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# Mathematical model to predict the dry matter intake of dairy cows on pasture

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ABSTRACT

In pasture-based dairy systems, there is a close relationship between milk production and dry matter intake (DMI), hence the importance of measuring these variables, although obtaining this information implies high labour and costs. The objective of this study was to design a mathematical model to predict DMI for grazing dairy cows. This model was based on the basic principle of the fill-unit system. In this scheme, cows and feedstuffs were described in terms of feed intake capacity (FIC) and fill (unit/amount of feed), respectively. The FIC was determined by the animal's ability to regulate feed intake which depends on factors such as body size, age and lactation status. The "fill" was determined by the nutritional properties of the feedstuff such as its dry matter (DM) digestibility and crude protein (CP) content, among others. In the design of the model, *ad lib.* feed consumption was assumed. Parity, state of lactation and gestation were considered to estimate the cow ingestion capacity. Satiety values (SV) were determined for *Festuca arundinacea* and *Lolium multiflorum* and these values were incorporated into the model, including DM, CP, neutral detergent fibre (NDF) and *in vitro* digestible organic matter (dOM). The fixed parameters of the model were determined by adjusting a polynomial regression to the data from three experiments with lactating Holstein cows from Baja California, Mexico (n=30).The model allows predicting DMI, using as inputs, easily measured data and does not require knowing daily milk yield (MY) or body weight (BW), so the model is practical and consistent. The results obtained from the model were satisfactory because they were similar to those attained experimentally. Average DMI was 21.68 kg/d in one group and 23.44 kg/d in the other; when applying the model, we obtained an estimate of 22.82 kg/d for a cow with characteristics similar to those of the cows under study.

**Key words**: Dairy cows, Dry matter intake, Grazing, Mathematical model

Milk production on pasture depends on a large extent on the amount of forage consumed by cows. The age, body size, and pregnancy of the cow, as well as the chemical composition and nutritive value of the forage grazed influence forage intake. The purpose of this study was to design a mathematical model for estimating dry matter intake (DMI) for dairy cows on pasture. In order to develop such a model for estimating DMI, it is important to consider the characteristics of both the cows and the forage available. In the literature, there are various models that take into account these traits (Doole and Romera 2013, Gregorini *et al.* 2013). However, most of these remain constant, so that is not possible to apply existing models to predict DMI without considering certain differences in each grazing system, such as forage species, grazing patterns, among others (Mármol 2006). Zom *et al.* (2012) had proposed formulas to determine DMI; their model was based on the fundamental principle of the fill-unit system (Jarriage *et al.* 1986) and considers the main genetic and physiological characteristics that describe the animal in terms of feed intake capacity (FIC). The model proposed in the present research was based on the same system and, therefore, we contemplated these formulas.

There are many other models to predict DMI (Baudracco *et al.* 2010a, Krizsan *et al.* 2014, Berry *et al.* 2014) but these are based on milk yield or body weight (Zom *et al.* 2012) or do not contemplate characteristics of the animal or forage. The formulas proposed by Zom *et al.* (2012) were simplified by taking fewer constants that were obtained by polynomial regression from experimental data obtained from three separate experiments with dairy cows in Baja California, Mexico. The inputs related to the animal are the age, parity, lactation status, gestational state and gestational rate whose measurement is feasible. Inputs related to the forage depend on the grazing system such as type of forage, dry matter digestibility (DMD) and nutritional value. The model has more freedom to describe its qualities by the satiety value (SV) that will be described

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by dry matter (DM), as input; crude protein (CP), neutral detergent fibre (NDF), *in vitro* digestible organic matter (dOM) were estimated from forage DM.

