Evaluation of an application for dynamic feeding of dairy cows

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Abstract

Dynamic feeding is an innovative application for concentrate feeding of dairy cows. Daily individual settings are derived from the actual individual milk yield response to concentrate intake. This response is estimated using an adaptive dynamic linear model. Optimal daily individual settings for concentrate supply are directed to achieve the maximum gross margin milk returns minus concentrate costs. This response curve plays a key role in the application. The response curve is derived from a mechanistic model for milk production and can also be established empirically from daily milk yield development during early lactation when concentrate supply increase is linear. A test application for dynamic feeding ran for several months in 2008 and results from 145 cows at one farm on 17 December 2008 have been used to demonstrate the variation in individual response. The gross margin, milk returns minus concentrate costs, varied from 2.52 to 26.32 €/day. The estimated response parameters provide insight in variation between individuals concerning the effects of concentrate and base ration intake on daily milk yield. Economical and nutritional aspects can be evaluated for each individual. Individual dynamic feeding towards an economic optimum indicates that excessive changes in individual bodyweight[i] can be prevented.

Keywords: response curve, dynamic linear model, economic optimum, energy balance, concentrate feeding

Introduction

Automation of concentrate feeding and milking enables application of individual cow settings for concentrate allocation and milking frequency. An adaptive model has been developed to estimate the individual dynamic milk yield response to concentrate intake and milking interval. Based on estimated response parameters, a control algorithm calculates daily individual optimal settings, to maximize gross margin milk returns minus concentrate costs . This concept for precision dairy farming is an innovative approach to feeding and milking with promising economic results (André et al., 2007). The whole concept, also called dynamic feeding has been implemented on dairy farms throughout the Netherlands in cooperation with industrial companies (Bleumer et al., 2009).

The existence of individual and temporal variation is recognized in common practice and animal science. However, it is difficult to convince nutritionists, animal scientists and end-users that this variation can be utilized for improvement of feeding and milking. Within the dynamic concept milk yield response as function of concentrate intake plays a key role and a good understanding of the concept of dynamic feeding is essential for biometrical engineers to explain the functioning of dynamic feeding to animal scientists and farmers.

The objective of this paper is to improve understanding of the concept of dynamic responses. The response curve is derived from existing paradigms about feeding and milking. Results from individual cows are used to demonstrate individual variation and to evaluate the consequences for economical and nutritional aspects.

Material and methods

Farm situation and data

The research was performed at dairy research farm 'Waiboerhoeve' of the Animal Sciences Group in Lelystad. Cows (*Holstein Friesian*) were kept in four different herds, housed in 4 adjacent sections of the free-stall barn and had different types of floors, otherwise, housing conditions were similar for all cows. Cows from each herd were milked with a single unit AM-system (Lely Astronaut™). Water and a partially-mixed ration were available ad lib. The partially-mixed ration comprised grass silage, maize silage, grass straw and extracted soya bean (see Table 1). Daily settings for individual concentrate supply and milking interval were calculated with a test application for dynamic milking and feeding after André et al. (2007). For this investigation data was used concerning concentrate intake of 145 cows, collected on 17 December 2008. The test application had been running for several months prior to this.

Table 1. Content and intake of dry matter and energy of base ration components and concentrates.

Component	**Dry matter content** (%)	**Energy content** (VEM[a]/kg DM)	**Dry matter intake** (kg/day)	**Energy intake** (VEM/day)
Partially-mixed ration				
• Grass silage	40	1,000	8.00	8,000
• Maize silage	35	857	6.88	5,896
• Grass straw	84	700	0.32	224
• Extracted soya bean	87	1,160	0.80	928
Total			16.00	15,048
Concentrates	88	940	0.14 - 11.46	132 – 10,772

[a] 1 VEM = 6.9 kJ NE_L

Modelling the effect of concentrate and milking interval on milk production

At a specific moment during lactation milk secretion rate depends on the number of active alveoli and the energy status of the cow (Vetharaniam et al., 2003). The milk secretion rate is inhibited if the amount of milk in the udder M_m approaches the maximum udder capacity μ:

$$\frac{dM_m(C,I)}{dI} = \gamma(C)\left(1 - \frac{M_m(C,I)}{\mu}\right) \quad (1)$$

with:

