On farm

Reducing the costs of beef production through the genetic improvement of net feed conversion efficiency

Project number DAN.075
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ISBN 1 74036 759 6

November 2005

ABSTRACT

An eight-year project was undertaken to investigate and demonstrate the economic benefits of reducing the costs of beef production through genetic improvement of net feed efficiency. Net feed intake (NFI) is the recommended measure of efficiency and is defined as feed intake net of the expected requirements for maintenance of bodyweight and growth. The results show that NFI is moderately heritable (39%), and selection for lower NFI results in progeny that are more efficient in feed utilisation and slightly leaner than average. Expected potential benefit to the southern Australian beef industry is $162 million over 25 years at an annual adoption rate of 2% and a maximum adoption level of 30%. It is recommended that the beef cattle industry should incorporate selection for feed efficiency in its breeding programs.

EXECUTIVE SUMMARY

Profitability of beef production depends on both inputs and outputs. In the past, genetic improvement has been aimed mainly at output traits such as fertility and liveweight, and more recently carcass and meat quality traits, with little emphasis placed on reducing input costs. Providing feed to cattle is the single largest expense in most commercial beef production enterprises, thus any effort at improving the efficiency of feed use will help reduce input costs. Feed cost for maintenance is estimated to represent at least 60 to 65% of the total feed requirements for the cow herd, with considerable variation among individual animals independent of their body size. Therefore to improve whole production system efficiency, the measure of feed efficiency used should capture some of the genetic variation associated with maintenance efficiency. Variation in net feed efficiency targets variation in feed efficiency relating to maintenance and growth. The trait for this measure of efficiency is more appropriately called Net (or residual) Feed Intake (NFI), and is determined from an animal's feed intake and the expected energy requirements for maintenance and growth during a test period. Information on NFI in beef cattle in the early 1990s was limited, and as such this project was the most comprehensive research on feed efficiency in beef cattle in the world. The overall objective of the project therefore, was to investigate and demonstrate the economic benefits of reducing the costs of beef production through the genetic improvement of net feed intake.

The project commenced in 1992 with matings, by artificial insemination, of leading industry Angus bulls and Angus females from NSW Agriculture Research Centre at Trangie. The resulting 1993-born progeny, and progeny from subsequent Trangie matings up to 1998 were used in the study. Angus, Hereford, Poll Hereford and Shorthorn heifers purchased from industry herds participating in BREEDPLAN were also used. These industry heifers were born in 1994, 1995 and 1996. Automatic feed intake recorders at the Efficiency Testing Unit at Trangie were used to measure feed intake over a specified test period, on all the animals used in this study. Data collection for the project was completed in November 2000. The project design incorporated six major integrated component studies: postweaning performance, reproduction and maternal performance, mature cow efficiency, feedlot performance, carcass and meat quality evaluation, and a demonstration herd. It also included a comprehensive industry implementation program aimed at stimulating adoption of the outcomes of the project by the beef industry. The strategy for industry implementation of outcomes was to provide the means by which a BREEDPLAN Estimated Breeding Value (EBV) for NFI can be calculated to allow the Australian beef industry to implement genetic improvement in feed efficiency in their breeding programs.

The results show that genetic variation for postweaning NFI exists in Australian cattle population and that NFI is moderately heritable (heritability of 39%). This indicates that genetic improvement in the efficiency of feed utilisation can be made through selection for NFI. Feed intake and feed conversion ratio during the postweaning period were genetically correlated with NFI (0.69 and 0.66, respectively). There was a weak but significant genetic correlation between NFI and 12/13th rib fat depth (0.17). NFI was favourably correlated with the direct effects of 200-day (-0.45) and 400-day (-0.26) weights, although there was a weak unfavourable correlation with maternal effects on these two traits. Genetic correlations between NFI and other postweaning traits were close to zero. These results indicate that selection for low NFI will result in progeny that have similar postweaning performance as unselected progeny, but are more efficient in feed utilisation and are slightly leaner. These expectations were confirmed by the performance of the demonstration herd (selected for high or low NFI) progeny on pasture, on medium quality diet and on feedlot diets. Beef yield

and meat quality did not significantly differ among the high and low NFI progeny from the demonstration herds.

Considerable genetic variation in NFI was also found in mature cows. There was a strong genetic correlation between postweaning NFI and the feed intake and efficiency of cows, such that selection for improved efficiency (ie. lower postweaning NFI) will lead to correlated improvements in efficiency of the breeding herd. Selection for lower postweaning NFI will lead to slightly heavier cows that eat less, and are slightly leaner. The correlation with fat depth is low (0.2), and so ample scope exists to select efficient cows with adequate fat coverage. Despite the tendency for more efficient cows to have lower fat depth, selection for lower postweaning NFI will have little effect upon fertility (as assessed by the trait "days to calving") and lead to a slight reduction in milk production of cows. Again, the genetic correlation is only low (0.25), and should be noted that the estimation of milk production by the weigh-suckle-weigh technique used in this study, reflects that calf's milk demand and may not reflect the full genetic potential of the cow for milk production.

Two approaches were used in assessing the economic benefit from genetic improvement of NFI. In the first analysis, an evaluation of the benefit of recording net feed intake in industry breeding schemes using a model of investment and gene flow resulting from selection activities was conducted. The analysis considered breeding schemes targeting either the high quality Japanese export market (with steers fed for 210 days) or the grass-fed domestic market. Net feed intake measurement costs per bull ranging from $150 to $450 were used. Inclusion of NFI, measured on a proportion of bulls in the seedstock sector, as a selection criterion increase annual genetic gain in the breeding objective by up to 16% and 35% for breeding schemes targeting the domestic and Japanese markets, respectively. Recording NFI on the top 25% of young bulls (selected based on information available at weaning) in the breeding unit produced close to optimal profit. A premium of $153 per bull sold to the commercial sector was required to recover the costs of NFI measurement incurred by the breeding sector at this level of testing. The results indicate that inclusion of NFI as a selection criterion in beef cattle breeding schemes is profitable.

In the second economic analyses, a commercial cattle enterprise was modelled based on a 100-cow herd run on native pasture, with progeny being grown on improved pastures. In the production system modelled, surplus heifers were sold at 18 months of age into the domestic market and 80% of the steers were sold for feedlot finishing and subsequent sale as heavy export steers. Gross margin budget and cashflow analyses showed that, despite the initial cost of purchasing bulls genetically superior for efficiency, over a 25-year investment period the internal rate of return was a healthy 61% and the net present value (NPV) of surplus income over expenses was $21,907. This equates to an annual benefit per cow of $8.76. The estimated NPV of the benefit from genetic improvement in NFI to the commercial cattle sector of the southern Australian beef cattle industry, based on an expected rate of adoption 2%p.a. and maximum adoption level of 30%, is $162 million over 25 years.

It was therefore recommended that the beef cattle industry should incorporate selection for feed efficiency in its breeding programs. Net feed intake should be the trait to use, and it should be used in a multi-trait selection index framework, where selection can be based on NFI as well as other economically important traits. BREEDOBJECT provides a suitable framework for multi-trait selection and should be expanded to incorporate NFI.

Net feed intake is a new trait, therefore some development work was done to translate some of the research methodologies (such as, how long should the NFI test be?) into practical guidelines and protocols that can be implemented in the beef industry. A standards manual

(Testing Beef Cattle for Net Feed Efficiency ~ Standards Manual) has been produced that contains the guidelines that should be adhered to if BREEDPLAN EBVs are required. The success of the project generated significant industry interest and adoption of the outcomes of the project, starting from 1997, with the establishment of NFI test station at Vasse in Western Australia. To date there are five NFI test stations across the country. As well, two companies developed feed intake testing units, which are currently being marketed commercially. The number of industry bulls tested has risen substantially from 171 in 1997 to 509 in 2000. The estimated number of bulls that will be tested in 2001 is 580. The full cost of the test is borne by the owners of these bulls.

CONTENTS

1. BACKGROUND

Profitability of beef production depends on both inputs and outputs. In the past, genetic improvement has been aimed mainly at output traits such as fertility and liveweight, and more recently carcass and meat quality traits, with little emphasis placed on reducing inputs. Providing feed to cattle is the single largest expense in most commercial beef production enterprises, thus any effort at improving the efficiency of feed use will help reduce input costs. In beef cattle, attempts at genetic improvement of feed use have been based on gross feed conversion efficiency, which is defined as liveweight gain divided by amount of feed consumed. Studies conducted at Trangie and overseas have clearly shown that variation among growing animals in gross feed conversion efficiency is largely a reflection of differences in their growth rate.

Feed cost for maintenance is estimated to represent at least 60 to 65% of the total feed requirements for the cow herd, with considerable variation among individual animals independent of their body size. Therefore to improve whole production system efficiency, the measure of feed efficiency used should capture some of the genetic variation associated with maintenance efficiency. In contrast to gross feed conversion efficiency, variation in net feed conversion efficiency targets variation in feed efficiency relating to maintenance and growth. The trait for this measure of efficiency is more appropriately called Net (or residual) Feed Intake (NFI), and is determined from an animal's feed intake and the expected energy requirements for maintenance and growth during a test period. Throughout this document the trait will be referred to as net feed intake, except in some published documents in the appendices where it has been refereed to as net feed efficiency or residual feed intake. Research on NFI in beef cattle was limited in the early 1990s. However, extensive studies in poultry have shown that variation in NFI is mainly due to differences in maintenance energy requirements per kg of metabolic body weight.

2. PROJECT OBJECTIVES

The overall objective of the project was to investigate and demonstrate the economic benefits of reducing the costs of beef production through the genetic improvement of net feed intake. Under this major aim were specific objectives, which included:

- To demonstrate realised genetic responses and determine genetic and phenotypic parameters for postweaning NFI.
- To provide the first progeny test evaluations for NFI among contemporary industry sires.
- To demonstrate correlated responses and determine genetic and phenotypic relationships between postweaning NFI and calf growth, body composition, cow reproductive and maternal performance, mature cow feed costs, steer feedlot performance, carcass yield and meat quality.
- To provide recommendations on the benefits of central progeny testing for NFI in the Australian beef seedstock industry.
- To provide a pilot facility for commercialised central testing of industry cattle for NFE.

3. METHODOLOGY

The project commenced in 1992, with matings of the Angus females from the Trangie herd to leading industry Angus bulls by artificial insemination. The resulting 1993-born progeny, and progeny from subsequent Trangie matings up to 1998 were used in the study. Angus, Hereford, Poll Hereford and Shorthorn heifers purchased from industry herds participating in BREEDPLAN were also used. These industry heifers were born in 1994, 1995 and 1996. Automatic feed intake recorders at the Efficiency Testing Unit at Trangie (Plate 1) were used to measure feed intake during a specified test period, on all the animals used in this study. Data collection for the project was completed in November 2000.

Plate 1. The Efficiency Testing Unit at the Agricultural Research Centre, Trangie

The design of the animal experimentation aspect of the project is presented in Figures 1 and 2. The design incorporates six major integrated component studies. These studies are: postweaning performance, demonstration herd studies, reproduction and maternal performance, mature cow efficiency, feedlot performance and carcass and meat quality evaluation. Details of the experimental protocols for each of these studies have been outlined in Appendices 1, 2, 3, 4 and 9.

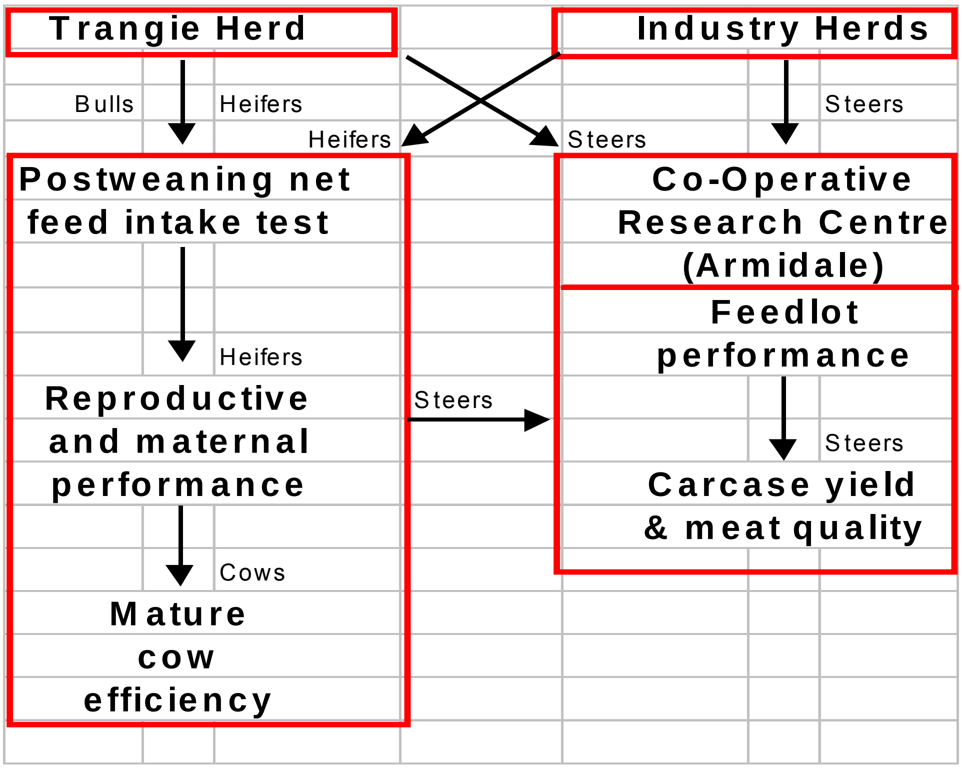


Figure 1: Design of net feed intake project

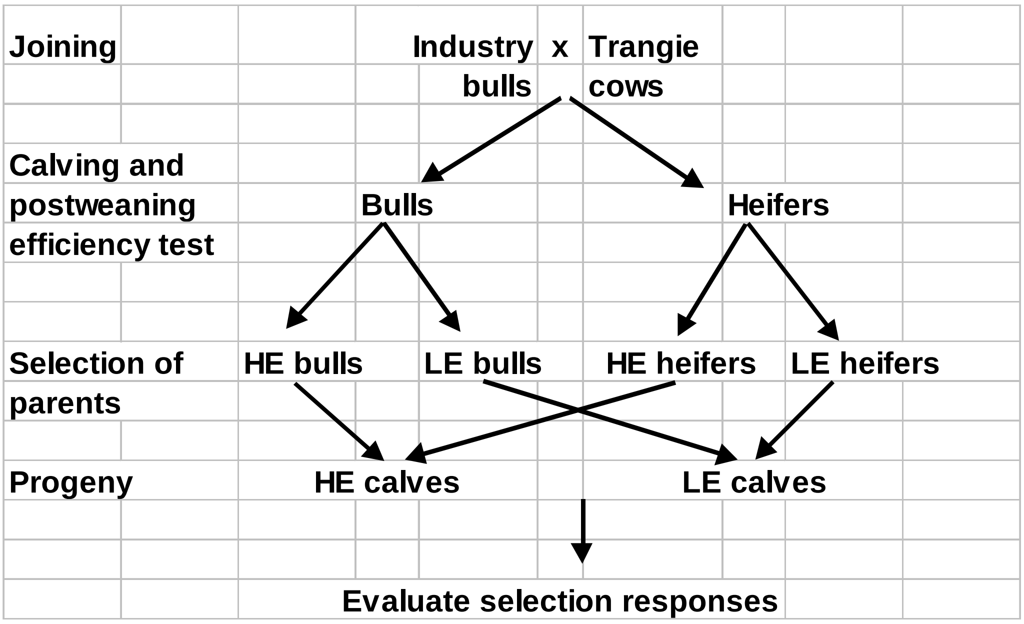


Figure 2: Creation of the selection lines in the NFI demonstration herd. HE and LE are High and Low efficiency lines respectively.

