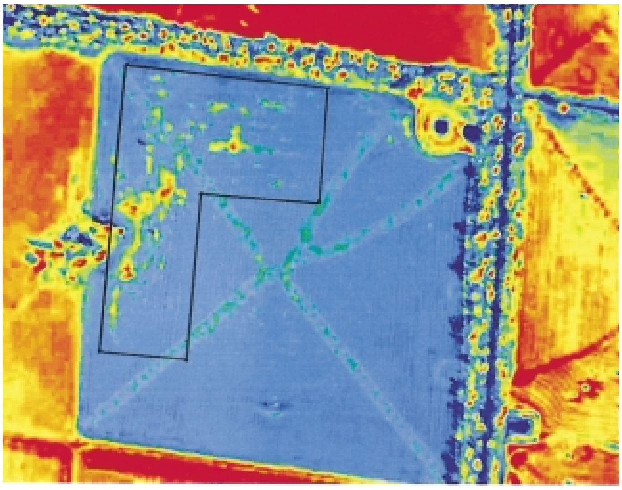
CSIRO Publishing

Australian Journal of Experimental Agriculture



VOLUME 41, 2001

. . . a journal publishing papers at the cutting edge of applied agricultural research

All enquiries and manuscripts should be directed to:

Australian Journal of Experimental Agriculture
CSIRO Publishing
PO Box 1139 (150 Oxford Street)
Collingwood, Vic. 3066, Australia

Telephone: +61 3 9662 7614
Fax: +61 3 9662 7611
Email: ajea@publish.csiro.au

CSIRO PUBLISHING

Published by CSIRO Publishing
for the **Standing Committee on Agriculture and Resource Management (SCARM)**

www.publish.csiro.au/journals/ajea

Australian Journal of Experimental Agriculture, 2001, **41**, 1057–1063

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

D. L. Robinson[AB] *and V. H. Oddy*[B]

Cooperative Research Centre for Cattle and Beef Quality
[A]Animal Genetics and Breeding Unit, University of New England, Armidale, NSW 2351, Australia; author for correspondence; e-mail: drobinso@lash.une.edu.au
[B]NSW Agriculture Beef Industry Centre, University of New England, Armidale, NSW 2351, Australia.

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:

$$\text{Feed intake} = \text{constant} + \beta_w \times \text{mean metabolic weight} + \beta_g \times \text{weight gain} + \text{error (i.e. RFI)} \qquad (1)$$

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 β_w and downward biases in β_g. For example, in a 105-day feed intake test of 44 steers (mean start/end weights 440/600 kg), the estimate of β_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 β_g was 0.40 using LIN and 1.67 using DIFFadj. These results illustrate the potential magnitude of the downward bias in β_g if inaccurate estimates of weight gain are used to fit equation 1. The higher estimates for β_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 β_g and β_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:

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

where intake is daily feed intake (kg, as fed); μ is a constant; mean metabolic weight is mean ($\text{weight}^{0.73}$) 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 β_w and β_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

10.1071/EA00040 0816-1089/01/071057

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 β_g and upward bias in the estimate of β_w.

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, β_w and β_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 Korean (group K, target slaughter weight 520 kg) or Japanese (group J, target slaughter weight 600 kg) markets (Upton *et al.* 2001). The steers arrived at Glen Innes in January 1997 and were transferred to the University of New England's research feedlot, Tullimba, on 25 June 1997. Unlike most other cohorts of CRC steers grown out at Glen Innes (Upton *et al.* 2001), this one was managed as a single group at Glen Innes with no attempts to create divergent growth pathways.

At Tullimba, after a 2-week introductory period, cattle were offered a standard finisher ration comprising 75% dry rolled barley grain (*Hordeum vulgare*), 10.5% sorghum hay (milled, 50 mm screen), 5% pelleted cottonseed meal, 8% Molafos (Ridley Corporation, Wacol, Qld, Australia), 1% finely ground limestone and 0.5% ammonium sulfate on a weight basis. Molafos is a molasses mix that contributed 0.8% urea, 25 mg/kg Monensin, trace minerals and vitamins to the final ration. Nutrient density of the ration was estimated to be 12.1 MJ ME (minimum 11.5 MJ ME) with a minimum of 150 g crude protein (Kjeldahl nitrogen $\times$ 6.25) per kg dry matter. Dry matter content of the ration was 880 g/kg.

