. The ratio of pasture allowance to PPI (RAPPI) is a measure of the pasture offered relative to the cow's demand for pasture, and is used to predict actual pasture intake. For instance, assuming a pasture allowance of 25 kg DM and a PPI of 19.3 kg DM, the RAPPI will be:

$$\text{RAPPI} = \frac{\text{Pasture allowance}}{\text{PPI}} = \frac{25.0\ \text{kg}}{19.3\ \text{kg}} = 1.30 \qquad (11)$$

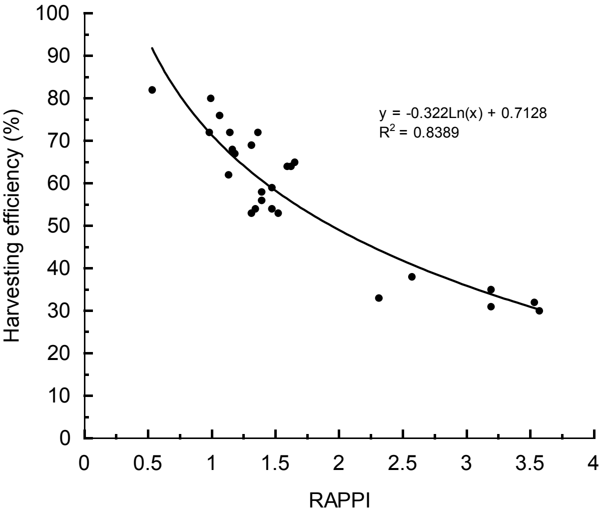
This theoretical framework was used to calculate the PPI and the RAPPI for 12 grazing studies in Argentina. In Figure 2, the RAPPI is plotted against the harvesting efficiency (ratio pasture consumed: pasture allowance) actually measured in those experiments.

The empirical equation derived from data presented in Figure 2 is used in the prediction of actual pasture intake and harvesting efficiency. Using the example given in Equation 11 (RAPPI = 1.30), harvesting efficiency and actual pasture intake can be predicted as follows:

Harvesting efficiency (y) = -0.322 x Ln (1.30) + 0.7128 = 0.63

Actual pasture DMI = allowance x harvesting efficiency = 25 x 0.63 = 15.8 kg DM/cow

FIGURE 2: Harvesting efficiency (pasture consumed: pasture allowance x 100) as a function of the ratio allowance: PPI (RAPPI), using data from 12 grazing experiments in Argentina (all on lucerne, except one on ryegrass-clover). Pasture allowance was measured 4 cm above ground level and pasture consumed was calculated as the difference between pre and post-grazing herbage mass, in all the studies. Pasture NDF ranged from 35.2% to 58.3%.



Validation data

Two datasets from Argentina, different from data used in Figure 2, were used to validate the model. Dataset 1 included 19 observations of intake by group of cows in commercial dairy farms under research programmes of INTA Rafaela. Average values of this dataset were: 550 kg Lwt, 14.1 kg pasture allowance, 43.0% pasture NDF, and 8.4 kg supplements consumed/cow daily (concentrates and conserved forages). The pasture used was lucerne (*Medicago sativa L.*).

Dataset 2 includes data for one year from a dairy research farm in Argentina (Tambo Roca, INTA Rafaela). The average herd intakes of each month of the year were compared with model predictions. Average values of this dataset were: 570 kg Lwt, 13.6 kg pasture allowance (lucerne), 44.9% pasture NDF (ranging from 43.3% to 47.7%), and 6.6 kg supplements consumed/cow daily.

Additionally, the present model was validated against a dataset from a trial with three strains of Holstein-Friesian cows grazing ryegrass-clover pastures in Ireland, with 849 individual measurements of intake (Horan *et al.*, 2005b). Data were grouped by month of lactation and strain of cow, resulting in 28 values of average intakes. Average values for this dataset were: 526 kg Lwt, 25.1 kg pasture allowance (ryegrass-clover), 45.3% pasture NDF (ranging from 32.6% to 52.1%), and 1.4 kg supplements consumed/cow/day. Pasture allowance was measured at 4 cm above ground level for the three datasets.

In the Argentine datasets, intake was measured as the difference between pre and post-grazing herbage mass and only a small amount of data was available for validation. Therefore, the Irish dataset was included, in order to test the model with a wider range of data, measured with greater accuracy (n-alkane technique).

Statistical analysis

Predicted pasture DMIs (P) were compared against actual observed pasture DMIs (A) using the mean-square prediction error (MSPE) defined as:

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

where n is the number of pairs of values of A and P being compared. The fitness of the model was evaluated by the square root of the mean-square prediction error (RMSPE), expressed as a percentage of the mean actual pasture intake. The accuracy of the prediction was considered satisfactory when the RMSPE was lower than 10% of the mean actual intake, relatively good for RMSPE between 10 and 20%, and unsatisfactory for RMSPE greater than 20% (Fuentes Pila et al., 1996).

