Modeling Dairy Cow Variations in Genotype to Determine the Expected Ranges of Response to Supplements

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EXTENDED ABSTRACT

Simulation models are often used to predict dairy cattle performance on pasture only, pasture plus supplements, or total mixed ration diets because they integrate multiple factors that affect performance. Yet, few models include direct representations of animal genotype or environmental sensitivity (ES) information and variations for these traits. These two factors can have a large influence on animal performance. Estimated breeding values (EBV) are an estimate of the genetic potential (genotype) of an animal for particular traits such as total lactation milk, fat and protein yield and body condition score. Environmental sensitivity information - EBV estimated as a function of production environment - provides an indication of how animals respond to additional feeding. This information has now been included in a dairy cattle simulation model for pastoral systems called MOOSIM, which can be used to predict animal performance and likely responses to supplements. The aim of this paper is to predict the mean and variation of absolute daily yields of milk, fat and protein, dry matter (DM) intake and live weight change, and responses to supplements of a generated herd of cows with different genetic indices exposed to four nutritional treatments using the MOOSIM simulation model.

Table 1. Summary of the nutritional treatments imposed in MOOSIM

Treatment	Pasture allowance (kg DM/cow/day)	Supplement ME content (MJ/kg DM)
L-H	25	12
L-M	25	11
H-H	45	12
H-M	45	11

The nutritional treatments imposed in MOOSIM are outlined in Table 1. In all instances, the cows were offered pasture with a metabolisable energy (ME) content of 12 Mega Joules (MJ)/kg dry matter (DM) and 1 kg DM/cow/day of supplement.

The procedure to generate the cows resulted in a herd of cows with the correct mean, degree of variation and correlation amongst variables for EBV of total lactation milk, fat and protein and body condition score, and ES values for milk, fat and protein. Cows offered the least amount of pasture, combined with the highest ME content supplement (L-H) achieved the greatest milk solids (MS: fat + protein) response to supplements. Considerable variation in absolute milk and MS yield, concentration of fat and protein in milk and DM intake, and responses to supplements (MS and immediate \$) existed between individuals. The marginal break-even price of consumed supplement at a payout of \$5.50/kg MS was 25, 22, 17 and 15 cents/kg DM for L-H, L-M, H-H and H-M. It was estimated that at payouts of \$5.50 kg/MS farmers could pay an additional 2.94 and 2.56 cents/kg DM supplement for each 1 MJ increase in supplement ME content at low and high pasture allowances for cows of this genetic merit and breed. The results illustrate the use of the MOOSIM model as a decision support tool to predict the range of immediate yield responses of cows of different genetic merit managed in a range of nutritional environments.

1. INTRODUCTION

Simulation models are often used to predict dairy cattle performance on pasture only, pasture plus supplements, or total mixed ration diets (Bryant *et al.* 2005; Hart *et al.* 1998; Uribe *et al.* 1996). These models integrate knowledge of the effect of milk production potential, current cow body condition score, the size of the feed deficit, the amount of supplement fed and the quality of the supplement on animal performance. Yet, few models include direct representations of animal genotype or environmental sensitivity (ES) information (Bryant *et al.* 2005). In addition, dairy cattle simulation models generally simulate the average cow in the herd with no reference to genetic variation between animals.

Genetic variation between individuals is an intrinsic feature of a population due to the different combination of alleles (or genes) inherited from the individual animal's parents (Lacy 1997). Estimated breeding values for particular traits provide an estimate of the expected combination of alleles inherited from an individual's parent (Falconer 1989). More recently, genes or quantitative trait loci have been identified whose expression is modified by environment (Lillehammer *et al.* 2007; Sonna *et al.* 2002). However, the exact combinations of "ES" genes inherited by an individual are not yet known.