After 1 and 3 weeks respectively on the standard finisher ration, groups K and J were moved into the automatic feeder (AF) pens. The computerised feeder in each AF pen (see Bindon 2001 for a full description and photographs of the automatic feeding facilities at Tullimba) recorded the animal's identity tag, amount of feed (kg) eaten during each feeding session and time at the start and end of the feeding session. Data were summarised into daily records (midnight to midnight) of total amount of feed eaten, as well as, on each day of weighing, the amount of feed eaten from midnight up to the time the steers were weighed.

Animals differed in their ability to learn to use the feeders. A few animals ate little or nothing in the first few days and so were removed to standard pens equipped with bunk feeders. After realimentation, they were re-introduced to an AF pen, containing, if possible, only a small number of animals. Those that failed to eat successfully on this second introduction — none in group K, 8 in group J — were returned to the standard pens with no further attempts to obtain feed intake measurements.

After excluding those failing to use the feeders on their second introduction to the AF pens, a total of 43 of the animals in group J (18 Angus, 15 Hereford and 10 Shorthorn steers) had feed intake measured for a period of 120 days. Those in group K, comprising 29 Angus, 22 Hereford and 15 Shorthorn steers, had 64 days of feed intake measurements. Steers were weighed at weekly intervals during their time in the AF pens.

Statistical analyses

Weight measurements in the AF pens, were modelled as:

$$\text{Weight} = \text{animal} + \text{animal} \times \text{day} + \text{animal} \times \text{day}^2 + \text{date of weighing} + i0 + i1 + i2 + i3 + i4 + i5 + i6 + i7 \qquad (2)$$

where weight is the weight of an animal; animal is a factor (1 level per animal) representing the intercepts of the growth curve equations for each animal; day is the day number (from 1 to the number of days in the AF pens) on which the weight was measured; animal $\times$ day are linear growth terms for each animal; animal $\times$ day^2 are quadratic growth terms for each animal; *i0* is the feed intake of the animal on the day of weighing from midnight until the time the animal was weighed; and *i1* to *i7* are daily feed intakes of the animal 1–7 days before the weight measurement.

To avoid confounding intake and animal effects, *i0* was standardised to have mean zero for each animal (by subtracting the mean of all values of *i0* for all weighings of that animal used in equation 2). The variables *i1* to *i7* were standardised in the same way. The terms in equation 2 were added sequentially to the model, to determine the reduction in the residual variation from adding each term and hence the need to fit it, in addition to the previous terms.

For Japanese market steers, equation 2 was fitted to all available weight measurements from day 15 to day 120 in the AF pens (16 weighings). To determine the effect of shorter intervals in the AF pens, equation 2 was also fitted to all weight measurements from day 15 to day 78 (10 weighings) and from day 15 to 50 (6 weighings). Day 15 was used as the start point to allow 2 weeks for the animals to adapt to the AF pens (see Robinson *et al.* 1999). Day 78 was used as the end of the intermediate period because an AF failed for 1 day the following week.

For Korean market steers, a number of AF pens also failed on day 13, making it impossible to adjust weights on day 15 for the amount of feed eaten 2 days earlier, so equation 2 was fitted to weight measurements from day 8 to day 64 in the AF pens.

Weight gains were then calculated for each animal as: (i) the simple difference between the first and last weights in the AF pen (excluding, as described above, the adaptation period on first entering the AF pens of 1 week for group K and 2 weeks for group J); (ii) the estimated linear regression coefficients in the model: weight = animal + animal $\times$ day, (i.e. fitting the first 2 terms in equation 2); (iii) the difference between first and last weighings adjusted for feed eaten on the current and previous 5 days using the regression coefficients for feed eaten derived by fitting all terms in equation 2 except *i6* and *i7*; (iv) the difference between predicted first and last weights from fitting all terms in equation 2 except *i6* and *i7*.

Equation 1, which calculates RFI, was then fitted separately to each of the 2 groups (K and J) and the different periods over which gain was estimated to determine the partial regression coefficients, β_w and β_g based on the different ways of estimating gain described above.

