Improving feed efficiency and net merit by including maintenance requirement in selection of dairy cattle

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Summary

Maintenance requirement ratio (MRR), i.e. the expected energy need for maintenance per kg energy correct milk produced, may be of interest in improving feed efficiency in dairy cattle. However, implementing the ratio as such into a selection index has constrains. In this study we applied Taylor series expansion to approximate MRR by a linear index including MRR's component traits metabolic body weight (MBW), and milk (M), protein (P) and fat (F) yields. The index was compared with four other indices to assess the potential of the index to improve feed efficiency and net merit. The required variance components for building selection indices were estimated from feed efficiency observation of 539 Nordic Red dairy cows including the traits M, P, F, MBW, metabolizable energy intake (MEI), energy conversion efficiency (ECE), residual energy intake (REI) and MRR. Compared to the reference index (including M, P and F), highest net merit (+28%) and progress in feed efficiency (+45%) were achieved with an index including M, P, F, MBW and REI, and almost as good was an index of the difference between the denominator (M, P, F) and nominator (MBW) traits of MRR. The transformed linear index for MRR increased net merit (+18%) and progress in feed efficiency (+23%), yielded highest progress in M, P, and F, and less negative trend in MBW compared to the best index. In conclusion, inclusion of MRR into a selection index would favour high yielding cows, penalize heavy cows with low production but not intake, and by this increase feed efficiency and net merit.

Keywords: Ratio traits, Taylor series expansion, selection index, net merit, feed efficiency

Introduction

Improving feed efficiency in dairy cattle has gained increasing economic and environmental importance. However, lack of sufficient feed intake measurements is still the major constraint for building genetic evaluations. The ratio of metabolizable energy (ME) requirement for maintenance over energy corrected milk (ECM), hereinafter MRR (maintenance requirement ratio), has been found to have high genetic correlation with energy conversion efficiency (ECE) (Lidauer et al., 2017), where ECE is defined as the ratio of ECM over ME intake (MEI), i.e. $ECE = {}^{ECM}/_{MEI}$. MRR can be calculated as: ${}^{c_{ME}MBW}/_{ECM}$, where c_{ME} = 0.515 MJ/kg is the ME requirement for maintenance per one kg metabolic body weight (MBW) (Luke, 2015) and MBW is (body weight)$^{0.75}$. MRR describes the cow's expected ME use for maintaining her body functions in relation to the amount of ECM produced. MRR may be of interest, because its calculation does not require feed intake.

Direct selection on MRR has limitations for several reasons, e.g., the denominator is a composite of production traits which are usually included with different weights into total merit indices, and that ratio traits fail to account for relative economic values of the nominator and the denominator. However, transferring MRR to a linear index, shall give the means to incorporate MRR into a selection index.

The aim of this study was to approximate MRR by Taylor series expansion and to assess how the use of such an index would affect genetic progress in feed efficiency and production traits as well as net merit.

Material and methods

Assuming MRR is the phenotypic ratio as given above and $MRR_g = {c_{ME} g_{MBW}}/{g_{ECM}}$ is the ratio of the genetic values for c_{ME} *MBW and ECM, where g_{ECM} can be expressed by a function of the genetic values for milk yield (g_M), protein yield (g_P) and fat yield (g_F), i.e., $g_{ECM} = c_M g_M + c_P g_P + c_F g_F$, with c_M, c_P and c_F being the coefficients to form ECM from the component traits (Sjaunja et al., 1990). Then, $\mathrm{MRR_g}$ can be linearly transformed using Taylor series expansion (Mode et al., 1987):

$$MRR_g = MRR_g(\mu_{MBW}, \mu_M, \mu_P, \mu_F) + \frac{\partial MRR_g}{\partial g_{MBW}}\Big|_{\mu_{MBW},\mu_M,\mu_P,\mu_F}(g_{MBW} - \mu_{MBW}) + \frac{\partial MRR_g}{\partial g_M}\Big|_{\mu_{MBW},\mu_M,\mu_P,\mu_F}(g_M - \mu_M) + \frac{\partial MRR_g}{\partial g_P}\Big|_{\mu_{MBW},\mu_M,\mu_P,\mu_F}(g_P - \mu_P) + \frac{\partial MRR_g}{\partial g_F}\Big|_{\mu_{MBW},\mu_M,\mu_P,\mu_F}(g_F - \mu_F) + terms\ of\ higher\ order. \quad (1)$$

