Residual metabolizable energy intake and its association with diet and test duration

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[1]*Livestock Development Division, Alberta Agriculture Food and Rural Development, Edmonton, Alberta, Canada T6H 5T6 (e-mail laki.goonewardene@gov.ab.ca);* [2]*Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, Canada T6G 2P5; and* [3]*Agriculture and Agri-Food Canada, Lethbridge, Alberta, Canada T1J 4B1.* *Received 25 July 2003, accepted 9 February 2004.*

Goonewardene, L. A., Okine, E., Wang, Z., Spaner, D., Mir, P. S., Mir, Z. and Marx, T. 2004**. Residual metabolizable energy intake and its association with diet and test duration.** Can. J. Anim. Sci. **84**: 291–295. The objective was to determine if end-of-test residual metabolizable energy intake (RMEI) is correlated with RMEI values calculated earlier in the test on steers fed two forage (silage) or four forage-grain diets. As the days on test increased the variation in RMEI decreased in all diets. In all but the 85% alfalfa + 15% barley grain diet, test duration for RMEI may be reduced from 105 to 84 d. In the 100% alfalfa silage diet, it may be further reduced from 105 to 63 d (Spearman $r = 0.90$; Pearson $r = 0.94$; $P < 0.01$). The duration of testing required to obtain reliable estimates of RMEI may therefore also depend on the type of diet being fed.

Key words: Residual metabolizable energy intake, crossbred steers, correlations, forage-grain diets, test duration

Goonewardene, L. A., Okine, E., Wang, Z., Spaner, D., Mir, P. S., Mir, Z. et Marx, T. 2004. **Ingestion d'énergie métabolisable résiduelle et liens avec la ration et la durée de l'essai**. Can. J. Anim. Sci. **84**: 291–295. L'objectif consistait à déterminer s'il existe une corrélation entre l'absorption d'énergie métabolisable résiduelle à la fin du test (RMEI) et les valeurs obtenues plus tôt. Les auteurs ont utilisé pour cela des bouvillons nourris avec deux sortes de rations fourragères (ensilage) ou quatre mêlant fourrages et céréales. Quand le nombre de jours de l'essai augmente, la RMEI varie moins pour toutes les rations. On peut toujours réduire la durée du test de 105 à 84 jours sauf pour la ration contenant 85 % de luzerne et 15 % d'orge. Quand la ration ne renferme que de l'ensilage de luzerne, on peut diminuer la durée du test à 63 jours (r = 0,90 selon la méthode Spearman; r = 0,94 selon la méthode Pearson; P < 0,01). La durée de l'essai requise pour obtenir une estimation fiable de la RMEI pourrait donc varier avec le genre de ration fournie aux animaux.

Mots clés: Ingestion d'énergie métabolisable résiduelle, bouvillons hybrides, ration fourrage-céréale, durée du test

Residual metabolizable energy intake (RMEI) or the equivalent residual metabolizable feed consumption is recognized as a more precise evaluation of feed efficiency (Arthur et al. 2001; Okine et al. 2003) than feed-to-gain ratio in beef cattle. It is the difference between metabolizable energy intake and metabolizable energy required for maintenance and gain, and is therefore independent of on-test gain and on-test maturing pattern (Fan et al. 1995; Okine et al. 2001). This concept has been used to identify efficient test station bulls, and negative RMEIs (or RFI) indicate that animals either require less energy than what is estimated or are eating less to produce a similar weight gain. A positive RMEI indicates that the animals' energy intake exceeds the predicted requirement (Okine et al. 2001) and such animals are considered less efficient. Since RMEI is moderately heritable ($0.35 < h^2 < 0.49$), it has been used as a criterion to select breeding stock in tests that have facilities to record individual feed intakes. Testing periods of between 70 and 150 d have been reported in the literature (Archer and Bergh 2000; Liu et al. 2000). A 140-d test is considered an industry standard for testing bulls for rate of gain in North America (Liu and Makarechian 1993; Archer et al. 1997), but Archer et al. (1997) and Archer and Bergh (2000) suggested that a 70-d test was adequate to get an accurate measure of RMEI in sires of British breeds and other biological types fed standard test station diets. Those recommendations were based on phenotypic and genetic correlations, and efficiency of selection. If the testing time can be shortened while maintaining the same degree of accuracy, by correctly classifying animals into their respective (positive or negative) RMEI categories with minimal rank changes, then on-test feeding costs may be reduced.

