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Validation of a bio-economic dairy production model

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Abstract

DairyMax is an internet-based bio-economic dairy production model that uses a deterministic cow model to establish response curves of milksolids (MS; fat plus protein) production to energy intake at different stages of lactation and nutrient requirements for different levels of production. Another component in DairyMax is a linear programming module that uses farm-related constraints, market prices for supplements, cost of pasture and silage production and cow-related constraints to optimise a feeding strategy based on a maximum profit algorithm. The objective of this study was to validate the cow model of DairyMax against published field work conducted in New Zealand. In DairyMax, the stocking rate was adjusted to get the same MS production as in the experiment. The dry matter intake (DMI) associated with the different production levels were compared assuming energy content of 11.2 MJ ME/kg dry matter, similar to that reported in a three-year field experiment. The ability of the model was satisfactory in predicting yearly DMI per cow (Concordance correlation coefficient = 0.98). Productive performance, DMI and feed conversion efficiency (ratio between DMI and MS) of dairy cows under different stocking policies can be predicted by DairyMax with satisfactory accuracy.

Keywords: modeling; linear programming; feed budget; maximum profit

Introduction

The use of simulation modelling is widely acknowledged as a valuable approach to establish the response of animals to nutrient intake. Bryant et al. (2005) mention a number of models that are used to predict dairy cattle performance under varying conditions.

A common approach in the formulation of dairy diets is the use of linear programming packages to optimise the combination of ingredients to meet animal requirements for a given production level (Varela- Alvarez & Church 1998, Pesti & Miller 1993, Weaver et al. 1988). The usual approach is to determine the nutrient requirements for a given production level and to minimise the cost of meeting these requirements. An alternative approach is to maximise profit from feeding, where the difference between the value of the output and the cost of production is maximised.

DairyMax is an internet-based bio-economic model that uses a maximum-profit algorithm to maximise the margin over feed (www.DairyMax.co.nz). A deterministic cow-model describes the maximum possible production level and the maximum dry matter intake (DMI) in different stages of lactation for a given cow-genotype and uses that information to build a constraint-set in a linear programming module.

As the reliability of recommendations based on the linear programming module from DairyMax depends on the accuracy of the inputs from the biological cow-model, the objective of this study was to compare DMI and milksolids (fat plus protein) production (MS) responses in pasture-based systems calculated by DairyMax with measured DMI and MS from research experiments, to validate the biological model.

Materials and methods

Model development

The first module of DairyMax is a deterministic component that simulates the response of MS to different levels of intake under some animal-related limits. The second module is a linear programming component that uses the results from the deterministic component to set constraints for optimization problems. DairyMax formulates a yearly feed budget for dairy farmers with the objective to provide the best combination of feed resources that give the maximum possible return from feeding within a given set of constraints. The most important types of constraints are related to the animal, the farm and the availability of feeds.

The deterministic module calculates lactation curves for a given cow-genotype at the maximum possible production level for that cow. After adjustment for parity, the lactation curve is split up in 10 monthly sections, and the average daily production level in each section is considered to be the maximum possible production level in the corresponding month of lactation. This maximum potential production level is used to establish response curves of energy intake to milk production. Further, maximum DMI is calculated for each month of the lactation and the dry period, based on metabolic and physical limitations. The response

Figure 1 A standard lactation curve for a Holstein-Friesian cow describing maximum potential of milk per period where the ten 30-day-periods are separated by vertical bars. The horizontal bars represent the mean calculated maximum production potential for Period 3 (60–90 days in milk), Period 6 (150–180 days in milk) and Period 9 (240–270 days in milk) as the maximum values for the curves presented in Figure 2.