In addition to the animal experimentation studies, economic analyses on the potential to improve profitability through genetic improvement of NFI were conducted using data obtain through the project. The first was a ZPLAN analysis, which models the flow of genes from the breeding sector to the commercial sector and uses selection index theory to calculate genetic gain and the discounted economic benefits accrued over a specified period. The second was a gross margin benefit – cost analysis. Details of the procedures and assumptions used in the economic analyses are presented in Appendices 5a and 5b.

The project included a comprehensive industry implementation program aimed at stimulating adoption of the outcomes of the project by the beef industry. Details of the strategies under this program are presented in Appendix 6. Plate 2 provides snapshots of one of the annual field days at Trangie. The strategy for industry implementation of outcomes was to provide the means by which a BREEDPLAN Estimated Breeding Value (EBV) for NFI can be calculated to allow the Australian beef industry to implement genetic improvement in feed efficiency in their breeding programs.

Plate 2: Feed Efficiency field day at Trangie

4. RESULTS AND DISCUSSION

A comprehensive review of existing scientific literature conducted at the beginning of the project revealed the paucity of information on genetic improvement of feed efficiency in beef cattle. The review also showed some evidence of genetic variation in feed efficiency in the slaughter generation. It however exposed the complete lack of information on relationships with traits in older cattle, especially those in the breeding herd. It was concluded from the review that selection for efficiency could be achieved by measuring feed intake on growing animals and utilising genetic correlations that are likely to exist between efficiency of growing animals and mature animals. It was concluded that estimated breeding values (EBV) for feed intake after phenotypic adjustment for growth and body weight (NFI) would be most practical to use, and that these EBVs would best be used in an economic selection index. The review recommended that further research be directed towards understanding the genetic relationships with other traits in the breeding objectives. The full text of the review is published in the Australian Journal of Agricultural Research and has been reproduced as Appendix 7.

The scientific literature contains reports on the optimal length of test for measurement of growth, but none for the measurement of feed efficiency. The optimal length of test for feed efficiency was therefore determined using the data from the first four NFI tests of 120 days in this project. The analyses indicated that, after a 21-day adjustment period, a 35-day test was sufficient for measurement of feed intake, whereas a 70-day test was required for measurement of growth rate and NFI without compromising accuracy. The results suggest that the measurement of NFI is not limited by the length of test required to measure feed intake, but by that required to measure growth. Therefore, any improvements in accuracy of measuring growth which result in reducing the length of test for growth will have a similar effect of reducing the duration of the NFI test. The full details of this study are published in the Journal of Animal Science, and have been reproduced as Appendix 8.

4.1 Genetic and Phenotypic Parameters for Postweaning NFI and other Postweaning Traits

Records on 1,180 young Angus bulls and heifers from the NFI tests were used to estimate genetic and phenotypic parameters for NFI and other postweaning traits.

Mean 200-day wt (200dWT), 400-day wt (400dWT), scrotal circumference (SC), 12/13th rib fat (RIBFAT), rump P8 fat (P8FAT) depths, eye muscle area (EMA), average daily gain (ADG), daily feed intake (FI), feed conversion ratio (FCR) and net (residual) feed intake (NFI) were 241 kg, 370 kg, 31.2 cm, 4.2 mm, 5.4 mm, 67.6 cm^2, 1.26 kg/day, 9.7 kg, 7.8 and 0.05 kg, respectively. Direct heritability estimates were all moderate (Table 1), ranging from 0.17 for 200dWT to 0.43 for SC. The heritability estimate for NFI was 0.39. Feed conversion ratio was genetically (r_g = 0.66) and phenotypically (r_p = 0.53) correlated with NFI. Feed conversion ratio was correlated (r_g = -0.62, r_p = -0.74) with ADG, whereas NFI was not (r_g = -0.04, r_p = -0.06). Genetically, both NFI and FCR were negatively correlated with direct effects of 200dWT (r_g = -0.45 and -0.21) and 400dWT (r_g = -0.26 and -0.09). The correlations between the remaining traits and the feed efficiency traits (FCR and NFI) were close to zero, except those between FI and FCR (r_g = 0.31, r_p = 0.23), FI and NFI (r_g = 0.69, r_p = 0.72), and RIBFAT and NFI (r_g = 0.17, r_p = 0.14).

The existence of both phenotypic and genetic variation in NFI and the associated moderate heritability imply that genetic improvement can be made through selection with minimal effect on other postweaning traits. Detailed results are published in the Journal of Animal Science and have been reproduced as Appendix 1.

Table 1: Additive variance and heritability (± standard error) for postweaning traits

Trait[a]	Additive variance	Heritability
200dWT-d	70.9	0.17 ± 0.03
200dWT-m	54.9	0.13 ± 0.02
400dWT-d	211.5	0.27 ± 0.03
400dWT-m	30.8	0.04 ± 0.01
SC	2.00	0.43 ± 0.06
RIBFAT	0.47	0.35 ± 0.04
P8FAT	1.04	0.38 ± 0.03
EMA	8.61	0.27 ± 0.04
ADG	0.0076	0.28 ± 0.04
FI	0.275	0.39 ± 0.03
FCR	0.267	0.29 ± 0.04
NFI	0.149	0.39 ± 0.03

[a]Trait abbreviations: 200dWT-d = direct effect of 200 d weight; 200dWT-m = maternal effect of 200 d weight; 400dWT-d = direct effect of 400 d weight; 400dWT-m = maternal effect of 400 d weight; SC = scrotal circumference; RIBFAT = 12/13th rib fat depth; P8FAT = rump P8 fat depth; EMA = eye muscle area; ADG = average daily gain; FI = daily feed intake; FCR = feed conversion ratio; NFI = net feed intake.

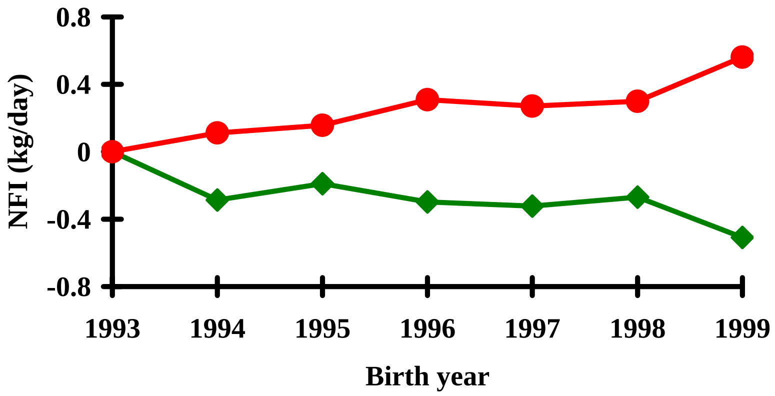
4.2 Realised Direct and Correlated Responses to Selection for Postweaning NFI

Data collected from the high and low efficiency selection lines of the demonstration herd were used to assess the realised direct and correlated responses to selection. The correlated responses evaluated were for birth, weaning and yearling weights, post weaning average daily gain, daily feed intake, feed conversion ratio, subcutaneous fat depth, eye muscle area, scrotal circumference, pelvic area and linear body measurements.

After 5 years of selection in the demonstration herd, the generation interval was 2.5 yr in both lines, resulting in 1.73 and 1.96 generations of selection in the High Efficiency line (High line) and Low Efficiency Line (Low line), respectively. The high effective population sizes of 42 and 43 per generation for High and Low selection lines, respectively, resulted in a low inbreeding rate (0.6% for dams and 1.6% for calves). Average selection differentials per year were –0.318 kg/day and 0.387 kg/day for the High and Low efficiency selection lines, respectively, resulting in an average annual divergence of 0.212 kg/day between the selection lines. Realised heritability was 0.33 ± 0.02.

Significant (P<0.05) correlated annual responses of 0.195 ± 0.04 kg/day, 0.195 ± 0.03, 0.342 ± 0.04 mm and 0.329 ± 0.05 mm were obtained in feed intake, feed conversion ratio, 12/13 rib fat and rump P8 fat depths, respectively, resulting in an annual percentage change of 1.9%, 2.4%, 3.6% and 3.4% in their respective base population (1994-born) means. The trend was for the High efficiency line to have lower feed intake, feed conversion ratio and less subcutaneous fat. Responses in eye muscle area, scrotal circumference and body length were also significant (P<0.05) but their effect on the base population means were minimal (less than 1%). Similar results were obtained when the genetic responses were assessed by annual changes in estimated breeding values (Figure 3). These results indicate that selection for low NFI (for more efficient animals) will result in progeny that consume less feed, are slightly leaner, and have similar production performance, up to yearling age, as those selected for high NFI. Detailed results for this study have been provided in Appendix 2.

Figure 3: Trends in estimated breeding values for NFI for the High (υ) and Low (λ) efficiency selection lines.



4.3 *Genetic and Phenotypic Relationships between Postweaning NFI and Cow Traits*

Analyses were conducted to examine the genetics of cow performance, including feed intake, efficiency, weight, fertility and milk production, and the relationship of these traits with post-weaning performance including net feed intake and related traits. Records of mature cow weight from industry Angus herds extracted from the NBRS database were also used in the analyses to account for sampling of sires within the experiment. Results from the analyses showed that:

- Considerable genetic variation in net feed intake of mature cows exists.

- There is a strong genetic correlation between post weaning net feed intake and the feed intake and efficiency of cows, such that selection for improved efficiency (ie. lower post-weaning net feed intake) will lead to correlated improvements in efficiency of the breeding herd.

- Selection for lower post-weaning net feed intake will lead to slightly heavier cows which eat less, and are also *slightly* leaner (as assessed by subcutaneous fat depths). The correlation with fat depth is low (around 0.2), and so ample scope exists to select efficient cows with adequate fat coverage. There is no relationship between post-weaning net feed intake and eye muscle area of cows.

- Despite the tendency for more efficient cows to have lower fat depth, selection for lower net feed intake post-weaning will have little effect upon fertility (as assessed by the trait “days to calving”).

- Selection for low post-weaning net feed intake (more efficient cattle) will lead to a slight reduction in milk production of cows. This relationship agrees with that estimated between post-weaning net feed intake and the maternal component of weaning weight. Again, the correlation is only low (approximately 0.25). It should be noted that the estimation of milk production by the weigh-suckle-weigh technique used in this study, reflects that calf's milk demand and may not reflect the full genetic potential of the cow for milk production.

Detailed results for this study have been provided in Appendix 3.

4.4 Correlated *Responses in Steer Feedlot Performance, Carcass and Meat quality Traits*

A total of 312 steers generated at Trangie over three years, from the high and low efficiency lines of the demonstration herd, were transferred to Glen Innes for backgrounding and finished at the Beef CRC Tullimba Research Feedlot. The steers were then slaughtered and their carcass and meat quality attributes assessed. Highlights of the results are provided below and the full details are contained in Appendix 4.

The steers were fed in the feedlot for four months with growth, feed intake and feed efficiency measured over a 70-day NFI test. Mean parental estimated breeding value (EBV) for NFI (mean of sire and dam EBVs) were used as an estimate of progeny EBV. There was no difference (P>0.05) between the progeny of parents selected for high efficiency (low NFI; HE) or low efficiency (high NFI; LE), in liveweight (LW) at the start of the NFI-test period, ADG, LW at the end of the test, dry matter intake (DMI), feed conversion ratio (FCR) or NFI. However correlations of mean parental EBV for postweaning NFI (EBV_{NFI}) with ADG, NFI and FCR (r_{ADG}=-0.10, r_{NFI}=0.15 P<0.05, r_{FCR}=0.07 P<0.1) provided evidence for genetic association of postweaning NFI with these feedlot traits. There were significant differences between the HE and LE steers in carcass traits measured ultrasonically before slaughter. The HE steers had less subcutaneous fat over their 12/13 rib and rump P8 (rib 10.2 v 11.6 mm P<0.05; rump P8 13.3 v 14.8 mm P=0.06) and a smaller cross-sectional area of the eye-muscle (EMA: 67.1 v 70.5 cm^2 P<0.05). There was no difference (P<0.05) in hot carcass weight or in fat depth at the rump P8 site on the carcass but there was a trend to HE steers having a slightly lower dressing percentage (DP) compared to the LE steers (52.1 v 52.9 P=0.07). There was no difference (P>0.05) between carcasses from HE and LE steers in visual scores for marbling, meat colour, fat colour or muscularity, nor in retail beef yield predicted on the basis of weights of trimmed primal cuts. Four carcass traits were correlated with mean parental EBV_{NFI}: r_{rib}=0.14, r_{rump}=0.14, r_{EMA}=0.09, r_{DP}=0.14 (P=<0.05).

Objective measurements of meat tenderness and intramuscular fat (IMF%) were collected for the year 1 and year 2 animals representing cattle killed at light and heavy market LWs, respectively. There were no differences (P>0.05) between the HE and LE steers in intra-muscular fat (IMF%), nor in shear force or compression values for meats samples aged for one or for 14 days. Mean parental EBV_{NFI} was negatively correlated with IMF% (r=-0.09 P=0.09) and positively correlated with shear force measured after one day of ageing (r=0.14 P<0.05). This experiment found that divergent selection for postweaning NFI was genetically associated with differences in ADG, FCR and NFI by steer progeny. Selection for reduced NFI should produce steers that are more feed efficient, with no adverse effects on growth performance in the feedlot, beef yield or meat quality. The genetic associations of postweaning NFI with subcutaneous fatness, EMA, DP and IMF% suggest that carcass weight, fatness and marble score should be monitored in association with on-going selection for NFI. Detailed results for this study has been provided in Appendix 4.