There are many studies relating the duration of performance tests for growth rate and feed conversion ratio or its reciprocal in bulls (Brown et al. 1991; Liu and Makarechian 1993). However, there are few studies (Archer et al. 1997; Archer and Bergh 2000) addressing duration of performance

Abbreviations: **ADG**, average daily gain; **ALF**, alfalfa; **DMI**, dry matter intake; **FEN**, fenugreek; **LSM**, least square mean; **RFI**, residual feed intake; **RMEI**, residual metablolizable energy intake

Table 1. Means ± SD for residual metabolizable energy intake (RMEI, Mcal d^{-1}), average daily gain (ADG) and dry matter intake (DMI) by test day, RMEI overall (0–105 d) and differences in RMEI least square means and SE, Spearman (rank) and Pearson (product-moment) correlations of RMEI, and Pearson correlations of ADG and DMI in selected periods by diet

Diet[z]	Test day	RMEI (Mcal d^{-1})	ADG (kg d^{-1})	DMI (kg d^{-1})	RMEI (0–105 d)	Period comparisons	Difference in RMEI (Mcal d^{-1})	RMEI r [y,x]	RMEI r [y,w]	ADG r [w]	DMI r [w]
1	42	1.87 ± 2.32	0.71 ± 0.23	5.41 ± 0.62	2.82*a*	0–42 d and 0–105 d	–1.35 ± 0.49**	0.78**	0.79**	NS	0.78**
1	63	2.85 ± 1.63	0.69 ± 0.16	5.87 ± 0.57	± 0.49	0–63 d and 0–105 d	–0.36 ± 0.39	0.90**	0.94**	0.81**	0.93**
1	84	3.36 ± 1.43	0.65 ± 0.11	6.05 ± 0.56		0–84 d and 0–105 d	0.14 ± 0.24	0.83**	0.91**	0.86**	0.98**
1	105	3.22 ± 1.38	0.68 ± 0.11	6.27 ± 0.59							
2	42	1.16 ± 1.61	0.78 ± 0.15	5.35 ± 0.84	1.30*b*	0–42 d and 0–105 d	–0.18 ± 0.49	0.76*	0.73*	NS	0.90**
2	63	0.91 ± 1.50	0.82 ± 0.10	5.71 ± 0.68	± 0.49	0–63 d and 0–105 d	–0.44 ± 0.39	0.65*	0.73*	NS	0.96**
2	84	1.79 ± 1.17	0.73 ± 0.07	5.88 ± 0.65		0–84 d and 0–105 d	–0.44 ± 0.24	0.83**	0.73*	0.64*	0.99**
2	105	1.34 ± 1.03	0.79 ± 0.08	6.07 ± 0.67							
3	42	–0.59 ± 2.01	1.13 ± 0.21	6.25 ± 0.49	–0.41*c*	0–42 d and 0–105 d	–0.42 ± 0.49	0.88**	0.81**	0.78**	0.90**
3	63	–0.55 ± 1.87	1.09 ± 0.20	6.59 ± 0.56	± 0.49	0–63 d and 0–105 d	–0.37± 0.39	0.73*	0.85**	0.92**	0.94**
3	84	–0.31 ± 1.69	1.03 ± 0.18	6.70 ± 0.61		0–84 d and 0–105 d	–0.14 ± 0.24	0.93**	0.89**	0.93**	0.99**
3	105	–0.18 ± 1.63	1.02 ± 0.16	6.83 ± 0.59							
4	42	–0.75 ± 2.37	0.69 ± 0.26	4.86 ± 0.70	0.05*bc*	0–42 d and 0–105 d	–1.26 ± 0.49*	0.88**	0.91**	0.89**	0.88**
4	63	0.00 ± 1.87	0.63 ± 0.21	5.41 ± 0.73	± 0.49	0–63 d and 0–105 d	–0.49 ± 0.39	0.73*	0.87**	0.93**	0.98**
4	84	0.45 ± 1.48	0.66 ± 0.15	5.63 ± 0.71		0–84 d and 0–105 d	–0.05 ± 0.24	0.93**	0.95**	0.96**	0.99**
4	105	0.50 ± 1.59	0.69 ± 0.15	5.92 ± 0.70							
5	42	–0.32 ± 1.49	0.76 ± 0.15	5.24 ± 0.52	–0.86*cd*	0–42 d and 0–105 d	0.71 ± 0.49	0.78**	0.70*	0.76*	0.89**
5	63	–0.93 ± 1.82	0.86 ± 0.16	5.79 ± 0.53	± 0.49	0–63 d and 0–105 d	0.10 ± 0.39	NS	0.66*	0.71*	0.98**
5	84	–1.15 ± 1.27	0.88 ± 0.12	6.05 ± 0.60		0–84 d and 0–105 d	–0.12 ± 0.24	0.85**	0.85**	0.93**	0.99**
5	105	–1.03 ± 1.13	0.89 ± 0.12	6.34 ± 0.65							
6	42	–1.72 ± 1.72	0.99 ± 0.25	5.68 ± 0.87	–1.88*d*	0–42 d and 0–105 d	–0.09 ± 0.49	0.87**	0.91**	0.93**	0.91**
6	63	–2.17 ± 2.09	1.02 ± 0.21	6.07 ± 0.82	± 0.49	0–63 d and 0–105 d	–0.53 ± 0.39	0.77**	0.81**	0.93**	0.97**
6	84	–1.98 ± 2.01	0.96 ± 0.20	6.21 ± 0.78		0–84 d and 0–105 d	–0.34 ± 0.24	0.83**	0.93**	0.97**	0.99**
6	105	–1.63 ± 1.90	0.96 ± 0.21	6.47 ± 0.81							

