Residual intake and body weight gain: A new measure of efficiency in growing cattle

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ABSTRACT: Interest in improving feed efficiency in cattle is intensifying. Residual feed intake (RFI), which is the difference between expected intake and that predicted based on energy demands, is now the most commonly used measure of feed efficiency over a given time period. However, RFI, as commonly defined, is independent of growth rate, which may affect its acceptance by industry. Residual BW gain (RG) has also been proposed as a measure of feed efficiency and is represented as the residuals from a multiple regression model regressing ADG on both DMI and BW. In this study, we propose a new trait, residual intake and BW gain (RIG), which retains the favorable characteristic of both RFI and RG being independent of BW, but animals superior for RIG have, on average, both greater ADG and reduced DMI. Phenotypic and genetic analyses were undertaken on up to 2,605 purebred performance-tested bulls. Clear phenotypic differences in DMI and ADG existed between animals divergent for RIG. The heritability of RIG was 0.36 ± 0.06, which is consistent with the heritability estimates of RFI and other feed efficiency traits measured in the study. The RIG trait was both phenotypically and genetically negatively correlated with DMI and positively correlated with ADG; no correlation existed between RIG and BW. The advantages of both reduced daily DMI and greater ADG in animals superior for RIG are demonstrated compared with animals superior for either RFI or RG.

Key words: beef cattle, feed efficiency, residual feed intake, residual intake and body weight gain

INTRODUCTION

There is a growing interest, in the scientific literature at least, in the use of residual feed intake (RFI; Koch et al., 1963) as a measure of feed efficiency in growing cattle (Berry, 2008). The cited advantages of RFI are that it is heritable (Arthur et al., 2001; Robinson and Oddy, 2004; Crowley et al., 2010) and independent of the energy sinks included in the least squares regression model to estimate RFI (Kennedy et al., 1993). This independence may be either phenotypic or genetic depending on whether the variables in the regression model are at the phenotypic or genetic level (Kennedy et al., 1993).

Most studies on RFI include both (metabolic) BW and ADG as energy sinks (Herd and Bishop, 2000; Arthur et al., 2001; Crowley et al., 2010). This therefore implies that RFI is not correlated with ADG, and although RFI may be a good indicator of feed efficiency, it may lack acceptance by producers because slow-growing animals eating relatively small amounts of feed may actually have good RFI.

Residual BW gain (RG) is in principle similar to RFI except that instead of regressing feed intake on BW and ADG in the calculation of RFI, ADG is regressed on feed intake and BW in the calculation of RG (Crowley et al., 2010). Hence, improved RG is, on average, associated with faster growth rates but is not associated with differences in feed intake.

The objective of this study was to evaluate a newly defined index trait, residual intake and BW gain (RIG), which combines RFI and RG and can subsequently be used to identify efficient, fast-growing animals, while still being independent of BW. The independence with BW is cited to be important to ensure that selection on RFI or RG has a minimal impact on mature cow BW.

MATERIALS AND METHODS

The data used in the present study originated from a database on purebred bulls in a performance test sta-
tion in Ireland. Therefore, it was not necessary to secure animal care and use committee approval in advance of conducting this study. The data used are identical to the data described in detail by Crowley et al. (2010).

**Data**

Records were available on 3,531 purebred bulls from the national beef bull performance test center at Tully, Kildare, Ireland, from September 1983 to February 2007, inclusive. Bulls were performance tested at the center in, on average, 3 separate batches annually. Duration of the test period across the years varied from 82 to 225 d.

Initial BW was recorded after acclimatization and subsequently every 14 d from the start of test with the exception of between 1995 and 2005 when bulls were weighed at 21-d intervals. The diet offered was composed of concentrates and a restricted forage (hay/ lucerne) allowance.