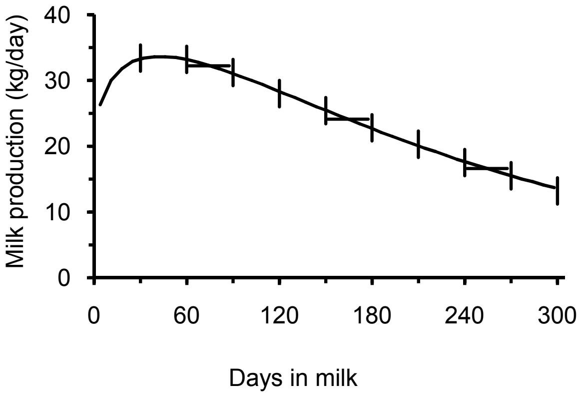
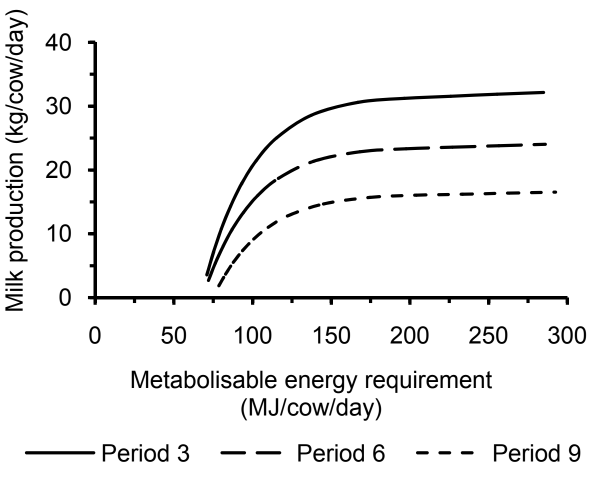


Figure 2 Response curves of daily milk production for a 515 kg Holstein-Friesian cow to changes in metabolisable energy intake during Period 3 (60–90 days in milk), Period 6 (150–180 days in milk) and Period 9 (240–270 days in milk) during a simulated standard lactation curve divided into ten 30-day-periods shown in Figure 1.



curves and maximum DMI are used in the linear programming module to set up constraints.

In order to set up the constraints related to feed availability in the linear programming module, the system uses inputs from the farm description including number of hectares in grass, a grass growth pattern for the farm, nutritional composition of pasture in different times of the year, supplements that can be acquired, and nutritional composition of supplements.

Prices for feed resources are derived from the cost of maintaining pasture such as fertiliser and pasture renewal, or directly taken as the cost of commercially available supplements.

A linear programming algorithm to maximise profit from feeding is described by Varela- Alvarez et al. (1998), Pesti et al. (1993), Hulme et al. (1986) and Dean et al. (1969). DairyMax uses a similar approach, although the static system of one maximum production level is extended to a series of monthly maximum production levels, similar to the approach taken by McCall et al. (1999) and McCall & Clark (1999). The model generates response curves of milk production to energy intake for each month of lactation. The lactation curve for the maximum possible production level for a given type of cow is split up in monthly sections, and the average maximum production level in a particular period is considered to be the maximum possible production for that month (Fig. 1). For each month, a response curve is established that describes the milk production response to energy intake. The response curves are linearised in order to be able to use them in a linear program. The maximum possible response is determined by the stage of lactation (Fig. 2).

Other nutritional constraints are added which are mainly related to rumen health. There is a minimum requirement for the percentage of physically effective neutral detergent fibre in the daily ration. This is set at 33% of DMI, which is considered a safe level (Zebeli et al. (2007).Thee is also a maximum for fat from supplements that is set at 5% of DMI (NRC 2001). The linear program produces a per-month feeding regime within the limitations described above. Apart from the energy requirements for different production levels in different stages of lactation, including requirements for maintenance, the requirements for other nutrients are included in the calculation as well, like crude protein, macro minerals and trace minerals.

Model validation

A dataset by Macdonald et al. (2008) was used to compare DMI and MS production with the calculated feed budgets from DairyMax. Macdonald et al. (2008) described an experiment where dairy cows were fed at five different stocking rates and actual feed intake was estimated.

Pasture utilisation in the experiment was derived by dividing the DMI per hectare per year by the total DM production per hectare per year (Table 1). With the assumption that the pasture utilisation was constant throughout the year, stocking rate was adjusted in DairyMax to obtain the same milksolids production as in the experiment. Stocking rate was the only variable that was changed to match milksolids production between the trial and DairyMax, after all other variables were set to be the same as in the experiment.

