Genetic improvement in feed efficiency in beef cattle

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Summary

Net feed conversion efficiency (NFCE) describes whether an animal eats more or less feed than expected for its size and growth rate. Early results from the Trangie NFCE Project, and from the Beef CRC, show that considerable variation in NFCE exists within each of the British breeds tested and is moderately heritable. Estimates of heritability for average daily gain, 365–day weight, feed intake, net feed intake, feed conversion ratio, fat depth at the 12th/13th rib and eye muscle area are 0.41, 0.68, 0.59, 0.44, 0.31, 0.47 and 0.31 respectively. Phenotypic correlations of net feed intake with average daily gain, 365–weight and eye muscle area are non-significant, while correlations with feed intake, feed conversion ratio and rib fat depth are 0.52, 0.5 1 and 0.19. For the postweaning phase of beef production, initial results indicate that feed costs could be reduced by using cattle of above average postweaning NFCE.

Introduction

The central tenet of this paper is that there exists genetic variation in the relationship between feed intake and growth in cattle such that breeding can be used to reduce the feed costs of beef production. Genetic improvement in feed efficiency of livestock is only one of the tools available to beef producers but has the advantage over non-genetic methods of being cumulative and maintained without further input costs after the initial costs of selection of superior breeding stock. In the absence of deleterious genotype by environment interactions, genetic improvement can be additive to improvement made by management.

For producers feeding young cattle for slaughter the most important determinant of profitability is the differential between prices for buying and selling cattle, both in the U.S.A. (Lee, 1993) and Australia (Crawford, 1994). Next most important are the price paid for feed, and feed conversion efficiency (FCE). Management practices that increase the amount of feed energy ingested by cattle usually increase the rate of liveweight gain and improve FCE. Such practices include increasing the proportion of grain in the ration, processing the grain and the inclusion of fats. Utilising cattle that have a propensity for faster growth will also generally improve FCE. Examples include young cattle, cattle undergoing compensatory gain, cattle implanted with a growth promotant, and cattle of a breed or crossbreed capable of faster growth. Management practices that shelter cattle from stress and environmental extremes will also influence FCE.

The aim of genetic improvement in feed efficiency is to reduce the feed costs of beef production. Genetic selection to improve FCE (feed eaten/weight gain) has been used in the past. The term Net FCE (NFCE) is introduced to describe whether an animal eats more or less feed than expected for its size and growth rate. It is measured as net feed intake which is the difference between actual feed intake and the expected feed requirement for maintenance of liveweight and for growth. Cattle of the same size and with the same growth rate have the same expected feed intake (whether calculated from feed efficiency test data or from standard feeding tables). Individuals that actually eat less than expected have a negative net feed intake and superior NFCE. This paper describes recent advances in our knowledge on genetic variation in NFCE in Australian cattle.

Previous research

Animal genetic improvement programs in feed efficiency in the past have concentrated on increasing production, and little attention has been given to reducing the cost of production due to our inadequate knowledge of the phenotypic and genetic relationships between feed intake and production. There have been attempts at genetic improvement of feed utilisation based on FCE.

The results of such studies have indicated that selection for reduced feed conversion ratio would result in increased growth rate leading to bigger cattle, which is not always desirable. Mrode et al. (1990) and Bishop et *al.* (199 1) estimated strongly negative genetic correlations of -0.62 and -0.66, respectively, between growth rate and feed conversion ratio. However, eight years of selection for reduced feed conversion ratio did not significantly increase growth rate but tended to reduce it (Mrode et *al.* 1990). Further, the prediction of the outcome of selection for improved feed conversion ratio is complicated by the antagonism between the desirable responses in the numerator (*i.e.* reduced feed) and denominator (i.e. increased growth), and the unknown relative selection pressure on the numerator versus the denominator.

The major drawback in defining the efficiency of feed utilisation in terms of feed conversion ratio is that it does not account for the feed used for maintenance. The costs of feed for maintenance is estimated to represent at least 60–70% of the total feed requirements for the cow herd, with considerable variation among individual animals that is independent of their body size (Montano–Bermudez et *al.* 1990). Herd (1992) reported that a significant proportion of the variation in weight of calf weaned per unit of feed consumed by the cow-calf unit was independent of the body size and growth rate among the cows and calves. Thus any trait which attempts to accurately measure variation in the efficiency of feed utilisation should include consideration of feed requirements for both maintenance and production.