[z] Diet 1 = 100% alfalfa (ALF), 2 = 85% ALF + 15% barley grain (BG), 3 = 70% ALF + 30% BG, 4 = 100% fenugreek (FEN), 5 = 85% FEN + 15% BG, 6 = 70% FEN + 30% BG.

[y] Any pair-wise period comparison of correlations is not significant ($P > 0.05$), according to Z-tests of multiple comparisons of r (Stockburger 1996).

[x] = Spearman correlation.

[w] = Pearson correlation.

a–d Means with different letters for RMEI in Mcal d^{-1} (0–105 d) denote significance ($P < 0.05$)

*, ** $P < 0.05$ and $P < 0.01$, respectivelky; NS, $P > 0.05$.

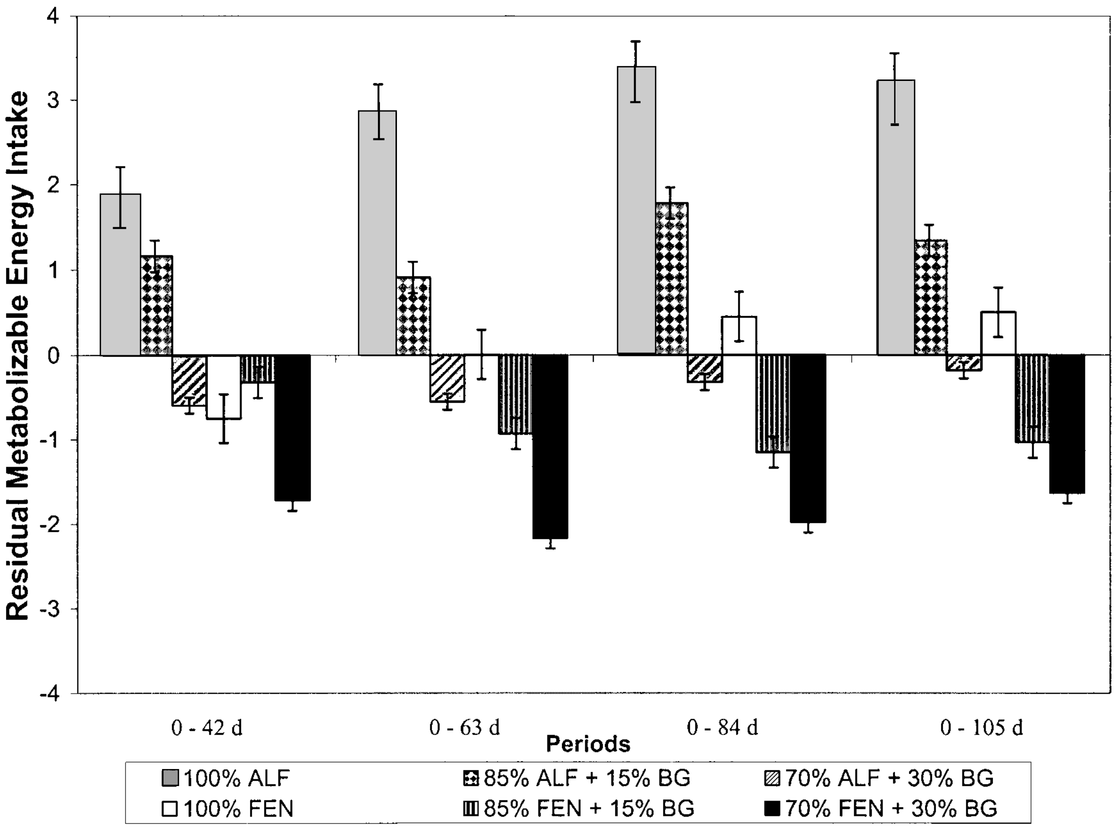

Fig. 1. Diet × period interaction least square means and SE for residual metabolizable energy intake (Mcal d^{-1}); ALF = alfalfa, BG = barley grain, FEN = fenugreek.

tests for RMEI, and both relate to testing bulls on a standard test station diet. There is no information on the relationship between RMEI during early and late testing periods, or the ranking and rank change among animals during the test period when animals were simultaneously fed different diets.

The objective of this initial study was to determine if end-of-test RMEI values are related to RMEI values calculated prior to the end-of-test, in steers fed two forage (silage) and four forage-grain diets.

The data were obtained from a study by Mir et al. (1998) in which 60 crossbred steers (initial weight 237 ± 18 kg) were individually fed one of six diets with 10 steers per diet for 105 d. Feed intakes were individually recorded daily while steer weights were recorded at 21-d intervals. The six diets were: 100% alfalfa (*Medicago sativa* L.) silage, 85% alfalfa silage + 15% barley (*Hordeum vulgare* L.) grain, 70% alfalfa silage + 30% barley grain, 100% fenugreek (*Trigonella foenum graecum* L.) silage, 