The DMI associated with the production levels of the five different stocking rate groups between the experiment and DairyMax were compared. The average metabolisable energy (ME) value in DairyMax was assumed to be 11.2 MJ/kg dry matter (DM), the same as reported for the experiment. The

Table 1 Production parameters for increasing stocking rates, shown in bold, as reported by Macdonald et al. (2008) and calculated using DairyMax. DMI = Dry matter intake; MS = Milk solids (Fat + Protein).

Source	Measurement	Production with increasing stocking rate				
Macdonald et al. (2008)	Stocking rate	**2.2**	**2.7**	**3.1**	**3.7**	**4.3**
	DMI (kg/cow/yr)	5,597	5,216	4,755	4,569	4,282
	MS (kg/cow/yr)	407	360	338	295	265
	Lactation length (months)	10	9	8	8	7
	Pasture production (kg DM/ha/yr)	18,048	18,050	19,484	18,538	20,394
	Pasture utilisation (%)	72	81	77	86	82
	kg DMI/kg MS	13.8	14.5	14.1	15.5	16.2
DairyMax	Stocking rate	**2.3**	**2.6**	**2.9**	**3.4**	**3.8**
	DMI (kg/cow/yr)	5,583	5,113	4,884	4,545	4,304
	MS (kg/cow/yr)	406	360	336	297	264
	Lactation length (months)	10	9	8	8	8
	Pasture production (kg DM/ha/yr)	18,007	18,007	19,497	18,585	20,410
	Pasture utilisation (%)	72	81	77	86	82
	kg DMI/kg MS	13.8	14.2	14.5	15.3	16.3

feed budgets were calculated from August through to the following July.

The publication of Macdonald et al. (2008) mentions different pasture DM production ranging from 18,045 to 20,394 kg DM/ha/yr. In the validation, the pasture growth pattern of Horsham Downs in the Waikato region of New Zealand (total yearly production: 14.7 t DM/ha) (DairyNZ 2010), was used to represent a grass growth pattern of a similar geographical area as where the experiment was held. These values were multiplied by 1.23, 1.23, 1.33, 1.27 and 1.39 for stocking rates 2.2, 2.7, 3.1, 3.7 and 4.3, so that the accumulated total was similar to the pasture DM production for the different stocking rates reported by Macdonald et al. (2008).

The total DMI from the experiment was compared with the total DMI from DairyMax, simulated with different stocking rates. Values of ME for pasture in DairyMax were set to 10.7, 10.3, 9.8, 10.5, 11.0, 11.4, 11.9, 12.1, 12.1, 11.9, 11.6, 11.3 MJ/kg DM for the months of January to December, which approximates to the pattern described by Litherland & Lambert (2007) and N.W.Mouton (Personal communication), which averages to a value of 11.2 MJ/kg DM. The average cow weight was set to 515 kg.

The ability to predict DMI required for the given production levels was evaluated by the relative prediction error (RPE) (Fuentes-Pila et al. 2003) and the concordance correlation coefficient (CCC) (Lin 1989) was calculated as:

$$\text{RPE} = (\text{MPE}/\ \bar{A}) \times 100$$

$$\text{CCC} = \frac{2S_{AP}}{S_A^2 + S_P^2 + (\bar{A} - \bar{P})^2}$$

where

$$\text{MPE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(A_i - P_i)^2}$$

A_i is the ith observed actual value and P_i is the ith predicted value by Dairymax. Means ($\bar{A}$ and $\bar{P}$) variances (S_A^2 and S_P^2) and covariance (S_{AP}) of Ai and Pi are calculated in the usual way.