Environmental sensitivity information can be obtained through the estimation of linear or higher order reaction norms, where breeding values for production traits are estimated as a function of nutritional environment information (Bryant *et al.* 2006; Calus and Veerkamp 2003). Presented in Figure 1 is an average Friesian cow, based on the results obtained by Bryant *et al.* (2006), whose EBV for total lactation milk yield is +500 kg in an average New Zealand herd environment, but has +459 and +541 kg EBV for total lactation milk yield at relative herd total milk solids (MS; fat plus protein) yield of -75 and +75 kg. This demonstrates that a single EBV (i.e. at a relative herd total MS of 0 kg) is not sufficient to predict performance with ES information also needed. The degree of ES differs between individual animals (Bryant *et al.* 2006; Calus and Veerkamp 2003; Kolmodin *et al.* 2004).

Genetic variation in EBV and ES are major contributors to observed variations in animal performance and response to supplements (Ferris *et al.* 1999; Horan *et al.* 2005; Veerkamp *et al.* 1994). Consequently, an easy to use decision support tool which includes this information would be a valuable tool to help identify the individuals in which supplement use will be profitable. A dairy cattle simulation model for pastoral systems, MOOSIM, has recently been developed incorporating information on EBV for total lactation yields of milk, fat and protein, live weight and body condition score, and breed-specific ES (Bryant 2006). The cow's age, current body condition score (BCS) and live weight is also used in predictions. Pasture and supplementary feed allowance and quality are then used to predict milk, fat and protein yields, live weight change, feed intake and ultimately the expected responses to supplements.

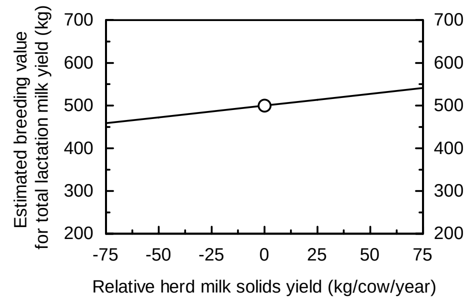

Figure 1. Illustrative example of the estimated breeding value for total lactation milk yield for an average Friesian cow across the trajectory of relative herd average milk solids yield.

The objectives of this study were 1) to simulate genetic variation in milk, fat and protein yield, body condition and ES, and 2) predict individual animal responses to 1-kg DM of supplement at two pasture allowances and two supplementary ME concentrations.

2. METHOD

A simulation model, MOOSIM, which considers how dairy cow genotypes respond to different environments has been developed using the VB.net programming language (Bryant 2006; a full description of the model and equations is available on request). The model is static with a discrete time step of one day but has been applied dynamically to estimate animal performance for every day of lactation (Bryant 2006). The model uses a combination of mechanistic and deterministic equations. Five modules relating to maintenance, pregnancy, growth, body energy stores and lactation represent the dairy cow, with various environmental factors influencing processes within each module. The lactation representation incorporates the effect of nutrition, cow BCS, age and EBV for production traits on mammary gland cellular dynamics based on Bryant *et al.* (2007). Initially, nutritional

	Milk EBV	Fat EBV	Protein EBV	BCS EBV	ES Milk	ES Fat	ES Protein
Milk EBV	981 (329) *981 (332)*	0.73	0.91	-0.09			
Fat EBV	*0.73*	30.8 (13.6) *30.8 (14.7)*	0.82	-0.04			
Protein EBV	*0.86*	*0.83*	33.4 (9.6) *33.4 (10.3)*	-0.03			
BCS EBV	*-0.09*	*-0.09*	*-0.06*	-0.08 (0.16) *-0.08 (0.15)*			
ES Milk					0.55 (1.17) *0.55 (1.10)*	0.75	0.84
ES Fat ($\times 10^{-3}$)					*0.76*	1.64 (53.1) *1.64 (52.8)*	0.90
ES Protein ($\times 10^{-3}$)					*0.83*	*0.90*	9.12 (39.3) *9.12 (38.0)*