Forage was offered on an individual basis at a daily rate of 1.5 kg (fresh weight) per animal as a source of roughage to maintain healthy rumen function. No refusals were weighed. Because forage offered over the years remained the same for all animals, its effect on concentrate intake (CI) was not taken into consideration in this study. Concentrate refusals of each bull were weighed 1 d each week and subtracted from the cumulative feed offered the previous 7 d to obtain total concentrate fresh weight consumed over this time period. Although CI was therefore calculated weekly, only data on CI averaged over a 14-d period were available across the years 1983 to 1991, whereas CI averaged over a 21-d period was available from 1992 to 2005. From 2006 to 2007, however, average weekly CI was available for inclusion in the analysis.

Composition and DM of the concentrate offered before 1992 were not available. Between 1992 and 2007, two different concentrates were used. The concentrate offered between September 1992 and September 2002 had a DM of 875 g/kg and an estimated ME concentration of 12.1 MJ/kg of DM. The concentrate offered from October 2002 to February 2007 had a DM of 860 g/kg and an estimated ME concentration of 14.5 MJ/kg of DM. The forage was assumed to have a constant DM concentration of 850 g/kg and a ME concentration of 8.6 MJ/kg of DM throughout the years 1992 to 2007.

**Data Editing**

Data from bulls not on test for at least 96 d (n = 202) were discarded. Concentrate intake and BW records in the last 70 d of the test period were retained. This will be subsequently referred to as the test period. Additionally, the most recent BW record before the 70-d cut-off was also retained if it was within 92 d of the end of test. All bulls had to have at least 4 BW and CI records during the 70-d test period. A total of 3,153 bulls remained after these edits. Bulls younger than 160 d (n = 38) and older than 360 d (n = 28) on entry to the station were omitted, as were bulls younger than 330 d (n = 85) and older than 480 d (n = 46) at the end of the test. Data on bulls that could not be clearly allocated to a contemporary group or batch (n = 45) were discarded. Only purebred Aberdeen Angus, Charolais, Hereford, Limousin, and Simmental bulls were retained. Bulls with no pedigree information (n = 11) were discarded for the genetic analysis but included in the phenotypic analysis. Data for a further 50 bulls were discarded due to abnormal growth rates (Crowley et al., 2010).

Because of the unavailability of diet composition and DM data before the year 1992, 2 separate data sets were generated: 1) all bulls (n = 2,605); and 2) bulls with records after September 1992 (n = 2,102) when information on diet composition was available. The first data set was used in the phenotypic analysis, whereas the second data set was used in the phenotypic analysis as described later.

**Performance Traits**

Average daily gain during the test period for each bull was calculated by fitting a linear regression through all BW observations of each bull. Mid-test BW was represented as BW 35 d before the end of the test which was estimated from the intercept and slope of the regression line. Similarly mid-test metabolic BW (i.e., BW0.75) was estimated from the intercept and slope of the regression line after fitting a linear regression through all metabolic BW observations. Mean daily CI was calculated as the arithmetic mean daily intake of concentrate, as fed, across the test period. Mean daily DMI and ME intake (MEI; MJ/kg of DM) was also calculated for the 2,102 bulls tested after 1992 when diet composition was available.

Feed conversion ratio was calculated as average intake (either DMI or CI depending on whether it was the phenotypic or genetic analysis) divided by ADG. Relative growth rate (RGR) and Kleiber ratio (KR) were computed as follows:

\[
RGR = 100 \times \frac{\log_e(\text{end BW}) - \log_e(\text{start BW})}{\text{d on test}},
\]

\[
KR = \frac{\text{ADG}}{\text{mid-test BW}^{0.75}}.
\]

Residual feed intake was assumed to represent the residuals from a multiple regression model regressing MEI on ADG and BW0.75 with batch included as a contemporary group effect. Similarly, RG was assumed to represent the residuals from a multiple regression model regressing ADG on MEI and BW0.75 with batch included as a contemporary group effect in the model. Concentrate intake rather than MEI was used in the
calculation of RFI and RG for the genetic analysis resulting in an increase in the number of animals for genetic analysis.

