Improving estimates of weight gain and residual feed intake by adjusting for the amount of feed eaten before weighing

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Abstract. In Australia, a trait under consideration for genetic selection to improve feed efficiency is residual feed intake (RFI), which is defined as the amount of feed eaten by an animal less what would be expected from the animal’s growth rate and body weight. Accurate estimates of RFI therefore require accurate estimates of weight gain. Results presented here on steers finished in a feedlot to liveweights of 540 or 600 kg show that, when feed intake is being measured, weight gain can be estimated more accurately using the amount of feed eaten in the previous 3–5 days (as an adjustment for gut fill) than if feed eaten in the 80 h before weighing is ignored. This is demonstrated by a much lower residual mean square from modelling the weight of each animal as a quadratic growth curve over time if terms are included for feed eaten on the current and previous 3–5 days.

An analysis of measurement errors associated with fitting the equation used to calculate RFI:

\[
\text{Feed intake} = \mu + \beta_w \times \text{mean metabolic weight} + \beta_g \times \text{weight gain} + \text{error (i.e. RFI)} (1)
\]

indicates that the relatively high measurement errors associated with weight gain but comparatively low measurement errors associated with metabolic weight will result in upward biases in the partial regression coefficient \(\beta_w\) and downward biases in \(\beta_g\). For example, in a 105-day feed intake test of 44 steers (mean start/end weights 440/600 kg), the estimate of \(\beta_g\) was 1.26 based on weight gain estimated by a simple linear regression of each animal’s weight over time (LIN), compared with 2.20 using weight gain estimated from the difference between first and last weight of each animal adjusted for the amount of feed eaten on the current and previous 5 days (DIFFadj). From a shorter test, based on weight gains from day 15 to 50 in the automatic feeder pens, the estimate of \(\beta_g\) was 0.40 using LIN and 1.67 using DIFFadj. These results illustrate the potential magnitude of the downward bias in \(\beta_g\) if inaccurate estimates of weight gain are used to fit equation 1. The higher estimates for \(\beta_g\) obtained using DIFFadj may still have some downward bias but are closer to the theoretical values published by SCA (1990) for the amount of metabolisable energy required for weight gain. Adjusting for the amount of feed eaten before weighing therefore increased the accuracy of estimated weight gain and reduced the biases in \(\beta_g\) and \(\beta_w\), so providing better and more stable estimates of residual feed intake.

Additional keywords: beef cattle, feed intake, feed efficiency.

Introduction

Feedlot finishing entails relatively high feed costs, so the economic advantages of reducing feed intake while maintaining growth rate are considerable. In Australia, a trait under consideration for genetic selection is residual (or net) feed intake (RFI), for which trial EBVs have already been published (Anon. 1999). RFI is defined as the amount of feed eaten by an animal less what would be expected from the growth of the animal and its body weight (used as an indicator of maintenance requirements). More precisely, RFI is calculated as the error term when fitting the equation:

\[
\text{Intake} = \mu + \beta_w \times \text{mean metabolic weight} + \beta_g \times \text{weight gain} + \text{error (i.e. RFI)} (1)
\]

where intake is daily feed intake (kg, as fed); \(\mu\) is a constant; mean metabolic weight is mean (weight^{0.73} of the animal for the feed intake test period; and weight gain is liveweight gain (kg/day) over the feed intake test period.

A problem is that the standard least squares regression equations to estimate \(\beta_w\) and \(\beta_g\) produce unbiased results only if the independent variables (mean metabolic weight and weight gain) are free from measurement error. In contrast, if measurement errors are large compared with the inherent variation between animals, biases may be substantial, as will be shown later in this paper.

Feed intake can be measured with moderate repeatability over a period as short as 5 weeks (Archer et al. 1997). Mean
metabolic weight can be measured with high accuracy over the same period, because the errors in each individual weight measurement are averaged out by taking the mean of several weight measurements, for example at weekly intervals. However, unless measured over a relatively long interval of time, accuracy of weight gain may be low (Archer et al. 1997). For datasets in which weight and weight gain are highly correlated, this is likely to produce a substantial downward bias in the estimate of $\beta_w$ and upward bias in the estimate of $\beta_g$.