Table 2: Actual (upper diagonal), realised (lower diagonal) genetic correlations between EBV for total lactation milk, fat and protein yield, BCS, ES (kg Δ/ kg Δ herd MS yield) for milk, fat and protein yield, with actual and realised (italics) mean (standard deviation) trait values on the diagonal.

environment is defined by specifying pasture and supplementary feed allowances. This information is then used to generate an environment-specific herd (or individual) EBV, which are then used to scale mammary gland alveoli numbers. Mammary gland alveoli numbers act as a mechanism driving feed intake and milk production. EBV for fat and protein yield determines daily fat and protein concentration, and fat and protein yield. EBV for BCS determines cow live weight gains or loses depending on the nutritional or thermal environment. Information on how each breed responds (MS yield, live weight change, DM intake) to production (nutritional) environment is included in the model based on results presented in Bryant *et al.* (2006). The predictive ability of the MOOSIM model has been tested using information from a prior study with 1990's Holstein-Friesian dairy cattle of North American or European or New Zealand origin managed in a pasture-based system in early to peak lactation. The model simulated to a high degree of accuracy, mean values for yields of milk, fat and protein, and concentrations of fat and protein (Bryant 2006).

2.1 Herd generation

In this set of simulations, a herd consisting of 500 Friesian cows was created. Information on mean, standard deviations, genetic correlations between EBV and ES linear regression coefficients (Table 2) was used to generate correlated variables using the NtRand add-in (NtRandMultiNorm function) (www.numtech.com/NtRand) for Microsoft Excel. Information on the genetic correlation between total lactation milk, fat and protein yield and BCS were based on the values reported by Pryce and Harris (2006). Mean and standard deviations for linear ES regression coefficients for total lactation milk, fat and protein yield were calculated from the analysis of Bryant *et al.* (2006). Mean EBV for milk, fat and protein yield for all Friesian cows born in 2003 were used (Livestock Improvement 2006). Mean BCS EBV, along with standard deviations for total lactation milk, fat and protein and BCS EBV were obtained from www.aeu.org.nz on the 11th of March, 2007. To allow the identification of the cows with the most desirable genetic characteristics to achieve high responses to supplements, all cows were assumed to be day 55 of lactation, 450 kg live weight and current BCS of 4.5 on the 1-10 scale.

2.2 Feeding Scenarios Tested

Using the MOOSIM simulation model, four different feeding scenarios (Table 1) were applied to each generated cow on day 55 of lactation to predict individual daily milk yield, fat and protein concentrations, MS yield, live weight change, DM and MJ ME intakes, and responses to supplements (g MS, kg live weight change and cents/kg DM supplement). In all instances, the cows were offered pasture with a ME content of 12 MJ/kg dry matter (DM) and 1 kg DM/cow/day of supplement. The cows grazed flat land in thermo neutral conditions, with the protein content of pasture and supplements non-limiting and a cost of supplement of 25 cents/kg DM assumed in all instances.

3. RESULTS

3.1 Herd generation

The procedure to generate the cows resulted in a herd of cows with the correct mean and degree of variation for EBV of total lactation milk, fat and protein and BCS, and ES values for milk, fat and protein (Table 2). Strong correlations between EBV for yield traits, and ES values for all yield traits were observed in the generated herd, and were similar to correlations between traits seen in the national dairy cow or sire population (Table 2 and Figure 2). Weak correlations between EBV for BCS and EBV for yield traits were observed in the generated herd, not unlike those observed in the national dairy cow population (Table 2).