4.5 Correlated Responses in Performance of Cattle on Pasture

The key assumption of improved efficiency on pasture following selection for superior postweaning NFI was examined in three experiments. The first was on cows with calves at foot; the second in yearling-age steers growing on improved pastures, and the third was a modelling study on steers raised on improved phalaris/sub clover pasture on the NW slopes and Upper Hunter in NSW. Detailed reports on the experiments are provided in Appendix 9.

Briefly, the first experiment showed a phenotypic association between the postweaning NFI of the young heifer and her subsequent feed efficiency as a lactating cow on pasture, viz- heifers assessed as being efficient immediately postweaning are also efficient as lactating cows on pasture. The second experiment showed that selection for low postweaning NFI (high efficiency) was genetically associated with improved feed conversion by steers growing on pasture. Together these results support the key assumption that selection for postweaning NFI will bring correlated improvement in feed efficiency in cows and steers at pasture. The results of the third study indicate that grazing an additional eight high efficiency steers would result in monthly pasture availability being unchanged to that of an unimproved (not selected for NFI) herd (Figure 4), while additional profit would be realised through an increase in kg of beef produced. Alternatively, if stocking rates are maintained at the original levels while running high efficiency steers, the additional pasture available would minimise the effect of drought and lower the cost of supplementary feeding.

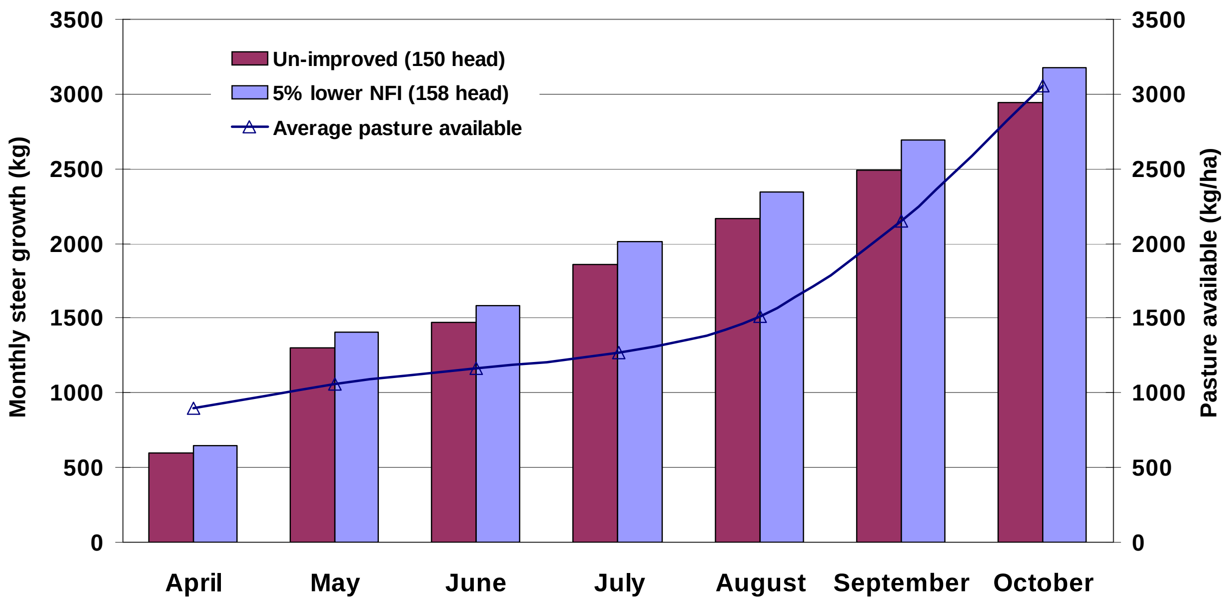


Figure 4: Additional growth from grazing high-efficient steers (5% lower NFI) at a stocking rate that resulted in the same monthly pasture availability for each group.

5. ECONOMIC BENEFITS FROM SELECTION FOR NFI

In the first economic analysis, an evaluation of the benefit of recording net feed intake in industry breeding schemes using a model of investment and gene flow resulting from selection activities was conducted. The analysis considered breeding schemes targeting either the high quality Japanese export market (with steers fed for 210 days) or the grass fed domestic market. Net feed intake (NFI) measurement costs per bull ranging from $150 to $450 were used. Inclusion of NFI, measured on a proportion of bulls in the seedstock sector, as a selection criterion increase annual genetic gain in the breeding objective by up to 16% and 35% for breeding schemes targeting the domestic and Japanese markets respectively. Recording NFI on the top 25% of young bulls (selected based on information available at weaning) in the breeding unit produced close to optimal profit across the breeding scheme for the range of objectives, NFI measurement costs and breeding sector efficiencies considered. Additional profit per cow from one round of selection was $7.84 and $1.41 for breeding schemes targeting the Japanese and domestic markets respectively (assuming a measurement cost of $300). A premium of $153 per bull sold to the commercial sector was required to recover the costs of NFI measurement incurred by the breeding sector. The results indicate that inclusion of NFI as a selection criterion in beef cattle breeding schemes is profitable. Additional details on this analysis are provided in Appendix 5a.

In the second economic analyses undertaken, a commercial cattle enterprise was modelled based on a 100-cow herd run on native pasture, with progeny being grown on improved pastures. In the production system modelled, surplus heifers were sold at 18 months of age into the domestic market and 80% of the steers were sold for feedlot finishing and subsequent sale as heavy export steers.

For this typical production system the benefits from improvements in efficiency in calves and in the cow herd accrue slowly but are cumulative as genes for high efficiency spread through the herd. Gross margin budget and cashflow analyses for the 100-cow herd showed that, despite the initial cost of purchasing bulls genetically superior for efficiency, over a 25-year investment period the internal rate of return was a healthy 61% and the net present value (NPV) of surplus income over expenses was $21,907. This equates to an annual benefit per cow of $8.76.

The estimated NPV of the benefit from genetic improvement in NFI to the commercial cattle sector of the southern beef cattle industry from research to date, based on an expected rate of adoption 0.5%p.a., is $52million over 25 years. The additional benefit in savings in feed costs in feedlots is $5million to be shared between the producers of more efficient feeder steers, feedlots and other industry sectors. The total NPV of the benefit to the southern beef cattle industry is $62million.

However, without ongoing work to continue to demonstrate the value of genetic improvement in NFI to a conservative industry there is a risk of low adoption and failure to capture more of the potential benefit from improvement in feed efficiency. The benefit: cost analysis was redone to include 5 further years of new work designed to encourage an industry adoption rate of at least 2%p.a., to achieve 30% adoption after 16years. The NPV of the benefit to industry from this increase in adoption is $162million over 25 years (Figure 5). This is equivalent to an internal rate of return of 291% and has a benefit: cost ratio of 41:1. As shown in the following figure, new R&D that increases industry adoption will greater increase the potential benefit to the beef industry of genetic improvement in efficiency. Additional details on this analysis are provided in Appendix 5b.

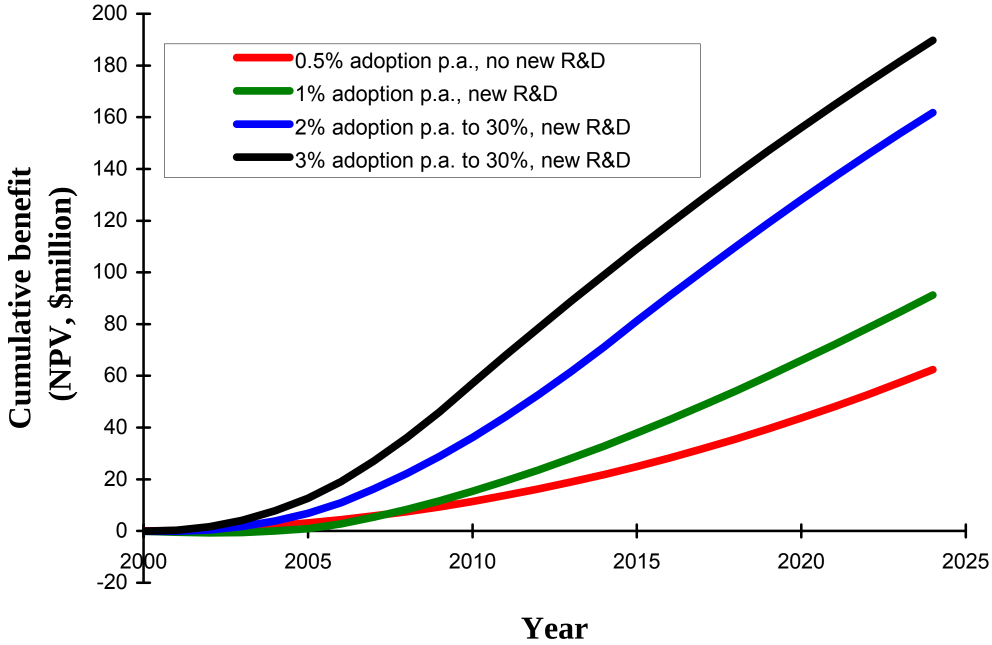


Figure 5: Cumulative industry benefit from research on genetic improvement of NFI at different levels of adoption.

6. INDUSTRY ADOPTION OF NFI TECHNOLOGY

During the course of the project an industry implementation program was developed and initiated to stimulate adoption of the results. These strategies included:

- organisation of and presentations at field days
- solicited and unsolicited producer articles in popular producer magazines and newspapers
- development and production of industry standards for testing cattle for NFI
- national accreditation of NFI testing facilities
- production of Trial EBVs for NFI for both research and industry tested bulls.

Additional details on the industry implementation program are provided in Appendix 6.
As a result of the industry implementation program, industry adoption of NFI technology has increased since 1997. Figure 6 shows the number of industry bulls tested for NFI each year. The bulls were tested at one of five NFI test stations across the country. The full cost of the test was borne by the owners of these bulls.

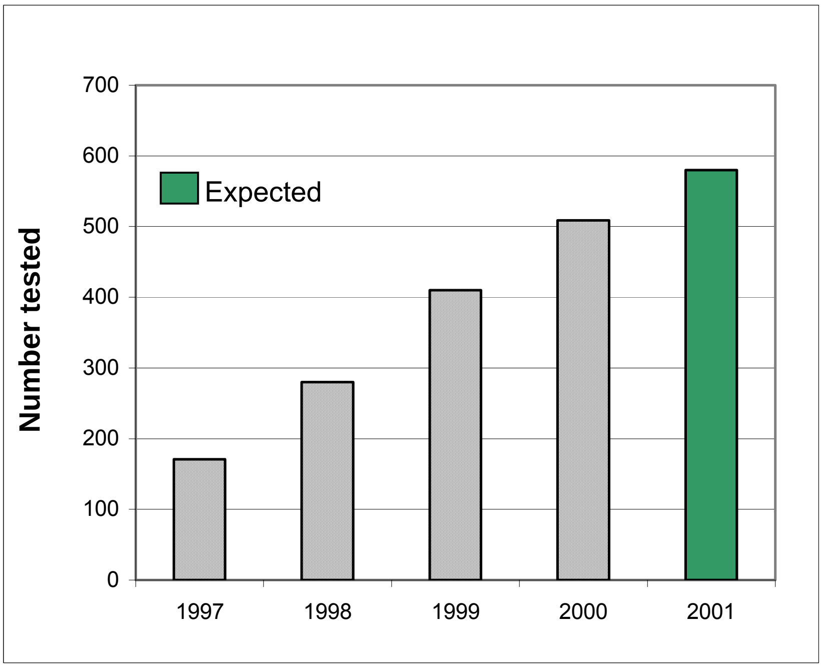


Figure 6: Number of industry bulls tested since 1997. The 2001 data are based on actual test station bookings.

In anticipation of future demand resulting from increased industry adoption of NFI testing, two companies have developed feed intake testing units, and are currently being marketed commercially. One of the commercial feeders is shown in Plate 3.

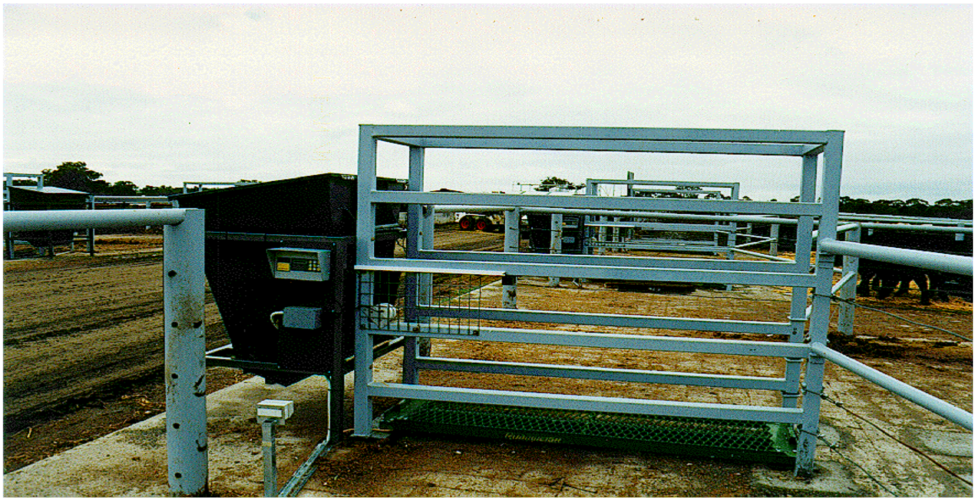


Plate 3: Ruddweigh Feed Intake Recorder by International Scale Company, Guyra

7. SUCCESS IN ACHIEVING OBJECTIVES

At the beginning of the project very little was known about the genetics of net feed intake in beef cattle. There was therefore the initial risk of the project not coming off as planned. To try and minimise the risk and avoid duplication, a comprehensive review of the literature was done and subsequently published, as a first step. Secondly, the principal investigators collaborated with scientists all around the world, known to have reasonable size feed intake data for beef cattle, to re-analyse their data. This resulted in re-analyses of data from South Africa, the United Kingdom, France and Canada. These initial steps provided the confidence that the project is novel and has a high probability of success. In addition, some of the methodologies to be used had not been well developed at the time. There was a learning component in the early days of the project as well as some developmental phase where procedures for NFI testing were concurrently developed.

The project was successful and all the objectives were achieved. The exception was the fifth specific objective of using the facilities and expertise at Trangie to provide a pilot facility for commercialised central testing for industry cattle for NFI. Detailed plans were made for commercialised testing for NFI at Trangie. However, they were not implemented due to Bovine Johnes Disease (BJD) issues. At the proposed time for implementation the Trangie research centre had a TN2 BJD status. Therefore industry cattle which could be allowed at the research centre should have similar or higher BJD status. Of the industry herds which had expressed interest in testing their bulls at Trangie only few met the BJD criteria. The pilot testing at Trangie was therefore cancelled. To compensate for this setback, the expertise of the project staff was put into promoting and facilitating central testing for NFI at the Rutherglen and Hamilton research centres in Victoria and the Vasse research centre in Western Australia. The team assisted other central testing stations and to date there are five accredited facilities. Details of these facilities are listed in Appendix 6. Effort was also expended in developing and promoting on-farm testing for NFI.