Residual intake and BW gain was calculated as the sum of \(-1 \times \text{RFI}\) and \(\text{RG}\), both standardized to a variance of 1. Multiplying RFI by \(-1\) was to account for a negative RFI being favorable compared with a positive RG being favorable. The RIG is a linear function of both RFI and RG which in turn are linear functions of their component traits feed intake, ADG, and BW. Therefore, an alternative approach, if contemporary group (or other fixed effects) is not included in the model to estimate either RFI or RG, is to use selection indexes to calculate the appropriate weighting (i.e., \(b\)) on the component traits (Kennedy et al., 1993; van der Werf, 2004); the (co)variance components among feed intake, ADG, and BW must be estimated for inclusion in the selection index. Similarly, a restricted selection index could be used (Eisen, 1977).

**Statistical Analysis**

The 2,102 bulls with information on diet composition after 1992 were split evenly, within breed, into 3 groups: high, medium, and low RIG. Least squares means for performance and other efficiency measures were determined for the different RIG categories across breeds.

Phenotypic and genetic (co)variance components among traits were estimated, across breeds, using an animal model in ASREML (Gilmour et al., 2009). A total of 2,605 bulls were included in the across-breed analysis. Because diet composition was not available on all bulls, CI and variables using CI in their calculation were expressed on a fresh-weight basis. Fixed effects considered for inclusion in the model were batch \((n = 84)\), breed of bull \((n = 5)\), dam lactation number \((1, 2, 3 \text{ to } 4, \geq 5, \text{ and missing})\), and age of the bull at the end of test (continuous variable). Nonlinear associations with age at the end of the test as well as a 2-way interaction between age at the end of the test and breed were also tested. Animal was included as a random effect, and average genetic relationship among bulls was accounted for by tracing both sides of the pedigree back at least 4 generations. The pedigree file consisted of 11,428 animals.

**RESULTS AND DISCUSSION**

The objective of this study was to present a potential new index trait, to be used in growing cattle, for identifying animals growing fast and eating proportionally less than expected, yet with no difference in mean BW. This was to overcome the shortcoming of RFI, which is, by definition, not phenotypically correlated with ADG and therefore could result in poor industry acceptance of this trait because slow-growing animals could rank highly on RFI over a given time period.

The purpose of RIG is to identify animals that require a shorter duration in the feedlot (i.e., faster ADG) but also have a less than expected daily feed intake to support such growth while simultaneously accounting for any differences in maintenance (i.e., BW) requirements of the animal.

Mean performance for all traits, excluding RIG, are discussed in detail by Crowley et al. (2010) and are summarized in Table 1. The bulls were on average 309 d of age and 476 kg of BW when the test began. Mean performance of the animals was similar to that reported in many other international studies (for review, see Crowley et al., 2010). The variation in performance of the bulls in the present study tends to be larger than in most other studies, but the number of breeds represented in this study is greater than in other studies, which is likely to contribute to greater variation in performance within the overall data set.

Mean performance of animals divergent for RIG are summarized in Table 2. Although statistically significant differences in age and BW of the animals existed between the 3 divergent groups of animals, the differences were nonetheless biologically small. Difference in BW existed despite RIG being independent of BW because animals were stratified by RIG within breed and fixed effects were included in the model to estimate the least squares means. Clear differences in DMI and ADG existed with the poorer (i.e., low) RIG animals eating, on average, the most yet growing on average