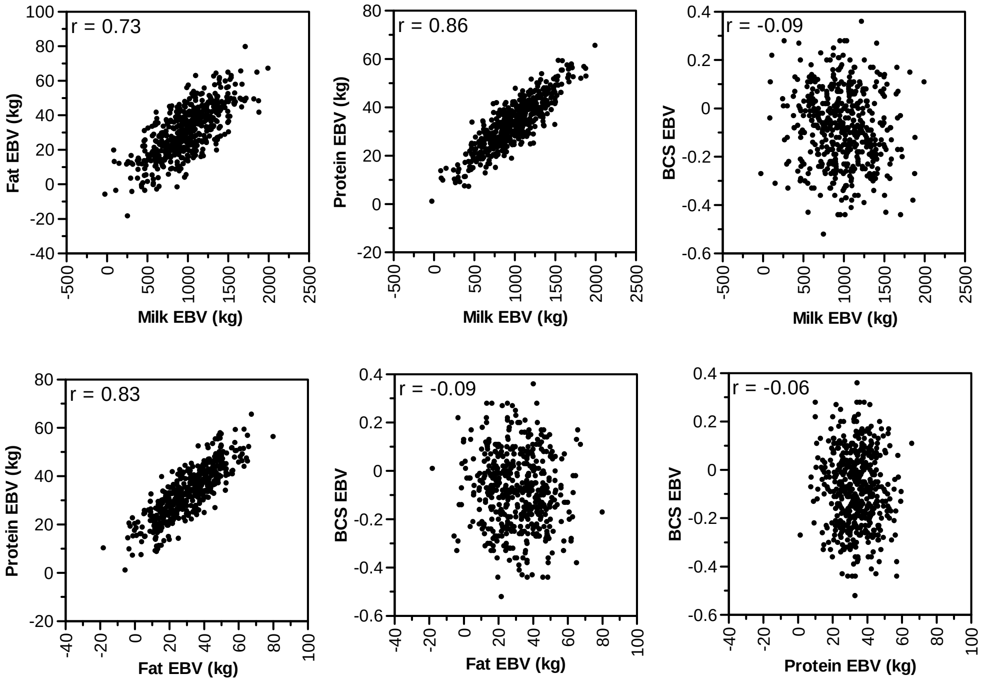

Figure 2. Simulated relationships between EBV for total lactation yields of milk, fat and protein and BCS

Table 3. Model predicted mean, standard deviation (in brackets) and range of daily milk yield, fat and protein concentrations, MS yield, live weight change, DM intake and ME intake for the L-H, L-M, H-H and H-M treatments.

	Milk yield (kg)	Fat %	Protein %	MS yield (kg)	Live weight change (kg)	DM Intake (kg)	ME intake (MJ)
L-H	23.4 (2.5)	4.03 (0.43)	3.15 (0.24)	1.67 (0.12)	-0.33 (0.02)	15.7 (0.8)	189 (9.9)
	15.8 to 31.6	2.78 to 5.35	2.49 to 3.98	1.30 to 2.01	-0.40 to -0.26	13.5 to 18.3	162 to 220
L-M	23.3 (2.5)	4.02 (0.43)	3.13 (0.24)	1.66 (0.12)	-0.33 (0.02)	15.9 (0.8)	189 (9.9)
	15.8 to 31.5	2.78 to 5.36	2.49 to 3.98	1.30 to 2.01	-0.40 to -0.27	13.6 to 18.5	162 to 220
H-H	26.9 (3.1)	3.78 (0.47)	3.14 (0.25)	1.85 (0.16)	-0.15 (0.03)	17.6 (1.0)	212 (12.3)
	17.6 to 36.8	2.48 to 5.36	2.45 to 4.06	1.34 to 2.34	-0.23 to -0.06	14.5 to 21.2	174 to 254
H-M	26.8 (3.1)	3.78 (0.46)	3.14 (0.25)	1.84 (0.15)	-0.15 (0.03)	17.8 (1.0)	212 (12.3)
	17.6 to 36.6	2.48 to 5.35	2.45 to 4.06	1.34 to 2.32	-0.24 to -0.07	14.6 to 21.3	175 to 255

Table 4. Predicted daily yields of milk and MS, DM intake, live weight change, responses to supplements (MS and cents), along with corresponding EBV for milk, MS and BCS and ES values for milk and MS for the cows with the highest and lowest responses to supplements in the L-H treatment.