A composite trait referred to as net (residual) feed intake has been used in the poultry industry to describe NFCE (Luiting, 1990). Net feed intake is the difference between actual feed intake and the expected feed requirement for maintenance of liveweight and for production--the latter being, for example, growth in beef cattle or milk production in dairy cattle. There is some evidence of genetic variation in net feed intake in growing steers (Koch et *al.* 1963), and in beef (Fan *et al.* 1994) and dairy (Jensen et *al.* 1992) bulls.

Current research

In 1993, a research project was commenced at the Trangie Agricultural Research Centre to investigate and demonstrate the potential for achieving genetic improvement in NFCE in beef cattle. The project includes the estimation of genetic and phenotypic parameters for NFCE, and its relationships with lifetime productivity, including mature cow feed costs. The Trangie project is genetically linked to the progeny test program of the CRC for the Cattle and Beef Industry (Beef CRC), the latter including feed efficiency testing of some progeny during feedlot finishing near Armidale. An outline of the NFCE project is given in Figure 1.

The Trangie Agricultural Research Centre has developed an automated feeding system which records actual feed intake of each animal. Two groups of weaned calves undergo a 120–day postweaning NFCE test each year, after an adjustment period of at least 21 days. Animals have *ad* libitum access to a pelleted ration

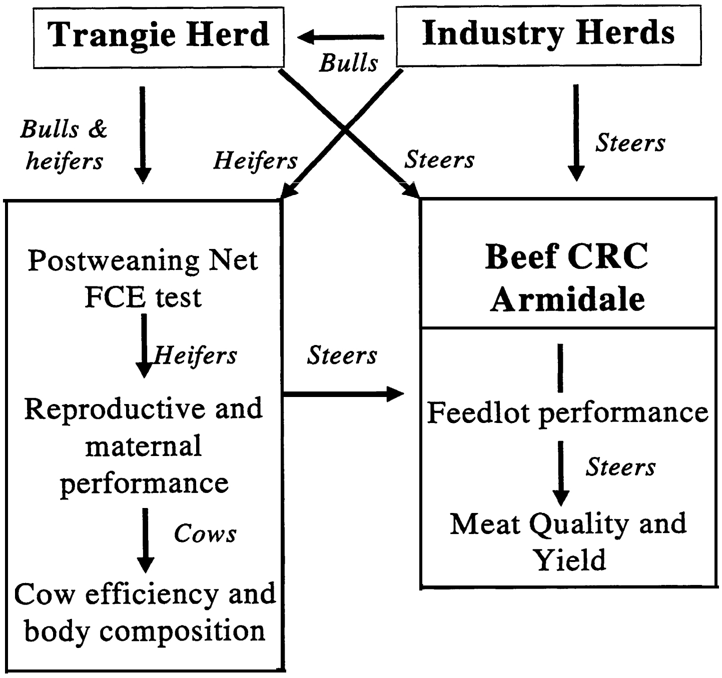

Figure 1 Design of the net feed conversion efficiency project.

consisting of 70% lucerne hay and 30% wheat with a metabolizable energy (ME) concentration of 10 to 10.5 MJ/kg dry matter and 16 to 18% crude protein for which feed intake is recorded. In addition 0.5 kg/head per day of oaten straw (containing 6.7 MJ/kg dry matter) is fed in open troughs. All animals are weighed weekly, and measurements of subcutaneous fat depth at the 12th/13th rib site, eye muscle area and linear body dimensions are taken at the start, middle and end of the test.

Growth of each animal during the test period is described by linear regression of weight against time (SAS, 1989) and the regression estimates were used to calculate average daily gain and weights at the start, middle and end of the test. Feed intake over 120 days is calculated by adding the ME intake of the straw to the ME intake of the pelleted ration. This intake value is divided by 10 to convert it to kilograms of feed with a concentration of 10 ME/kg dry matter. NFCE is measured as net feed intake, being the difference between actual feed intake and expected feed intake. Expected feed intakes are calculated from a linear model of actual feed intakes regressed against average daily gains and metabolic midweights (mean of the start and end weights, raised to the power of 0.73), fitted separately for each test-sex group.