85% fenugreek silage + 15% barley grain, and 70% fenugreek silage + 30% barley grain. Four overlapping periods were created: 0–42 d, 0–63 d, 0–84 d and 0–105 d to study correlations of RMEI between the end-of-test and prior to end-of-test. Information on the management of the animals and other experimental details such as the diet composition and animal performance was reported by Mir et al. (1998). RMEI was calculated by the procedures outlined by Okine et al. (2001) within diet, for each animal by period subclass. All steers were cared for in accordance with the Canadian Council on Animal Care (1993) guidelines.

Raw (unadjusted) means and standard deviations were obtained for RMEI, average daily gain (ADG) and dry matter intake (DMI) within diet at 42, 63, 84 and 105 d on-test. Residual metabolizable energy intake was further analyzed with the Mixed Model procedure of SAS software (SAS Institute, Inc., Version 8e) with diet as a fixed effect, period as a fixed repeated effect and animal within diet as a random error term to test diet. The variance-covariance matrix was chosen for the statistical model using an iterative process wherein the best fit was based on Schwarz's Bayesian criterion. The Kenward-Roger method was used to determine denominator degrees of freedom. Least square means were separated using the pdiff option for significant ($P < 0.05$) fixed effects. Spearman (rank) correlations (r) were obtained between 42 d, 63 d, 84 d and 105 d for RMEI rankings. Pearson (product moment) correlations (r) were obtained (SAS Institute, Inc. 1989) for RMEI, ADG and DMI values between periods 0–42 d, 0–63 d, 0–84 d and 0–105 d. The significance between correlations was tested by converting the correlations to Z scores where

