Commercialization of Net Feed Efficiency

John A. Basarab[1], Mick A. Price[2] and Erasmus K. Okine[2]

[1]Alberta Agriculture, Food and Rural Development, Western Forage Beef Group, Lacombe Research Centre, 6000 C & E Trail, Lacombe, Alberta, Canada T4L 1W1; [2] Dept. Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, Canada T6G 2P5;

Key Points

- Improving feed efficiency has an economic impact four times greater than improving growth rate.
- Net Feed Intake (NFI) is a more useful measure of feed efficiency than Feed Conversion Ratio (FCR) and is moderately heritable.
- Benefits from selecting for NFI are improved competitiveness, increased value of genetic seed-stock through the generation of genetic merit values and potential reductions in methane emissions and manure production by efficient cattle.
- NFI can be used to select cattle for lower maintenance and feed consumption, without affecting body size and growth rate, or adversely affecting carcass characteristics, composition of live weight gain or distribution of fat depots.
- Preliminary results indicate that post-weaning NFI is highly related to mature cow efficiency and cow reproduction is unaffected.
- The GrowSafe® System in combination with customized software is a robust and accurate system for non-invasively monitoring individual animal feed intake under commercial conditions.

1.0 Introduction

1.1 Why measure feed efficiency

The cost of feed is second only to fixed costs in importance to the profitability of commercial beef operations (Basarab, 1999) and 70-75% of the total dietary energy cost in beef production is used for maintenance, including maintenance of the dam (Ferrell and Jenkins 1985; NRC 1996). In addition, a 5% decrease in feed efficiency could have an economic impact four times greater than a 5% improvement in average daily gain (Gibb and McAllister 1999). Thus improvements in feed efficiency will have a tremendous influence on the unit costs of production and value of breeding stock, embryos and semen since NFI is moderately heritable.

1.2 Defining feed efficiency

Feed efficiency can be defined in many different ways. However, there are two ways of defining feed efficiency that are useful in genetic improvement. The first is feed conversion ratio (FCR), which is the amount of feed consumed by an animal divided by its live weight gain. Feed Conversion Ratio is also referred to as Gross Feed Efficiency because it does not attempt to break down feed requirements into sub-components of maintenance and gain. For this reason, FCR is not very useful for measuring feed efficiency in the breeding herd, where females are not growing. In addition, many studies suggested that the measurement of individual animal feed intake was unnecessary due to the strong, negative genetic correlation (r_g =-0.46 to -0.67) between FCR and growth rate (Arthur et al. 2001). Thus, if one selected for average daily gain, improvements in feed efficiency would also occur. This dogma was held within the beef industry for at least five decades, with little if any improvement in feed efficiency due to genetic selection. The problem is that FCR is more related to growth, body size, composition of gain and appetite than to the energy required for maintenance. What appears to have happened was that we selected for a faster growing, larger animal with an increased appetite, but with no improvements in feed efficiency.

The second more useful measure of feed efficiency is net feed intake (NFI) or net feed efficiency. **NFI is defined as the difference between an animal's actual feed intake and its expected feed requirements for maintenance and growth. Thus, it is the variation in feed intake that remains after the requirements for maintenance and growth have been removed.** Take for example a British cross steer on a finishing diet consisting of 22% barley silage, 73.3% steam rolled barley, 1.6% molasses and 3.1% feedlot supplement. If this steer averaged 453.6 kg (1000 lb) in body weight over the last 120 days on feed and its ADG was 1.76 kg/day, the "Nutrient Requirements of Beef Cattle" (NRC 1996) would predict an average feed intake of 14.5 kg/day over this same period. If the actual feed intake for this steer was 10.2 kg/day, this would be 4.3 kg/day less feed than expected, and its NFI would be minus 4.3 kg/day. Like a golf score, a negative value is better and indicates a more efficient animal.