$\frac{dM_m(C,I)}{dI}$	milk secretion rate (kg/day)
I	interval length (day)
C	concentrate intake (kg/day)
$M_m(C,I)$	milk yield (kg) at interval length I and concentrate intake C
$\gamma(C)$	maximum milk secretion rate reflecting energy status (kg/day)
μ	maximum udder capacity (kg)

This model is equivalent to the mechanistic model described by France and Thornley (1984) after Knight (1982) and Mepham (1976). Integration (1) gives $M_m(C,I)=\mu\left(1-e^{-\frac{\gamma(C)I}{\mu}}\right)$ a nonlinear function that can be approximated by a linear quadratic function:

$$M_m(C,I)\approx\left(\alpha_0+\alpha_1C+\alpha_2C^2\right)I+\beta_2I^2 \tag{2}$$

This response function describes milk yield at each *milking* and forms the base for dynamic feeding. The milk yield per *day* depends on the number of milkings per day $\left(n=I^{-1}\right)$. The response curve for milk yield per day is:

$$M_d(C,I)=nM_m(C,I)\approx\alpha_0+\alpha_1C+\alpha_2C^2+\beta_2I=\alpha_0^*+\alpha_1C+\alpha_2C^2 \tag{3}$$

assuming that the milkings are at regular intervals and simplified by defining $\alpha_0^*=\alpha_0+\beta_2I$.

During early lactation daily milk yield increases rapidly from around calving to a peak a few weeks later. Three processes, controlled by the cow, occur during this transition period:

1. The number of active alveoli increases to a maximum, determining the maximal potential milk yield. This process is known as cell proliferation.
2. Roughage intake increases to a maximum intake capacity, to fulfil the cows increasing nutrient requirement.
3. Generally, especially for high yielding cows, nutrient intake comprising solely of roughage is insufficient to meet requirements and the cow will mobilize body reserves.

In order to stimulate the increasing production during early lactation concentrates are added to the ration. Although roughage intake declines during this period substitution with concentrates ensures that the total nutrient intake is increased. Common strategy in the Netherlands for concentrate feeding after calving is to start with a low level followed by a linear increase of 0.5 kg/day during the first 2 to 3 weeks. Consequently, mobilization of body reserves is decreased and actual milk yield will approach the potential milk yield. The course over time of potential milk yield (not limited by nutrient intake), base milk yield (feeding only roughage) and actual milk yield (feeding roughage with linear increase of concentrates) is schematically displayed in Figure 1.

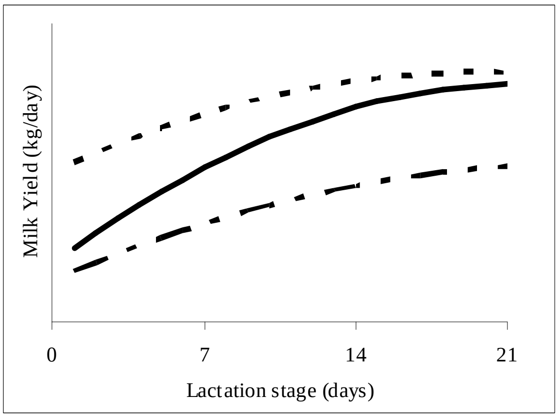

Figure 1 Development of actual (—), potential (- - -) and base milk yield (- · -) during early lactation.

Actual milk yield M_{Act} can be described by a linear quadratic function of time t:

$$M_{Act,t} = a_0 + a_1 t + a_2 t^2 \tag{4}$$

Concentrate intake can be described as a linear function of time:

$$C_t = b_0 + b_1 t \Rightarrow t = \frac{C_t - b_0}{b_1} \tag{5}$$

By substitution of (5) into (4) $M_{Act,t}$ can also be described by a linear quadratic function of C_t:

$$M_{Act,t} = \left\{ a_0 - \frac{a_1 b_0}{b_1} + \frac{a_2 b_0^2}{b_1^2} \right\} + \left\{ \frac{a_1}{b_1} - \frac{2 a_2 b_0}{b_1^2} \right\} C_t + \left\{ \frac{a_2}{b_1^2} \right\} C_t^2 \tag{6}$$

resulting in a response function equivalent to (3).

Estimation of the response curve during early lactation enables forecasting of future milk yields. The according concentrate intake is calculated using (5). For example, the maximum milk yield is the prediction from (4) at $t_{Max} = -\frac{a_1}{2a_2}$. Note that exactly the same result is achieved by prediction from (3) at $C_{Max} = -\frac{\alpha_1}{2\alpha_2}$.