Some of the significant achievements of the project include:

- The only review paper on the efficiency of feed utilisation in beef cattle published in a reputed journal in recent years.
- A world-first definitive study to provide recommendations on the duration of test for feed intake and efficiency in beef cattle.
- The most comprehensive, quality assurance guidelines and standards ever published on feed intake and efficiency recording for beef cattle.
- The most comprehensive study in the world to provide genetic parameters for NFI and its relationship with other economically important traits over the whole beef production system.
- World-first production of estimated breeding values for NFI for beef industry use.
- World-first selection experiment on NFI (calculated by regression) in beef cattle, providing empirical data to support expectation of genetic gain from genetic parameter estimates.
- Provision of resources required for the first set of in-depth studies on the physiological basics for genetic variation in NFI.

8. IMPLICATIONS FOR SCIENCE

DAN.75 addressed issues at the interface of genetics and nutrition, and brings new questions to both disciplines. For the discipline of nutrition, which has in the past developed sophisticated models which predict *mean* animal performance, the scientific data generated from DAN.75 show that the notion of *variation between individuals* in the processes of intake and growth is unavoidable. The challenges to the disciplines of physiology and nutrition are firstly to better understand the processes driving intake and growth, and the critical pathways at which individual animal variation is introduced and governed by genetic differences. Secondly, the challenge is to develop and refine models able to describe *variation* in animal performance in addition to prediction of *mean* performance.

The challenges which DAN.75 presented to the discipline of genetics are somewhat related to those facing nutrition. Quantitative genetics is based around a "black box" approach which implies that one does not need to understand the biological drivers of genetic variation in order to be able to empirically describe and utilise the variation. This philosophy has been useful in many respects, and during the last two decades the discipline of genetics has been very successful in delivering useful tools and outcomes to improve animal production. However, the approach does not make good use of much of the knowledge of biological processes of animal production, and avoids making predictions of absolute levels of performance. This became evident during DAN.75 when trying to model relationships between feed intake and growth with the purpose of identifying individuals or sire-lines which break the relationships. The approach taken during DAN.75 to this problem was very simplistic. Taking a simplistic approach is entirely defendable, as it was important to ensure that outcomes could be delivered. However it must also be recognised that much scope exists for applying better models of feed intake and growth in the genetic evaluation process.

Essentially the challenge to genetics and nutrition is the same – to integrate knowledge and to develop models able to describe both mean performance and variance due to environmental and genetic influences. The development of nutrition and genetics as separate disciplines has been a logical approach consistent with the scientific method – to isolate systems and first study them at the simplest level possible. However, the real world does not consist of isolated systems, and the challenge is now to bring these approaches together. The concept of nutrition and genetics as separate disciplines should now become obsolete, but the skills and knowledge from each area are needed in combination with a wider systems perspective. To achieve this might still require somewhat of an isolationist approach – eg. work on combining genetics and nutrition into single models (or at least models which can communicate in the same language) will likely not initially consider plant-animal interactions. However, during the process scientists should be looking ahead to the next components, so that a combined genetics-nutrition animal production model will be able to be matched with a plant-animal interaction model in the next step without re-inventing the whole process again.

At the same time, a rapid increase in the ability of molecular approaches to contribute in this area should not be ignored. DAN.75 raised questions as to what the biological mechanisms driving variation in the relationship between feed intake and growth are. While research suggested that certain areas (such as regulation of protein turnover) are candidate mechanisms, knowledge of the genes responsible for the observed variation might help elucidate the biology of these mechanisms. The current MLA and CRC projects searching for genetic markers for net feed intake will likely contribute to this. A description of functional expression of genes regulating candidate mechanisms responsible for observed variation would also generate useful information, providing sufficient resolution to describe small quantitative differences were available. The application of such knowledge may lie in fields other than agriculture (eg. it might generate outcomes useful to understanding regulation of human intake and obesity). However, for the core business of MLA and NSW Agriculture, the challenge will be to combine knowledge generated from molecular approaches with other approaches to deliver useful products to the livestock production industry(s). At this early stage the vision for how this might occur is understandably incomplete.

DAN.75 has contributed towards highlighting some of the scientific challenges outlines above. These challenges are important to advancing scientific knowledge, but are equally important for application to animal production. The major gains in productivity are likely to come from manipulation of genetics and management systems (nutrition) in combination rather than in isolation. Currently the producer is left with the most difficult task of taking pieces of information delivered in isolation and combining these into applied systems. The requirement still remains to deliver packages which integrate genetics, nutrition and management solutions, and in doing so consider both mean and variation in performance.

9. IMPACT ON MEAT AND LIVESTOCK INDUSTRY

Throughout the course of the project, the beef industry has shown great interest in its outcomes. This interest resulted in 180 industry bulls being tested for NFI at the owners' expense in 1997. The number of industry bulls tested for NFI has increased each year thereafter, to over 500 bulls in 2000. In anticipation of future demand resulting from this rising trend in industry adoption of NFI testing, two companies have developed feed intake testing units, which are currently being marketed commercially.

The economic analyses of the value of genetic improvement of feed efficiency, using NFI (Appendices 5a and 5b), indicate that there would be substantial benefits for the southern Australian beef industry from the adoption of NFI technology. Adoption rate to date is low and this needs to be improved. Structures which will enhance the application of the NFI technology in industry (such as testing standards, accreditation, national database, BREEDPLAN EBV, incorporation into BREEDOBJECT), have either been put in place or are currently being developed. The major task is to get seedstock breeders to commit to producing sale bulls with EBVs for NFI. It is estimated that an annual adoption rate of 2% to achieve a maximum adoption level of 30% will result in a benefit of $162 million to the southern Australian beef industry over a 25-year investment horizon.

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

- Genetic variation exists in Australian cattle population for NFI. The trait is moderately heritable (heritability of 39%), and lends itself to genetic improvement.
- Selection for lower postweaning NFI results in progeny that are more efficient than average in feed utilisation on pasture and in the feedlot.
- Reduced postweaning NFI (improved feed efficiency) is genetically associated with improved efficiency of feed utilisation in cows, slight reduction in maternal ability, slightly reduced fatness, and no adverse association with other traits of economic importance.
- Genetic improvement in NFI will therefore lead to overall improvement in production system efficiency. For the southern Australian beef industry, the potential economic

benefit is estimated to be $162 million over 25 years at an annual adoption rate of 2% and a maximum adoption level of 30%.

10.2 Recommendations

(a) The beef cattle industry should incorporate selection for feed efficiency in its breeding programs.

(b) For genetic improvement of feed efficiency the trait should be called Net Feed Intake (NFI), and defined as feed intake over and above the requirements for maintenance of bodyweight and growth.

(c) For genetic improvement, the trait should be used in a multi-trait selection index framework, where selection can be based on NFI as well as other economically important traits. BREEDOBJECT provides a suitable framework for multi-trait selection and should be expanded to incorporate NFI.

(d) The guidelines outlined in the NFI Standards Manual (Appendix 11) should be adhered to if BREEDPLAN EBVs are required.

(e) Net feed intake is an expensive measure and therefore may not be profitable to record on all bulls. It is recommended that a two-stage selection process be adopted whereby only the top 25% of young bulls (selected based on information available at weaning) in the breeding unit are tested for NFI. As an adoption strategy, it is therefore logical to target influential bulls (with large influence on the gene pool of the particular breed) and seedstock producers, in the initial phase.

(f) Additional R&D required include:

- Incorporation of production systems models for demonstrating benefits on pasture as well as other practical ways for producers to utilise the trait to reduce cost and improve profitability.

- Estimation of the genetic relationships between seedstock and steer feedlot measures of NFI and associated traits. These relationships need to be known in order to accurately combine information from seedstock NFI tests on bulls with feedlot steer progeny test to produce EBVs.

- Development of cost-effective ways of identifying animals genetically superior for NFI. The strategies should include:

    - Reducing the cost of measuring feed intake and efficiency.

    - Search for gene markers for NFI.

    - Evaluation of the Insulin Growth Factor 1 axis as indirect marker for NFI.

    - Design breeding schemes to optimise the use of direct and indirect selection for NFI.

- Additional investigations into the physiological basis for the genetic variation in NFI.

- The computation of expected feed intake which is used in calculating NFI can be obtained either by regression (as in this project) or by using feeding standards formulae. These procedures have developed independently and do not always yield similar results. There is therefore the need to integrate knowledge and develop models that describe both mean performance as well as variation due to environmental and genetic influences.

The management structure of the project, which comprised of a team of research and extension officers working together, and an industry advisory group (TTAG), contributed to the success of the project. It ensured a high industry awareness of the results through the life of the project, and that the outcomes were relevant to the beef industry. This project management structure is highly recommended for future projects.

11. PUBLICATIONS EMANATING FROM THE PROJECT

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Appendices

Appendix 1	Genetic and phenotypic variance and covariance components for feed intake, feed efficiency, and other postweaning traits in Angus cattle
Appendix 2	Direct and correlated responses to divergent selection for postweaning residual feed intake in Angus cattle
Appendix 3	Relationship between postweaning net feed intake and cow performance
Appendix 4	Changes in feedlot performance, carcass and meat attributes of beef steers following divergent selection for postweaning residual feed intake.
Appendix 5a	Economic analysis of net feed intake in industry breeding schemes incorporating two-stage selection.
Appendix 5b	The economic benefits to the Southern Australian beef industry from investment in genetic improvement in net feed efficiency.
Appendix 6	Industry implementation program.
Appendix 7	Potential for selection to improve efficiency of feed use in beef cattle: a review.
Appendix 8	Optimum postweaning test for measurement of growth rate, feed intake, and feed efficiency in British breed cattle.
Appendix 9	Correlated improvement in efficiency of cows and steers on pasture following selection to improve postweaning net feed efficiency.
Appendix 10	Trial net feed intake EBVs for Angus sires.
Appendix 11	Testing beef cattle for net feed efficiency – Standards Manual.
Appendix 12	Samples of newspaper and magazine articles.

APPENDIX 2

For Submission to Journal of Animal Science

RUNNING HEAD: Response to Selection in Angus cattle

Direct and correlated responses to divergent selection for postweaning residual feed intake in Angus cattle[1]

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ABSTRACT: An experiment to evaluate the effects of divergent selection for postweaning residual feed intake (RFI) in Angus cattle was started in 1993, with the creation of Low RFI (more efficient in feed utilisation) and High RFI (lest efficient in feed utilisation) selection lines. This paper describes the design, and the realised direct and correlated responses to selection up to yearling age. Generation interval after 5 years of selection was 2.5 yr in both lines, resulting in 1.73 and 1.96 generations of selection in the Low and High RFI lines, respectively. The high effective population sizes of 42 and 43 per generation for Low and High RFI lines, respectively, resulted in a low inbreeding rate (0.6% for dams and 1.6% for calves). Average selection differentials per year were –0.318 kg d and 0.387 kg d for the Low and High RFI lines, respectively, resulting in a significant ($P<0.05$) average annual response (divergence between the lines) of 0.212 ± 0.03 kg d. A significant ($P<0.05$) response to selection was also obtained when the genetic change was measured by annual changes in estimated breeding values. Realised heritability were 0.33 ± 0.02. Correlated responses in birth, weaning and yearling weights, post weaning ADG, daily feed intake, feed conversion ratio, subcutaneous fat depth, longissimus muscle area, scrotal circumference, pelvic area and linear body measurements were evaluated. Significant ($P<0.05$) correlated annual responses of 0.195 ± 0.04 kg d, 0.195 ± 0.03, 0.342 ± 0.04 mm and 0.329 ± 0.05 mm were obtained in feed intake, feed conversion ratio, 12/13 rib fat and rump P8 fat depths, respectively, resulting in an annual percentage change of 1.9%, 2.4%, 3.6% and 3.4% in their respective base population (1994-born) means. The trend was for the Low RFI line to have lower feed intake, feed conversion ratio and less subcutaneous fat. Responses in longissimus muscle area, scrotal circumference and body length were also significant ($P<0.05$) but their effect on the base population means were minimal (less than 1%). Similar results were obtained when the genetic responses were assessed by annual changes in estimated breeding values. These results indicate that selection for low RFI (for more efficient animals) will result in progeny that consume less feed,

[1] This work was funded by NSW Agriculture and Meat & Livestock Australia. The assistance provided by E. Richardson, K. Dibley, D. Burton, J. Wright, C. Oswin, R. Snelgar, D. Mula, T. Patterson and former staff of the cattle section at Trangie is gratefully acknowledged.

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are slightly leaner, and have similar production performance, up to yearling age, as those selected for high RFI.

Key Words: Beef Cattle, Selection, Feed Efficiency, Residual Feed Intake

Introduction

Providing feed for cattle is the single largest expense in most beef cattle enterprises. To date, little emphasis has been placed on genetic improvement of feed efficiency, whereas output traits such as growth, fertility and meat quality have received greater attention. Attempts at improving feed efficiency have been based on feed conversion ratio, which is the amount of feed consumed per unit liveweight gain. In beef cattle, the two major selection experiments on feed efficiency (based on feed conversion ratio by Bishop et al., 1991, and on lean feed conversion ratio by Mrode et al., 1990), indicated a high correlated response in growth rate.

Feed cost for maintenance is estimated to represent at least 60 to 65% of the total feed requirements for the cow herd, with considerable variation among individual animals independent of their body size (Montaño-Bermudez et al., 1990; Parnell et al., 1994). Therefore any trait which attempts to improve the efficiency of feed utilisation should take into account feed requirements for both maintenance and production. Residual feed intake is an alternative measure of feed efficiency. It is the difference between actual feed intake and the expected feed requirements for maintenance of body weight and some measure of production (such as growth in beef cattle or milk production in dairy cattle). In 1993 a research project was started at the Agricultural Research Centre, Trangie, NSW, Australia to investigate the potential for genetic improvement in postweaning feed efficiency as a means of improving whole beef production system efficiency. An aspect of the project was an experiment to evaluate the effects of selection for residual feed intake. The objective of this study was to evaluate the realised direct and correlated responses to divergent selection for postweaning residual feed intake in Angus cattle, up to yearling age.