Effects of measurement errors

For a series of 6 weighings at constant intervals, say w_1 to w_6, representing fortnightly weighings over a 70-day test, on-test weight (estimated as the mean of all 6 weighings) has variance v/6, if the error variance of a single measurement is v. In contrast, the error variance of weight gain, calculated as $(w_6 - w_1)$ is 2v, 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:

$$\text{Weight} = \text{start weight} + \alpha.\text{day} \quad (3)$$

where weight is the weight of an animal; α 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 α 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 1.43v. Least squares regression therefore reduces the error variance by 29%, provided gain is linear over the measurement period. If this is not the case, for example when feed intake is restricted, or as animals approach maturity, the reduction in variance from fitting a linear regression may be outweighed by increased error from an inappropriate model.

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, $\underline{y} = \beta\underline{x} + \underline{c}$ + error, it can be shown that the estimate of the slope, β, is unbiased only if the $\underline{x}$ variable has no measurement errors (as in the example of linear regression for gain). In contrast, if we can measure only an errored version, $\underline{x} + \underline{e}$, of $\underline{x}$ (with errors $\underline{e}$ uncorrelated with $\underline{x}$), then β is biased downward by the factor variance($\underline{x}$)/variance($\underline{x} + \underline{e}$). If $\underline{e}$ is large compared with the variation in $\underline{x}$, 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 β_g in equation 1, but an upward bias in β_w 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, β_g, is therefore transferred to β_w, leading to upward bias of β_w and downward bias of β_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.

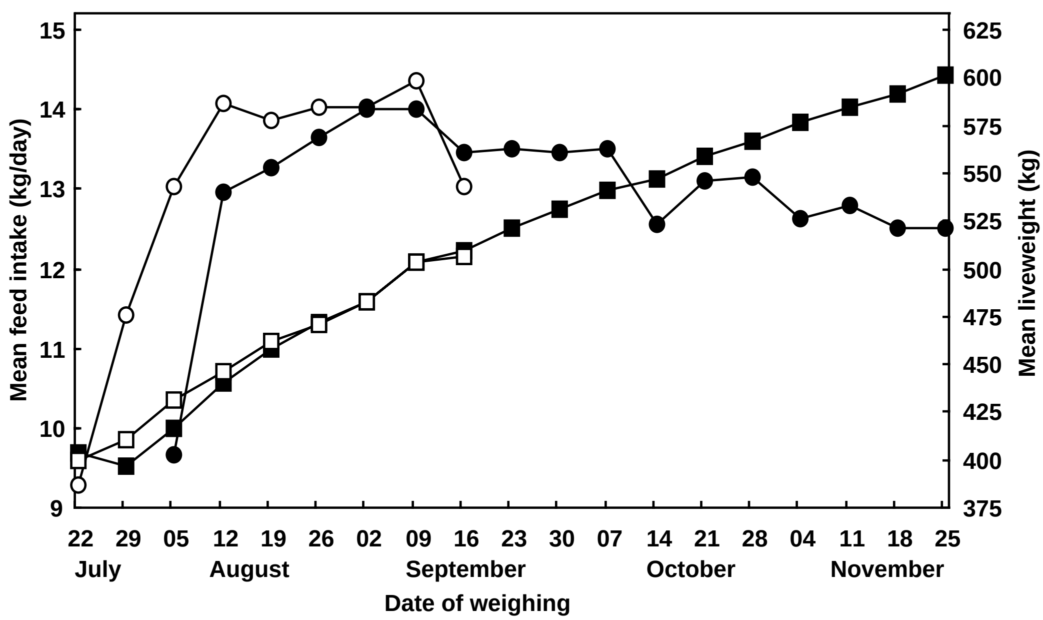


Figure 1. Mean liveweights (kg; □, ■) and feed intake (kg/day; ○, ●) during the week before each weighing for 2 groups of animals destined for the Korean (open symbols) and Japanese (solid symbols) markets. For Korean market steers, weights are shown for the period in the automatic feeder (AF) pens. 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