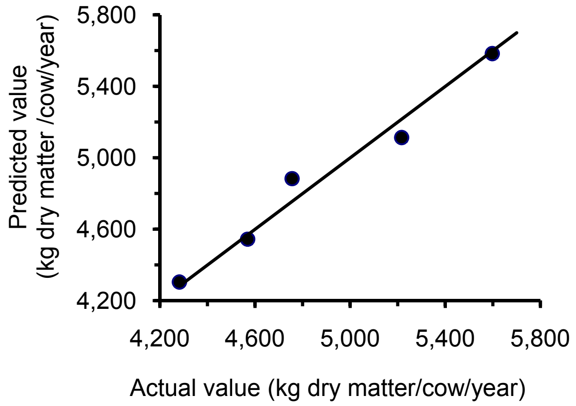
Fuentes-Pila et al. (1995) suggested that a RPE value lower than 10% is an indication of satisfactory prediction, whereas a RPE between 10% and 20 % indicates a relatively acceptable prediction, and a REP greater than 20% indicates poor prediction. Values corresponding to the CCC and their significance are as follows: Fair prediction – from 0.21 to 0.40; Moderate prediction – from 0.41 to 0.60; Substantial prediction – from 0.61 to 0.80; and almost Perfect prediction – from 0.81 to 1.00.

Results and discussion

The DMI and milksolids production observed in the trial of Macdonald et al. (2008) and simulated with DairyMax for different stocking rates are presented in Table 1.

The production of total milksolids per cow predicted by DairyMax was made to agree with the actual values reported by Macdonald et al. (2008), by adjusting the stocking rate. The stocking rates used in DairyMax to match the production of milksolids observed in the trial are lower than the actual values of stocking rates (RPE = 9.79, CCC = 0.90). Although Macdonald et al. (2008) mention that silage made from surplus pasture was kept within the each farmlet corresponding with a particular stocking rate, the data suggest that silage made on the farmlets for stocking rate 2.2, 2.7 and 3.1 was transferred to the farmlets for stocking rates 3.7 and 4.3, as the latter consumed more silage than was made on the corresponding farmlets. Also supplementary feed was provided for stocking rates 3.7 and 4.3. In the simulations no external resources were used and DMI was assumed to come from pasture or silage. This could be an additional reason for the lower stocking

Figure 3 Actual (X-axis) values from Macdonald et al. (2008) and predicted (Y-axis) values from DairyMax for yearly dry matter intake required for the calculated production levels of kg dry matter intake per kg milk solids. The solid line is the line of perfect agreement.



rates needed in DairyMax to achieve the same MS production.

The values of DMI predicted by DairyMax agree well with the actual values reported in the trial of Macdonald et al. (2008) (RPE = 1.6%, CCC = 0.99) (Fig. 3).

The ratio between kilograms of DMI and kilograms of milksolids in DairyMax is in the same range as in the experiment (14.1 to 16.3 vs 13.8 to 16.2, RPE = 1.7% and CCC = 0.96).

Woodward et al. (2011) reported a range of feed conversion efficiencies of 10.3 and 14.4 kg DM/kg MS between cows of high and low genetic merit. Tolosa et al. (2001) report a feed efficiency of approximately 9.3 and 9.4 kg DM/kg MS for heavy and light Holstein-Friesians. Jensen et al. (2005) reported an estimated feed efficiency of 12.8 kg DM/kg MS observed from the Resource Efficient Dairying trial. Values ranging from 9.1 to 15.6 can be derived from Holmes et al. (2007) for Friesian cows producing 0.7 to 2.1 kg MS per day, depending on body weight. This range increases when weight loss and weight gain are taken into account. Feed conversion efficiency in this study ranged from 13.8 to 16.2 (Experiment) and 14.1 and 16.3 (DairyMax).

It is possible that the differences between the predicted values by DairyMax and actual values for feed efficiency can be attributed to differences in weight change during lactation. DairyMax allows for body weight change during lactation, with the restriction that body weight change across the year is zero. When cows gain or loose weight, there is inefficiency in the conversion of energy to body fat and vice versa. This decreases the utilisation of energy and increases the total energy requirement.

A conclusion from this study is that under the described conditions of pasture based-systems, productive performance and feed conversion efficiency can be predicted by DairyMax with satisfactory accuracy.

References

Bryant J, Lopez-Villalobos N, Holmes C, Pryce J 2005. Simulation modelling of dairy cattle performance based on knowledge of genotype, environment and genotype-environment interactions: current status. Agricultural Systems 86: 121–143.