Variation in the contents of the alimentary tract of cattle during the course of a day may cause substantial variation in liveweight (Hughes 1976). This paper investigates whether accuracy of weight gains can be improved by adjusting for the amount of feed eaten before weighing as an indicator of gut fill. We also examine the effect of more accurate estimates of gain on the partial regression coefficients, $\beta_w$ and $\beta_g$ and discuss the implications for industry use of RFI.

Materials and methods

Animals and measurements

The cattle used for this study were a subset of the larger experiment of the CRC for Cattle and Beef Quality research herd (Bindon 2001; Upton et al. 2001). They were Bos taurus weaner steers transported to NSW Agriculture’s Glen Innes Research and Advisory Station to be grown out to an average weight of 400 kg for finishing in a feedlot to NSW Agriculture’s Glen Innes Research and Advisory Station to be grown out to an average weight of 400 kg for finishing at Glen Innes with no attempts to create divergent growth pathways. They were Bos taurus weaner steers transported to NS...
weight gain, calculated as \((w_6 - w_1)\) is \(2\nu\), 12 times greater than that of
the mean of 6 weighings. Gain may also be calculated by least squares
regression for each animal, i.e., using least squares regression to fit:

\[
\text{Weight} = \text{start weight} + \alpha \cdot \text{day}
\]

where weight is the weight of an animal; \(\alpha\) is the regression coefficient
for gain (kg/day); and day is the number of days from the first weighing.

It can be shown that the least squares estimate of \(\alpha\) above is
mathematically identical to the expression: 0.714 \((w_6 - w_1) + 0.429 (w_5 - w_2) + 0.143 (w_4 - w_3)\), which has variance 1.43\(\nu\). Least
squares regression therefore reduces the error variance by 29\%.

In the previous example of estimating gain by linear regression
using equation 3, the \(x\) (or independent) variable (number of days from
first weighing) was known exactly, i.e. not subject to measurement
error. In contrast, when fitting equation 1, the independent variables,
mean metabolic weight and weight gain, are subject to considerable
measurement errors of different magnitudes. For a simple regression,
\(y = \beta x + \varepsilon\) [error, it can be shown that the estimate of the slope, \(\beta\), is
unbiased only if the \(x\) variable has no measurement errors (as in the
example of linear regression for gain). In contrast, if we can measure
only an errored version, \(x + \varepsilon\) of \(x\) (with errors \(\varepsilon\) uncorrelated with \(x\)),
then \(\beta\) is biased downward by the factor variance(\(x\))/variance(\(x + \varepsilon\)). If
\(\varepsilon\) is large compared with the variation in \(x\), the former may dominate the
estimate, resulting in a substantially lower estimate than the true value.

The situation for estimating 2 partial regression coefficients, such as
equation 1, is more complex, especially if one independent variable
(e.g. weight) can be measured considerably more accurately than the
other (e.g. gain). Consider, for example, the situation where weight and
weight gain are strongly correlated, which will often arise if a group of
similarly aged animals have been grown out in the same environment.
Heavier animals are likely to be heavier because they grew faster before
testing and are therefore likely to do so in the future, provided feed
intake is not restricted. This may result in a relatively strong correlation
between weight and weight gain over the period of feed intake testing.
Inability to measure gain accurately will, therefore, not only result in
downward bias in the estimate of \(\beta_{w}\) in equation 1, but an upward bias
in \(\beta_{g}\) because the correlation between true gain and weight may be as
high as the correlation between true and measured gain. Part of the
partial regression coefficient for gain, \(\beta_{g}\), is therefore transferred to \(\beta_{w}\),
leading to upward bias of \(\beta_{w}\) and downward bias of \(\beta_{g}\).

The magnitude of these effects is illustrated for calculation of
residual feed intake using the 2 groups of steers.