	Korean market steers							Japanese market steers						
	i0	*i1*	*i2*	*i3*	*i4*	*i5*	*i6*	*i0*	*i1*	*i2*	*i3*	*i4*	*i5*	*i6*
i1	0.14							0.09						
i2	0.16	0.19						0.15	0.19					
i3	0.20	0.25	0.18					0.17	0.37	0.14				
i4	0.28	0.32	0.40	0.24				0.09	0.36	0.32	0.21			
i5	0.16	0.26	0.27	0.41	0.21			0.15	0.30	0.32	0.40	0.19		
i6	0.07	0.27	0.24	0.30	0.25	0.20		0.16	0.26	0.24	0.30	0.35	0.22	
i7	0.11	0.29	0.36	0.34	0.29	0.33	0.08	0.10	0.27	0.26	0.28	0.33	0.33	0.22

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%

Table 2. Residual variances from modelling weight in relation to feed intake in the week 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

	Korean market	Japanese market		
No. of animals	66	43	43	43
No. of weighings	9	16	10	6
First and last weighings (day numbers in AF pens)	8–64	15–120	15–78	15–50
Terms used in model	Residual variation (kg^2)			
Animal + animal.day	70.5	99.1	78.2	65.3
+ day of weighing	53.2**	64.2**	56.3**	53.8**
+ animal.day^2	43.7**	54.8**	48.7**	49.0 n.s.
+ feed intake (FI) on day weighed (dw) (*i0*)	39.4**	47.5**	41.5**	42.0**
+ FI dw–1 (*i1*)	32.0**	39.4**	34.9**	34.2**
+ FI dw–2 (*i2*)	30.4**	36.3**	32.5**	32.9*
+ FI dw–3 (*i3*)	29.3**	33.7**	31.3**	33.1 n.s.
+ FI dw–4 (*i4*)	28.8*	33.0**	30.6**	33.1 n.s.
+ FI dw–5 (*i5*)	28.3*	32.7*	30.7 n.s.	33.0 n.s.
+ FI dw–6 (*i6*)	28.0*	32.8 n.s.	30.7 n.s.	32.2 n.s.
+ FI dw–7 (*i7*)	27.8 n.s.	32.8 n.s.	30.8 n.s.	32.4 n.s.

*$P<0.05$; **$P<0.01$; n.s., not significant ($P>0.05$).

grain with about 10 MJ ME/kg dry matter, compared with a rolled whole grain and milled hay diet at Tullimba with an average of 12 MJ ME/kg dry matter. Another difference between the Trangie and Tullimba systems is that animals at Trangie are limited to eating 1–1.5 kg feed per session, after which animals must wait at least 20 min before they are permitted to eat again. In addition, animals at Trangie are run in a large group with access to a block of 10 feed units. The ability to feed at any of a number of units (which may reduce queuing time), limited meal size and differences in the physical form of the diet, may together reduce the variation in gut fill over the course of a day and so increase accuracy of weight measurements without having to adjust for feed intake. In addition, the mean weight of animals during the testing period at Trangie was 349 kg (Archer *et al.* 1998), compared with 460 and 530 kg for the Korean and Japanese market steers analysed here. The higher error variation at Tullimba before adjustment for feed intake might also be partly explained if errors in weight measurements are proportional to the size of the animal.

Effect of measurement error on partial regression coefficients

To illustrate the effect of errors on estimates of partial regression coefficients for gain and metabolic weight, Table 4 shows the effect of fitting equation 1 to the Korean and Japanese market steers using weight gains estimated as: (i) the simple difference between start and end weights without adjustment for feed intake in the previous 5 days (DIFF); (ii) the simple difference between start and end

Table 3. Partial regression coefficients (mean ± s.e.) for feed eaten up to the time of weighing (*i0*) and daily feed intake 1–7 days (*i1*–*i7*) before each weighing when fitting the terms in Table 2 to weight measurements of Korean market steers from day 8 to day 64 in the AF pens, and for weight measurements of Japanese market steers from day 15 to day 120, day 15 to day 78, and day 15 to day 50

Period of measurement	*i0*	*i1*	*i2*	*i3*	*i4*	*i5*	*i6*	*i7*
				Korean market				
Day 8–64	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
				Japanese market				
Day 15–120	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
Day 15–78	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
Day 15–50	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