2.0 Measuring net feed intake

2.1 The tool and its cost

Net feed intake can be measured on young bulls and replacement heifers (seed-stock test) or can be measured on steer progeny in the feedlot (commercial test). In each test, 75-80 animals that have been tagged with radio frequency transponders are placed in front of a machine that automatically and non-invasively records the feed intake of each animal in the pen. The machine used is called the GrowSafe® System (GrowSafe Systems Ltd., Airdrie, Alberta) and consists of an antenna or rubberized sensing mat, 10 feed tubs with two load bars per tub, a PC computer and GrowSafe data acquisition and analysis software. Each feed tub or "node" can hold approximately 0.5 days feed for 8-9 feeder cattle on a finishing diet. Presently, the GrowSafe System can be constructed for $80,000-$100,000. This facility could test 160 animals per year for net feed intake as long as there were two tests/year. If the cost of the facility plus 10%/year for maintenance and upgrade were spread over five years then the cost per animal would be estimated at $150 to $188. The labour requirements for monitoring the system are estimated at 0.25 person years.

2.2 Accuracy

The GrowSafe® System has been found to be a robust and accurate system for monitoring individual animal behaviours at the feed bunk (Schwartzkopf et al. 1999; Sowell et al. 1998). Studies at the Lacombe Research Centre (Basarab et al. 2002) have shown that the GrowSafe hardware and acquisition software in combination with independently developed software (Feed Intake from Raw GrowSafe Data, version 6.1 for SAS) had accuracies of 98.7% and 98.4% for the determination of feeding event (Figure 1) and daily feed intake (Figure 2), respectively. In addition, this system of hardware and software accounted for 98.6% of the feed delivered to the tubs by the feed truck. The GrowSafe Compile Intake III software (Version 1.818), which comes as a stock item with the GrowSafe hardware, had accuracies of 93.7% and 89.5% for the determination of feeding event and daily feed intake, respectively (Basarab et al 2002).

2.3 Procedure

Animals, 6-8 months of age, are accustomed to the diet and the GrowSafe® System during a 21-28 day pre-test adjustment period. The pre-test period is followed by a 70-day test where daily feed intake is recorded for each animal and the animals are allowed *ad libitum* access to feed. The animals are weighed every two weeks using traditional weigh scales or can be weighed daily using an in-pen automatic, non-invasive weigh scale. The growth of each animal over the test period is modeled by linear regression of weight on time. Initial weight, average daily gain (ADG), and mid-point weight (MIDWT) are calculated from the regression coefficients of each animal's growth curve. Mean daily feed intake (as fed basis) of each animal during the test period is standardized (SFI) to 10 MJ/kg DM and then regressed against ADG and metabolic MIDWT to give the equation $SFI = a_o + b_1ADG + b_2MIDWT^{0.75}$ (Archer et al. 1997; Arthur et al. 2001). The residuals (actual minus expected feed intake) are used as net feed intake. Thus, animals with low or negative net feed intake values are more efficient than their pen mates with high or positive net feed intake values.

3.0 Benefits

3.1 Improved competitiveness and value of genetic seedstock

In 2000 and 2001, researchers at the Lacombe Research Centre in Alberta, Canada, measured feed intake, growth rate and NFI on 148 steers from five genetic strains (Basarab et al. 2002). Steers grew at 1.52 kg/day and had dry matter intakes of 8.5 kg/day. Individual animals varied in NFI from an efficient -1.95 kg/day to an inefficient +1.82 kg/day (Figure 3). This represented a difference in actual feed intake of 3.77 kg/day between the most and least efficient steers. This variation in NFI represented a difference of $45.69 in feed costs (assuming feed costs of $0.101/kg as fed) during a 120-day test period or approximately $109 million annually when extrapolated to Alberta's 2.4 million feeder cattle. The benefit to cow-calf and seed-stock producers is unknown but is estimated to be at least as high. Similar results have been reported by Australian researchers at the Trangie Agricultural Research Centre in Australia where 1166 calves and 116 sires from different breeds were evaluated for post-weaning NFI (http://www.augusaustralia.com.au/Breedplan/NFI/; Archer et al. 1998). Thus, considerable variation exists among individual animals within breeds or genetic strains in NFI. This infers that substantial progress can be made in NFI or feed efficiency since the heritability of the trait is approximately 40% (Archer et al. 1998; Arthur et al. 2001).

3.2 Estimated Breeding Values (EBV) for NFI

The Breedplan program for the Angus Society of Australia has generated EBVs for NFI that ranged from –1.32 to +1.23 kg/day, with accuracies ranging as high as 87%. Their website can be visited at: (http://www.angusaustralia.com.au/Breedplan/NFI/). A useful quote from their website clearly explains the benefits of EBVs for NFI.