**Results and discussion**

Figure 1 shows mean liveweight and mean daily intake
(over the 7 days before each weighing) for the 66 Korean
market steers that entered the AF pens on 15 July and the
43 Japanese market steers that entered the AF pens on
25 July 1997. For at least the first 2 weeks in the AF pens,
mean feed intake for the Korean steers was significantly
lower than in the remaining weeks. For Japanese market
steers, feed intake increased dramatically after the first week,
then rose slowly over the next 4 weeks, followed by a gradual
decline until their exit from the AF pens. Mean weight gains
for both groups were relatively consistent over the whole
period, except for Japanese market steers in the 2-week
period before entering the AF pens. Mean growth paths were
approximately linear for both groups, though there was a
small but noticeable amount of curvature in the mean growth
path of Japanese market steers. Other groups not used in this
study (see Robinson et al. 1997) have exhibited a greater
amount of curvature in their growth paths.

![Figure 1](image-url)

**Figure 1.** Mean liveweights (kg; □, ■) and feed intake (kg/day; ○, ●) during the week before each weighing for
2 groups of animals destined for the Korean (open symbols) and Japanese (solid symbols) markets. For Korean
market steers, weights are shown for the period in the automatic feeder (AF) pens. For Japanese market steers,
weights are shown for the period in the AF pens and the 2 preceding weeks.
Table 1. Repeatability of daily feed intake measurements in the same week, indicated by correlation matrices for feed eaten up to the time of weighing ($i0$) and daily feed intake 1–7 days ($i1$–$i7$) before weighing (before subtraction of the means for each animal) for the Korean and Japanese market steers, excluding the first 2 weeks in the automatic feeder pens

<table>
<thead>
<tr>
<th></th>
<th>Korean market steers</th>
<th>Japanese market steers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$i0$</td>
<td>$i1$</td>
</tr>
<tr>
<td>$i1$</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>$i2$</td>
<td>0.16</td>
<td>0.19</td>
</tr>
<tr>
<td>$i3$</td>
<td>0.20</td>
<td>0.25</td>
</tr>
<tr>
<td>$i4$</td>
<td>0.28</td>
<td>0.32</td>
</tr>
<tr>
<td>$i5$</td>
<td>0.16</td>
<td>0.26</td>
</tr>
<tr>
<td>$i6$</td>
<td>0.07</td>
<td>0.27</td>
</tr>
<tr>
<td>$i7$</td>
<td>0.11</td>
<td>0.29</td>
</tr>
</tbody>
</table>

Repeatability of daily feed intake measurements

Repeatability of daily feed intake measurements within the same week is shown by the correlation matrices for $i0$ and $i1$ to $i7$ (Table 1). These correlations were computed before subtracting the means for each animal. Thus they show the repeatability of feed intake measurements for any particular animal and week. Feed intake on the day of weighing up to the time animals were weighed was not highly correlated with total intake on other days during the previous week (average value 0.15, Table 1). Thus the amount eaten up to the time of weighing is not particularly useful in predicting the total amount eaten over the course of a day. Correlations between intakes on successive days were also relatively low, averaging 0.19 (Table 1). Correlations between intakes on non-adjacent days were higher, averaging 0.31. The latter value indicates the general repeatability of daily intake measurements for the same animal in the same week. The lower correlation for successive days implies that the amount eaten on 1 day affected the amount eaten on the next. Thus, when an animal ate more than average on any particular day, it tended to eat less the next day and vice versa. The reduced repeatability of feed eaten from 1 day to the next increases the amount of variation that can be explained by adjusting for feed eaten on days immediately before and on the day of weighing, because the measurements of feed eaten on these days are not highly correlated, but relatively independent of each other.

Reductions in residual variance from adjusting for feed intake in the week before weighing

Residual variances from sequentially fitting the terms in equation 2 are presented in Table 2. A simple intercept plus linear regression slope for each animal was a relatively poor fit in all cases, with residual variances ranging from 65–99 kg$^2$ (Table 2). The worst 2 fits were Japanese market steers from 15 to 78 and 15 to 120 days, probably because growth, at least for some animals, could no longer be considered linear over the entire weight range. Adding day of weighing and individual quadratic regression curves for each animal (Table 2, term animal.day$^2$) reduced the error variance to 44–55 kg$^2$. Fitting the amount of feed eaten in the days before weighing was highly significant, reducing the residual variance to 28–33 kg$^2$. These results suggest that more accurate estimates of weight gain may be obtained by adjusting weight records for the amount of feed eaten in the previous 3–5 days.