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

DIFF, simple difference between start and end weights; DIFFadj, difference between start and end weights, after adjustment for amount eaten on current and previous 5 days; LIN, linear regression coefficients from model: wt = animal + animal × day; PRED, difference between predictions for first and last days from the model: weight = animal + animal × day + animal × day^2 + date of weighing + intake for each animal in current and previous 5 days; β_w, β_g, partial regression coefficients for mean metabolic weight i.e. mean (weight)$^{0.73}$ and weight gain

Group	Period in the AF pens	DIFF		LIN		DIFFadj		PRED	
		β_w	β_g	β_w	β_g	β_w	β_g	β_w	β_g
K[A]	Day 8–64	0.207	0.675	0.213	0.562	0.203	0.849	0.202	0.638
J	Day 15–120	0.182	0.982	0.181	1.258	0.167	2.197	0.170	2.027
J	Day 15–78	0.203	1.146	0.206	1.011	0.192	1.776	0.196	1.589
J	Day 15–50	0.225	0.533	0.228	0.398	0.200	1.672	0.206	1.531

[A]Analysis of 58 animals with complete feed intake records for 5 days before the first and last weighings in the AF pens.

weights with adjustment for feed intake in the previous 5 days (DIFFadj); (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 partial regression coefficients of 0.228 for metabolic weight and 0.398 for weight gain (Table 4).

The variability of estimated partial regression coefficients for the same group of animals, and general decrease in β_w and increase in β_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 β_w = 0.173 and β_g = 2.157 for group J and β_w = 0.204 and β_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.

References

Anon. (1999) '1999 Autumn Angus GROUP BREEDPLAN Genetic Evaluation Report (Sire Summary).' Angus Society of Australia, Armidale.

Archer JA, Arthur PF, Herd RM, Parnell PF, Pitchford WS (1997) Optimum postweaning test for measurement of growth rate, feed intake and feed efficiency in British breed cattle. *Journal of Animal Science* **75**, 2024–2032.

Archer JA, Arthur PF, Herd RM, Richardson, EC (1998) Genetic variation in feed efficiency and its component traits. *Proceedings of the 6th World Congress on Genetics Applied to Livestock Production*. **25**, 81–84.

Archer JA, Arthur PF, Herd RM, Richardson, EC, Burton DA (1999) Potential for reducing the length of net feed intake testing by weighing cattle more frequently. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* **13**, 247–249.

Arthur PF, Herd RM, Wright J, Xu G, Dibley K, Richardson EC (1996) Net feed conversion efficiency and its relationship with other traits in beef cattle. *Proceedings of the Australian Society of Animal Production* **21**, 107–110.

Bindon BM (2001) Genesis of the Cooperative Research Centre for the Cattle and Beef Industry: integration of resources for beef quality research (1993–2000). *Australian Journal of Experimental Agriculture* **41**, 843–853.

Hughes JC (1976) Short-term variation in animal live weight and reduction of its effect on weighing. *Animal Breeding Abstracts* **44**, 111–118.

Jarrige R (1989) Recommended allowances and feed tables. In 'Ruminant nutrition'. Table 18.1. (Ed. R Jarrige) (Institut National de la Recherche Agronomique: Paris)

Robinson DL, Oddy VH (1999) Modelling feed intake and efficiency in feedlot cattle. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* **13**, 496–499.

Robinson DL, Oddy VH, Smith C (1999) Preliminary genetic parameters for feed intake and efficiency in feedlot cattle. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* **13**, 492–495.

Robinson DL, Skerritt JW, Oddy VH (1997) Measurement of intake and feed efficiency in feedlot cattle. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* **12**, 287–291.

SCA (1990) 'Standing Committee on Agriculture — ruminants subcommittee.' Feeding Standards for Australian Livestock. (CSIRO: Melbourne)

Upton W, Burrow HM, Dundon A, Robinson DL, Farrell EB (2001). CRC breeding program design, measurements and database: methods that underpin CRC research results. *Australian Journal of Experimental Agriculture* **41**, 943–952.

Received 28 March 2000, accepted 10 December 2000