Materials and Methods

Location and Environment

The experiment was conducted at the Trangie Agricultural Research Centre, (31^0 150'S, 147^0 57'E), located on the Central Western Plains of New South Wales (N.S.W.), Australia. The average long term annual rainfall at the research centre is 480 mm, and is typically non-seasonal and variable. Perennial pastures included windmill grass (*Chloris truncata*), spear grass (*Stipa spp.*), and wallaby grass (*Danthonia sp.*). Annuals were primarily barley grass (*Hordeum leporinum*), rats-tail fescue (*Vulpia myuros*), burr-medic (*Medicargo spp.*) and crowsfoot (*Erodium sp.*). Much of the summer feed consisted of dry residue from winter annuals.

Foundation Population

The original breeding herd females used in this experiment were from an earlier project designed to evaluate the effects of divergent selection for yearling growth rate on each of the major components of beef herd profitability (Parnell et al., 1997). The low growth rate selection line was disbanded after that selection experiment and by 1992 only females from the high and control growth rate selection lines were left. A major project on feed efficiency was started in 1992, with this study being one of the components. A detailed description of the entire feed efficiency project has been described by Arthur et al. (1996). In 1992 and 1993, the females were mated by artificial insemination to industry sires. The resulting progeny, which were born in 1993 and 1994, formed the foundation herd from which the selection lines were created.

Starting with the 1993 born animals, a feed intake and efficiency test was conducted each year using an automated feeding system, developed and located at the research centre, which delivers and records individual animal feed intake. The animals were brought to the testing facility a few weeks (generally 4 to 6 weeks) after weaning. At the testing facility, a pre-test adjustment period of at least 21 days was allowed for the animals to adapt to the feeding system and diet, followed by a 70-day test as recommended by Archer et al. (1997). The average age at the start of test was 268 days. Records taken during the test were used to calculate residual feed intake for each animal. Details on the operation of the feed intake and efficiency test, diet composition and computation of residual feed intake have already been provided by Arthur et al. (2001a).

Formation of Residual Feed Intake Selection Lines

This study commenced in 1994 with the establishment of a Low and a High residual feed intake selection line. Starting with the 1993 born animals, the females were allocated to the Low residual feed intake line (Low RFI line) and the High residual feed intake line (High RFI line), based on their postweaning individual residual feed intake (RFI) values. Females with low RFI values are more efficient (consume less feed than that predicted for growth and maintenance) and were allocated to the Low RFI line, and those with higher RFI values were allocated to the High RFI line. The three bulls with the lowest RFI values in the 1993-born group were allocated to the Low RFI line and the three bulls with the highest RFI values to the High RFI line.

Throughout the study, the sole selection criterion for all replacement bulls and heifers was individual RFI. Only animals with gross structural problems or severe illness were excluded as candidates for selection. This low and high design was chosen to provide a rapid divergence in RFI between the selection lines. It was anticipated that the divergent design would generate differences between the High and Low lines over a 5 year period that would approximate the responses achieved over a 10 year period in a conventional uni-directional selection program.

Herd Structure and Management

Only 200 animals could be tested in the feed intake and efficiency facility at any one time, and for this study a maximum of 100 males and 100 females were tested per year. For this reason, there was very little selection in the females. In the males however, three to six bulls were selected per line each year, depending on the number of females available to be mated. Throughout the project bulls and heifers were mated at approximately 14 months of age, and bulls were used for only one mating season except for the 1997 and 1998 mating seasons where, for each selection line, one bull from the previous year was used again for mating. Animals from each selection line were grazed together throughout the year, except during mating. Within selection line, allocation of females to the selected bulls was completely random, except for the avoidance of half-sib and son-dam matings.

All matings were by natural service. Heifers were placed with selected bulls in mating paddocks at about 14 months of age and remained in these mating groups for a total of 12 weeks. The mating season of the main breeding cow herd was a 9 week period, which started 3 weeks after the heifer mating season. Calves were nursed by their dams until weaning at approximately 200 days of age. The breeding herd was on pasture all year round, with supplementary feed (chopped alfalfa hay, silage and irrigated forage crops) being offered in years of limited pasture growth.

Traits Studied

A comprehensive performance recording program provided a large database of records for the analysis of responses over time in each of the selection lines. During the feed intake and efficiency test, all animals were weighed weekly, and ultrasonic measurement of 12/13th rib fat depth, rump P8 fat depth and area of the longissimus muscle (*M. longissimus dorsi*) between the 12th and 13th ribs were taken at the end of test. The area of the longissimus muscle was not measured in the 1997-born progeny. Measurement of fat depth at the rump P8 site is a common practice in Australia. The P8 site is located at the intersection of an imaginary line drawn from the dorsal tuberosity (*tuber ischii*) parallel to the sawn chine and another imaginary line drawn at 90º to it, starting at the spinus process of the third sacral vertebra (Arthur et al., 1995). The scrotal circumference of bulls was measured near the end of the test.

The traits studied were birth weight, weaning weight, and various yearling measures which included end of test weight, shoulder and hip heights, body length, girth, area of pelvic opening, scrotal circumference for bulls, ultrasound measurements of 12/13th rib fat depth, rump P8 fat depth, longissimus muscle area, test period ADG, daily feed intake, feed conversion ratio and residual feed intake.

The growth of each animal during the test was modelled by linear regression of weight on time (days), and the regression estimates were used to calculate ADG (the regression coefficient) and weight at start and end of test. Feed intake was calculated by adding the daily energy intake of the pelleted ration and straw, and then adjusted to a common concentration of 10 MJ ME/kg dry matter. Feed conversion ratio was calculated as feed intake divided by ADG. The mean weight (**MWT**) of an animal during the test was computed as the average of the start and end of test weights. Metabolic body weight (**MMWT**) was calculated as $MWT^{0.73}$. Using SPLUS (MathSoft, Inc. Seattle, Washington), a linear regression model of feed intake on MMWT and ADG, with test group and sex included as class variables, was fitted to data for all test animals up to the 1996-born group. The regression coefficients from this model were used to predict feed intake of all animals, based on ADG and MMWT. Residual feed intake was calculated as the actual (measured) feed intake minus that predicted using the regression equation.

Genetic and Statistical Analyses

Generations and Selection Differentials. The generations of selection applied were calculated as $GC = 1+(GC_s+GC_d)/2$ (Brinks et al., 1961), where GC is the generation coefficient of the calf, and subscripts 's' and 'd' refer to sires and dams, respectively. Foundation animals were assigned a GC of zero. Generation interval was calculated as the average age of the parents when their progeny were born, being the inverse of the regression of GC on year of birth of calf (1995-1999). Annual selection differentials were calculated from the difference between the average performance of those animals selected as parents each year and the average performance of all animals in each respective line.

Effective Population Size and Rate of Inbreeding. The effective population size N_e for each selection line during each year of the experiment, was calculated using the formula: $N_e=4N_mN_f/(N_m+N_f)$, where N_m was the number of male parents and N_f was the number of female parents represented in each annual calf drop (Falconer, 1989). The rate of inbreeding for each selection line was determined from the average inbreeding coefficients, as computed from the diagonal element of the inverse numerator relationship matrix for all animals (Henderson, 1976).

Realised Direct and Correlated Responses. Annual realised direct and correlated responses to divergent selection for residual feed intake were measured as the difference between the average performance of animals in the two selection lines. Average performance for each year born group was computed using linear mixed models procedures in ASREML (Gilmour et al., 1995), and fitting selection line and sex as fixed effects and sire as random effect. Age of dam and age of the animal at the time the measurement was taken, were fitted as covariates. Least squares means and standard errors were predicted from the ASREML output using SPLUS (MathSoft, Inc. Seattle, Washington). Since the management of animals in each line was identical, any observed differences in the mean performance between the lines could be attributed to genetic selection response.

Average annual response was estimated by linear regression of the annual responses for each trait on year of birth. The selection lines originated from the same population, therefore the regression was constrained to pass through the origin, as suggested by Hill (1972) and confirmed by Baker et al. (1991). The average annual response to selection was given by the regression coefficient.

BLUP Estimates. For each selection line, estimated breeding values for each trait were computed by fitting pedigree (5 generations) information and data on that trait, to a best linear unbiased prediction (BLUP) animal model using genetic parameters obtained from the Trangie herd (Parnell et al., 1997; Arthur et al., 1997, 2001a) and fitting non-genetic effects of contemporary group and age. For all traits, the calculated estimated breeding values were for direct effects, whereas for birth weight, weaning weight and yearling weight, the genetic effect was partitioned into direct additive (*a*), maternal additive (*m*) and interaction between *a* and *m*. Permanent maternal environmental effect was also fitted for these three traits. Records on 1993 born animals were used as the base for calculation of estimated breeding values. Annual responses in estimated breeding values were measured as the difference between the average estimated breeding values of the two lines. Average annual response in estimated breeding values was estimated by linear regression of the annual responses for each trait on year of birth, with the regression constrained to pass through the origin.

Realised Heritability. The realised heritability for residual feed intake was determined by regressing the average annual selection responses against the cumulative selection differentials, with the regression constrained to pass through the origin (Hill, 1971). The regression coefficient represented realised heritability.

Results and Discussion

The population structure of the selection lines during the experiment is presented in Table 1. Between the two selection lines, means for effective population size and generation interval were similar. The use of yearling bulls for mating with heifers and younger cows resulted in a lower generation interval, thus increasing the annual rate of genetic progress. The relatively large effective population sizes ensured low rates of inbreeding in each of the lines (average of 0.6% for dams and 1.6% for calves), minimising the impact of inbreeding depression on the rates of the selection responses. This is in contrast with the relatively high (10%-40%) inbreeding rates obtained in some earlier selection experiments in beef cattle (Brinks et al., 1965; Nwakalor et al., 1986). Inbreeding rates obtained in recent selection experiments (Baker et al., 1991; Parnell et al., 1997) in beef cattle are low and similar to those of this study.

Direct Response to Selection

Least squares means for postweaning residual feed intake for the 1994-born base animals and for the progeny of each of the selection lines born in 1995 to 1999 are presented in Table 2. The actual response measured in any particular year fluctuated in each line due to genetic sampling, however the overall trend showed a divergence of the Low and High RFI selection lines. A summary of the population parameters, selection differentials for each selection line and direct response, over all the years of the study, is presented in Table 3. The total divergence between the High and Low selection lines (1.061 kg d) was significant ($P<0.05$) and represents the expected response after approximately four generations of uni-directional selection for postweaning residual feed intake. The annual selection responses and cumulative selection differentials are presented in Figure 1. The realised heritability was 0.33 ± 0.02, which is similar to the 0.39 ± 0.03 obtained by

REML procedures from a larger data set that included the data for this study (Arthur et al., 2001a). Trends in average estimated breeding values for residual feed intake in each of the selection lines are presented in Figure 2. The differences in the breeding values over time generally reflected the trend in realised differences between the selection lines. The annual response in estimated breeding values for residual feed intake was 0.160 ± 0.02, and was significantly (P<0.05) different from zero.

In beef cattle the use of residual feed intake as a measure of feed efficiency is limited, although the interest in this trait has increased in recent years. With the exception of the study reported by Renand et al. (1998), the authors did not come across any selection experiment based on residual feed intake in beef cattle. Residual feed intake can be calculated using regression or feeding standards formulae. As discussed by Arthur et al. (2001b) and Robinson et al. (1999), the two methods do not usually yield similar results, therefore, it is not appropriate to directly relate the results of experiments using one method to those of an experiments using the other method. Residual feed intake was computed by regression in this study and by feeding standards formulae in the study by Renand et al. (1998). However, as was the case in this experiment, the study by Renand et al (1998) showed significant response in residual feed intake through selection. The review by Archer at al. (1999) and results from recent studies (Herd and Bishop, 2000; Arthur et al., 2001a,b) using variance components procedures, indicate that residual feed intake is moderately heritable in beef cattle. Therefore the direct responses to selection obtained in this study were as expected.

Correlated Responses to Selection

Least squares means for the pre- and post-weaning traits for the 1994-born base animals and for the progeny of each of the selection lines born in 1995 to 1999 are presented in Table 2. The correlated responses to selection in these traits are presented on Table 4. As with residual feed intake, the actual responses measured in a particular year fluctuated in each line due to genetic sampling. Of the 15 traits studied (excluding residual feed intake), significant (P<0.05) responses to selection were obtained in only seven traits (Table 4). These results indicate that selection for low RFI (more efficient cattle) results in a corresponding reduction in daily feed intake, feed conversion ratio (improved gross feed efficiency) subcutaneous fat, longissimus muscle area and scrotal circumference; and an increase in body length. For these significant correlated traits, the percentage annual responses relative to the base population means for longissimus muscle area (0.4%), scrotal circumference (0.5%) and body length (0.2%) were very small. For daily feed intake, feed conversion ratio, 12/13th rib fat and rump P8 fat depths, however, the percentage annual responses were greater than 1% (Table 4). All the other traits were not significantly affected by selection for feed efficiency using residual feed intake.

Residual feed intake computed by regression is, by definition, phenotypically independent of the component production traits (average daily gain and metabolic weight). The lack of significant response in ADG and yearling weight, indicates that, to a large extent, this relationship is true at the genetic level. In a study by Renand et al. (1998), where selection was based on final liveweight and residual feed intake in Charolais bulls, responses in average daily gain, final liveweight, residual feed intake and muscle weight were observed. Single-trait selection was employed in this study while the study by Renand et al. (1998) used a selection index based on residual feed intake and liveweight. It is therefore not possible to directly compare the results of the two studies because of the differences in the selection methods and also in the method used for computing residual feed intake (regression *versus* feeding standards formulae).

Annual trends in estimated breeding values for selected traits are presented in Figures 3, 4 and 5. The annual trends showed divergence of the two selection lines for some traits (eg. daily feed intake and feed conversion ratio) while no clear divergence was evident for other traits (eg. yearling weight and ADG). The traits which showed significant (P<0.05) correlated responses to selection, as assessed by changes in trait means, were also significant (P<0.05) when assessed by changes in estimated breeding values (Table 4). Liveweight traits are known to be affected by maternal effects therefore the estimated breeding values for birth, weaning and yearling weights were partitioned into additive direct and maternal components. Significant (P<0.05) correlated responses to selection were obtained for the additive direct effects on birth and weaning weights and for the maternal effect on birth weight. When assessed by trait means, the responses in birth and weaning weights were not significant. The apparent discrepancy in the two results could be due to the partitioning of the estimated breeding values for the liveweight traits into their component direct and maternal effects whereas the trait means were not.

These results clearly illustrate that for most economically important traits up to yearling age, the performance of the Low RFI line was similar to that of the High RFI line, except that the progeny of the Low RFI line achieved that performance with less feed, and were slightly leaner. In a study by Richardson et al. (2001) that used animals generated through this project, the chemical composition of carcasses from first generation progeny of Low and High RFI line steers was assessed. The results showed that differences in fatness accounted for only a small proportion of the variation in feed efficiency and that other biological mechanisms were likely to be involved, such as protein turnover (McDonagh et al., 2001).