"If bull A has a NFI EBV of –0.6 and bull B has a NFI EBV of +0.4, after adjusting for weight and gain of the progeny, we predict that the progeny of bull A will eat 0.5 kg/day less feed (half the difference between the EBV's) than the progeny of bull B. Thus animals with lower (more negative) EBVs will have a lower feed intake at the same weight and growth rate than those with a positive EBV. "

Little if any change will occur in ADG or weight since NFI is not correlated with either growth rate or body size. In practice, seed-stock producers could select for NFI and growth, thus improving both traits simultaneously. The advantage of NFI over FCR is that NFI allows breeders to place different emphasis on growth and feed efficiency.

3.3 Reduction of methane, manure, N, P and K

Methane emissions from cattle range from 2 to 12% of gross energy intake. This represents not only a substantial loss in efficiency of production, but the methane emitted contributes to greenhouse gases. Cattle with negative NFI values may produce less methane and manure than cattle with positive net feed intakes. Okine and co-workers (Okine et al. 2001) recently calculated the methane emission and manure production from feeder steers with low, medium and high NFI. They found no difference in methane emission as a percent of gross energy among NFI groups. However, yearly methane emissions from low NFI steers were 21% lower than for high NFI steers (56.6 vs. 68.5 kg/year). These results have been confirmed by Herd et al. (2002) who showed that cattle selected for low NFI produced 15% less ($P<0.001$) enteric methane per day than cattle selected for high NFI. Methane and nitrous oxide production from faeces were also lower by 15% and 17%, respectively, for low NFI cattle. Okine et al. (2001) also reported that low NFI steers had lower ($P < 0.05$) yearly manure (14.5%), N (16.9%), P (17.0%) and K (17.1%) production than high NFI steers.

There appears to be a cumulative benefit from genetic selection for both growth rate and NFI. For example, steers with low NFI and above average daily gain (1.46 kg/day) are estimated to produce 45.9% less methane than steers with high NFI and below average daily gain (52.5 vs 76.6 kg/year; Okine et al. 2001). Assuming that a carbon credit is worth $7.50 CAN/tonne of carbon dioxide equivalence, the methane credit for the low NFI steers with above average daily growth rate would be worth $3.80 CAN/ head/yr relative to a high NFI steers with below average daily gain.

4.0 Consequences of selecting for NFI

4.1 Growth, body size and feed intake

In 1993, Australian researchers began mating the top 5% of efficient bulls (negative net feed intake) to the top 50% of efficient heifers, while the bottom 5% of inefficient bulls (positive net feed intake) were mated to the bottom 50% of inefficient heifers (Arthur et al. 2001). The results revealed that after two generations of selection for NFI, the progeny from efficient parents had lower NFI, actual feed intake and FCR than the progeny of inefficient parents (Table 1). There was no correlated response in either yearling weight or average daily gain. Canadian researchers (Basarab et al. 2002) have also shown that steers with low NFI consumed 6.4% and 10.4% less dry matter than medium and high NFI steers, respectively (8.00 vs. 8.55 vs. 8.93 ± 0.05 kg DM/day; $P < 0.01$). FCR was improved in low and medium NFI steers by 9.4% and 4.2% as compared to high NFI steers (5.39 vs. 5.70 vs. 5.95 ± 0.06 kg DM/kg gain; $P < 0.01$). Growth rate and body size were similar ($P > 0.10$) among the NFI groups.

4.2 Carcass characteristics

In a study conducted by Basarab et al. (2002), NFI was slightly and positively related to carcass marbling ($r = 0.15, P = 0.07$), dissectible carcass fat ($r = 0.14, P = 0.09$), gain in ultrasound backfat thickness ($r = 0.22, P < 0.01$), gain in ultrasound marbling ($r = 0.22, P < 0.01$) and negatively related to dissectible carcass lean (r = -0.21, P = 0.01). Thus, steers with high NFI (inefficient) had slightly more subcutaneous and marbling fat than steers with low NFI. These results suggest that selection for animals with negative NFI will result in a slightly leaner animal. Similar results were obtained by Richardson et al. (2001), who reported that the progeny from cattle selected for low NFI had 12.4% less carcass fat than the progeny from cattle selected for high NFI (Table 2). The efficient progeny also tended (P < 0.10) to have 7.9% less total dissectible fat than the inefficient progeny. This lower carcass fat content in the efficient progeny raises several concerns, such as the potential genetic antagonisms of NFI with marbling and reproductive fitness and the effect that composition of gain has on the true energetic efficiency of the animal. Thus it is possible that differences in net feed intake were partially due to differences in fattening and not due to inherent differences in the energy required for maintenance and growth of specific animal types.