<table>
<thead>
<tr>
<th>Trait</th>
<th>Mean</th>
<th>SD</th>
<th>(h^2 \pm \text{SE})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrate intake, kg/d</td>
<td>10.7</td>
<td>1.52</td>
<td>0.49 (0.06)</td>
</tr>
<tr>
<td>Metabolic BW, kg</td>
<td>113</td>
<td>11.40</td>
<td>0.69 (0.07)</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td>1.64</td>
<td>0.306</td>
<td>0.30 (0.06)</td>
</tr>
<tr>
<td>Feed conversion ratio</td>
<td>0.67</td>
<td>0.128</td>
<td>0.30 (0.06)</td>
</tr>
<tr>
<td>Relative growth rate</td>
<td>0.13</td>
<td>0.027</td>
<td>0.33 (0.06)</td>
</tr>
<tr>
<td>Kleiber ratio</td>
<td>1.45</td>
<td>0.268</td>
<td>0.31 (0.06)</td>
</tr>
<tr>
<td>Residual BW gain, kg/d</td>
<td>0.00</td>
<td>0.021</td>
<td>0.28 (0.06)</td>
</tr>
<tr>
<td>Residual feed intake, kg/d</td>
<td>0.00</td>
<td>0.866</td>
<td>0.45 (0.06)</td>
</tr>
<tr>
<td>Residual intake and BW gain</td>
<td>0.00</td>
<td>0.876</td>
<td>0.36 (0.06)</td>
</tr>
</tbody>
</table>
the slowest. The superior (i.e., high) RIG animals ate, on average, the least, yet grew the fastest. This clearly shows the benefit of combining both RFI and RG into 1 trait to reap the benefits of both measures. Unlike in the study by Crowley et al. (2010) who compared mean performance in different measures of feed efficiency for animals divergent in either RFI or RG, there was a clear and consistent trend of improved feed efficiency, irrespective of what definition was used, as RIG improved. This was further substantiated by the moderate to strong phenotypic correlations between RIG and the other measures of feed efficiency (Table 3).

**Genetics of Residual Intake and BW Gain**

Animal breed and age were associated (*P* < 0.05) with RIG; dam parity was not associated (*P* = 0.38) with RIG. The ranking of breeds (least squares means ± SE) from worse to best was Aberdeen Angus (−2.01 ± 0.18), Hereford (−1.03 ± 0.14), Simmental (−0.71 ± 0.06), Limousin (0.40 ± 0.05), and Charolais (0.65 ± 0.06); differences (*P* < 0.05) existed between all pairwise breed comparisons. Residual intake and BW gain declined at a reducing rate as age increased. The heritability of RIG was 0.36 ± 0.06 (Table 1) and was between the heritability estimates of its component traits of RFI and RG. This heritability estimate is also consistent with heritability estimates previously reported for feed efficiency traits in other studies (Herd and Bishop, 2000; Arthur et al., 2001; Robinson and Oddy, 2004). The strong genetic correlations (Table 3) between RIG and both RFI (−0.87) and RG (0.83) is expected given the part whole relationship between them. The lack of a significant genetic correlation with mid-test metabolic BW is also expected. The significant genetic correlations between RIG and both CI and ADG clearly show that selection on RIG alone will result in improved ADG and reduced daily CI during the growing period included in the calculation of RIG.

**Advantages of Residual Intake and BW Gain**

Like RFI, RG, and other proposed measures of feed efficiency, RIG is moderatelyheritable with significant genetic variation, implying that genetic selection for RIG is feasible. The ability to derive RIG using selection index methodology means that it can be calculated at either the phenotypic or genetic level. Optimal selection on all 3 traits, DMI, ADG, and BW using selection index methodology would, however, yield similar responses to selection on RIG and may be a more transparent index for exploitation by the end user. This is discussed in detail by van der Werf (2004) using RFI as an example including the implications of including RFI on the economic values of its component traits in the total merit index. Therefore, it is not recommended to include feed efficiency traits that themselves are a linear combination of other traits, in an overall total merit index.