Individual economic optimal concentrate feeding

From an economic point of view feeding towards maximum milk yield per day is suboptimal. The economic optimum is calculated by maximizing the gross margin S, milk returns minus concentrate costs, depending on the prices for milk π_M and concentrates π_C:

$$S = \pi_M \left(\alpha_0^* + \alpha_1 C + \alpha_2 C^2 \right) - \pi_C C \tag{7}$$

The maximal gross margin is achieved at $C_{Opt} = -\frac{\pi_M \alpha_1 - \pi_C}{2\pi_M \alpha_2}$.

Usually: $\alpha_1 > 0$ and $\alpha_2 < 0$, so $0 \le C_{Opt} \le C_{Max}$.

Allowing for variation between and dynamic variation within individuals the parameters of the response curve are estimated for each cow separately using a first order dynamic linear model (West and Harrison, 1997). Observational time series consist of daily accumulated milk yield per milking M_{it}, daily accumulated interval lengths ΣI_{it} and the moving average over the previous three days of concentrate intake $\bar{C}_{it}$ per day. The observation equation is $M_{it} = \left(\alpha_{0,it} + \alpha_{1,it} \bar{C}_{it} + \alpha_{2,it} \bar{C}_{it}^2 \right) \Sigma I_{it} + \beta_{2,it} \Sigma I_{it}^2 + \varepsilon_{it}$; $\varepsilon_{it} \sim N\left(0, \sigma_{it}^2\right)$. The system equation is $\left(\alpha_{0,it} \quad \alpha_{1,it} \quad \alpha_{2,it} \quad \beta_{2,it} \right)' = \left(\alpha_{0,it-1} \quad \alpha_{1,it-1} \quad \alpha_{2,it-1} \quad \beta_{2,it-1} \right)' + \boldsymbol{\delta}_{it}$, assuming that the parameters are locally constant. The system error $\boldsymbol{\delta}_{it} \sim MVN\left(\mathbf{0}, \mathbf{W}_{it}\right)$ is estimated as a fixed proportion of the covariance-matrix of the parameters by using discount factors.

Results and discussion

Economical aspects

Table 2 shows the predicted optimal results for 7 cows on 17 December 2008. The cows are selected based on gross margins, resp. the 5, 25, 50, 75 and 95 percentile including the minimum and maximum within the 145 cow herd. During early lactation high yielding cows are supplied higher gifts of concentrate and achieve the highest gross margins. Note also the effect of higher milk prices. The concentrate price $\pi_C = 0,279$ €/kg.

Table 2. Predicted optimal results for 7 cows out of a herd of 145 cows on 17 December 2008.

Gross Margin (€/day)	**Percentile**	**Optimal Concentrate Intake** (kg/day)	**Optimal Milk Yield** (kg/day)	**Days in lactation**	**Milk Price** (€/100 kg)
2.52	min.	0.0	5.7	410	43.76
5.86	5%	0.2	13.5	321	43.90
8.81	25%	0.0	20.0	449	44.12
10.19	50%	3.0	25.0	409	44.20
12.86	75%	6.5	38.6	254	37.98
18.43	95%	6.4	42.4	40	47.65
26.32	max.	8.5	50.9	38	56.34

The predictions in Table 2 are based on the parameter estimates given in Table 3. The intercept corrected for interval length and the effect of optimal concentrate intake can be predicted from the estimates.

Table 3. Parameter estimates, predicted intercept corrected for interval length and concentrate effect for 7 cows out of a herd of 145 cows on 17 December 2008.

Percentile	α_0	α_1	α_2	β_2	α_0^*	$\alpha_1 C_{Opt} + \alpha_2 C_{Opt}^2$
min.	8.4	0.49	-0.061	-10.3	5.7	0.0
5%	16.6	0.65	-0.033	-11.5	13.3	0.2
25%	22.2	0.15	-0.051	-5.2	20.0	0.0
50%	24.2	1.39	-0.129	-11.2	21.9	3.1
75%	30.6	2.68	-0.148	-13.2	27.5	1.1
95%	39.3	1.39	-0.061	-15.0	36.0	4.4
max.	46.0	1.62	-0.064	-21.4	41.8	9.1

Figure 2 shows optimal results for all cows within the herd. The gross margin is also divided into the effect of optimal concentrate intake $\pi_M\left(\alpha_1 C_{Opt} + \alpha_2 C_{Opt}^2\right) - \pi_C$ and milk returns due to the corrected intercept $\pi_M \alpha_0^*$.