	EBV			ES		Daily				Immediate response per kg DM supplement	
Cow	Milk (kg)	MS (kg)	BCS	Milk	MS	Milk (kg)	MS (kg)	DM Intake (kg)	Live weight change (kg)	MS (grams)	cents
					Highest response to supplement						
328	1497	111	0.13	0.55	0.12	24.7	1.79	16.6	-0.30	75.8	41.7
103	1990	133	0.11	-0.45	-0.07	28.8	2.00	18.3	-0.30	74.3	40.8
180	1536	122	-0.09	2.58	0.24	25.3	1.79	16.6	-0.33	72.9	40.1
191	1655	118	0.17	0.83	0.07	26.9	1.90	17.5	-0.29	72.4	39.8
409	1579	103	-0.08	0.94	0.13	26.0	1.75	16.5	-0.33	69.6	38.3
					Lowest response to supplement						
410	383	26	-0.08	0.16	-0.11	20.7	1.60	15.0	-0.33	23.8	13.1
104	-28	-5	-0.27	1.54	0.09	18.7	1.38	13.5	-0.36	22.2	12.2
327	465	17	-0.29	0.54	-0.10	22.5	1.59	15.1	-0.36	20.5	11.3
315	251	-8	0.01	-1.38	-0.12	20.5	1.43	14.1	-0.32	20.1	11.1
179	426	6	-0.07	-1.49	-0.22	21.5	1.55	14.9	-0.33	18.6	10.2

3.2 Daily performance

The highest milk and MS yield, DM intakes and ME intake was achieved by the H-H cows that were offered a high quality supplement (12 MJ/kg DM) at generous pasture allowances of 45 kg DM/cow/day (Table 3). The cows offered the most pasture (H-H and H-M) lost the least weight and had the lowest concentrations of fat in milk, some with fat concentrations of less than 3%. The mean difference in milk and MS yield and DM intake between the two pasture allowances was 3.5, 0.18 and 1.9 kg, respectively. Slightly increased yields of milk and MS were observed when offering higher quality supplements. Considerable variation between cows existed for milk and MS yield, fat and protein concentration, DM and ME intake. Less variability existed for live weight change. Cows with negative EBV for BCS lost more weight than cows with positive EBV for BCS.

3.3 Responses to supplements

The highest responses to supplements were achieved for the cows offered the least pasture, but the highest quality supplement (L-H; Figure 3). The mean MS responses to supplements were 45.8, 40.4, 31.0 and 26.4 g/kg DM supplement for L-H, L-M, H-H and H-M, corresponding to immediate returns of 25.2, 22.1, 17.1 and 14.5 cents/kg DM supplement at a payout of $5.50/kg MS. The smallest reduction in live weight loss was realised for the cows at the highest pasture allowance offered medium quality supplement (H-M). The individual cows that achieved the greatest responses to supplements (g MS and $/kg DM supplement) had high indices for milk, fat and protein EBV, and/or positive ES values (Table 4). Conversely, the cows in whom supplement use is unlikely to be profitable had low indices for milk, fat and protein EBV, and/or negative ES values.

4. DISCUSSION

Results of this study agree with previous experimental work that dairy cows have the highest milk production responses to supplementation when offered high quality supplements at low pasture allowances (Penno *et al.* 2006). In the present study, only 2 of the 500 cows made an immediate profit to supplementary feed usage in the H-M treatment, compared to 252 of the 500 cows making an immediate profit in the L-H treatment. Laborde *et al.* (1998) showed that maize silage feeding on a seasonal dairy farm would only be profitable 66, 52 and 12% of the time if the marginal responses were 91, 79 and 59 g MS/kg DM of supplement, respectively.