Evaluating the Taylor series expansion at the means of the components (μ_{MBW}, μ_M, μ_P, μ_F) and ignoring the higher order terms gives:

$$MRR_g \cong \frac{1}{\mu_{ECM}} g_{MBW} - \frac{\mu_{MBW}}{\mu_{ECM}^2}(c_M g_M + c_P g_P + c_F g_F), \quad (2)$$

where $\mu_{ECM} = c_M \mu_M + c_P \mu_P + c_F \mu_F$.

As presented by Lin & Aggrey (2013), linearization of the ratio allows maximizing the net merit (*H*), which is the linear combination of the genotypes (g_{MBW}, g_M, g_P, g_F) weighted by their relative economic values (a_{MBW}, a_M, a_P, a_F): $H = \boldsymbol{g'Va}$, where $\boldsymbol{V} = -\boldsymbol{T}$, because a reduction in MRR is desired, and $\boldsymbol{T}$ is a transformation matrix including the transformation weights of (2).

Assessing the potential of using maintenance requirement in selection

The value of considering MRR in selection to improve feed efficiency and net merit was evaluated by comparing different selection indices utilizing phenotypic (**P**) and genetic (**G**) (co)variances estimated among eight traits, which were milk yield (M), protein yield (P), fat yield (F), MBW, MEI, ECE, residual energy intake (REI) and MRR. The aim was that a selection index *i* should maximize the net merit $H = \boldsymbol{g'a}$, where the genetic values are $\boldsymbol{g'} = [g_M \quad g_P \quad g_F \quad g_{MBW} \quad g_{MEI} \quad g_{ECE} \quad g_{REI} \quad g_{MRR}]$ and $\boldsymbol{a}$ contains economic values for M, P, F and MEI and zero otherwise, i.e. $\boldsymbol{a'} = [a_M \quad a_P \quad a_F \quad 0 \quad a_{MEI} \quad 0 \quad 0 \quad 0]$. The studied five selection criteria were: 1) selection based on M, P and F (current situation); 2) selection based on M, P, F, MBW and REI, i.e. in analogy to Feed Saved (Pryce et al., 2015); 3) Selection based on the difference between denominator (M, P, F) and nominator (MBW) of MRR; 4) Selection based on the transformed linear index for ECE; and 5) Selection based on the transformed linear index for MRR. For 1), 2) and 3), selection index coefficients $\boldsymbol{b}_i$ were calculated as $\boldsymbol{b}_i = \boldsymbol{P}^{-1}_{n_i \times n_i}\boldsymbol{G}_{n_i \times m}\boldsymbol{a}_m$, where $\boldsymbol{P}^{-1}_{n_i \times n_i}$ is the $n_i \times n_i$ submatrix of $\mathbf{P}$ with respect to the traits included in the index i, $\boldsymbol{G}_{n_i \times m}$ is a submatrix of $\mathbf{G}$ which includes the genetic (co)variances between the index traits and traits included in H, and $\boldsymbol{a}_m$ includes the economic values. For 4) and 5), index coefficients $\boldsymbol{b}_i$ were calculated as $\boldsymbol{b}_i = \boldsymbol{P}^{-1}_{n_i \times n_i}\boldsymbol{G}_{n_i \times m}\boldsymbol{V}_{m \times m}\boldsymbol{a}_m$, where for 4), $\boldsymbol{V}_{m \times m}$ included the transformation weights of (2) with respect to ECE and for 5), $\boldsymbol{V}_{m \times m} = -\boldsymbol{T}$ with $\boldsymbol{T}$ including transformation weights of (2) with respect to MRR. Note, that for 5) optimization of the genetic ratio MRR_g was suboptimal, because $\boldsymbol{a}_m$ includes the economic value of MEI instead of MBW. The expected genetic responses ($\boldsymbol{\Delta}_i$) in each of the eight traits, based on applying selection criterion i, were calculated by: $\Delta_i = {\boldsymbol{G}\boldsymbol{b}_{8i}}/{\sqrt{\boldsymbol{b}_i{}'\boldsymbol{P}_i\boldsymbol{b}_i}}$,

