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Estimation of heritabilities for milk urea and efficiency of crude protein utilization by day of lactation in a New Zealand dairy cow herd

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Abstract

The objective of this study was to estimate the heritability (h^2) of milk urea (MU) and the efficiency of crude protein utilization (ECPU) in grazing dairy cows. Data consisted of 1,866 herd-test records for MU and ECPU from 380 cows. Genetic parameters for traits were estimated using a random regression test-day model (RRM). Herd-test date and parity had a significant effect on MU and ECPU suggesting that improvement of the traits can be made through management practices. Estimates of daily h^2 ranged from 0.25 to 0.49 for MU and 0.02 to 0.41 for ECPU. The highest h^2 estimates for both traits were found during late lactation. Genetic improvement of MU and ECPU should consider the genetic potential to change the lactation curves of these traits and their correlation with other productive and reproductive traits.

Keywords: milk urea; efficiency of crude protein utilization; dairy cows; heritability; random regression model

Introduction

Agriculture contributes to nearly 50% of the greenhouse gas emission (GHG) in New Zealand (Ministry for the environment 2016) which is much higher compared to other developed countries of the world, where GHG from agriculture accounts for only 11% (DairyNZ 2019). Nitrogen is one of the major elements of GHG and can be released to the environment as nitrous oxide from urine, faeces, or fertiliser depositions. Excess soluble N from urine patches is the key source of N pollution of ground and surface waters. Freshwater pollution through excess N fertilizers is minor compared to pollution through urine (Parliamentary Commissioner for the Environment 2018).

Urea is the primary non-protein N component in milk; urea is produced in cattle as a product of the detoxification of ammonia. Most of urea formed during the metabolism of nitrogen is released to the environment in urine, however, some of the urea circulating in the bloodstream passes into the milk. Nitrogen found in milk urea is known as milk urea nitrogen (MUN). In New Zealand, the level of milk urea (MU) is high in grazing cows owing to the high protein content of pasture, compared to cows fed a total mixed ration that is balanced for protein and energy (Garcia-Muniz et al. 2013). Milk urea can be routinely measured using samples collected for routine herd-testing. In carefully controlled trials, there has been shown to be a high positive correlation between MUN and urine-N, therefore, MUN has been suggested as a useful predictor of urea-N concentration in urine (Jonker et al. 1998). Other studies have suggested the use of MUN as an indicator of the efficiency of crude protein utilization (ECPU) in dairy cows (Baker et al. 1995; Hof et al. 1997).

There is evidence to suggest that feeding high ruminally-degradable CP decreases ECPU in lactating dairy cows (Huhtanen et al. 2008) and the association between rumen-degradable protein and MUN is positive (Hojman et al. 2004). Efficient N utilization means more protein is being captured by the cow which maximizes the

amount of the protein included in milk, and consequently minimizing the dietary N wasted as urea.

Recent studies have reported that the additive genetic variances and h^2 for MUN vary throughout lactation and that the correlations between MUN and production traits are not constant at different stages of lactation (Hosseinzadeh & Ardalan 2011). As a result, studies based on accumulated records over 305-days, which do not account for fluctuation in additive genetic variance over lactation, might produce estimates of less relevance for selection. The use of random regression models (RRM), which account for variation in additive genetic and permanent environment effects at different days over the lactation will produce more relevant estimates of traits. The objective of this study was to estimate h^2 and repeatability of MU and ECPU by day of lactation using a RRM.

Materials and methods

Data collection and data editing

Test-day records from Dairy 1 and Dairy 4 farms of Massey University, Palmerston North for two seasons (2016/17 and 2017/18) were analysed in this study. Milk samples collected from cows in three herd-tests per season representing early (September), mid (December) and late (March) lactations were used to determine MU. Daily ECPU was estimated as the ratio of crude protein yield (CPY) and crude protein intake (CPI). Crude protein intake was determined as a product of dietary CP concentration (estimated by feed quality analysis) and estimates of dry matter intake (DMI). Dry matter intake was estimated based on the metabolisable energy requirements for maintenance, pregnancy, production and daily weight variation. Fat yields (FY) and CPY were calculated using the fat and protein percentages multiplied by the corresponding milk yields (MY) of the herd-tests. Live weight (LWT) records of cows were collected at the same time as herd-tests by measurements generated using an automatic walk-over

scale. Records from cows with a minimum of two herd-test records and at least 150 days in milk (DIM) were analysed.