$$Z = 0.5\ln\,[1 + r/1 - r]\ \text{(Stockburger 1996).}$$

Means and standard deviations for RMEI, ADG and DMI by test day are shown in Table 1. In general, the variances decreased for RMEI and ADG as the days on test increased. The change in variance between the earlier days on test (42 and 63 d) was greater (6.5% decrease) than the change in the later days on tests (84 and 105 d) (2.5% decrease). In all diets the variation in RMEI at 84 d was similar to that at 105 d.

The RMEI values differed ($P < 0.01$) for diets and diet × period interaction. The overall (0–105 d) RMEI least square means are also shown in Table 1. In general, steers fed 100% alfalfa silage had more positive RMEI values, those fed 70% fenugreek silage + 30% barley grain showed more negative RMEI values, and those fed 100% fenugreek silage showed mean RMEI values closer to zero. The diet × period interaction least square means for RMEI are shown in Fig. 1. The animals on either the 100% alfalfa or the 85% alfalfa + 15% barley grain diets showed positive RMEI values at each period with the former being more positive than the latter. The largest positive LSM was at 84 d in both diets (100% alfalfa = 3.36 Mcal d^{-1} ; 85% alfalfa + 15% barley grain = 1.78 Mcal d^{-1}). Steers on either the 85% fenugreek + 15% barley grain diet, or the 70% fenugreek + 30% barley grain, showed negative RMEI values in each period with the latter diet being more negative than the former. The largest negative LSM for RMEI in the 70% fenugreek + 30% barley grain diet was –2.17 Mcal d^{-1} at 63 d on test and the largest negative LSM in the 85% fenugreek + 15% barley grain diet was –1.15 Mcal d^{-1} at 84 d on test.

Differences in diet × period interaction means for RMEI compared for selected periods are shown in Table 1. In all diets, the mean differences between the end-of-test RMEI and 0–63 d or 0–84 d were not significant ($P > 0.05$), suggesting that these values were close and similar. In the 100% alfalfa silage, 70% alfalfa + 30% barley grain, 100% fenugreek, and 85% fenugreek + 15% barley grain diets the mean differences in RMEI between 0–84 d and 0–105 d were within ± 0.14.

The ranks of RMEI values at 105 d were strongly correlated ($r = 0.93$; $P < 0.01$) with RMEI rank at 0–84 d in 70% alfalfa + 30% barley grain and 100% fenugreek diets (Table 1). Pearson correlations were also high ($r \geq 0.89$) for the same periods in the same two diets. In the 100% alfalfa diet, the correlations of RMEI at 0–63 with 0–105 d were also high [$r = 0.90$ (rank) and $r = 0.94$ (Pearson); $P < 0.01$]. The correlations of ADG and DMI between the earlier periods (0–42 and 0–63) and 0–105 d were lower than the correlations of 0–84 d with 0–105 d in all diets. The best predictor of ADG and DMI over 105 d was that at 0–84 d in all diets.

The studies reported in the literature have usually estimated RMEI (or RFI) in bulls, fed a single balanced diet containing adequate nutrients to express their full genetic growth potential (Liu et al. 2000; Arthur et al. 2001; Okine et al. 2003). In those studies, the objective was to recognize superior bulls for breeding based on RMEI, which is established as a more reliable measure of efficiency independent of on-test weight and gain. Our results indicate that as the proportion of alfalfa silage increased (or barley decreased) the RMEIs became more positive in the alfalfa-based diets, and as the proportion of fenugreek decreased (or barley increased) the RMEIs became more negative in the fenugreek-based diets. These trends were independent of feed intake, as animals on 100% alfalfa showed intakes of 5.41 ± 0.62, 5.87 ± 0.57, 6.05 ± 0.56 and 6.27 ± 0.59 kg d^{-1} at 42, 63, 84 and 105 d, respectively, while those on the 70% fenugreek + 30% barley grain diet showed similar intakes of 5.68 ± 0.87, 6.07 ± 0.82, 6.21 ± 0.78 and 6.47 ± 0.81 kg d^{-1} at 42, 63, 84 and 105 d on-test, respectively (Table 1). The crossbred steers used in our study were randomly allocated to each of the dietary treatments, and this process ensured that genetically superior animals were not preferentially included in any one dietary treatment.