4.3 Body composition and composition of gain

A study just completed at the Lacombe Research Centre has provided new insight into the relationship between composition of gain and NFI. Basarab and coworkers (Basarab et al. 2002), in cooperation with Beef Booster Cattle Alberta Ltd., measured the individual feed intake of 148 steer calves (333 kg; 7-8 months of age). Steers from each of the five Beef Booster strains (M1, M2, M3, M4 and TX) were equally represented and all animals were adjusted to a high-barley diet. The steers were processed at the Lacombe Research Centre abattoir and carcass, organ and tissue weights were obtained and body composition evaluated. Multiple regression analysis revealed that metabolic mid-point weight, ADG, gain in empty body fat and gain in empty body water accounted for 67.9%, 8.6%, 3.9% and 1.1%, respectively, of the variation in actual feed intake. Simple correlation analysis across years showed that the relationship between NFI and gain in empty body fat, either expressed in grams per day (r = 0.26, P = 0.0015) or grams per kilogram of metabolic weight per day (r = 0.30, P = 0.0002), was positive (Figure 4), and gain in empty body fat accounted for 6.8% to 9.0% of the variation in NFI. The relationship between NFI and gain in empty body protein, either expressed in grams per day (r = -0.11, P = 0.1637) or grams per kilogram of metabolic weight per day (r = -0.13, P = 0.1170), was numerical negative, but not statistically significant (Figure 5). These results suggest that steers with low NFI had a slightly slower rate of empty body fat deposition than steers with high NFI (Table 3). Richardson et al (2001) reported that less than 5% of the variation in parental NFI was explained by variation in body composition of their steer progeny. In their study, this small relationship in NFI to body composition manifested itself as a trend (P < 0.1) toward a 2.2% increase in protein gain by low NFI steers as compared to high NFI steers. Adjustment for this bias in body composition may be achieved by measuring animals for ultrasound backfat thickness and marbling score at the beginning and end of the test period.

4.4 Heat production (net energy for maintenance plus heat increment of feeding)

The Canadian study also revealed that high NFI steers consumed 4.6% more metabolizable energy (MEI) and produced 5.3% more heat than medium NFI steers and consumed 11.3% more MEI and produced 10.3% more heat than low NFI steers (Table 3). High NFI steers also partitioned more of the increase in MEI towards heat production and less toward retained energy than either medium or low NFI steers. This result may be partially explained by the finding that low and medium NFI steers had lower weights of liver (P <0.01), small and large intestine (P = 0.09), and stomach and intestine (P < 0.01) than high NFI steers. Other researchers (NRC 1996; Ferrell and Jenkins 1998) have reported that the efficiency of ME use for retained energy is not constant, but decreases as MEI increases. Ferrell and Jenkins (1998) suggested that a portion of non-linearity in the relationship of retained energy on MEI was due to a depression in metabolizability of the diet at high levels of intake, higher maintenance cost or heat increment of feeding at higher levels of feed intake and heavier organ weights of stomach complex, intestines, heart, lung, kidney and spleen.

4.5 Cow reproduction and lifetime productivity

Several studies are presently underway in Canada and Australia on the longer-term consequences of selecting for post-weaning NFI on cow reproduction and efficiency. Preliminary results suggest that there is a high genetic correlation between post-weaning NFI and mature cow efficiency, and cow reproduction is unaffected (P. F. Arthur, 2002, personal communication).

5.0 Implications

There is strong scientific evidence to support net feed intake as an indicator of the maintenance energy requirements of an animal. This trait is moderately heritable, indicating that genetic progress could be made in net feed intake by incorporating it into already existing genetic improvement programs. In addition, net feed intake can be used to select animals for lower maintenance requirements and feed consumption, without adversely affecting growth rate. Some effort is required to adjust net feed intake for differences in the chemical composition of gain so as not to adversely affect carcass characteristics and fat deposition in breeding females. Improving feed efficiency by measuring net feed intake also has the potential to reduce methane emissions from cattle and, possibly, result in new agriculture investment due to methane credits being sold to the energy sector.