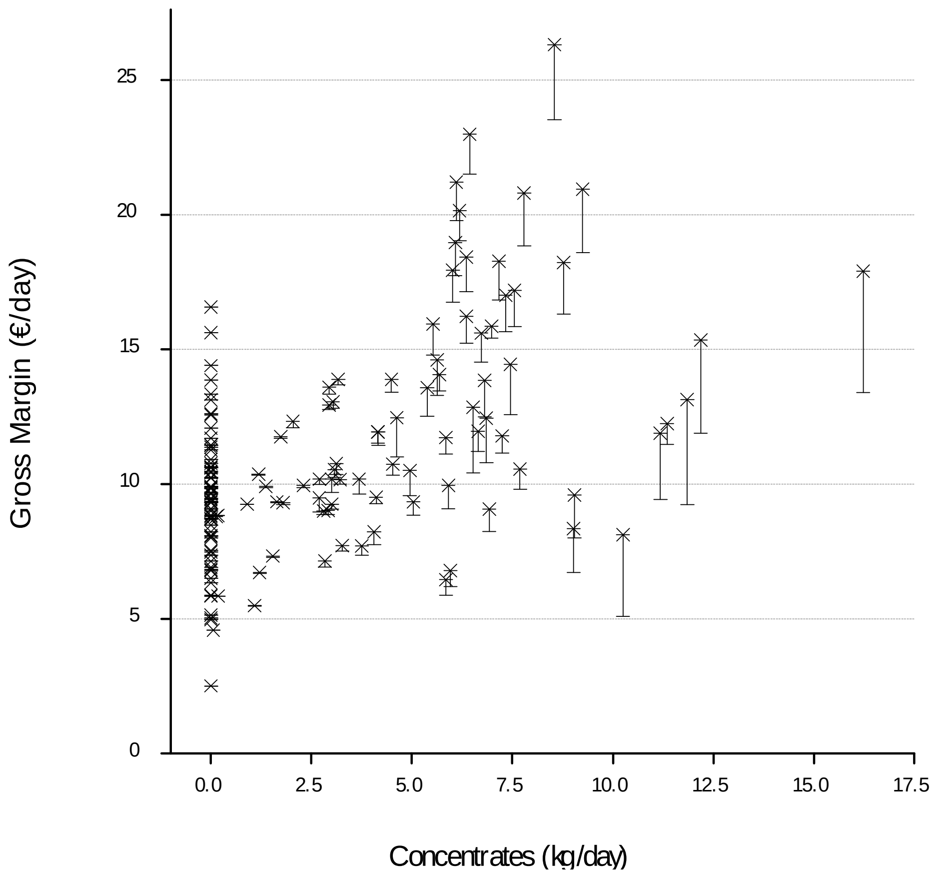

Figure 2 Predicted gross margin (×) at optimal concentrate intake for 145 cows on 17 December 2008. The vertical bar shows the effect of concentrates and the lower end of the bar represents the milk returns to the intercept corrected for interval length.

For 64 cows (44%) $C_{Opt} = 0$ kg/day the base ration is sufficient to achieve the maximal gross margin. For 40 cows (28%) C_{Opt} lies between 0 and 5 kg/day showing a small effect of concentrate intake on the gross margin. For 36 cows (25%) C_{Opt} lies between 5 and 10 kg/day showing a moderate effect of concentrate intake on the gross margin. The highest gross margins were achieved within this group. For the remaining 6 cows (3%) $C_{Opt} > 10$ kg/day displayed the greatest effects of concentrate intake on gross margin. Since a great part of cows display $C_{Opt} = 0$ this would suggest that the base ratio is amply sufficient for these cows to meet their requirements.