RMEI is moderately heritable (Liu et al. 2000; Arthur et al. 2001); however, a portion of the variability is non-genetic and diet may account for a part of this. Our results indicate that steers exhibiting negative RMEIs on one diet may not necessarily show the same trend when fed another, although both diets have been balanced to provide adequate nutrients for maintenance and growth. An earlier study (Okine et al. 2001) indicated that although alfalfa fed as silage alone or in combination with barley grain had higher metabolizable energy (12.33–12.44 MJ kg^{-1} for alfalfa vs. 11.58–11.92 MJ kg^{-1} for fenugreek), net energy for maintenance (8.32–8.37 MJ kg^{-1} for alfalfa vs. 7.69–7.93 MJ kg^{-1} for fenugreek), and net energy for gain (5.60–5.64 MJ kg^{-1} for alfalfa vs. 5.02–5.23 MJ kg^{-1} for fenugreek) than fenugreek fed as silage or in combination with grain, the RMEIs were more negative for steers on fenugreek compared with alfalfa. Animals tested in one dietary management system may not necessarily perform at the same level in another due to genetic and non-genetic differences. As RMEI is a function of feed intake, if test duration affects the accuracy of intake it will influence the accuracy of RMEI prediction. Australian studies have shown that as marked differences in feeding patterns exist between *Bos taurus* and *Bos indicus* in the same feedlot (Robinson et al. 1997), differences between breeds required to obtain reliable estimates of feed intake may exist (Archer et al. 1997). However, in a subsequent study Archer and Bergh (2000) concluded that there is little evidence to suggest that differences exist between genotypes in the duration of performance tests required to accurately measure traits such as RMEI. Our study indicates that with respect to the accuracy of RMEI prediction, the duration of the test may also depend on the type of diet provided.

Based on the reduction in variance over time on test, mean differences in RMEI over selected periods, Spearman and Pearson correlations, an 84-d testing period appears to be adequate for the 100% fenugreek silage and 70% fenugreek + 30% barley grain diet for reliable estimations of RMEI, whereas in the 100% alfalfa diet, a shorter 63-d test appears to be adequate. The absence of large fluctuations in rank correlations observed in the 100% alfalfa, 100% fenugreek, 70% alfalfa + 30% barley grain, and 70% fenugreek + 30% barley grain diets further suggests that there are no major changes in the ranking of animals with respect to RMEI values within the diets. The Pearson correlations obtained for the comparison of 0–84 d with 0–105 d ranged from 0.85 to 0.93 in all but the 85% alfalfa +15% barley grain diet. These correlations are similar to phenotypic correlations of 0.90 reported for a 0–70 d period (Archer et al.

1997). The results of our study support the work of Archer et al. (1997) and Archer and Bergh (2000) who suggested that a 70–84 d period was adequate to evaluate RMEI with no loss in end-of-test accuracy in bulls of different biological types.

Correlating overlapping periods using the Pearson correlation means that there is some autocorrelation, hence the expectation of higher correlations towards the end of test. As such, both Pearson and Spearman correlations, and differences in least square estimates were used to study the relationships of RMEI between testing times for each diet. Due to the small sample size in each diet (n = 10) further studies are suggested.

As differences in Residual metabolizable energy intake exist in the way animals respond to different diets, the duration of testing required to obtain reliable estimates of residual metabolizable energy intake may also depend on the type of diet being fed in addition to the accuracy in measuring gain and intake. Studies on genotype × diet interactions are needed to ensure a more global application of residual metabolizable energy intake.

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