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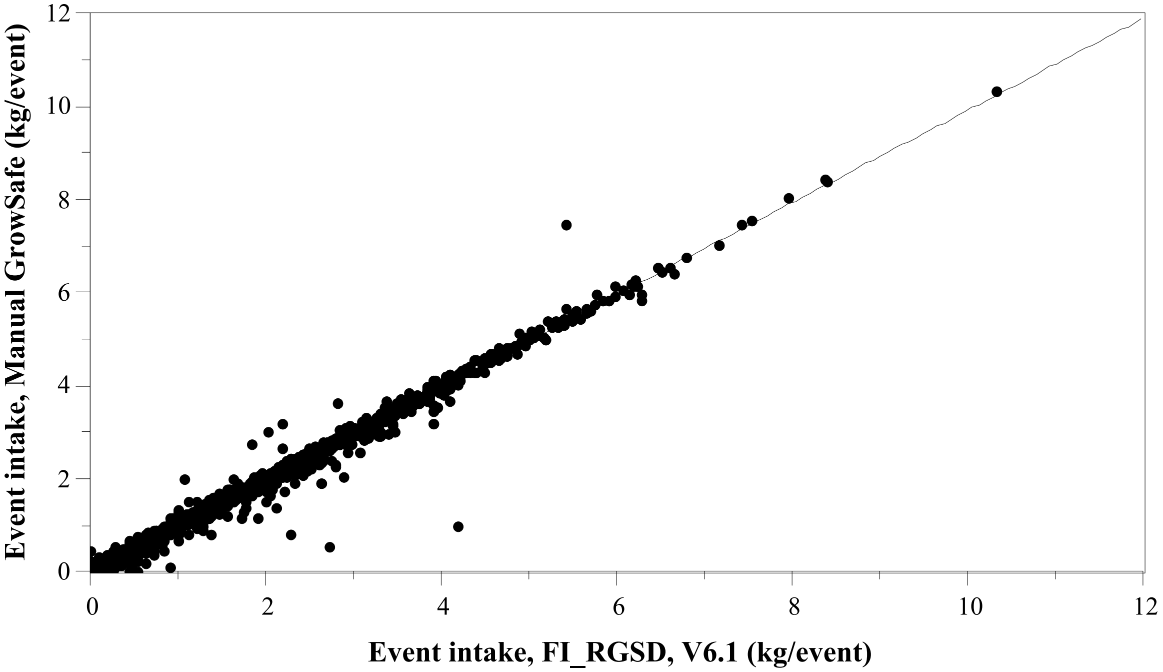

Figure 1. Relationship between event feed intake (EFI) as determined by Manual GrowSafe and FI_RGSD (version 6.1 for SAS). $EFI_{ManualGS} = 0.0064 + 0.990 \times EFI_{FI\_RGSD}$, n=1663, R^2=0.987.