On the basis of the results of the NFCE tests, bulls and heifers are divided into either a high efficiency or low efficiency demonstration herd. Heifers remain in the demonstration herds for two calvings to evaluate their reproductive performance and lifetime efficiency, prior to future evaluation of maintenance feed requirement and body composition as mature cows. Progeny from the demonstration herds will also be evaluated for postweaning NFCE. In addition to animals evaluated at Trangie, steer siblings of both the Trangie bred animals and the heifers sourced from industry herds will be evaluated for feedlot performance, carcase characteristics and meat quality at the Cattle and Beef Industry CRC at Armidale. The overall design will provide the genetic and phenotypic parameters between NFCE and all important traits in the breeding and finishing phases of beef production.

Genetic and phenotypic variation

Data from five groups of animals tested for efficiency at the Agricultural Research Centre, Trangie, were used. A total of 966 records were available, representing 93 sires. Animals from groups 1, 3 and 5 consisted of bulls and heifers and were progeny of the Angus cow herd at the Agricultural Research Centre, sired by popular industry bulls. These animals were born in Winter/Spring of 1993, 1994 and 1995 and were tested for efficiency after weaning in autumn of the following year. Animals from groups 2 and 4 consisted of Angus, Hereford, Poll Hereford and Shorthorn heifers purchased from 17 industry herds. These animals were born in Autumn of 1994 and 1995 were brought to Trangie and efficiency tested after weaning the following Spring.

Variance and covariance components, and phenotypic correlations, were estimated using DFREML software (Meyer, 1993). The fixed effects fitted included test group, sex, breed and herd of origin. Age at the start of the test was fitted as a covariate. Random effects included a term for direct additive genetic effect. An additional term for maternal permanent environmental effect was fitted for traits where a preliminary analysis showed this effect to significantly improve the model.

The performance of the animals for a range of traits is given for each sex-test group in Table 1. Within a test/sex group, the group mean expected feed intake will equal the group mean actual feed intake and therefore the difference, net feed intake, will equal zero. Table 2 gives the overall mean for each trait, the heritability and the phenotypic correlation of each trait with net feed intake. The permanent maternal environment effect was only significant for 365–day weight, and so was not included in the model for the other traits. All traits examined were moderately to highly heritable. The heritability of net feed intake was 0.44 ± 0.07, suggesting that genetic variation exists for NFCE of growing cattle. Phenotypic correlations of net feed intake with average daily gain and 365–day weight were non-significant as was expected (because the model used to calculate net feed intake included a

Table 1 Means (± sd) by test and sex for average daily gain, 365–day weight, actual feed intake, net feed intake, feed conversion ration (FCR), fat depth and eye muscle area at the end of the test.

Test	Sex	Average daily gain (Kg/day)	Adj. 365–day weight (kg)	Actual feed intake (kg over 120 d)	Net feed intake (kg)	FCR (kg/kg)	Rib fat (mm)	Eye muscle area (cm^2)
1	Bulls	1.31 ± 0.20	454 ± 42	1499 ± 156	0 ± 78	9.7 ± 1.1	6.8 ± 2.5	85 ± 9
1	Heifers	1.01 ± 0.14	389 ± 41	1368 ± 155	0 ± 57	11.5 ± 1.0	8.6 ± 2.6	76 ± 9
2	Heifers	1.21 ± 0.12	377 ± 37	1196 ± 129	0 ± 64	8.4 ± 1.1	7.0 ± 1.9	60 ± 8
3	Bulls	1.42 ± 0.16	467 ± 34	1452 ± 141	0 ± 72	8.7 ± 0.9	7.5 ± 2.6	79 ± 5
3	Heifers	1.13 ± 0.12	406 ± 32	1347 ± 129	0 ± 61	10.1 ± 0.9	11.1 ± 2.3	73 ± 6
4	Heifers	1.17 ± 0.12	383 ± 35	1205 ± 114	0 ± 70	8.8 ± 1.0	7.9 ± 2.5	65 ± 6
5	Bulls	1.32 ± 0.15	441 ± 42	1391 ± 145	0 ± 65	8.9 ± 0.9	7.4 ± 2.2	71 ± 7
5	Heifers	1.12 ± 0.12	391 ± 35	1307 ± 112	0 ± 61	9.8 ± 0.8	10.3 ± 2.2	68 ± 5

phenotypic adjustment for average daily gain and liveweight). The correlation between net feed intake and eye muscle area was also non-significant. Net feed intake was positively correlated with feed conversion ratio, although the correlation was only moderate (0.51), indicating that these indices of efficiency represent different traits. A low but significant positive correlation was found between net feed intake and fat depth at the 12th/13th rib, suggesting that low efficiency animals had a slight tendency to deposit a greater amount of subcutaneous fat.