Statistical Analysis

Descriptive statistics were obtained using the MEANS procedure of the statistical package SAS 9.4 (SAS Institute Inc., Cary, NC, USA). A univariate random regression model was used separately for daily MU or ECPU to estimate (co)variance components of additive genetic (σ_a^2), within lactation permanent environment ($\sigma_{p(w)}^2$), across lactation permanent environment ($\sigma_{p(a)}^2$) and residual effects (σ_e^2) using the restricted-maximum likelihood (REML) procedure in ASREML (Gilmour et al. 2009). Fixed effects included in the model were herd-test day, parity, regression on the deviation from median calving date, the proportion of Holstein-Friesian breed, effect of Friesian-by-Jersey heterosis, and regression on DIM modelled using a 2nd order orthogonal polynomial. Additive genetic variance of both traits was modelled using a 2nd order orthogonal polynomial and a constant $\sigma_{p(a)}^2$ was also fitted in the model. A first-order orthogonal polynomial was used for modelling $\sigma_{p(w)}^2$ for ECPU while $\sigma_{p(w)}^2$ for MU was constant throughout the lactation. These models were chosen based on the Akaike information criterion after running models with different orders of polynomials. Heterogeneity in the residual variance over DIM was fitted by assigning different residual variance for five stages of lactation; 1-50,

51-100, 101-150, 151-200 and 201-240 days in milk. Cows in lactation four and above were pooled into a single class. Estimates of h^2 on i^{th} DIM was estimated as $h^2_i = \sigma_{ai}^2 / (\sigma_{ai}^2 + \sigma_{p(w)i}^2 + \sigma_{p(a)}^2 + \sigma_{ei}^2)$ and repeatability across the lactation estimated as $\text{repeatability}_i = (\sigma_{ai}^2 + \sigma_{p(w)i}^2 + \sigma_{p(a)}^2) / (\sigma_{ai}^2 + \sigma_{p(w)i}^2 + \sigma_{p(a)}^2 + \sigma_{ei}^2)$.

Results

The descriptive statistics for the yields of the milk production traits (MY, FY and CPY), and for LWT, DMI, MU, and ECPU are shown in Table 1.

The fixed effects of herd-test day and parity had a significant effect on MU and ECPU. The estimates of the regression coefficients of MU on proportion of Holstein-Friesian breed showed that pure Holstein-Friesian had a 2.46 mg/dL higher MU than pure Jersey (SEM=0.36; $P < 0.001$) and the regression on the deviation from median calving date indicated that for every 1 day deviation from the median calving date, MU increased by 0.06 mg/dL (SEM=0.01; $P < 0.001$). The estimates of the regression coefficients of ECPU for heterosis between Holstein-Friesians and Jerseys was 0.63% (SEM=0.25; $P < 0.01$).

Estimates of the parameters additive genetic, residual and total variances were high at the beginning of lactation and gradually reduced towards midlactation before they increased again during late lactation (Table 2). The highest

Table 1 Descriptive statistics for milk yield (MY), fat yield (FY), crude protein yield (CPY), live weight (LWT), dry matter intake (DMI), milk urea (MU), and efficiency of crude protein utilization (ECPU) in grazing dairy cows from two mix-breed herds in New Zealand.

Trait	N	Min	Mean	Max	SD
MY (kg/day)	6,618	0.70	17.52	40.40	6.51
FY (kg/day)	6,618	0.10	0.861	2.500	0.27
CPY (kg/day)	6,618	0.10	0.690	1.400	0.200
LWT (kg)	8,149	320.0	490.9	770.0	64.6
DMI (kg/day)	4,584	5.10	14.69	25.12	2.74
MU (mg/dL)	1,866	6.08	25.68	61.70	8.31
ECPU (%)	1,866	4.00	24.44	45.54	6.65

Table 2 Estimates of heritability (h^2), repeatability (t) and variance components for milk urea (MU) and efficiency of crude protein utilization (ECPU) at different days in milk in grazing dairy cows in New Zealand.