## MATERIALS AND METHODS

*Essential principles of the model:* The model for predicting DMI of grazing dairy cows is based on the fundamental principle of the fill-unit system (FUS). The fill unit is defined as 1 kg DM of a reference young pasture grass having a fill value (FV) of one fill unit both in sheep (1 FUS) and in cattle (1 FUC). Its VDMI (in g/kg$^{0.75}$) amounts to 75 by the standard sheep (SS) and 122.6 by the standard lactating cow (SLC; 600 kg live weight, 17 kg daily milk yield) (Jarriage *et al.* 1986). In the FUS, an animal is described by the FIC (fill-units/d) and feed in terms of fill (fill-units/amount of feed) (Zom *et al.* 2012).

Zom *et al.* (2012) proposed to calculate DMI by means of the ratio between FIC and Fill according to the following equation:

$$\mathrm{DMI}\left(\frac{\mathrm{kg}}{\mathrm{day}}\right) = \frac{\mathrm{FIC\ (fill-unit/day)}}{\mathrm{Fill\,[fill-unit\ (kg\ DM)]}}$$

For the model, the same formula was chosen since it is possible to include and modify characteristics of both the cow and forage and there is no dependence between the two.

The FIC determined by the animal's ability to process forage, which depends on factors such as body size, age and lactation status. The Fill established by forage properties such as dry matter digestibility (DMD) and its chemical composition. An *ad lib.* feed assumed that cows will eat until the total amount of fill-units is equal to that of FIC.

*Festuca arundinacea* and *Lolium multiflorum,* two forage commonly present in pasture-based dairy farms in Mexico were considered. Each type of feed has its own quality:

$$\mathrm{DMI} = \frac{\mathrm{FIC}}{\sum_{i=1}^{n} f_i SV_i}$$

where [FIC=α+β (1–e$^m$) (re$^n$)] and considering n types of feed present in the grazing system, $f_i$ represents the feed fraction i and $SV_i$ its respective satiety value. Thus, $\Sigma_{i=1}^{n}$ fiSVi is the total satiety value.

The formula given is based on the work of Zom*et al.* (2012a) where α is a constant that describes the average base capacity of forage DMI, β represents the change in DMI capacity with respect to the days in milk, 1–e$^m$ represents the behaviour of the forage intake and e$^n$ describes the forage DMI during gestation.

For the forage quality, $f_iSV_i$ is determined by the chemical composition and DMD of the forage.

For the type of forage, i is the DM which considered to contained CP, NDF and dOM from DM in each type of forage.

The age of t cows is calculated as (p–1) + d / 365. Cows were assumed to be 'dry' at day 220 of gestation. To obtain the constant parameters, the interpolation method with Lagrange polynomials to the data provided by three separate experiments with Holstein cows in Baja California, Mexico, was applied.

The implementation of the algorithm was executed using the mathematical software MATLAB (Matrix Laboratory). To obtain the FIC, the input parameters were: parity, days in milk, days pregnant and gestation rate.

To obtain $\Sigma_{i=1}^{n} f_iSV_i$ the following variables were considered as inputs: DM, CP, NDF, and dOM; these were estimated from each forage, which were obtained by an adjustment of data (Table 1).

When executing the program, the following window appears requesting inputs of the cow, the dry matter of each forage and the proportion of each forage on the pasture (Fig. 1).

The characteristics of cows considered were parity, days in milk, days pregnant and rate of gestation. The characteristics of the forage are: DM of *Festuca arundinacea* and of *Lolium multiflorum* and their respective proportion in the pasture where the cows grazed.

Table 1. Chemical composition of *Festuca arundinacea* and *Lolium multiflorum*.

| DM (g/kg) | CP (g/kg DM) | NDF (g/kg DM) | dOM (g/kg DM) |
|---|---|---|---|
| *Festuca arundinacea*[a] | | | |
| 386.9 | 105.1 | 623.8 | 605.3 |
| 400.3 | 90.8 | 604.1 | 653.3 |
| 438.3 | 78.7 | 592.6 | 668.9 |
| 461.4 | 74.1 | 567.8 | 659.7 |
| 546 | 73.6 | 627.6 | 618.7 |
| *Lolium multiflorum*[b] | | | |
| 165 | 216 | 331 | 0.76 |
| 178 | 258 | 332 | 0.75 |
| 222 | 147 | 453 | 0.70 |
| 174 | 196 | 378 | 0.75 |
| 205 | 148 | 504 | 0.68 |

*Source:* [a]VanRensburg (2013), [b]Miguel *et al.* (2012).