Previous reports from this project indicate there is considerable variation in net feed intake of individual animals, and that significant differences between sire lines exist (Arthur *et al.* 1996a). The heritability estimate for net feed intake of 0.44 confirms that the trait is moderately heritable and genetic variation in net feed intake exists in Australian beef cattle. Therefore selection to reduce net feed intake should be possible, and lead to improvements in the efficiency of beef production and reduction in feed costs.

Table 2 Mean, heritability (h^2) and phenotypic correlation (r_p) with net feed intake for traits measured during the first five 120–day postweaning NFCE tests at Trangie (from Arthur *et al.* 1997).

Trait	mean	h^2	r_p
Average daily gain (kg/day)	1.204	0.41 ± 0.08	0.01
Adj. 365–day weight (kg)	407	0.68 ±0.08	–0.04
Actual feed intake (kg over 120 days)	1317	0.59 ± 0.07	0.52
Net feed intake (kg)	0	0.44 ± 0.07	1.00
Feed conversion ratio (kg/kg)	8.87	0.31 ± 0.09	0.51
Rib fat (mm)	8.2	0.47 ± 0.08	0.19
Eye muscle area (cm^2)	69.9	0.31 ± 0.08	–0.01

The phenotypic correlations indicate that net feed intake is unrelated to growth and to eye muscle area, whereas fat depth is decreased slightly in high efficiency animals. Consequently, it would be expected that there would be no adverse relationship between efficiency and meat yield. While genetic correlations are needed to predict the consequences of selection for net feed intake, such selection is unlikely to be accompanied by any undesirable response in production traits of growing animals.

Performance of Progeny of High versus Low NFCE Cattle

Heifers from the first postweaning NFCE test were split into high and low NFCE demonstration herds, and joined to the 4 most efficient bulls and the 3 least efficient bulls (of the 98 bulls tested). The resulting progeny were tested for NFCE in Autumn 1996. Records on 27 bulls and heifers fiom high NFCE parents and 30 bulls and heifers from low NFCE parents were available. Other animals also tested in the same group were included in the regression of feed intake against gain and midweight$^{0.73}$, so that data for a total of 104 bulls and 97 heifers were used. Data for each trait were analysed using a generalised linear model (GLM; SAS, 1989) which included the fixed effects of sex, group (high NFCE versus low NFCE) and the interaction of sex and group.

Least squares means by group for each trait are presented in Table 3. The interaction of sex and group was not significant for any of the traits examined. Significant differences between the progeny of high and low NFCE parents were found for net feed intake and feed intake. Animals from high efficiency parents had lower net feed intake (*i.e.* were more efficient) than animals from low efficiency parents, and consumed less feed over the 120 day test. No significant difference between the groups was found for feed conversion ratio, average daily gain, adjusted 365–day weight, fat depth at the 12th/13th rib at the end of the test, change in fat

Table 3 Least squares means (± se) for progeny of high efficiency and low efficiency bulls and heifers (from Herd et a/. 1997).

Trait	High efficiency	Low efficiency	Significance
Number of animals	27	30	
Net feed intake (kg)	–19 ± 10	49 ± 9	***
Actual feed intake (kg)	1262 ± 25	1354 ± 24	**
Feed conversion ratio (kg/kg)	8.78 ±0.15	9.05 ± 0.15	ns
Average daily gain (kg/day)	1.17 ± 0.03	1.21 ± 0.03	ns
Adj. 365 day weight (kg)	384 ± 7	384 ± 7	ns
Rib fat (at end of test) (mm)	7.4 ± 0.3	8.1 ± 0.3	ns
Change in rib fat (mm)	3.9 ± 0.3	4.3 ± 0.3	ns
Eye muscle area (at end of test) (cm^2)	66.1 ± 1.3	67.7 ± 1.2	ns

ns P>0.05; ** P<0.01; *** P<0.001

depth during the test and eye muscle area at the end of the test.