Day	h^2	t	σ_a^2	$\sigma_{p(w)}^2$	$\sigma_{p(a)}^2$	σ_e^2	σ_e^2	σ_{total}^2
MU								
1	0.35	0.44	10.36	0.50	2.09	2.59	16.36	29.31
60	0.27	0.38	6.28	0.50	2.09	2.59	13.99	22.86
120	0.32	0.35	6.12	0.50	2.09	2.59	10.36	19.07
180	0.39	0.49	10.47	0.50	2.09	2.59	13.26	26.32
240	0.49	0.55	21.86	0.50	2.09	2.59	19.56	44.01
Mean (SD)	0.34(0.06)	0.44(0.05)	9.31(4.13)	0.50(0)	2.09(0)	2.59(0)	14.50(2.99)	26.40(6.64)
ECPU								
1	0.41	0.60	5.76	1.87	0.87	2.74	5.61	14.11
60	0.02	0.16	0.25	0.59	0.87	1.46	8.78	10.49
120	0.12	0.23	1.09	0.04	0.87	0.91	6.55	8.55
180	0.16	0.29	1.33	0.28	0.87	1.15	6.00	8.48
240	0.38	0.62	3.32	1.29	0.87	2.16	3.35	8.83
Mean (SD)	0.16(0.10)	0.32(0.14)	1.49(1.08)	0.58(0.50)	0.87(0)	1.45(0.50)	6.09(1.77)	9.03(1.45)

variances were reported at the end of the lactation. However, within lactation permanent environmental variance for MU was constant throughout the lactation, therefore σ_c^2 of MU was stable (Table 2). The pattern of fluctuation of variance components for ECPU was similar to that of MU, however, the highest variances for all the components were reported at early lactation (Table 2).

The h^2 and repeatability of MU and ECPU fluctuated in a similar manner to the fluctuation of variance components (Table 2). MU was a moderately heritable (0.27 to 0.49) and moderately repeatable (0.35 to 0.55), whereas ECPU showed low heritability at 60, 120 and 180 days (0.02 to 0.16) but moderate h^2 (0.38) at 240 days. The repeatability for ECPU was low at 60, 120 and 180 days and high at 1 and 240 days.

The h^2 of MU ranged from 0.25 to 0.49 at 93 DIM and 240 DIM, respectively (Figure 1). Whereas, h^2 of ECPU ranged from 0.02 to 0.41 at 65 DIM and 240 DIM respectively (Figure 1). The stepwise variability in h^2 of MU and ECPU was observed in this study as a result of allocation of heterogeneity in residual variance in five blocks over the lactation.

Discussion

The range and the mean of milk production traits (MY, FY and CPY) and LWT are comparable with the previous studies using the same herds by Lopez-Villalobos et al. (2018). The mean MU concentration of 25.68 mg/dL and the range from 6.08 to 61.70 mg/dL found in the current study were similar to the previous findings of Lopez-Villalobos et al. (2018).

To make comparisons with other studies, MU was converted as MUN. The average MUN concentration recorded in this study was lower (11.41 mg/dL) compared to the overall concentrations reported by Beatson et al. (2019) (14.0 mg/dL) for mix-breed cow herds in New Zealand and within the range reported by some foreign studies (range=11.02–20.39 mg/dL) (Stoop et al. 2007; Miglior

et al. 2007; Wood et al. 2003). The mean ECPU reported in this study was 24.44% (range=4 – 45.54%) which is comparable with values reported by Lopez-Villalobos et al. (2018). However, different efficiencies reported in other studies (Woodward, 2011, Castillo et al., 2000) could be attributed to variation in the definition of protein efficiency, management conditions and animal effects.