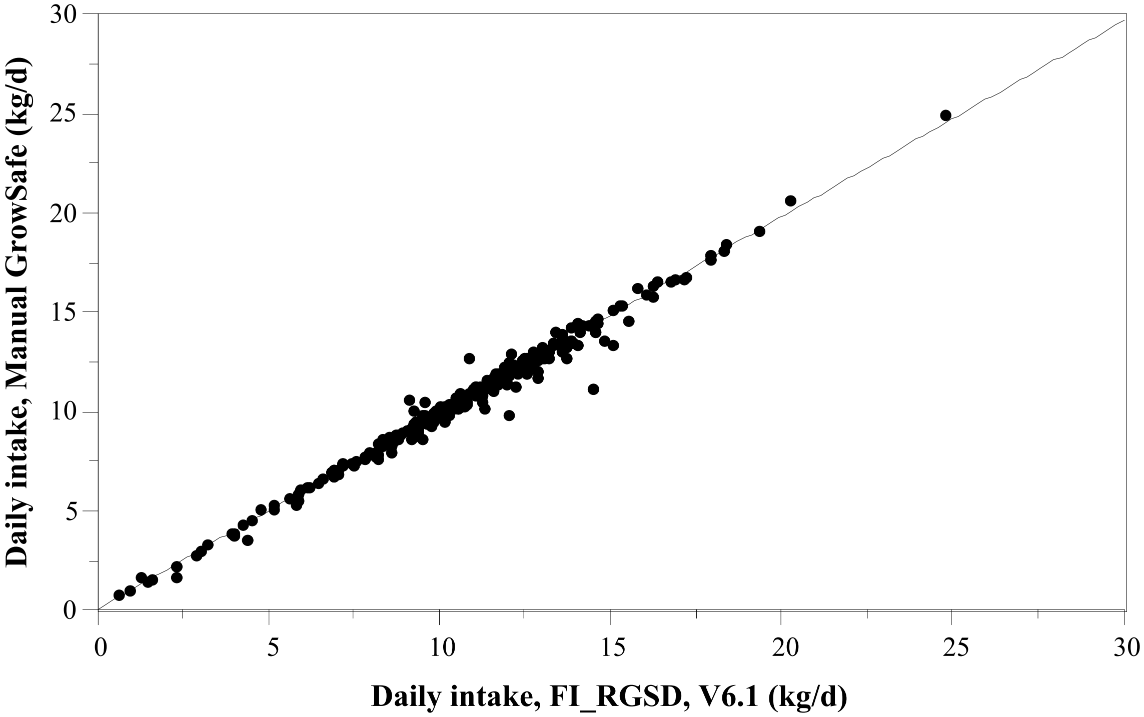

Figure 2. Relationship between daily feed intake (DFI) as determined by Manual GrowSafe and FI_RGSD (version 6.1 for SAS). $DFI_{ManualGS} = 0.0851 + 0.986 \times DFI_{FI\_RGSD}$, n=270, R^2=0.984.

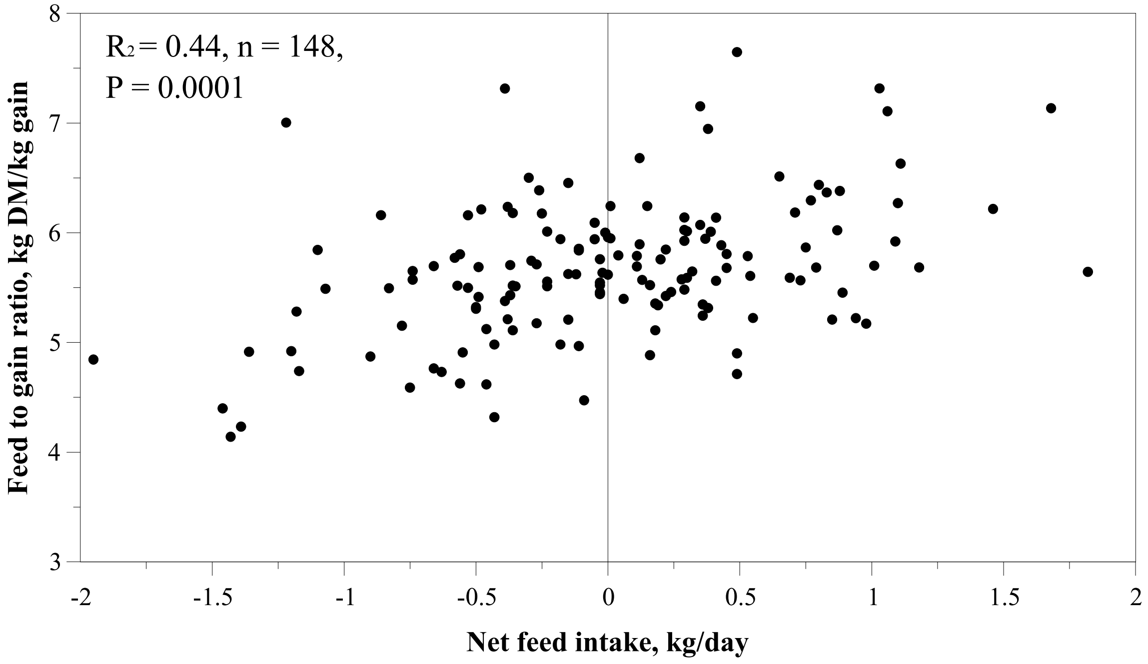

Figure 3. The relationship between feed conversion ratio (feed to gain ratio) and net feed intake.