Selection experiments in beef cattle are expensive and long-term in nature and thus are not usually replicated. Interpretation of correlated responses in selection experiments with no replication has sometimes been considered ambiguous. The results of this study are consistent with expectations based on available genetic parameters (Arthur et al., 2001a) obtained from variance component estimation procedures using the same data. It is also consistent with genetic parameter estimates from other studies using different data sets (Archer, et al., 1999; Robinson et al., 1999; Herd and Bishop, 2000; Arthur et al., 2001b). This study is the first experiment in beef cattle to provide comprehensive empirical information on selection on residual feed intake to improve feed efficiency.

Implications

This study has demonstrated the effectiveness of selection as a tool to genetically improve efficiency of feed utilisation in beef cattle using residual feed intake. Selection against postweaning residual feed intake (for more efficient animals) will result in progeny that consume less feed, are slightly leaner, and have similar production performance, up to yearling age, compared to those selected for residual feed intake. Feed cost is the largest single expenditure in most beef enterprises, therefore the cost of production can be reduced substantially through selection against residual feed intake.

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Table 1: Population structure for the low and high residual feed intake (RFI) selection lines

Year of birth	Low RFI line				High RFI line			
	Effective population size	Generation interval			Effective population size	Generation interval		
		Male	Female	Mean		Male	Female	Mean
1995	11	2.0	2.0	2.0	11	2.0	2.0	2.0
1996	11	2.0	2.5	2.3	12	2.0	2.5	2.3
1997	20	2.0	2.6	2.3	18	2.0	2.6	2.3
1998	23	2.2	3.2	2.7	22	2.2	3.0	2.6
1999	19	2.2	4.0	3.1	19	2.2	4.0	3.1
Mean	16.8	2.1	2.9	2.5	16.3	2.1	2.8	2.5

Table 2: Number of animals and least squares means (± SE) of pre- and post-weaning traits for the 1994-born base population and the 1995- to 1999-born progeny of the low and high residual feed intake (RFI) selection lines

	1994-born	**1995-born**		**1996-born**		**1997-born**		**1998-born**		**1999-born**	
Traits[a]	Base	Low RFI	High RFI	Low RFI	High RFI	Low RFI	High RFI	Low RFI	High RFI	Low RFI	High RFI
Number[b]	188	27	30	50	68	33	38	101	85	62	73
RFI, kg d	0.10 ± 0.04	0.07 ± 0.13	0.60 ± 0.13	-0.67 ± 0.13	-0.12 ± 0.12	0.38 ± 0.16	0.84 ± 0.15	-0.26 ± 0.12	0.35 ± 0.12	-0.54 ± 0.12	0.71 ± 0.17
BWT, kg	35.3 ± 0.3	33.2 ± 1.5	33.9 ± 1.5	35.7 ± 1.0	35.8 ± 1.0	34.7 ± 1.1	35.1 ± 1.0	35.9 ± 0.7	35.3 ± 0.7	37.7 ± 0.8	35.4 ± 0.7
WWT, kg	244.3 ± 1.7	215.7 ± 4.3	208.9 ± 4.1	231.8 ± 3.9	232.5 ± 3.5	204.3 ± 3.6	210.0 ± 3.5	189.8 ± 3.4	183.5 ± 3.6	232.5 ± 3.1	228.3 ± 2.9
YWT, kg	407.7 ± 2.7	365.2 ± 7.7	366.2 ± 7.4	375.5 ± 5.2	365.4 ± 4.8	340.4 ± 5.5	346.3 ± 5.2	339.6 ± 6.9	332.9 ± 7.1	384.3 ± 6.9	380.7 ± 6.7
ADG, kg d	1.31 ± 0.01	1.20 ± 0.04	1.27 ± 0.04	1.39 ± 0.03	1.29 ± 0.03	1.20 ± 0.03	1.19 ± 0.03	1.40 ± 0.04	1.35 ± 0.04	1.44 ± 0.03	1.40 ± 0.03
FI, kg d	10.5 ± 0.1	9.4 ± 0.0	10.0 ± 0.3	9.0 ± 0.2	9.3 ± 0.2	9.3 ± 0.2	9.9 ± 0.2	8.7 ± 0.2	9.2 ± 0.2	9.4 ± 0.3	10.6 ± 0.3
FCR	8.2 ± 0.1	8.1 ± 0.2	7.9 ± 0.2	6.6 ± 0.2	7.3 ± 0.1	7.9 ± 0.2	8.5 ± 0.2	6.5 ± 0.2	7.0 ± 0.2	6.6 ± 0.2	7.8 ± 0.2
RFAT, mm	9.4 ± 0.2	7.4 ± 0.4	8.1 ± 0.3	7.4 ± 0.3	8.3 ± 0.3	4.8 ± 0.3	5.9 ± 0.2	5.2 ± 0.1	6.2 ± 0.1	5.3 ± 0.2	7.2 ± 0.2
PFAT, mm	12.2 ± 0.2	10.1 ± 0.4	10.7 ± 0.4	9.8 ± 0.4	11.2 ± 0.4	6.1 ± 0.3	6.8 ± 0.3	6.3 ± 0.2	7.8 ± 0.2	6.7 ± 0.3	8.8 ± 0.3
LMA, cm^2	76.5 ± 0.5	66.4 ± 1.1	67.3 ± 1.1	67.6 ± 0.8	67.7 ± 0.7	-	-	66.8 ± 1.2	67.7 ± 1.2	72.1 ± 0.8	74.2 ± 0.7
SC, cm	38.0 ± 0.9	35.7 ± 0.6	35.8 ± 0.5	36.7 ± 0.4	36.8 ± 0.4	32.9 ± 0.6	33.9 ± 0.5	32.3 ± 0.6	33.2 ± 0.6	34.7 ± 0.5	35.6 ± 0.4
PA, cm^2	207.4 ± 1.1	211.7 ± 5.3	206.6 ± 5.2	199.4 ± 2.2	199.3 ± 1.9	183.9 ± 3.7	184.4 ± 3.6	172.0 ± 1.9	173.0 ± 2.0	193.7 ± 2.1	190.3 ± 2.0
SHT, cm	116.8 ± 0.3	113.5 ± 0.9	112.3 ± 0.8	113.7 ± 0.6	111.0 ± 0.6	106.9 ± 1.2	108.7 ± 1.2	106.0 ± 0.6	106.2 ± 0.6	111.1 ± 0.6	109.3 ± 0.6
HHT, cm	122.0 ± 0.3	119.7 ± 0.9	118.8 ± 0.8	119.4 ± 0.6	118.0 ± 0.6	112.2 ± 1.2	113.4 ± 1.2	111.1 ± 0.7	111.0 ± 0.7	116.5 ± 0.6	115.2 ± 0.6
LTH, cm	150.4 ± 0.4	150.3 ± 1.7	149.7 ± 1.7	155.6 ± 1.1	154.2 ± 1.0	139.6 ± 0.9	137.9 ± 0.9	133.1 ± 0.8	132.9 ± 0.9	140.0 ± 1.0	138.6 ± 1.0
GTH, cm	186.3 ± 0.5	186.7 ± 1.1	189.3 ± 1.1	185.5 ± 1.0	184.2 ± 0.9	170.0 ± 1.4	169.1 ± 1.4	162.8 ± 1.0	163.6 ± 1.1	173.3 ± 1.1	175.3 ± 1.1

[a]Trait abbreviations: RFI = residual feed intake; BWT = birth weight; WWT = weaning weight; YWT = yearling weight; ADG = average daily gain; FI = daily feed intake; FCR = feed conversion ratio; RFAT = 12/13th rib fat depth; PFAT = rump P8 fat depth; LMA = longissimus muscle area; SC = scrotal circumference; PA = area of pelvic opening; SHT = shoulder height; HHT = hip height; LTH = body length; GTH = girth.
[b]SC was measured only in males and the number of animals was approximately half of the number listed.

Table 3: Summary of population parameters, selection differentials and response in residual feed intake (RFI) in the low and high RFI selection lines

Item	Low RFI line	Response[a]	High RFI line
Generations of selection	1.73		1.96
Generation interval (year)	2.5		2.5
Number of bulls mated per year	3 - 6		3 - 6
Number of cows mated per year	27 - 103		30 - 85
Effective population size per generation	42		43
Average inbreeding coefficient (%)			
Calf	1.6		1.5
Dam	0.6		0.5
Average selection differential			
per year (kg/day)	-0.318		0.387
per year (phenotypic SD)	-0.430		0.523
per generation (phenotypic SD)	-1.241		1.333
Average selection response			
per year (kg/day)		0.212	
per year (phenotypic SD)		0.284	
per generation (phenotypic SD)		0.716	

[a]Mean difference between Low and High RFI selection lines.

Table 4: Direct and correlated responses, in pre- and post-weaning traits, to divergent selection for residual feed intake

	Progeny performance			Estimated breeding values[c]	
Trait[a]	Response per year (± SE)	Percentage annual response[b]	Response per generation	Response per year (± SE)	Response per generation
RFI, kg d	0.212 ± 0.03*§	212.0	0.503§	0.160 ± 0.02*§	0.480§
BWT, kg	0.223 ± 0.12	0.6	0.558	0.164 0.05*	0.493
WWT, kg	0.624 ± 0.65	0.3	1.559	0.897 0.22*	2.692
YWT, kg	0.853 ± 0.76	0.2	2.133	0.833 0.55	2.498
ADG, kg d	0.010 ± 0.01	0.8	0.026	0.005 0.002	0.016
FI, kg d	0.195 ± 0.04*§	1.9	0.487§	0.142 0.02*§	0.427§
FCR	0.195 ± 0.03*§	2.4	0.487§	0.125 0.01*§	0.374§
RFAT, mm	0.342 ± 0.04*§	3.6	0.854§	0.238 0.02*§	0.713§
PFAT, mm	0.397 ± 0.05*§	3.4	0.993§	0.281 0.03*§	0.843§
LMA, cm^2	0.329 ± 0.07*§	0.4	0.821§	0.122 0.037*§	0.366§
SC, cm	0.205 ± 0.03*§	0.5	0.513§	0.081 0.02*§	0.242§
PA, cm^2	0.311 ± 0.35	0.2	0.778	0.278 0.15	0.835
SHT, cm	0.173 ± 0.22	0.2	0.431	0.140 0.10	0.419
HHT, cm	0.143 ± 0.13	0.1	0.358	0.158 0.07	0.474
LTH, cm	0.297 ± 0.09*	0.2	0.742	0.189 0.03*	0.567
GTH, cm	0.413 ± 0.23§	0.2	1.032§	0.262 0.11§	0.787§
BWT - mat[d], kg	-	-	-	0.030 0.01*	0.089
WWT - mat[d], kg	-	-	-	0.007 0.12	0.020
YWT - mat[d], kg	-	-	-	0.064 0.11	0.193

[a]Trait abbreviations: RFI = residual feed intake; BWT = birth weight; WWT = weaning weight; YWT = yearling weight; ADG = average daily gain; FI = daily feed intake; FCR = feed conversion ratio; RFAT = 12/13[th] rib fat depth; PFAT = rump P8 fat depth; LMA = longissimus muscle area; SC = scrotal circumference; PA = area of pelvic opening; SHT = shoulder height; HHT = hip height; LTH = body length; GTH = girth.
[b]Response as a percentage of 1994-born base population mean.
[c]Response is for additive direct effect except where maternal effect is specified in the trait name.
[d]Represents additive maternal effect on the trait.

*Indicates significant (P<0.05) response.
§Indicates that the Low RFI line has lower means than the High RFI line.

Figure 1: Selection differentials and responses in postweaning residual feed intake.

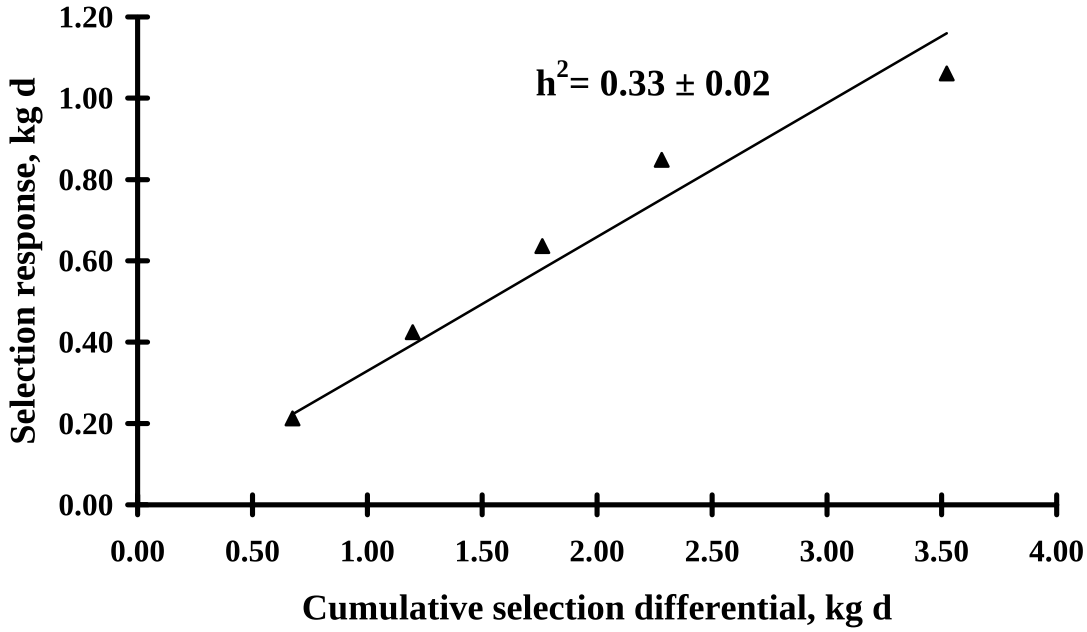
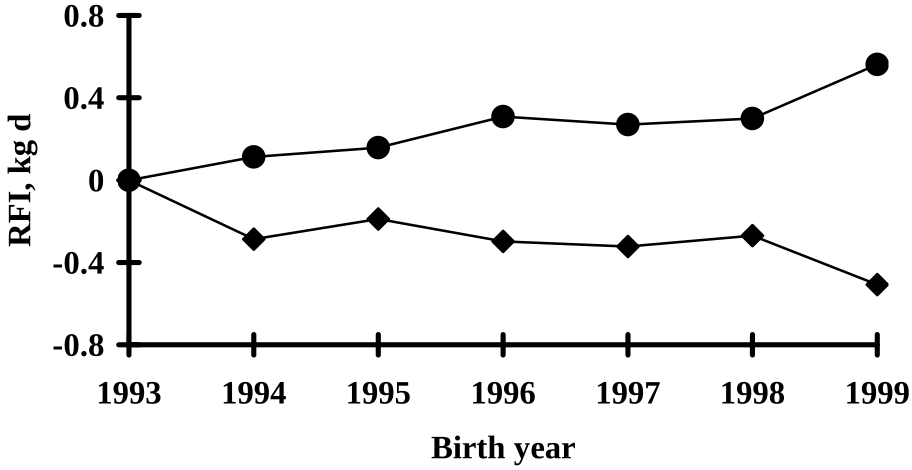


Figure 2 Trends in estimated breeding values for postweaning residual feed intake (RFI) for the Low (υ) and High (λ) RFI selection lines.