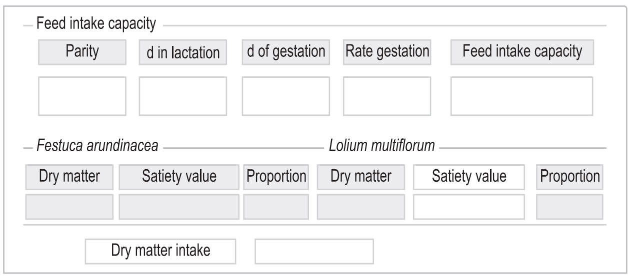


Fig. 1. Graphic User Interface (GUI) of MATLAB where the user types inputs from the model.

The model provides the forage intake capacity of each animal, the satiety value for *Festuca arundinacea* and *Lolium multiflorum*. Finally, it provides the amount of DM that the animal ingest daily in kg (Fig. 2).

*Program model validation:* Data from three commercial

Table 2. Dry matter consumption (kg/d)

| | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 6 | Week 7 | Average |
|---|---|---|---|---|---|---|---|---|
| Group 1 | 23.7 | 24.5 | 24.16 | 24.33 | 24.57 | 21.33 | 21.5 | 23.44 |
| Group 2 | 20.6 | 21.8 | 19.16 | 20.66 | 23.71 | 21.83 | 24 | 21.68 |

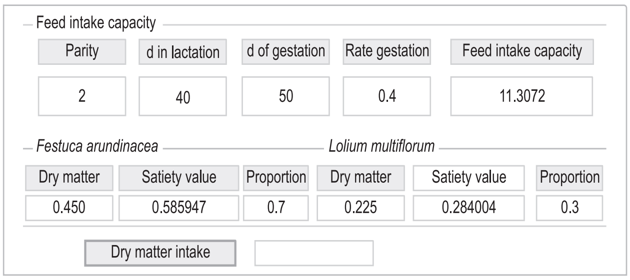


Fig. 2. The execution of the model estimates a feed intake of 22.826 kg. Of dry matter for a cow in its second parity.

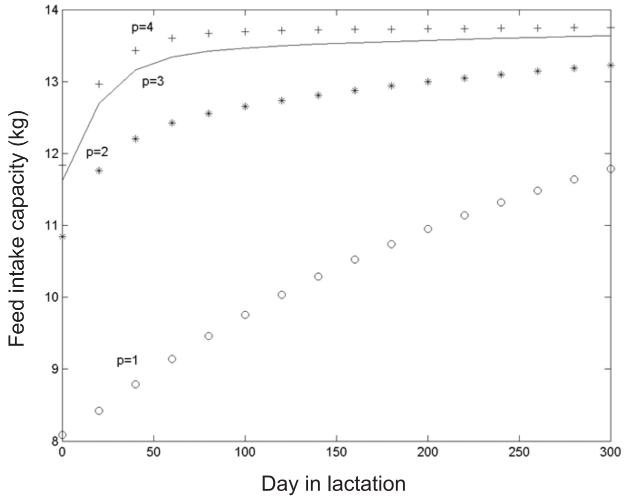


Fig. 3. Feed intake capacity (FIC) for 305-day lactation period for Holstein cows of different parities.

pasture-based dairy operations in southern Baja California, Mexico (including breed, age, season of lactation, gestation state and gestation rate) were obtained to validate the DMI prediction generated by the program. Data collected were DMI, daily milk production and diet ingredients and composition. The data were inserted in the generated model program for validating the results. Table 2 shows the average DMI obtained experimentally.