DairyNZ 2010. Facts and figures for New Zealand dairy farmers. DairyNZ, Hamilton, New Zealand. Pg 66-75. www.resources.dairynz.co.nz/DownloadReource.aspx?id=502 [Accessed 5 May 2012]

Dean GW, Bath DL, Olayide S 1969. Computer program for maximizing income above feed cost from dairy cattle. Journal of Dairy Science 52: 1008–1016.

Fuentes-Pila J, DeLorenzo MA, Beede DK, Staples CR, Holter JB 1996. Evaluation of equations based on animal factors to predict intake of lactating Holstein cows. Journal of Dairy Science 79: 1562–1571.

Holmes CW, Brookes IM, Garrick DJ, Mackenzie DDS, Parkinson TJ, Wilson GF 2007. Milk production from pasture. Principles and practices. Palmerston North, New Zealand. Massey University. Pg 53-68.

Hulme DJ, Kellaway RC, Booth PJ, 1986. The CAMDAIRY Model for formulating and analysing dairy cow rations. Agricultural Systems 22: 81–108.

Jensen RN, Beules PC, Clark DA, Macdonald KA 2005. Modelling dairy system efficiencies. Proceedings of the New Zealand Society of Animal Production 65: 203–208.

Lin LIK 1989. A concordance correlation coefficient to evaluate reproducibility. Biometrics 45: 255–268.

Litherland AJ, Lambert MG 2007. Factors affecting the quality of pastures and supplements produced on farms. In: Rattray PV, Brooks IM, Nicol AM. eds. Pastures and supplements for grazing animals. New Zealand Society of Animal Production, Hamilton, New Zealand. Occasional Publication No. 14. Pg 81–96.

Macdonald KA, Penno JW, Lancaster JAS, Roche JR 2008. Effect of stocking rate on pasture production, milk production and reproduction of dairy cows in pasture-based systems. Journal of Dairy Science 91: 2151–2163.

McCall DG, Clark DA, Stachurski LJ, Penno JW, Bryant AM, Ridler BJ 1999. Optimised Dairy Grazing Systems in the Northeast United States and New Zealand. I. Model description and evaluation. Journal of. Dairy Science 82: 1795–1807.

McCall DG, Clark DA 1999. Optimised Dairy Grazing Systems in the Northeast United States and New Zealand. II. System Analysis. Journal of Dairy Science 82: 1808–1816.

NRC 2001. Nutrient requirements for dairy cattle. 7th edn. Washington, USA: National Academy of Science. 381 p.

Pesti GM, Miller BR 1993. Formulating feeds for dairy cattle. In: Animal Feed Formulation, Economics and Computer Applications. New York, Chapman and Hall, Pg 55–71.

Tolosa MX, Caicedo-Caldas A, Holmes CW, Lopez-Villalobos N 2001. Intake, live weight and feed conversion efficiency of lactating Holstein-Friesion dairy cows which differ genetically in live

weight. Proceedings of the New Zealand Society of Animal Production 61: 221–223.
Varela-Alvarez H, Church DC 1998. Ration formulation. In: Kellems RO, Church DC eds. Livestock feeds and feeding. Fourth edition. Upper Saddle River, NJ, USA, Prentice-Hall, Pg 215–242
Weaver LD, Olivas MA, Galland JC 1988. Identifying features, performance and limitations of dairy ration formulation software: A comparison of three formulation programs. Journal of Dairy Science 71: 1104–1115.
Woodward SL, Waghorn GC, Bryant MA, Mandok K 2011. Are high breeding worth index cows more feed conversion efficient and nitrogen use efficient? Proceedings of the New Zealand Society of Animal Production 71: 109–113.
Zebeli Q, Dijkstra J, Tafaj M, Steingass H, Ametaj BN, Drochner W 2007. Modeling the adequacy of dietary fiber in dairy cows based on the responses of ruminal pH and milk fat production to composition of the diet. Journal of Dairy Science 91: 2046–2066