Nevertheless, index traits such as RFI, RG, or RIG are still of use: 1) if total merit breeding objectives are not available for the population or species under investigation, access to information on genetic merit for feed efficiency (e.g., a subindex) may be useful; 2) if breeders are particularly interested in marketing their germplasm on feed efficiency, then the ability to derive

<p>| Table 2. Least squares means for age, BW, growth, and efficiency traits for animals (n = 2,102) ranked high, medium, and low for residual intake and BW gain |
|----------------|----------------|----------------|----------|--------|</p>
<table>
<thead>
<tr>
<th>Trait</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual intake and BW gain</td>
<td>−1.63&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.60&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.030</td>
</tr>
<tr>
<td>Start age, d</td>
<td>312&lt;sup&gt;a&lt;/sup&gt;</td>
<td>307&lt;sup&gt;b&lt;/sup&gt;</td>
<td>308&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.86</td>
</tr>
<tr>
<td>Final age, d</td>
<td>392&lt;sup&gt;a&lt;/sup&gt;</td>
<td>386&lt;sup&gt;b&lt;/sup&gt;</td>
<td>388&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.86</td>
</tr>
<tr>
<td>Start BW, kg</td>
<td>483&lt;sup&gt;a&lt;/sup&gt;</td>
<td>473&lt;sup&gt;b&lt;/sup&gt;</td>
<td>473&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.98</td>
</tr>
<tr>
<td>Final BW, kg</td>
<td>603&lt;sup&gt;a&lt;/sup&gt;</td>
<td>605&lt;sup&gt;b&lt;/sup&gt;</td>
<td>617&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.14</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>11.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.84</td>
</tr>
<tr>
<td>ME intake, MJ/d</td>
<td>136.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>131.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>128.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.47</td>
</tr>
<tr>
<td>Mid-test BW, kg</td>
<td>552&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>548&lt;sup&gt;a&lt;/sup&gt;</td>
<td>555&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.05</td>
</tr>
<tr>
<td>Metabolic BW, kg</td>
<td>113.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>113.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>114.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.32</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td>1.49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.66&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.81&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.008</td>
</tr>
<tr>
<td>Feed conversion ratio</td>
<td>7.69&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.61&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.90&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.025</td>
</tr>
<tr>
<td>Relative growth rate</td>
<td>0.12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.14&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.15&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.001</td>
</tr>
<tr>
<td>Kleiber ratio</td>
<td>0.013&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.015&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.016&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.0001</td>
</tr>
<tr>
<td>Residual feed intake, total MJ/d</td>
<td>0.70&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>−0.71&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.024</td>
</tr>
<tr>
<td>Residual BW gain, kg/d</td>
<td>−0.20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.19&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.005</td>
</tr>
</tbody>
</table>

<sup>a–c</sup>Least squares means within a row with different superscripts differ (*P* < 0.05).

<sup>1</sup>Residual intake and BW gain group derived by dividing the data set equally into groups based on residual intake and BW gain.

<sup>2</sup>Pooled SE.

<sup>3</sup>Significance of the group effect.
a pertinent feed efficiency trait, separate from a total merit index, may be useful as a marketing tool; 3) if sufficient data on feed intake and other traits included in the index are not available to estimate genetic parameters, estimation of mean feed efficiency in groups of animals divergent for a given breeding objective can provide useful knowledge on the expected responses to selection; 4) similarly, they can be used to monitor past temporal trends in feed efficiency; 5) if diet × genetic merit for feed efficiency interactions exist, then animals may be partitioned based on genetic merit for feed efficiency and fed accordingly, and 6) phenotypes for feed efficiency may also be useful for nonbreeding purposes such as evaluation of different management strategies, including diet.

One of the main cited advantages of RFI and RG is their independence of BW included in the multiple regression model. Although a function of the residual and genetic covariances among traits as well as their respective heritability (van der Werf, 2004) the genetic correlation between both RFI and RG and BW are also close to 0 (Crowley et al., 2010). However, this independence does not necessarily imply genetic independence from mature cow BW because the genetic correlation between mature cow BW and BW in younger growing animals is not unity (McHugh et al., 2011). The impact of selection on RIG on mature cow BW merits further investigation.