The realised response observed after one generation of selection on net feed intake confirms the results from parameter estimates, i.e. that net feed intake has a genetic component with a moderate heritability. Net feed intake is calculated to be phenotypically independent of growth, but Kennedy *et al.* (1993) pointed out that it might still be genetically correlated with growth. The limited data available suggest that the observed response in net feed intake was not significantly correlated with either growth or carcass traits. If so, the genetic correlation observed response in net feed intake with growth may be low or near zero.

Results from Beef CRC Progeny Tests

Within the Beef CRC core breeding program, steers within sire progeny groups have their individual feed intakes measured whilst being fed for slaughter in the 'Tullimba' Research feedlot. Robinson *et al.* (1997) presented results for 308 steers from two groups of Bos *taurus* steers purchased at weaning in 1995 and 1996 from 9 Angus, 4 Shorthorn, 3 Hereford and 2 Murray Grey herds and a group of *Bos indicus* steers purchased in July 1994 from a Santa Gertrudis and a Brahman herd. The steers were grown on pasture to feedlot entry weights (group mean 400 kg). Within each group the steers were fed for the Korean (target 520 kg) or Japanese (target 640 kg) markets. Individual feed intakes of a barley finisher diet were measured by automated feeders. Calculation of residual feed intake and its relationships with actual feed intake and growth rate are described in Robinson *et al.* (1997).

For the *Bos indicus,* cattle the correlations between feed intake and growth rate were very high implying that it would be difficult to reduce voluntary feed intake without also reducing weight gain. However, for the *Bos taurus* cattle, correlations between feed intake and growth rate were lower, allowing some scope for reducing intake without lowering gain and providing evidence of variation in NFCE during feedlot finishing *in these Bos taurus* breeds.

Economic Benefit of Selecting Beef Cattle for NFCE

Benefit to a Beef Production Enterprise

The objective of this study (Arthur *et al.* 1996b) was to examine the economic benefit of feeding high NFCE beef cattle postweaning from 300 kg to a slaughter liveweight of 450 kg.

Data on 185 weaned bulls and 580 weaned heifers of straight-bred British breed cattle (Angus, Hereford and Shorthorn) from 4 groups tested for postweaning NFCE were used. Within each test group and sex, data on animals which ranked in the top 10%, 25% and 50% for net feed intake and data on all animals tested (which represented an unselected control), were used to derive the amount of feed each animal required to gain 150 kg liveweight. This weight of feed was converted into the equivalent of weight of lucerne hay with a ME content of 9.3 MJ/kg DM. The commercial price used for lucerne hay was $160/1000 kg in a normal season and $275/1000 kg under drought conditions. The data were analysed within sex, by least squares using the GLM procedure of SAS (1989) and fitting the effects of breed and test group as fixed effects.

Table 4 Least squares means (± se) for feed requirements of cattle, in different categories of net feed conversion efficiency (NFCE), grown from 300 kg to 450 kg liveweight (from Arthur *et al.* 1996b).

NFCE category	Days on feed	Total feed intake (kg)	Feed cost ($) Normal season	Feed cost ($) Drought conditions
Bulls				
Top 10%	110 ± 4	1385 ± 35[a]	222 ± 6[a]	381 ± 9[a]
Top 25%	111 ± 2	1400 ± 22[a]	224 ± 4[a]	385 ± 6[a]
Top 50%	113 ± 2	1421 ± 16[a]	228 ± 3[a]	391 ± 4[a]
Unselected control	112 ± 1	1486 ± 11[b]	238 ± 2[b]	409 ± 3[b]
Heifers				
Top 10%	133 ± 2	1430 ± 18[a]	229 ± 3[a]	393 ± 5[a]
Top 25%	134 ± 1	1456 ± 12[a]	233 ± 2[a]	400 ± 3[a]
Top 50%	134 ± 1	1490 ± 9[b]	238 ± 1[b]	409 ± 2[b]
Unselected control	134 ± 1	1538 ± 7[c]	246 ± 1[c]	423 ± 2[c]

[a,b,c] Means within the same column, and for the same sex, with different letters differ ($P<0.05$)

Table 4 shows that, within sex, all categories of cattle with above average NFCE required similar number of days, but consumed 3% to 7% less feed to gain the specified 150 kg Iiveweight. This translated to a reduction in feed costs of $10 to $17 per animal in a normal season and $14 to $30 per animal during drought conditions. Results for fat depth indicated that at the specified slaughter liveweight of 450 kg, the animals would meet the carcass fatness and carcass weight specifications of the Australian Hotel/Restaurant market, and some of the markets traditionally supplied by Australian beef exports, such as the lightweight end of the Korean and European Community markets. Thus for the postweaning grow-out phase of beef production, initial results indicate that feed costs could be reduced using cattle with above average postweaning NFCE.