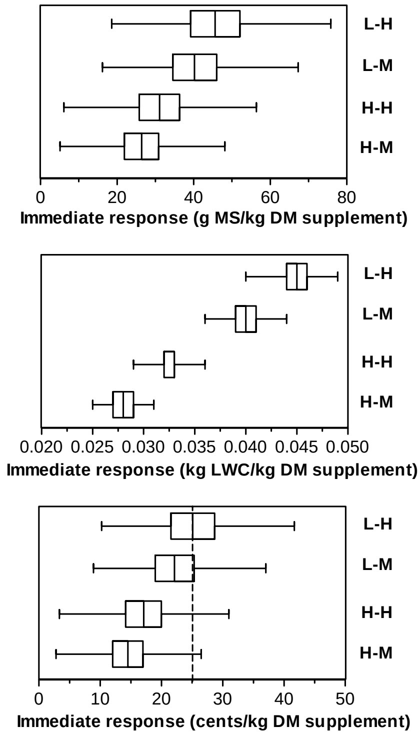

Figure 3. Box and wisker plots showing the minimum, 25th percentile, median, 75th percentile and maximum response (g milk solids [MS], kg live weight change [LWC] and cents per kg DM supplement) of cows for the L-H, L-M, H-H and H-M treatments.

The mean MS responses to supplements were 45.8, 40.4, 31.0 and 26.4 g/kg DM supplement for L-H, L-M, H-H and H-M. Kolver *et al.* (2005) reported immediate responses to supplements in NZ Friesian - roughly the same genetic merit as the ones simulated in the present study - of 37 g MS/kg concentrate DM when cows were offered high pasture allowances, and 3 to 6 kg DM/cow/day supplements. The supplement offered in their study consisted of 60% maize grain, 31% barley grain, 7% molasses and 2% broll with each of these constituents having a higher energy concentration than the one offered in this simulation study (Holmes *et al.* 2002). Horan *et al.* (2005) in Ireland reported responses to supplements in NZ Friesian of 42 g MS/cow/day.

Prior farmlet studies have shown animal variation in EBV and ES influence absolute yields and intakes and cow responses to supplements (Horan *et al.* 2005; Veerkamp *et al.* 1994). An in-depth analysis of individual cow responses to supplementation in the present study revealed the ideal cow characteristics to achieve high responses to supplementation. Cow 103, which achieved MS yield responses to supplementation of 74.3 g MS/kg DM supplement in the L-H treatment, had extremely high EBV for milk and MS, but negative values for ES ensured her response to supplement was less than cow 328. The other cows which achieved high responses to supplements, including 328, had highly positive ES values; these cows had a combination of genes which conferred an advantage when offered supplements or additional feed. Positive ES values did not result in high responses to supplements in individual cows which had low overall EBV for milk, fat and protein, as illustrated by the cows with the lowest responses to supplements.

Based on the response to supplements achieved in this simulation study, the marginal break-even price of consumed supplement at payouts of $5.50/kg MS was 25, 22, 17 and 15 cents/kg DM for L-H, L-M, H-H and H-M. This result is largely consistent with those of Kolver et al. (2005), where it can be estimated that the marginal break-even price of consumed supplement at payouts of $5.50/kg MS was 20.4 cents/kg DM with the marginal break-even price of consumed supplement lower at higher concentrate allowances and at lower dairy payouts. The estimate of profitability of supplements does not consider the additional carryover benefits of supplementation that can double the immediate response (Kellaway and Harrington 2004). The carryover benefits are due to increased BCS which can lift subsequent production after the supplementary feeding period has ended and the potential extension of lactation. The marginal response to a 1 MJ increase in ME content of the supplement was 5.34 and 4.65 g MS at low and high pasture allowance. Consequently, it can be estimated at a payout of $5.50 kg/MS that farmers could pay an additional 2.94 and 2.56 cents/kg DM supplement for each 1 MJ increase in supplement ME content at low and high pasture allowances for cows of this genetic merit and breed. The amount which farmers should pay for increased energy concentrations in supplements is lower at reduced milk prices.

5. CONCLUSION

The results illustrate the use of the MOOSIM model as a decision support tool to predict the range of immediate yield responses of cows of different genetic merit managed in a range of nutritional environments. This information can be used to estimate the maximum price farmers should pay for supplementary feed of different nutritional value.

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