The main motivation for deriving a new efficiency trait in this study was to minimize the likelihood of slow-growing animals being identified as efficient animals. One approach would be to combine RFI with ADG in an index, but because of the covariance between ADG and BW (Table 3), the independence between this new index and BW would have disappeared. The approach of summing RFI and RG each with equal weights will help identify well-performing animals with good feed efficiency; the weightings on the individual index traits need not necessarily be equal and can be modified by the end user. The consequence at the genetic level was also improved ADG and reduced intake with no expected change in BW (Table 3).

Additional advantages are that more positive RIG values are favorable unlike RFI where more negative values are favored, and RIG does not suffer from the unfavorable characteristics of genetic selection on ratio traits such as feed conversion ratio (Gunsett, 1984).

**Dual Objective of Residual Intake and BW Gain**

The existence of phenotypic and genetic correlations between RIG and both CI and ADG is in direct contrast to the lack of a correlation between RFI and ADG or between RG and CI, emphasizing the dual objective of RIG in improving animal efficiency by reducing daily feed intake but also the age to reach a given BW. The latter assumes that selection on RIG does not influence carcass characteristics (e.g., subcutaneous fat level),
which may deem the animal unsuitable for slaughter at a younger age.

To illustrate the advantage of the dual objective of RIG, the top 10% of animals ranked on RFI, RG, or RIG were assumed to be subjected to a finishing diet, the duration of which was determined by when the animal gained 300 kg of BW. The only variables permitted to vary were DMI and ADG, and the impact on other animal or carcass characteristics were ignored.

Average DMI and ADG of animals in the best 10% for RFI, RG, and RIG are reported in Table 4. As expected, the best RFI animals ate least on a daily basis, the best RG animals ate most, whereas animals excelling in RIG were intermediate. Similarly, the best RFI animals grew slowest, the best RG animals grew fastest, whereas animals ranked best on RIG were intermediate. The latter was reflected in a 30-d shorter finishing period required to gain 300 kg of BW for the top RG animals compared with the top RFI animals. However, the intermediate performance for daily DMI and ADG of the top RIG animals manifested itself in a decreased overall quantity of feed eaten during the finishing period. Although relatively small at an individual level, the impact may be considerable at a herd level. Furthermore, if such differences existed since birth, the absolute difference would be expected to be greater.

Nonetheless, not included in this simple analysis are any potential consequences in performance traits not measured such as carcass quality or animal health. Also, not included are the potential differences in fixed and variable costs associated with different selection strategies such as capital and labor costs. Faster growing animals may need less labor and capital investment per animal because they are younger at slaughter; however, this advantage may be negated by the additional cost of growing, harvesting, and having to feed these animals more daily. Furthermore, the impact of such traits on environment footprint, an issue of increasing concern, has not been evaluated; this is likely to be a tradeoff between shorter lifetime to slaughter and daily environmental impact.

**Conclusions**

This study proposes an alternative measure of efficiency in growing animals, taking into account both exploitable (genetic) differences in daily DMI as well as total DMI required to obtain a given change in BW (i.e., differences in growth rate). The trait RIG can easily be calculated as the sum of 2 already used definitions of feed efficiency or equivalently by using selection index methodology. Although RIG can be useful in evaluating animals subjected to different management systems (e.g., diet), arguably genetic selection for feed efficiency such as RIG (or RFI) would be better within an overall breeding objective that includes other traits such as mature cow BW if available. Nonetheless, genetic correlations between RIG and other performance traits, such as carcass characteristics, should be estimated, especially because the data are readily available given that correlations with the component traits of RIG have previously been estimated elsewhere (Herd and Bishop, 2000; Hoque et al., 2006; Bouquet et al., 2010). This is important to ensure no antagonistic correlations exist with RIG. Also, the existence of genotype × environment (i.e., management or sex of animal) should be investigated.

**LITERATURE CITED**