where the selection intensity was considered to be one, and $\boldsymbol{b}_{8i}$ was a vector of size eight including values of $\boldsymbol{b}_i$ and zeros for those traits not included in $\boldsymbol{b}_i$. Then, net merit for each selection criterion i was calculated as: $H_i = \boldsymbol{a}'\boldsymbol{\Delta}_i$. Applied economic values were derived based on marginal economic values developed by Hietala et al. (2014): a_M = €0.0013/kg, a_P = €4.56/kg, a_F = €1.23/kg and a_{MEI} = €–0.0164/MJ ME.

Estimating variance components

The observations used in this study were from 43243 daily records, collected from 539 primiparous Nordic Red dairy cows between 1998 and 2016 at Luke's experimental farms Rehtijärvi and Minkiö in Jokioinen. Daily observations were used to build 280d observations, from which lactation averages were formed. Observations deviating more than three standard deviations from the mean were excluded. All cows originated from the Nordic Red dairy cow nucleus breeding herd and their pedigree was traced to a maximum of 4 generations resulting in 3055 informative ancestors. Variance components were estimated by a multivariate analysis including all eight traits and applying for each trait the same model:

$$y_{t:ijk} = \sum_{q=1}^{2} b_{t:q}\, age_i^q + HCYS_{t:i} + a_{t:k} + e_{t:ijk}, \qquad (3)$$

where $y_{t:ijk}$ is an observation for trait t on animal k, $\sum_{q=1}^{2} b_{t:q}\, age_i^q$ is a quadratic polynomial on calving age, $HCYS_{t:i}$ is herd × calving year × calving season effect, $a_{t:k}$ is the random additive genetic effect, and $e_{t:ijk}$ is the random residual effect. Variance component estimation was by REML, implemented in the DMU package (Madsen & Jensen, 2013).

Results and Discussion

Lactation averages were μ_M = 27.0 kg, μ_P= 0.96 kg, μ_F= 1.15 kg, μ_{MBW}= 120 $kg^{0.75}$, μ_{MEI} = 211 MJ, μ_{ECE}= 0.134 kg/MJ, μ_{REI}= –0.07 MJ and μ_{MRR}= 2.21 MJ/kg. Estimated variance components were in good agreement with those estimated by Manafiaza et al. (2016) and Vallimont et al. (2011). For MBW, our estimates gave a negative genetic correlation with production traits (Table 1) and an unfavourable genetic correlation with ECE, REI and MRR. Similarly, Manafiaza et al. (2016) found a negative genetic correlation between body weight and ECM but a favourable genetic correlation with REI. MEI had a positive genetic correlation with production traits but with ECE and REI its genetic correlation was unfavourable. Of the efficiency traits, MRR had the highest genetic correlations with the production traits and the highest unfavourable genetic correlation with MBW. Nevertheless, the genetic correlation between MRR and MEI was close to zero. Some genetic correlations were associated with large standard errors due to the limit amount of data available.