Table 1. Performance of progeny from low (efficient) or high (inefficient) net feed intake bulls and heifers after five years of selection[z]

Traits	Low net feed intake parents	High net feed intake parents	Yearly Correlated response
Number of animals	62	73	
Net feed intake, kg/day	-0.54a	0.71b	0.25
365 day live weight, kg	384.3	380.7	0.72
Average daily gain, kg/day	1.44	1.40	0.01
Actual feed intake, kg/day	9.4a	10.6b	0.24
Feed conversion ratio, kg/kg	6.6a	7.8b	0.24

[z] Adapted from Arthur et al. (2001a)

b,c means in the same row differ, $P<0.05$

Table 2. Weight of carcass fat for yearling Angus steer progeny of parents selected for low (efficient) or high (inefficient) net feed intake[z]

Traits	Low net feed intake parents	High net feed intake parents	Sign.
Number of animals	16	17	
Cold carcass weight, kg	240	245	NS
Carcass fat (IM and SQ)[y], kg	42.1	48.5	$P < 0.05$
Carcass fat/final weight, %	9.9	11.3	$P < 0.05$
Total dissectible fat/final weight, %	19.8	21.5	$P < 0.10$

[z] Adapted from Richardson et al. (2001)

[y] IM = Intermuscular fat; SQ = Subcutaneous fat.

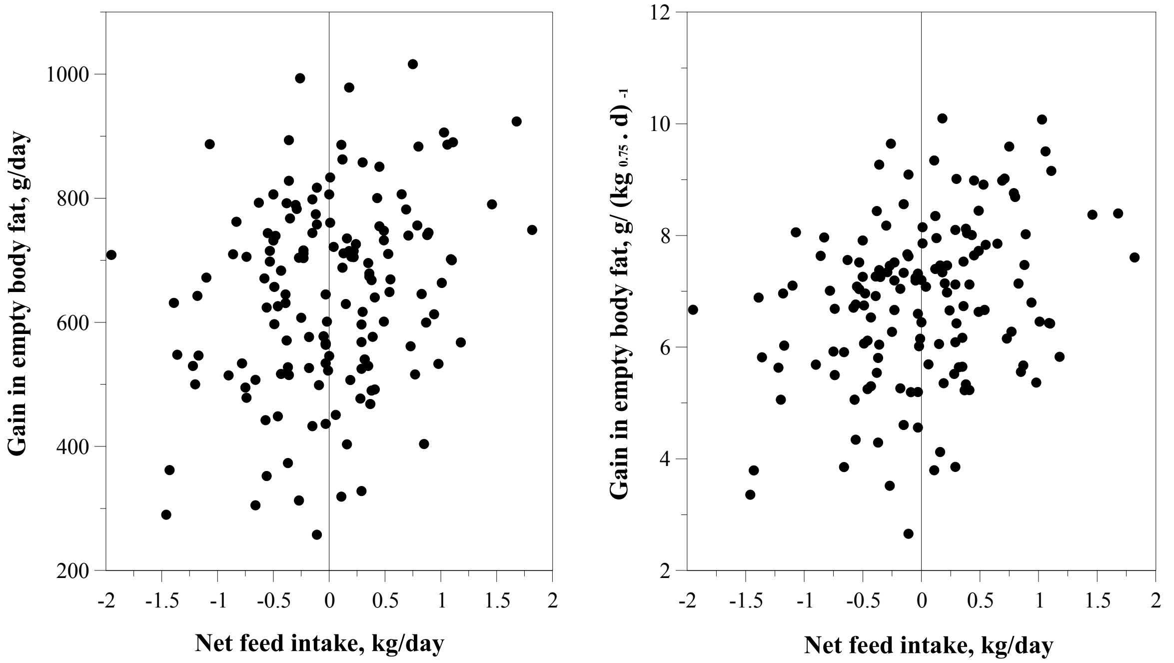

Figure 4. Relationship between net feed intake and gain in empty body fat in steers, expressed either in grams per day (r = 0.26, P = 0.0015, n=148) or grams per kilogram of metabolic weight per day (r = 0.30, P = 0.0002, n=148).