Equilibrium Displacement Modelling

The Equilibrium Displacement Model (EDM) of the Australian beef industry developed by Griffith and colleagues in Armidale was used to evaluate the total dollar benefit and resulting distribution of additional income to various sectors in the economy following adoption of improved NFCE cattle (Newsome, 1996). A 6% improvement in NFCE was assumed to be available to seedstock producers and to cattle being finished on grass or grain to Korean market specifications.

Gross margin analysis suggested a 2% and 3.5% decrease in cost of production per kg of beef produced from grass and grain respectively. In response the EDM predicted an increase in production of beef. The increase in supply would lead to a reduction in price paid by the consumer. The predicted outcomes were that about 76% of the total dollar benefit would be captured by consumers as more beef at a lower price, about 2 1% of the benefit would accrue to seedstock producers who produce for the vealer or feedlot market, and the remaining benefit would be shared between backgrounders, grass finishers and feedlots (Newsome, 1996).

Physiological Indicators for Net Feed Conversion Efficiency

Our objective was to examine animals for possible physiological indicators of NFCE. The approach taken was to compare high and low NFCE animals for differences in feed utilisation (via digestibility), haematology and plasma insulin-like growth factor-l and 2 (IGF–1, IGF–2). Red blood cells and related factors were examined for their oxygen carrying capacities; plasma proteins, lymphocytes and associated cells due to their connection with immune function; and IGF's since IGF-1 has been shown to be related to a number of traits including growth rate and body size, feed conversion efficiency and carcass characteristics.

In this investigation, beef cattle from test 2 and 3 of the first 5 postweaning NFCE tests conducted at Trangie were used. Test 2 comprised Angus, Hereford and Shorthorn heifers from industry herds (n = 193). Test 3 consisted of Trangie-bred Angus heifers and bulls (n = 194 and 188 respectively). Cattle in each test group were ranked for NFCE and samples were obtained from the 10 highest and 10 lowest ranked animals. Test 2 and 3 animals were sampled for blood and faeces at the completion of their test. Test 3 animals were also sampled 1 month before the end of the test to measure repeatability for the blood factors over time. Feed and faecal samples were analysed for alkane content and dry matter digestibility determined using C33 alkane as an internal marker. Further details of the test protocol are given in Arthur et *al.* (1996a) and methods used in Richardson et *al.* (1996).

Haematology

Many of the haematological characters were very variable (in particular white blood cells (WBC), lymphocytes (LYMP), neutrophils (NEUT), monocytes (MONO) and eosinophils (EOS)). Results for some of the less labile blood constituents demonstrated they might prove useful as indicators for NFCE. Table 5 summarises results for animals from tests 2 and 3. There were consistent, statistically significant differences between high and low NFCE animals in their levels of total plasma protein (TPP) and in the ratios MCH and MCV. None of the remaining blood constituents differed between high and low efficient animals ($P > 0.10$). Results indicated a tendency for high NFCE animals to have more red blood cells (RBC) with a lower haemoglobin content than low NFCE animals. The lower ratio of haematocrit to RBCs (MCV) in high NFCE animals suggests that they had more RBCs than low NFCE animals. These differences may be associated with capacity for transporting oxygen.

Table 5 Blood constituents that differed between High and Low NFCE animals at the end of tests 2 and 3 of the first five **120–day** postweaning NFCE tests conducted at Trangie (from Richardson ***et al.*** 1996).

Blood constituent	High NFCE	Low NFCE	Significance
Red blood cell (x 10^9cells/L)	8.58 ± 0.19	8.12 ± 0.19	+
MCH (haemoglobin / red blood cell)	14.84 ± 0.26	15.86 ± 0.26	**
MCV (haematocrit / red blood cell)	43.45 ± 0.94	46.19 ± 0.94	*
Total plasma protein (g/L)	65.20 ± 0.68	70.05 ± 0.68	**

+ $P < 0.10$; * $P < 0.05$; ** $P < 0.01$

The MCH ratio was highly repeatable over the last month of test 3 (r > 0.9; Table 6). MCV, TPP and RBCs were moderately repeatable (r > 0.5). This suggests that for these haematological parameters in which differences between high and low NFCE cattle were observed, the collection of blood samples to characterise animals might be possible before the end of a NFCE test. Other blood parameters that were moderately repeatable included haemoglobin in both sexes, and haematocrit and LYMP in bulls, but these were not associated with differences in NFCE.