Table 3 shows regression coefficients for feed intake from fitting all terms in equation 2. On average, 1 kg of feed eaten on the day of weighing resulted in about 1.25 kg more weight due to gut fill, presumably because eating is normally associated with water intake in order to maintain osmotic pressure of the rumen (Jarrige 1989). Regression coefficients for feed intake on the days before the day of weighing reduce progressively so that feed intakes 4 and 5 days before weighing are of questionable importance, with no significant effects for feed eaten 6 or more days before weighing (Tables 2 and 3).

Note that the magnitude of the residual variation has implications for the length of testing for feed efficiency. If a certain accuracy of weight measurements means a 70-day test is appropriate in 1 situation, in situations where the accuracy of weight measurements is halved (i.e. the residual variation is twice as high), twice the number of days on test would be required to achieve the same overall accuracy of estimated weight gain, which, of course, directly affects the accuracy of estimated residual feed intake.

The final model, fitting individual growth curves for each animal, date of weighing and feed intake 3–5 days before weighing resulted in a residual variance of 28–33 kg$^2$ (Table 2) for the CRC data. This was similar, or lower, than that obtained by fitting the simple model of intercept plus linear regression (animal + animal.day) to weight records obtained during the feed intake test carried out by NSW Agriculture at Trangie Research Station (J. A. Archer pers. comm.).

The feed intake test at Trangie is described in more detail by Archer et al. (1997) and Arthur et al. (1996). At Trangie, bulls and heifers are tested shortly after weaning and fed a finely ground pelleted diet of 70% lucerne hay and 30%
Adjusting weight gains for feed eaten before weighing

To determine the effect of shorter intervals of intake measurement, Japanese steers were analysed using all weight measurements from day 15 to day 120 (16 weighings, 105 days), as well as from day 15 to day 78 and from day 15 to day 50. Korean steers were modelled from day 8 to day 64 (9 weighings, 56 days) because a number of AF pens failed for 1 day before the weighing on day 15.

<table>
<thead>
<tr>
<th>Period of measurement</th>
<th>Partial regression coefficients for feed eaten up to the time of weighing and previous 1–7 days (i0–i7)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Korean market</strong></td>
<td></td>
</tr>
<tr>
<td>Day 8–64</td>
<td>1.19 ± 0.15, 1.01 ± 0.10, 0.55 ± 0.11, 0.35 ± 0.11, 0.33 ± 0.12, 0.29 ± 0.10, 0.16 ± 0.10, −0.17 ± 0.11</td>
</tr>
<tr>
<td><strong>Japanese market</strong></td>
<td></td>
</tr>
<tr>
<td>Day 15–120</td>
<td>1.28 ± 0.13, 0.88 ± 0.09, 0.68 ± 0.09, 0.54 ± 0.09, 0.35 ± 0.10, 0.21 ± 0.09, 0.00 ± 0.09, 0.04 ± 0.09</td>
</tr>
<tr>
<td>Day 15–78</td>
<td>1.20 ± 0.16, 0.80 ± 0.11, 0.62 ± 0.12, 0.43 ± 0.11, 0.34 ± 0.13, 0.04 ± 0.11, −0.09 ± 0.11, 0.08 ± 0.11</td>
</tr>
<tr>
<td>Day 15–50</td>
<td>1.25 ± 0.24, 1.05 ± 0.18, 0.55 ± 0.21, 0.23 ± 0.19, 0.30 ± 0.19, 0.25 ± 0.16, −0.31 ± 0.16, −0.08 ± 0.18</td>
</tr>
</tbody>
</table>

*P<0.05; **P<0.01; n.s., not significant (P>0.05).
weights with adjustment for feed intake in the previous 5 days (DIFFadaj); (iii) the linear regression coefficients from the model: weight = animal + animal.day (LIN); (iv) predictions based on the full model shown in Table 2, fitting feed intake on the current and previous 5 days (PRED).

The lowest partial regression coefficient for metabolic weight (0.167) and highest partial regression coefficient for gain (2.197) were derived from weight gain estimated by adjusting for feed intake in the previous 5 days and using the longest possible interval (day 15 to day 120) between start and end weights. In contrast, not adjusting for feed intake in the days before weighing and estimating weight gain by simple linear regression over a 35-day interval resulted in the partial regression coefficients reported above.