Table 1. Estimates of heritabilities (on the diagonal), genetic correlations (above the diagonal), and phenotypic correlations (below the diagonal) among production and efficiency

	M	P	F	MBW	MEI	ECE	REI	MRR
M	**0.48±.13**	0.88±.05	0.74±.10	-0.24±.22	0.35±.21	0.58±.15	0.06±.29	-0.81±.08
P	0.91	**0.32±.13**	0.82±.09	-0.29±.27	0.41±.24	0.57±.18	0.15±.35	-0.83±.09
F	0.79	0.83	**0.42±.13**	-0.28±.23	0.38±.21	0.62±.14	0.10±.31	-0.86±.06
MBW	0.03	0.10	0.04	**0.48±.13**	0.43±.21	-0.58±.19	0.24±.30	0.67±.15
MEI	0.43	0.44	0.41	0.37	**0.37±.13**	-0.44±.20	0.88±.10	-0.05±.24
ECE	0.58	0.60	0.65	-0.24	-0.38	**0.47±.13**	-0.66±.16	-0.81±.09
REI	-0.01	-0.04	-0.06	-0.02	0.78	-0.70	**0.25±.13**	0.11±.29
MRR	-0.81	-0.79	-0.84	0.43	-0.22	-0.71	0.03	**0.50±.13**

M = lactation average milk yield (kg); P = lactation average protein yield (kg); F = lactation average fat yield (kg); MBW = average metabolic body weight ($kg^{0.75}$); MEI = lactation average metabolizable energy intake (MJ); ECE = (lactation average energy corrected milk / MEI) (kg/MJ); REI = lactation average residual energy intake (MJ); MRR = (c_{ME}*MBW / lactation average energy-corrected milk) (MJ/kg).

The relative efficiencies of the five criteria were compared by relating net merits to the net merit of criterion 1). Selection based on M, P, F, MBW and REI was most efficient (+28%), followed by selection based on the difference between denominator and nominator (+24%) and selection based on the transformed linear index for MRR (+18%). In contrast, selection on the transformed linear index for ECE hardly increased the net merit (+2%).

The genetic responses in production and efficiency traits when improving the selection criterion by one standard deviation are in Table 2. Including MBW and REI (criterion 2) resulted largest decrease in MBW and REI but yielded –8.2% lower progress in production traits and a slight decrease in MEI. Similar responses were obtained when selection was based on the difference between denominator and nominator of MRR but here the response in REI was smaller. Selection based in the transformed linear index for MRR yielded increased progress in production (+4.0% compared to criteria 1) and a smaller negative response in MBW compared to the selection criteria 2) and 3). Unexpectedly, selection based on the transformed linear index for ECE yielded responses that are close to those when selection was based on M, P and F only.

Table 2.Genetic response in production and efficiency traits (in units of genetic standard deviation) when improving the selection index by one standard deviation, given by criteria.

Criterion	M	P	F	MBW	MEI	ECE	REI	MRR
1	0.68	0.61	0.63	-0.18	0.26	0.45	0.04	-0.61
2	0.61	0.58	0.57	-0.58	-0.07	0.65	-0.17	-0.75
3	0.63	0.62	0.61	-0.57	0.03	0.59	-0.06	-0.76
4	0.67	0.60	0.64	-0.20	0.24	0.48	0.01	-0.63
5	0.67	0.64	0.67	-0.39	0.16	0.55	-0.01	-0.73

Selection based on: 1) M, P, F; 2) M, P, F and Feed Saved; 3) difference between denominator and nominator of MRR; 4) transformed linear index for ECE; 5) based on transformed linear index for MRR. Abbreviations of traits defined as in Table 1.

Compared to criterion 1), the additional progress in feed efficiency (considering ECE), was 45%, 31%, 6% and 23% for the selection criteria 2), 3), 4) and 5), respectively. Results from this study indicate that incorporation of MRR into a selection index for dairy cattle would favour high yielding cows, penalize heavy cows, but would not penalize intake. An improvement in feed efficiency and net merit is achieved mainly by improving MRR.

Conclusion

Linear transformation of MRR by Taylor series expansion allows incorporation of maintenance requirement into a selection index. The MRR as such, or its linear transformation, utilizes genetic variation in feed efficiency that is not explained by REI, and furthermore it does not rely on feed intake. This makes MRR or its reciprocal (maintenance efficiency) a potential trait for genetic improvement of feed efficiency.

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