The concordance correlation coefficient (CCC) (Lin, 1989) was also calculated, in order to quantify the degree of deviation from the total agreement, namely the 45° line (A=P), and the deviation between A and P. The mean of the differences between A and P values divided by the mean actual intake was used to define the percentage of under or over prediction of the model.

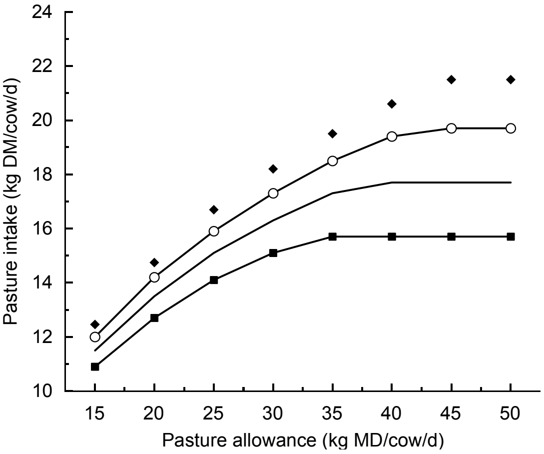
RESULTS

Model predictions

Actual pasture DMIs were predicted for different levels of pasture allowance and supplementation (Figure 3).

Predicted pasture DMI increased curvilinearly as pasture allowance increased, reaching a plateau at approximately 45, 40, 35, and 30 kg DM/day, for cows eating 0, 2, 4, and 6 kg DM/day of supplements, respectively.

FIGURE 3: Model predictions showing the effect of pasture allowance on pasture intake at different levels of supplement intake. (—■—) 6 kg DM supplements/cow, (——) 4 kg DM supplements/cow, (—○—) 2 kg DM supplements/cow, and (◆) unsupplemented cows. Calculations were based on a 550 kg Lwt cow, in the week 10th of lactation (30 kg potential milk yield), and a pasture with 42% NDF. Pasture allowance at 4 cm above ground level.