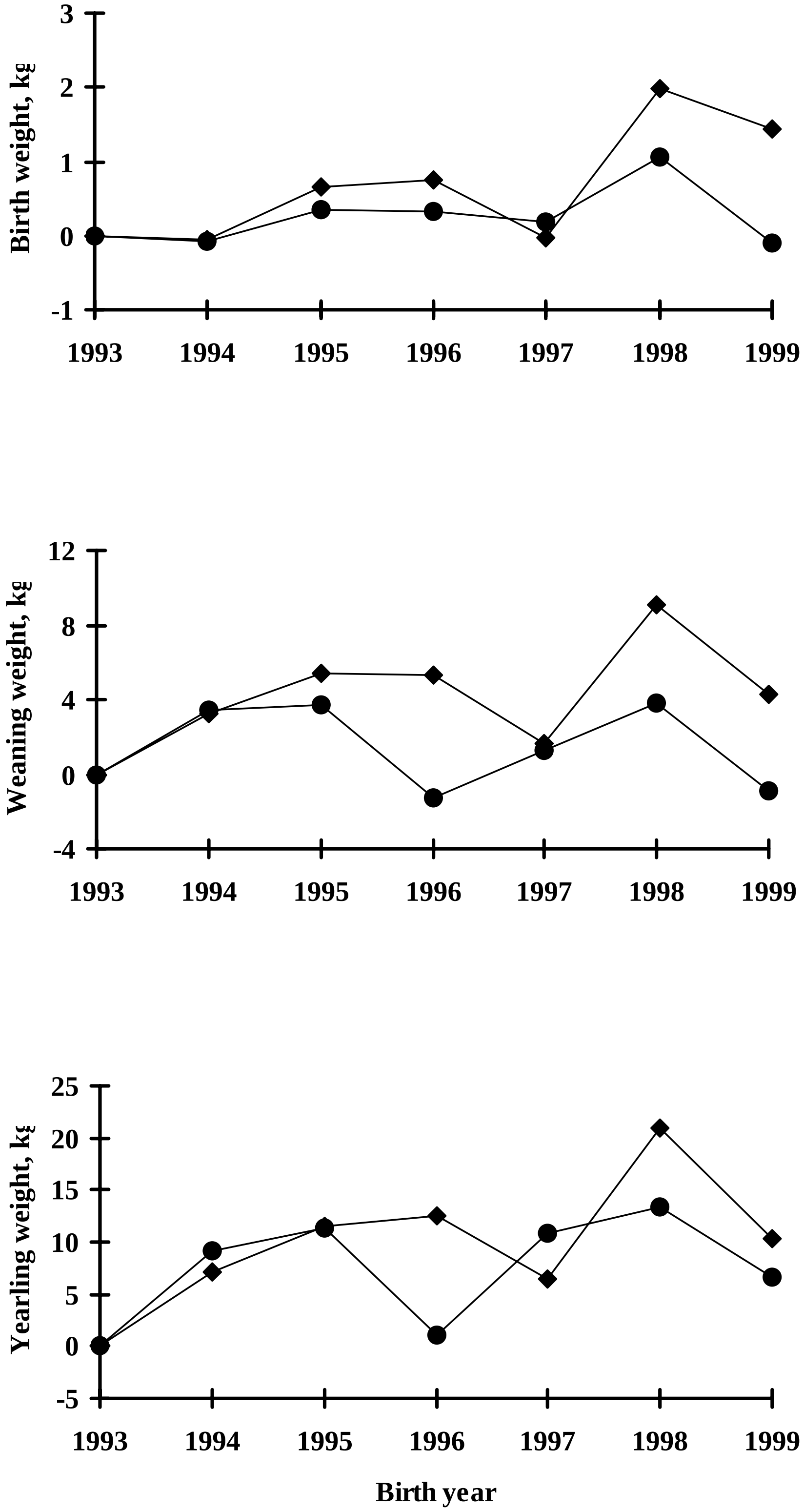


Figure 3: Trends in estimated breeding values for the additive direct effects on birth weight, weaning weight and yearling weight for the Low (υ) and High (λ) residual feed intake selection lines.

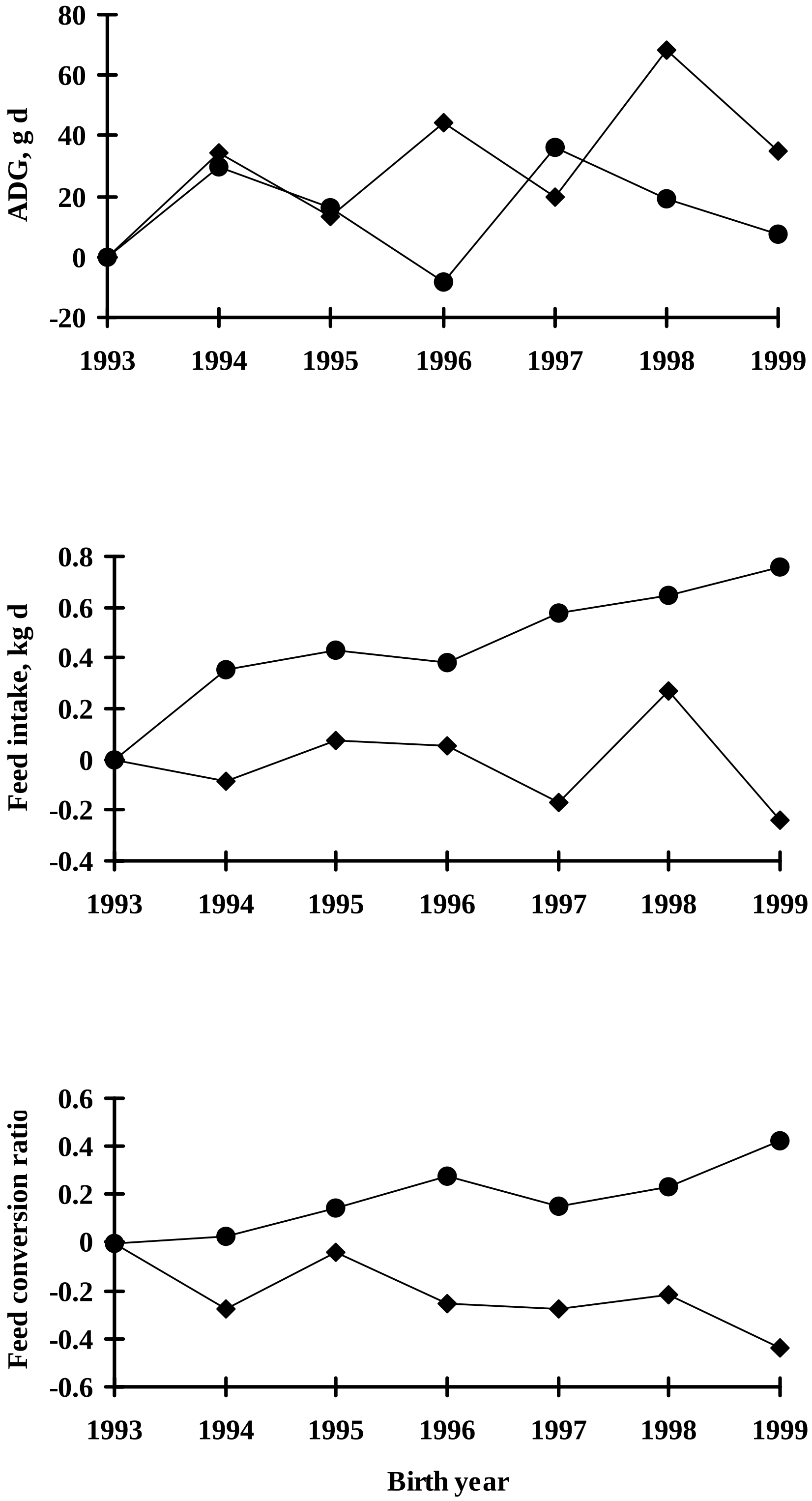


Figure 4: Trends in estimated breeding values for average daily gain (ADG), daily feed intake and feed conversion ratio for the Low (υ) and High (λ) residual feed intake selection lines.

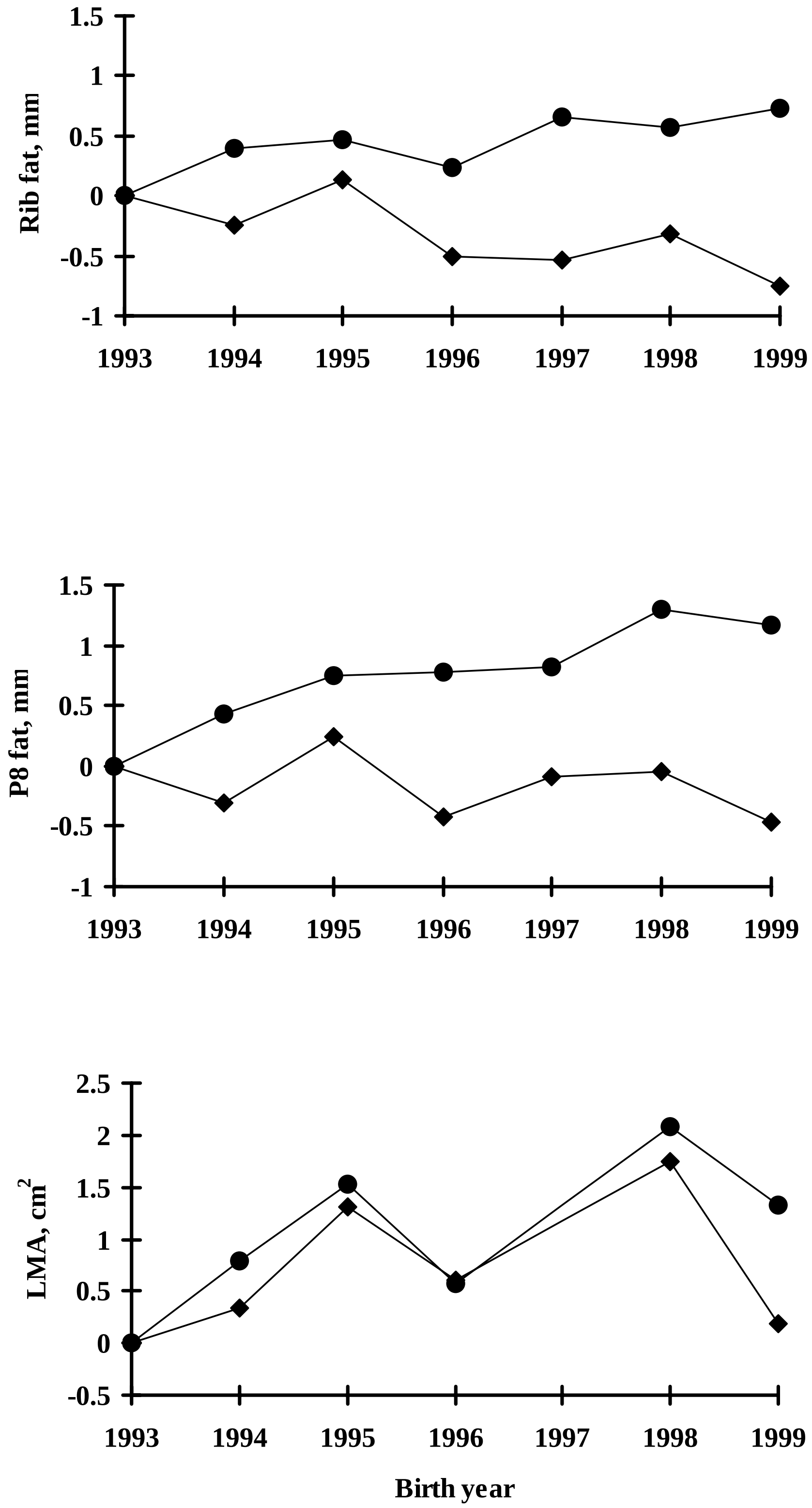


Figure 5: Trends in estimated breeding values for ultrasonically measured subcutaneous fat depths and longissimus muscle area (LMA) for the Low (υ) and High (λ) residual feed intake selection lines.

APPENDIX 3

Relationship Between Postweaning Net Feed Intake and Cow Performance

J. A. Archer

Two intakes of weaner heifers per year, one sourced from the Trangie herd (spring calving), and the other from industry autumn calving herds, were measured for postweaning net feed intake (NFI). Following the post-weaning NFI test, all heifers were retained in the cow herd at Trangie. The heifers and cows were run as either autumn or spring calving herds. Heifers were joined at approximately 15 months to calve as 2 year olds, and then re-joined to calve as 3 year olds. Females were pregnancy-tested three months after joining, and non-pregnant heifers and cows were rejoined at the next opportunity (ie. non-pregnant females in the spring-calving herd were re-joined with the autumn calving herd, and *vice versa*). Cows were only culled when they failed to calve twice in succession.

While in the cow herd, data was collected on cows as part of the routine measurement program at Trangie, including 5 weight measurements per year and 2 scans for fat depth. After the birth of their second calf, milk production of cows was estimated using the "weigh-suckle-weigh" technique. Cows were not joined after the birth of the second calf. Approximately 10 weeks after their second calf was weaned the cows were again measured for feed intake as mature, non-pregnant and non-lactating cows, and scan measurements of fat depth and eye muscle area taken. During this test the cows were fed *ad libitum* and gained weight at an average of 1.19 kg/day. After the mature cow test, the cows either re-entered the Trangie cow herd or were sold.

Analyses were conducted to examine the genetics of cow performance, including feed intake, efficiency, weight, fertility and milk production, and the relationship of these traits with post-weaning performance including net feed intake and related traits. Records of mature cow weight from industry Angus herds extracted from the NBRS database were also used in the analyses to account for sampling of sires within the experiment. Results from the analyses showed that:

Considerable genetic variation in feed intake and NFI of mature cows exists.