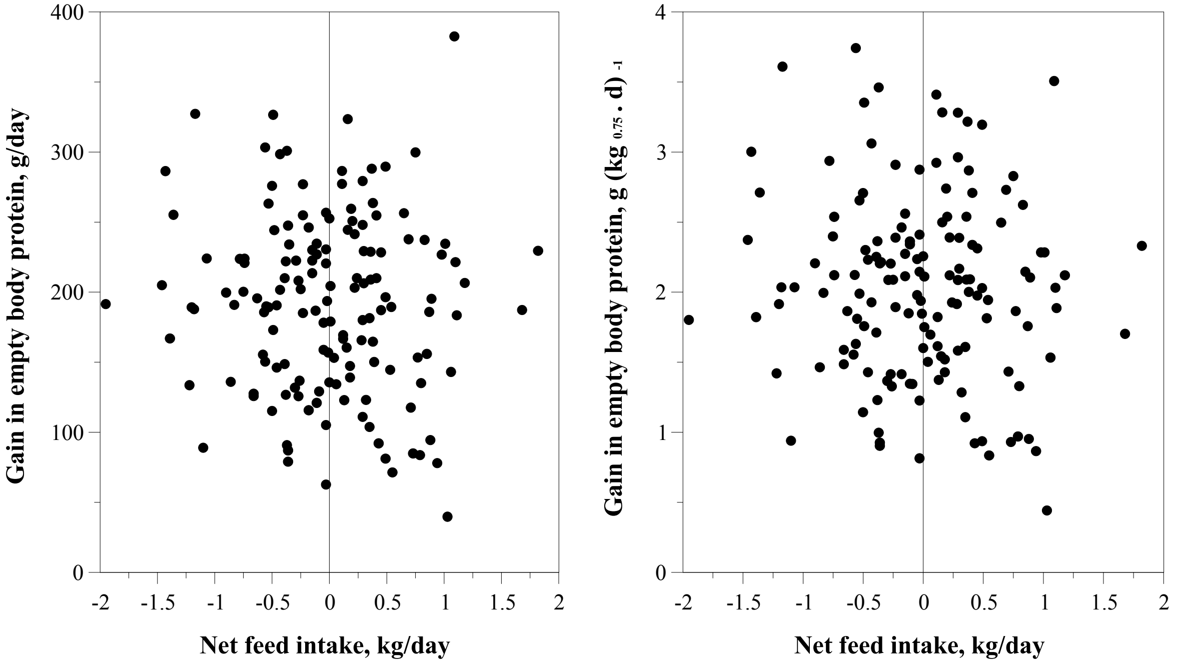

Figure 5. Relationship between net feed intake and gain in empty body protein, expressed either in grams per day (r = -0.11, P = 0.1637, n=148) or grams per kilogram of metabolic weight per day (r = -0.13, P = 0.1170, n=148).

Table 3. Body composition, daily accretion rates of protein, fat and energy, retained energy and heat production from steers with high, medium and low net feed intake.

Traits	Net feed intake group^z			SEM	Probability
	High	Medium	Low		
Number of steers	43	61	44		
Empty body composition					
Water, g/kg	510b	513b	526a	3.0	0.0148
Fat, g/kg	282a	281a	265b	3.8	0.0211
Protein, g/kg	167	165	167	1.5	0.7331
Ash, g/kg	41	40	42	0.6	0.1518
Energy, MJ/kg	15.0a	14.9a	14.3b	0.1	0.0106
Empty body component gain, g/(kg$^{.75}$ .day)$^{-1}$					
Water	5.32b	5.46b	6.11a	0.17	0.0364
Fat	7.18a	6.98a	6.19b	0.07	0.0050
Protein	2.15	2.03	2.08	0.07	0.6057
Ash	0.41	0.36	0.44	0.02	0.1637
ME intake, KJ/(kg$^{.75}$ .day)$^{-1}$	1083a	1035b	973c	4.4	< .0001
Retained energy, KJ/(kg$^{.75}$ .day)$^{-1}$	332a	322a	292b	6.1	0.0018
Heat Production, KJ/(kg$^{.75}$ .day)$^{-1}$	751a	713b	681c	7.3	< .0001