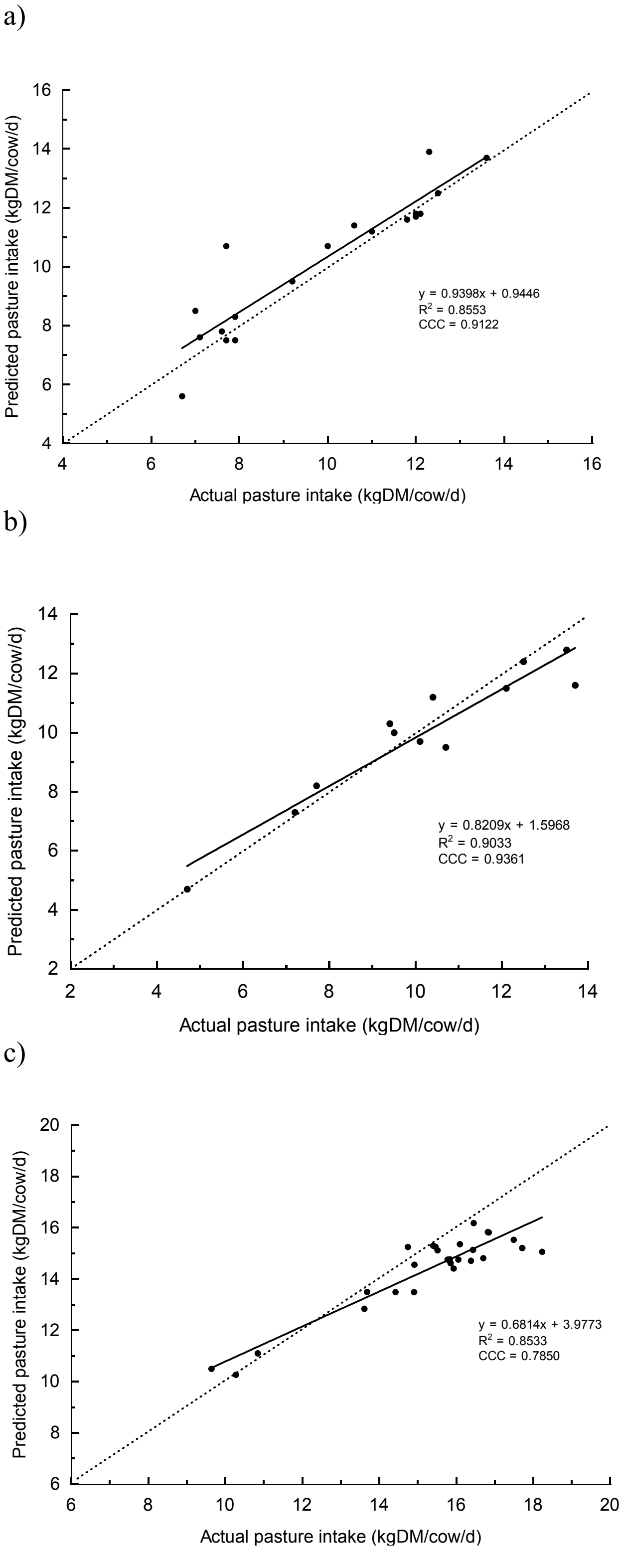


Similarly, model predictions indicated that pasture intake increased from 12.5, 12.0, 11.5 and 10.9 kg DM, up to 21.5, 19.7, 17.7, and 15.6 kg DM per cow/day as pasture allowance increased from 15 to that which maximised total DMI for cows fed 0, 2, 4, and 6 kg DM supplements, respectively. This represents an average increment of 0.31 kg DM of pasture per kg DM extra pasture allowance. Average substitution rates were 0.26, 0.43, 0.63 and 0.97 kg DM of pasture per kg DM of supplement at 15, 25, 35 and 45 kg DM pasture allowances, respectively.

Model validation

The average predictions overestimated pasture DMI by 3.6% for Argentine dataset 1, and underestimated pasture DMI by 2.2% for Argentine dataset 2, and by 5.9% for the Irish dataset (Figure 4). The RMSPE (expressed as a percentage of the mean actual intake) were 9.6% and 7.3% for the Argentine datasets 1 and 2, respectively, and 8.1% for the Irish dataset. Measured intakes were close to predicted intakes, with CCC of 0.9122, 0.9361 and 0.7850 for the Argentine datasets 1 and 2, and the Irish dataset, respectively.

FIGURE 4: Actual and predicted pasture DMI of grazing dairy cows. (a) Argentine dataset 1 (lucerne pastures), (b) Argentine dataset 2 (lucerne pastures), and (c) Irish dataset (ryegrass-clover pastures). The dashed line indicates x=y. The solid line indicates the fitted regression equation.



DISCUSSION

The current model represents a simple approach to the prediction of daily pasture DMI, with more emphasis on animal factors than on sward factors.

The strong effect of pasture allowance on pasture DMI reflected by the current model is in agreement with the findings of many other studies (Holmes, 1987; Meijs & Hoekstra, 1984; Romero *et al.*, 1995).

The model predicted that pasture DMI reached a plateau at 45 kg DM pasture allowance, resulting in a high intake (21.5 kg DM/cow/day) for unsupplemented cows. For unsupplemented dairy cows grazing lucerne pastures in Argentina, it was reported that pasture DMI increased up to pasture allowances of 30-33 kg DM (Comeron *et al.*, 1995) and up to pasture allowances of 45 kg DM (7.5% Lwt) for 550 kg Lwt cows (Castillo & Gallardo, 1995). The model may have overestimated pasture DMI at high allowances for unsupplemented cows, because it does not consider physical constraints such as the amount of time available for grazing, which can prevent very high pasture DMI at grazing (Kolver, 2003). The allowances reported in this study will be lower than those reported from grazing studies in New Zealand and Australia, because the model, and Argentine studies, consider allowance at 4 cm above ground level, in contrast to New Zealand and Australia, where allowance is usually measured at ground level.

For every extra kg DM increase in pasture allowance, an increment of 0.5 kg DMI was reported for cows grazing lucerne pastures in Argentina, with 2,500 kg DM/ha or more as pre-grazing herbage mass (Romero *et al.*, 1995). The model predicted an average increase of 0.31 kg DM per kg extra pasture allowance, but the equation used in the present model (Figure 2) was derived from studies with pre-grazing herbage mass from 1300 kg DM/ha (all expressed at 4 cm above ground level).

Meijs and Hoekstra (1984) reported substitution rates of 0.5 for cows grazing ryegrass-clover pastures in the Netherlands, at 24 kg organic matter pasture allowance (4 cm above ground level). This is similar to the substitution rate of 0.43 predicted for a pasture allowance of 25 kg DM.

High values for CCC were obtained in the validation of the model. However, the present model overestimated pasture DMI at lower DMIs, and underestimated pasture DMI at higher DMIs in the Argentine dataset 2 and the Irish dataset. Possibly, the simplification of the effects of sward factors on pasture intake in the present model reduced the accuracy of model predictions. However, the predictive accuracy of the model, tested by the RMSPE as a percentage of the mean actual pasture intake, was satisfactory (<10%) for both the Argentine and the Irish dataset.

CONCLUSIONS

The variables used in the model explained most of the variation observed in the datasets from Argentina on lucerne and Ireland on ryegrass-clover pastures. Predictions for grazing conditions other than Argentina may be improved by using data from particular grazing conditions in the empirical equation relating potential pasture intake and pasture allowance. The predicted values for DMI, harvesting efficiency and substitution rates for grazing dairy cows in Argentina will be useful for dairy farmers in deciding on the level of supplements and the stocking rates to be used. Additionally, the model can be used as part of a whole-farm model to predict the effects of stocking rate on farm productivity and profitability.

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