Nutritional aspects

In order to balance the dairy cows' ration the energy supply in the base ration (E_R) and supplemental concentrates (E_C) should provide sufficient to meet the requirement for maintenance, including addition for growth and gestation, $\left(E_O\right)$ and actual milk production $\left(E_M\right)$ (Van Es, 1978), so:

$$\begin{aligned} E_R + E_C &\geq E_O + E_M \\ E_C &\geq E_O + E_M - E_R \end{aligned} \qquad (8)$$

The energy requirements $E_O = 5,323\,\text{VEM}$ and $E_M = 460 M_d\,\text{VEM}$ are based on accepted standards (CVB, 2005); energy supply in the base ration $E_R = 15,048$ VEM is calculated from average feed intake, ration of diet composition and chemical analysis. The minimal concentrate requirement C_{Rq} kg/day is calculated from the energy content of the concentrates (see table 1):

$$C_{Rq} = \frac{E_C}{940 \times 0.88} = \frac{5,323 + 460 M_d - 15,048}{940 \times 0.88} \tag{9}$$

Note that in this *requirement* curve concentrate supply is a function of milk production but that in the *response* curve milk production is a function of concentrate intake. The *response* curve enables an acceptable prediction of the *expected* milk production in relation to concentrate intake while the *requirement* curve is intended to calculate the required concentrate supply in relation to the *actual* daily milk production. Another important distinction is that the *requirement* curve is based on the *assumption* that roughage intake is 16 kg dm/day (equivalent to 15,048 VEM/day), while the *response* curve *estimates* the actual performance of each individual cow. In Figure 3 the *requirement* curve is displayed together with the *response* curve for the 50% percentile median cow (see table 3 for the response parameters).

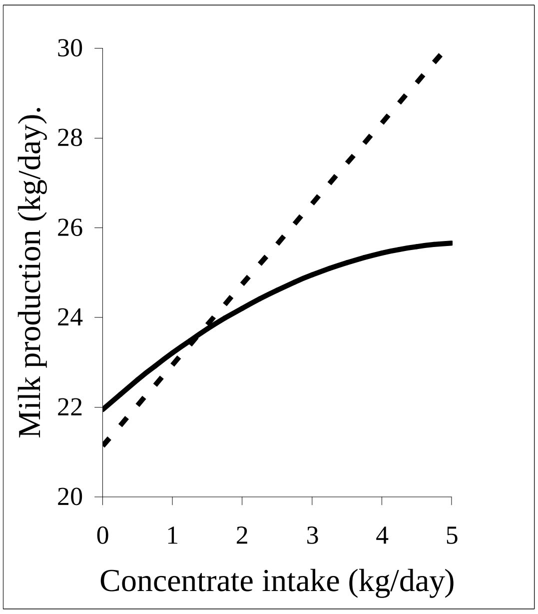

Figure 3 Response curve for the median cow (—) and requirement curve (- - -).

At the intersection between the response and requirement curve $\left(C_{Rq} = 1.4\right.$ kg/day $M_{Rq} = 23.6$ kg/day) the cow is *assumed* to be fed in balance. If concentrate intake is lower, the cow is *assumed* to be in a negative energy balance and mobilising body reserves and if concentrate intake is higher, the cow is *assumed* to be in a positive energy balance and growing (Broster and Thomas, 1981). If the assumption of a roughage intake equal to 16 kg dm/day holds for the median cow, this cow will grow at an optimal concentrate intake $C_{Opt} = 3.0$ kg/day. But in this research individual roughage intake and body weight change were not measured. Consequently, it is difficult to form an opinion on the energy balance.

Note that feeding to the economic optimum results in higher milk yield $M_{Opt} = 25.0$ kg/day and higher gross margins ($S_{Opt} = 10.19$ €/day) than feeding in balance ($S_{Rq} = 10.05$ €/day). Remember that $0 \le C_{Opt} \le C_{Max}$ which indicates that excessive weight change[1] can be prevented with dynamic feeding towards an economic optimum.

Conclusions

Daily milk yield can be described as a linear quadratic response function to daily concentrate intake. During early lactation, when concentrate supply increases linearly, this response function can already have been established. A few weeks into lactation the response parameters can be adequately estimated by using an adaptive model. Based on estimated parameters optimal daily concentrate supply can be determined for individual cows and applied to maximize economic results. Furthermore, the parameters provide insight into the variation between individuals concerning the effects of concentrate and base ration on daily milk yield. This then allows an evaluation of economical and nutritional aspects on an individual basis. For a reliable evaluation of the nutritional aspects, daily observation of individual roughage intake and body weight change are advisable. However, dynamic feeding towards an economic optimum indicates that excessive weight change[1] can be prevented.

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[i] With high concentrate prices and/or low milk prices loss of body weight might occur, so only excessive growth can be prevented.