Plasma proteins differed between high and low NFCE animals at the end of the tests (68.3 ± 0.6 v 70.1 ± 0.6 g/L; P < 0.05). However, there was no difference in ALB protein between high and low NFCE animals (0.5 14 ± 0.006 v 0.511 ± 0.006 g/g; P > 0.05), and hence no evidence for an increase in globulins in one efficiency group of cattle over the other at the end of the tests. There was therefore no evidence of greater exposure to infection in one group of cattle than in the other. The higher TPP levels found in low NFCE cattle may reflect metabolic differences, for example in rates of protein synthesis and degradation.

Blood samples from test 2 animals showed no difference (P > 0.05) in circulating levels of IGF–1 (276 ± 7 v 249 ± 17mg/mL) and IGF–2 (174 ± 5 v 180 ± 9mg/mL) between high and low NFCE animals. Previous research has found associations between IGF-1 and many growth-related measurements, including feed conversion ratio. NFCE is calculated to be independent of liveweight and growth rate and this may explain its apparent poor association with IGF-1. IGFs circulate bound to binding proteins, which restricts their actions relative to those characteristic of free IGF and restricts permeability of IGF through capillaries, inhibiting access to membrane receptors and dampening their biological activity. Therefore failure to demonstrate strong association between simple measures such as total plasma IGF-1 and IGF-2 with NFCE should not discount a role for hormones of the growth axis in influencing NFCE.

Digestibility

Over the 2 tests, high NFCE animals tended to be slightly more able to digest feed than low NFCE animals (DMD = 68.1 ± 0.5% and 67.1 ± 0.5%, respectively: P<0. 10). The tendency towards higher DMD by high NFCE animals suggests a concomitant improvement in feed utilisation. The difference of 1% unit in DMD might appear small but it is not trivial. Simple calculations show that a 1% unit improvement in DMD could reduce by 2.3% the feed required per day for 450 kg cattle growing at 1.3 kg/day and eating feed with a DMD of 69%, typical of cattle in these tests. The difference in average feed intake between the high and low NFCE cattle during the week preceding and week of faecal sampling, in tests 2 and 3, was about 16%. This 1% unit difference in DMD could account for about 14% (2.3/16) of the observed difference in feed eaten.

Ideally measurements that are predictive of subsequent performance should be able to be taken at the start of the test. Development of this type of screening procedure could justify the expense of putting animals through a NFCE test. So far results are only from samples taken at the end of the 120 day test. While these may be associated with differences in NFCE over the test, they might well be a consequence of performance during the test rather than responsible for the differences observed in NFCE. However this study has shown that physiological differences exist between high and low NFCE animals, and indicates areas where research could be intensified.

Acknowledgments

This work is funded by NSW Agriculture, the Beef CRC and the Meat Research Corporation. The input to the initial project design by P. Parnell and G. Lee is gratefully acknowledged, as is the capable assistance given by S. Exton, J. Wright, K. Dibley, D. Burton, I. Colditz (haematology), R. Hegarty (alkanes), T. Snelgar, T. Patterson, D. Mula and S. George.

References

Arthur, P.F., Herd, R.M., Wright, J., Xu, G., Dibley, K., and Richardson, E. (1996a). Net feed conversion efficiency and its relationship with other traits in beef cattle. *Proceedings of the Australian Society of Animal Production* 21,107-l 10.

Arthur, P.F., Thomas, M., Exton, S., Dibley, K., and Herd, R.M. (1996b). Economic benefit from selecting for net feed conversion efficiency in beef cattle. *Proceedings of the Animal Science Congress of the Asian-Australian Association for Animal Production,*

Table 6 Repeatability estimates using correlation coefficients between 2 measurements for blood constituents (Red Blood Cells (RBC), Haemoglobin (HGB), Haematocrit (HCT), MCV (HCT/RBC), MCH (HGB/RBC), Total Plasma Protein (TPP) and Lymphocytes (LYMP) between week 15 and 19 of test 3 (from Richardson et *al.* 1996).