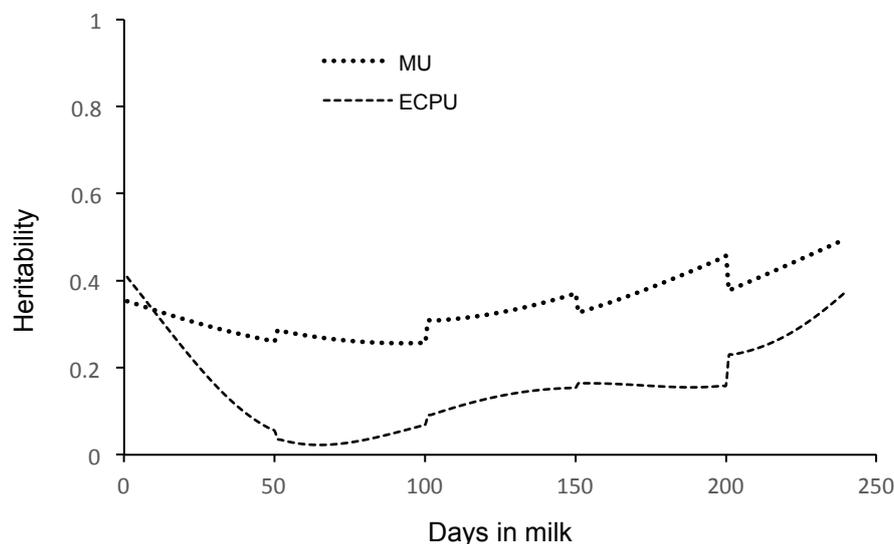
Effects of herd-test day and parity were significant on MU and ECPU. Several studies have reported a significant influence of fixed effects on MU (Miglior et al. 2007; Hossein-Zadeh & Ardalan 2011) suggesting that MU can be improved by management practices such as stocking rate, and diet composition. The effect of breed on MU was significant ($P < 0.001$) and purebred Friesian cows produced on average 2.46 mg/dL (SEM=0.36) more MU than purebred Jersey. However, the effects of breed on ECPU and heterosis between Friesian and Jersey for MU and ECPU were minor, comparable with the values reported by Lopez-Villalobos et al. (2018).

Highest estimates of genetic variance and h^2 at the extremes of the lactation have been reported elsewhere (Rekaya et al. 1999). However, the accuracy of estimates at the extremes of the lactation could be low due to few number of records at peripheries of the lactation therefore, these results should be used with caution in selection. Consequently, selection using breeding values at the highest σ_a^2 and the highest h^2 of the traits may not necessarily ensure the highest genetic gain. Instead, use of a selection index that considers the genetic potential to alter the lactation curve of traits would be beneficial.

Estimates of h^2 for MU over the lactation ranged from 0.27 to 0.49 (mean=0.34) in this study, which was lower than the range reported by Wood et al. 2003 (0.44 to 0.59) and Miglior et al. 2007 (0.38 to 0.41) and greater than the estimates reported by Beatson et al. (2019) (mean=0.22) and other studies (Mitchell et al. 2005; Stoop et al. 2007; Hossein-Zadeh & Ardalan 2011; Mucha & Strandberg 2011; Lopez-Villalobos et al. 2018).

The estimated h^2 for each day of the lactation for ECPU ranges from 0.02 to 0.41. Average h^2 of the trait was 0.16 which is comparable with the estimates by Li et al. (1998) and Lopez-Villalobos et al. (2018) but, lower than the estimate by Hayes 2002. Inconsistency in estimates among studies may be attributed to variation in the model used for data analysis, where RRM are known to produce higher estimates compared to other animal models, differences in the data structure (Strabel et al. 2005) and length of the period of data collection (Mucha & Strandberg 2011). Reports on estimates of h^2 for each day of the lactation for

Figure 1 Estimates of heritability at each day of the lactation for milk urea (MU) and efficiency of crude protein utilization (ECPU) in grazing dairy cows in New Zealand.



ECPU are not available in the literature.

Results of the current study indicate that there is genetic variation for MU and ECPU fluctuating over the lactation. However, the best selection strategy for genetic improvement should consider the genetic potential to alter the lactation curve and the genetic correlations with other economically important traits.

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