## RESULTS AND DISCUSSION

The models that use body weight (BW) and milk yield (MY) inputs are not precise in predicting dry matter intake (DMI) because MY and BW are variables that depend on DMI (Huhtanen *et al.* 2011, Zom *et al.* 2012). The proposed model does not present such lack of precision because BW and MY do not appear as inputs.

The model considered two types of forage; however, due to the prototype structure, it has the potential to predict DMI in different grazing systems, by adding the corresponding inputs. Since it predicts DMI for each cow and in various grazing systems, the model is plastic, practical and robust.

Parity is an input of the model; therefore, it is possible to estimate DMI as a function of parity. This confirms that there is a directly proportional relation with calving number (p), as seen in Fig. 3.

The direct relationship can be attributed to the high correlation between age and cow body size. The larger the animal, the higher the digestive tract capacity (Allison 1985, Doreau *et al.* 1985). On the other hand, Boudon *et al.* (2009) suggest that rumen fill depends on maturity. In fact, Fig. 3 shows that the animal's ingestion capacity increases as days in milk increase to an asymptotic level. Also, increasing parity leads to greater capacity for forage DMI.

Along with increasing the day of milk, and increased in number of parturitions (p), the DMI was increased. In the model, the main variables of cows, such as parity, days in milk and gestation were taken into account. The age of the cow was described in terms of parity and days in milk represented the physiological state of the cow, which generates changes in FIC and DMI as shown in Figs 3 and 4. We concluded that as parity and day in milk increase, the maximum forage DMI capacity is greater, and therefore, there is an increase in DMI. However, it is clear that the forage intake capacity tends to be the same for parities greater than or equal to three (Fig. 4). Berry *et al.* (2014) found that DMI ranged from 15.6 to 24.9 kg/d; with our model DMI estimates ranged from 16 to 25 kg/d (Fig. 4), with close coincidence between both models. Volden *et al.* (2011) report a minimum DMI of 9.7 kg/d and a maximum

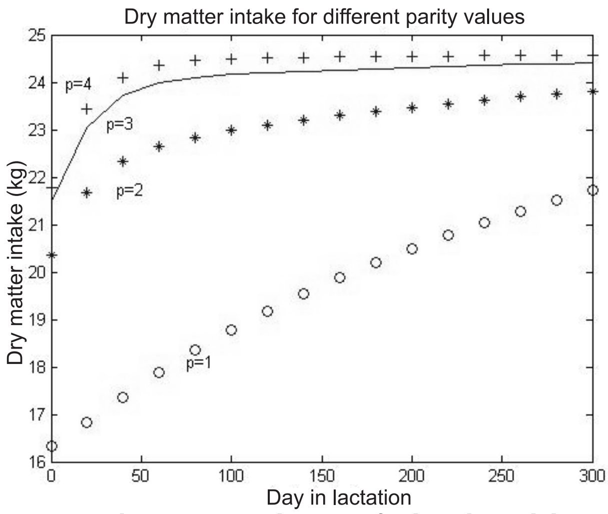


Fig. 4. The association between feed intake and days in milk, as a function of parity (p).

of 32.3 kg/d, which shows significant differences with the proposed model. These differences can be attributed to metabolic regulation (Volden *et al.* 2011) and to the fact that environmental factors influencing DMI are not considered (Mertens 1994, Ingvartsen 1994).

Unlike the NRC model published in 2001, which only uses animal characteristics as inputs, and therefore over-predicts DMI (Jensen *et al.* 2015), our study considers characteristics of both cows and forage. Although environmental characteristics are not considered, the model estimates are consistent and do not differ significantly from results of other studies. Another advantage to consider with respect to the model of Zom *et al.* (2012) is that DM, CP, NDF and dOM of forages are considered in that model, whereas the model described here only needs DM. We conclude that the model presented in the present study is consistent because the average DMI in group 2 was 21.68 kg/d and in group 1 it was 23.44 kg/d. The model estimates a DMI of 22.83 kg/d for a cow that meets, on average, the characteristics of the cows under study.

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