	RBC	HGB	HCT	MCV	MCH	TPP	LYMP
Heifers	0.86**	0.72**	0.29^{ns}	0.70**	0.94**	0.71**	0.36 ^{ns}
Bulls	0.78**	0.68**	0.56**	0.91**	0.95**	0.53**	0.61**

^{ns} P>0.05; * P < 0.05; ** P < 0.01

Makuhari, Chiba, Japan, 13–18 October 1996 **8**, 22–23.

Arthur, P.F., Archer, J.A., Herd, R.M., Richardson, E.C., Exton, S., Wright, J.H., Dibley, K.C.P., and Burton, D.A. (1997). Genetic and phenotypic variation in feed intake, feed efficiency and growth in beef cattle. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* **12**, 234–237.

Bishop, M.D., Davis, M.E., Harvey, W.R., Wilson, GR., and VanStavern, B.D. (1991). Divergent selection for postweaning feed conversion in Angus beef cattle: II. Genetic and phenotypic correlations and realised heritability estimate. *Journal of Animal Science 69,* 4360–4367.

Crawford, N. (1994). Influence of growth pattern and compensatory growth on feed efficiency – the industry perspective. *Proceedings of the Growth and Development Workshop, Armidale, 19-20 September* **1994.** Beef CRC: Armidale.

Fan, L.Q., Bailey, D.R.C., and Shannon, N.H. (1995). Genetic parameter estimation of postweaning gain, feed intake and feed efficiency for Hereford and Angus bulls fed two different diets. *Journal of Animal Science* **73**, 365–372.

Herd, R.M. (1992). Changing the size of beef cattle – Implications for cow feed requirements. *Proceedings of the Australian Association of Animal Breeding and Genetics* **10**, 334–337.

Herd, R.M., Archer, J.A., Arthur, P.F., Richardson, E.C., Wright, J.H., Dibley, K.C.P., and Burton, D.A. (1997). Performance of progeny of high vs low net feed conversion efficiency cattle. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* **12**, 742–745.

Jensen, J., Mao, I.L., Andersen, B.B., and Madsen, P. (1992). Phenotypic and genetic relationships between residual energy intake and growth, feed intake, and carcass traits of young bulls. *Journal of Animal Science* **70**, 386–395.

Kennedy, B.W., van der Werf, J.H.J., and Meuwissen, T.H.E. (1993). Genetic and statistical properties of residual feed intake. *Journal of Animal Science* **71**, 3239-3250.

Koch, R.M., Swiger, L.A., Chambers, D., and Gregory, K.E. (1963). Efficiency of feed use in beef cattle. *Journal of Animal Science* **22**, 486–494.

Lee, B. (1993). Nutrition and management of feedlot cattle. *Recent Advances in Animal Nutrition in Australia* 1993, pp. 61-69. University of New England: Armidale, N.S.W.

Luiting, P. (1990). Genetic variation of energy partitioning in laying hens: causes of variation in residual feed consumption. *World Poultry Science 46,* 133–1 52.

Meyer, K. (1993). *DFREML v2.1 User notes.* ABGU, University of New England: Armidale, N.S.W.

Montano-Bermudez, M., Nielsen, M.K., and Deutscher, GH. (1990). Energy requirements for maintenance of crossbred beef cattle with different genetic potential for milk. *Journal of Animal Science* **68**, 2279–2288.

Mrode, R.A., Smith, C., and Thompson, R. (1990). Selection for rate and efficiency of lean gain in Hereford cattle. 2. Evaluation of correlated responses. *Animal Production* **51**, 35–46.

Newsome, T.J.P. (1996). The economic impact of isolating genes for net feed conversion efficiency in the beef cattle industry. Fourth Year Project Dissertation, Univeristy of New England: Armidale, N.S.W.

Richardson, E.C., Herd, R.M., Arthur, P.F., Wright, J., Xu, G, Dibley, K., and Oddy, V.H. (1996). Possible physiological indicators for net feed conversion efficiency in cattle. *Proceedings of the Australian Society of Animal Production* **21**,103–106.

Robinson, D.L., Skerritt, J.W., and Oddy, V.H. (1997). Measurement of feed intake and feed efficiency in feedlot cattle. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* **12**, 287-291.

SAS Institute Inc. (1989). *SAS/STAT Users Guide.* Version 6. 4th ed. SAS Institute Inc.: Cary, NC.