The variability of estimated partial regression coefficients for the same group of animals, and general decrease in $\beta_w$ and increase in $\beta_g$ with increased accuracy of estimated gain demonstrate the consequences of inaccuracies of estimated weight gain when fitting equation 1 to estimate residual feed intake. However, even with the longest period of measuring gain (day 15 to day 120 for the Japanese market steers), the partial regression coefficient for metabolic weight (0.167) was still substantially higher than the averages of 0.09 to 0.12 reported by Robinson and Oddy (1999) for 21 groups of cattle, totalling 958 head, which had feed intake measured while being finished at Tullimba for the Korean and Japanese markets. The partial regression coefficients for these 958 head were derived using an alternative approach of fitting random regression models to weight data for most of the time animals were in the feedlot and using the model to predict weight gain (called modelled gain) over the desired period (time in the AF pens excluding the first 2 weeks). Robinson and Oddy (1999) then used equation 1 to derive the partial regression coefficients reported above.

In fact, the partial regression coefficients calculated by the method described by Robinson and Oddy (1999) using modelled gain for the 2 groups of steers analysed in this paper were $\beta_w = 0.173$ and $\beta_g = 2.157$ for group J and $\beta_w = 0.204$ and $\beta_g = 1.850$ for group K. Thus use of modelled gain can achieve fairly similar results to those obtained by adjusting for the amount of feed eaten before weighing. A combination of both methods (modelling and adjusting for the amount of feed eaten) may produce the most accurate results of all.

Use of automatic weighing equipment

Archer et al. (1999) suggested that use of automatic weighing equipment might make it possible to reduce the length of the test period required to calculate residual feed efficiency in a commercial situation. In our data, weights were influenced not just by feed intake on the day of weight measurement, but by intakes on at least the 3 previous days. Thus it might be desirable to adjust for the amount of feed eaten on the previous 3–5 days, even if automatic weighing equipment is used. In most situations, estimating the final weight by a function of weight measurements over the previous few days may suffice, but in cases where some animals go off their feed, or the amount of feed intake differs over the course of the test (see Fig. 1), adjusting for feed eaten may still be worthwhile.

Conclusion

Results in this paper show that, when feed intake is being measured, weight gain can be estimated more accurately by using the amount of feed eaten in the previous 3–5 days as a method of adjusting for gut fill. This helps to reduce biases and increases the accuracy of calculating residual feed intake, thus contributing to more effective genetic improvement of this trait.

Acknowledgments

Thanks are due to all those who have assisted with the CRC’s feed efficiency work, including Alex Ball, Thomas Engellandt, Graham Furley, Reid Geddes, Robert Herd, Stuart Murphy, Toni Reverter, James Skerritt, Chris Smith, Chris Webber and Reg Woodgate.

Table 4. Partial regression coefficients for metabolic weight ($\beta_w$) and for gain ($\beta_g$) fitting: feed intake (FI) = $\mu + \beta_w \times$ mean metabolic weight $+ \beta_g \times$ weight gain $+ \text{error (RFI)}$, by method of calculating gain and time interval in the automatic feeder (AF) pens

<table>
<thead>
<tr>
<th>Group</th>
<th>Period in the AF pens</th>
<th>DIFF</th>
<th>LIN</th>
<th>DIFFadaj</th>
<th>PRED</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>Day 8–64</td>
<td>0.207</td>
<td>0.675</td>
<td>0.213</td>
<td>0.203</td>
</tr>
<tr>
<td>J</td>
<td>Day 15–120</td>
<td>0.182</td>
<td>0.982</td>
<td>0.181</td>
<td>1.258</td>
</tr>
<tr>
<td>J</td>
<td>Day 15–78</td>
<td>0.203</td>
<td>1.146</td>
<td>0.206</td>
<td>1.011</td>
</tr>
<tr>
<td>J</td>
<td>Day 15–50</td>
<td>0.225</td>
<td>0.533</td>
<td>0.228</td>
<td>0.398</td>
</tr>
</tbody>
</table>

AAnalysis of 58 animals with complete feed intake records for 5 days before the first and last weighings in the AF pens.
References

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