There is a strong genetic correlation between post weaning net feed intake and the feed intake and efficiency of cows, such that selection for improved efficiency (ie. lower post-weaning NFI) will lead to correlated improvements in efficiency of the breeding herd.
Selection for lower post-weaning net feed intake will lead to slightly heavier cows which eat less, and are also *slightly* leaner (as assessed by subcutaneous fat depths). The correlation with fat depth is low (around 0.2), and so ample scope exists to select efficient cows with adequate fat coverage. There is no relationship between post-weaning net feed intake and eye muscle area of cows.

Despite the tendency for more efficient cows to have lower fat depth (and the hypothesised relationship between fat depth and fertility, which is supported by this study), selection for lower net feed intake post-weaning will have little effect upon fertility (as assessed by the trait "days to calving").

Selection for post-weaning net feed intake will lead to a slight reduction in milk production of cows. This relationship agrees with that estimated between post-weaning net feed intake and the maternal component of weaning weight. Again, the correlation is only low (approximately 0.25), and scope exists to select cattle which break this relationship. It should be borne in mind that the estimation of milk production by the weigh-suckle-weigh technique reflects that calf's milk demand and may not reflect the full genetic potential of the cow for milk production.

APPENDIX 4

Running Head: Feedlot performance of high or low efficiency steers

Changes in feedlot performance, carcass and meat attributes of beef steers following divergent selection for postweaning residual feed intake[1,2]

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[1]This work was funded by NSW Agriculture, Meat and Livestock Australia and the Cattle and Beef Industry Co-operative Research Centre.
[2]The assistance by K. Dibley, T. Snelgar, C. Oswin, R. Woodgate, C. Quinn, K. Zirkler, J. Thompson, D. Perry, H. Oddy, R. Geddes, M. Wolcott, C. Smith, P. Reynolds, A. Blakely and other staff of the NSW Agriculture Trangie Research Centre, Glen Innes Experiment Station and ShannonVale Field Station and the Beef CRC "Tullimba" research feedlot is gratefully acknowledged.
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ABSTRACT: Residual feed intake (RFI) is a measure of feed efficiency calculated as the amount of feed consumed net of predicted feed intake based on liveweight (LW) and growth rate. Cattle with negative RFI consume less feed than expected for their size and growth rate and are therefore more efficient. This experiment investigated the consequences of a single generation of divergent selection on postweaning RFI to steer performance in the feedlot, their carcasses and meat attributes. Steers born over three years were fed for slaughter at light, heavy and medium LWs respectively. Following grow-out on pasture the steers were fed in a research feedlot for four months with growth, feed intake and feed efficiency measured over a 70-day RFI test. There was no difference (P>0.05) between the progeny of parents selected for high efficiency (low RFI; HE) or low efficiency (high RFI; LE) in LW at the start of the RFI-test period, ADG, LW at the end of the test, DMI, FCR or RFI. However correlations of mean parental estimated breeding value for postweaning RFI (EBV_{RFI}) with ADG, RFI and FCR (r_{ADG}=-0.10, r_{RFI}=0.15 P<0.05, r_{FCR}=0.07 P<0.1) provided evidence for genetic association of postweaning RFI with these feedlot traits. There were significant differences between the HE and LE steers in carcass traits measured ultrasonically before slaughter. The HE steers had less subcutaneous fat over their 12/13 rib and rump (rib 10.2 v 11.6 mm P<0.05; rump 13.3 v 14.8 mm P=0.06) and a smaller cross-sectional area of the eye-muscle (EMA: 67.1 v 70.5 cm^2 P<0.05). There was no difference (P<0.05) in hot carcass weight or in fat depth at the rump site on the carcass but there was a trend to HE steers having a slightly lower dressing percentage (DP) compared to the LE steers (52.1 v 52.9 P=0.07). There was no difference (P>0.05) between carcasses from HE and LE steers in visual scores for marbling, meat colour, fat colour or muscularity, nor in retail beef yield predicted on the basis of weights of trimmed primal cuts. Four carcass traits were correlated with mean parental EBV_{RFI}: r_{rib}=0.14, r_{rump}=0.14, r_{EMA}=0.09, r_{DP}=0.14 (P=<0.05). Objective measurements of meat tenderness and intramuscular fat (IMF%) were collected for the year 1 and year 2 animals representing cattle killed at light and heavy market LWs, respectively. There were no differences (P>0.05) between the HE and LE steers in IMF%, nor in shear force or compression values for meats samples aged for one or for 14 days. Mean parental EBV_{RFI} was negatively correlated with IMF% (r=-0.09 P=0.09)

and positively correlated with shear force measured after one day of ageing (r=0.14 P<0.05). This experiment found that divergent selection for postweaning RFI was genetically associated with differences in ADG, FCR and RFI by steer progeny. Selection for reduced RFI should produce steers that are more feed efficient, with no adverse effects on growth performance in the feedlot, beef yield or meat quality. The genetic associations of postweaning RFI with subcutaneous fatness, EMA, DP and IMF% suggest that carcass weight, fatness and marble score should be monitored in association with on-going selection for RFI.

Key Words*:* beef cattle, feed efficiency, feedlot performance, carcass, meat quality

Introduction

Feeding cattle is a major cost of beef production. Previous attempts at genetic improvement of feed use have been based on growth rate and feed conversion ratio (FCR). Selection on this measure for feed efficiency has indicated a high correlated response in growth rate (Arthur et al., 2002) which is not always desirable in beef cattle.

Residual (or net) feed intake (RFI) was proposed by Koch et al. (1963) as an alternate measure of feed efficiency that would be independent of size and growth rate. It is calculated as the amount of feed consumed net of that predicted based on liveweight (LW) and ADG. Cattle with negative RFI eat less than expected for their size and growth rate and are therefore more efficient. Postweaning tests of young bulls and heifers from a number of beef breeds have shown RFI to be heritable (Arthur et al., 2001) and to respond to selection (Renand et al., 1998; Arthur et al., 2002). Genetic variation in RFI in feedlot steers being fed for slaughter has also being shown (Robinson et al., 1999). Apart from results in a preliminary report by Richardson et al.(1998) it is not known whether selective matings of bulls and heifers tested for postweaning RFI will result in progeny that are more efficient and profitable to feed as steers for slaughter.

Variation in postweaning RFI is negatively genetically correlated with subcutaneous fat depth over the ribs in young cattle (Herd and Bishop, 2000; Arthur et al., 2001). Differences in fat depth over the ribs and rump have being measured in young bulls and heifers following 5 years (about 2 generations) of divergent selection on postweaning RFI (Arthur et al., 2002). In feedlot steers negative genetic correlations between RFI and subcutaneous fat depths have been reported (Robinson et al., 1999) and selection against postweaning RFI was accompanied by slight reductions in subcutaneous fat thickness in feedlot steers in the preliminary report by Richardson et al. (1998). Together these results demonstrate a genetic association between body composition and variation in RFI such that selection against RFI (to improve efficiency) may lead to changes body composition, particularly fatness, that alter the market suitability, and hence monetary value, of steer progeny.

Divergent selection for postweaning RFI has been followed by higher levels of calpastatin (an inhibitor of calpain proteases) and a higher myofibril fragmentation index (a measure of the breakdown of these structural elements) in postmortem samples of *m. Longissimus dorsi* from steer progeny from parents selected for high efficiency (low RFI), compared to those from steer progeny of parents selected for low efficiency (high RFI; McDonagh et al., 2001). No difference in objective measurements of tenderness following a single generation of divergent selection were detected by McDonagh et al. (2001) but they cautioned that on-going selection for low RFI may negatively affect meat tenderness.

This study was designed to investigate the consequences of divergent selection on postweaning RFI to steer performance in the feedlot and carcass and meat attributes. Steers born over three years were fed for slaughter at light, heavy and medium LWs respectively, and heavier than those in the earlier study by (Richardson et al., 1998). Because of the importance of tenderness to consumers, meat samples were taken from steers killed at the light and heavy LW market specifications for subsequent laboratory evaluation, and for the heavy LW specification also for consumer sensory assessment.

Methods and Materials

Cattle breeding. Cattle breeding and postweaning tests for RFI were done at the NSW Agriculture Research Centre, Trangie, NSW, Australia. The establishment in 1994 of high efficiency (low RFI) and low efficiency (high RFI) is described by Arthur et al. (2002). Briefly, RFI tests were conducted each year: one for Trangie-bred Angus bulls and heifers, and the second for Angus, Shorthorn, Hereford and Poll Hereford heifers purchased from industry herds. Details of the postweaning test procedure are given in Arthur et al. (1997). At the end of their test the Trangie Angus bulls were ranked for efficiency and the top 5% and bottom 5% selected each year. The heifers from each test were also ranked for efficiency and the top 50% of heifers were then mated to the high efficiency bulls and the bottom 50% of heifers mated to the low efficiency bulls to produce High Efficiency (“HE”) and Low Efficiency (“LE”) progeny. Selection line bull and heifer progeny from the matings of the Trangie bulls to Trangie-bred Angus heifers underwent postweaning RFI testing to evaluate the direct and correlated responses to this divergent selection and the results are reported by Arthur et al. (2002). The male progeny of the matings of Trangie bulls to industry-bred heifers were not used for breeding and were castrated for subsequent evaluation as steers. This pattern of testing industry-purchased heifers for RFI followed by divergent selection and mating was repeated over four years. The calves were purebred (Angus dam) or crossbred (Hereford, Poll Hereford or Shorthorn dam). The heifers calved from March to May. Progeny born in 1996 were evaluated as steers in the report by Richardson et al. (1998). Progeny born in 1997, 1998 and 1999 were used in this experiment. The steers were weaned at about seven months of age and then grown on pasture and finished in a feedlot before slaughter. They were by the same sires and were born approximately six months after the young Angus bulls and heifers born in 1996, 1997 and 1998 respectively in the report by Arthur et al. (2002).

The 1997-born steers were weaned in September 1997 and comprised 47 Angus steers (19 HE; 28 LE) and 104 Angus-crossbred steers (53 HE; 51 LE). They were the progeny of 5 HE sires and 5LE sires. Approximately three months later the steers were transported from Trangie to the CSIRO Pastoral Research Centre “Chiswick”, south of Armidale, NSW, to be grown on pasture. Drought at that time necessitated that the steers were placed in the feedlot earlier than planned. The younger, and hence lighter, of the crossbred steers (n=26: 10 HE; 16 LE) were sold in April 1998. The Angus and remaining crossbred steers (n= 78: 43 HE; 35 LE) were transported to the Cattle and Beef CRC Research Feedlot “Tullimba”, 50 kilometres west of Armidale, NSW. They were approximately 13 months old and weighed on average 314kg at feedlot entry.

The steers born in 1998 were weaned in October 1998 and comprised 47 Angus steers (22 HE; 25 LE) and 83 Angus-crossbred steers (36 HE; 47 LE). They were the progeny of 5 HE sires and 5 LE sires. One month later the steers were transported from Trangie to the NSW Agriculture Station at Glen Innes, NSW, to be grown on pasture. In March 2000 the steers were trucked to the “Tullimba” Research Feedlot. They were approximately 24 months old and weighed on average 502kg at feedlot entry.

The 1999-born steers were weaned in October 1999 and comprised 36 Angus steers (17 HE; 19 LE) and 40 Angus-crossbred steers (19 HE; 21 LE). They were the progeny of 5 HE sires and 6 LE sires. Approximately two weeks later the steers were transported from Trangie to the NSW Agriculture Field Station "Shannon Vale", approximately 10 kilometres east of Glen Innes, NSW, to be grown on pasture. In June 2000 the steers were transported to the “Tullimba” Research Feedlot. They were approximately 15 months old and weighed on average 338kg at feedlot entry.

Measurements in the feedlot. After receival at the "Tullimba" research feedlot the steers were rested on pasture with hay available and one week later inducted into the feedlot. At induction the steers were drenched to control internal parasites (Ivermectin, Merial Australia Pty Ltd, Parramatta, NSW, and Fasinex, Novartis Animal Health Canada Inc, Mississauga, Ontario) and vaccinated (Ultravac 5-in-1 vaccine, CSL Ltd, Parkville, Victoria). Over the next three weeks the steers were accustomed to rations of increasing grain content until consuming a standard finishing ration. This ration consisted of approximately 75% grain, 10% sorghum hay, 5% protein pellets, plus molasses and vitamin and mineral additives (fresh weight basis). The grain was dry-rolled with barley used in the first two years and oats in the third year. Across the three years, values for the dry matter (DM) content of the ration were 85.5, 86.5 and 88.5%; for protein 14.9, 14.4 and17.0%DM; and acid-detergent fibre 9.1, 12.5 and 17.5%DM respectively. Protein and acid-detergent fibre were determined *in-vitro* by Agrifood Technology Pty Ltd, Toowoomba, Queensland. Metabolizable energy (ME) content of the rations was calculated from the values for protein and acid-detergent fibre using the equation of Low et al. (1983), and were 12.3, 11.8 and 11.5MJ ME/kg DM. To reduce the possible influence on feed intake from differences in ME-content of the diets over the three years, daily feed intakes were calculated and expressed as kilograms per day of a ration equivalent to 12MJ ME/kg DM.

Once judged to be accustomed to eating the finisher ration, the steers were then divided into groups of about ten animals for feed efficiency testing. Care was taken to ensure that each group contained similar numbers of light and heavy HE and LE animals. Each group was moved into a separate feedlot yard that contained a single automated feeder (pictured in Robinson et al., 1999) to record feed eaten by each steer. The steers were given three weeks to adapt to feeding from the feeder. Steers that failed to adapt, as identified by atypically low feed intake, were removed, fed separately and then re-introduced. A second failure to adapt resulted in the steer being considered a "shy" feeder and its removal from the experiment. Individual feed intakes were then recorded for a further period of approximately 70 days, as recommended by Archer et al. (1997) for experiments to investigate variation in individual animal feed intake and feed efficiency. This "feed efficiency test" period was 66, 69 and 73 days long in the first, second and third year.

Before the feed efficiency test the steers were weighed (no fast) fortnightly, then weekly during the test in the first year and fortnightly in years 2 and 3. Before the start of the test, and again at the final weighing of the test period, the steers had their subcutaneous fat depth at the rib and rump and eye-muscle area measured ultrasonically. Subcutaneous rib (12/13th) and rump (Australian P8 site) fat depths were measured by a trained technician using an Aloka 500 ultrasound scanner. The area of the eye-muscle (LD; at the 12/13th rib) was measured subsequently by computer analysis of stored images. Animals were processed in their small groups to minimise the time they were away from their feedlot yard. The same machine and technician were used for all ultrasound measurements taken in this experiment. Start-of-test, mid-test and end-of-test LW, and average daily gain (ADG) for individual steers were calculated from the linear regression for each steer of its weekly (year 1) or fortnightly (years 2 and 3) LW against time.

The automated feed-intake recorders not only stored data on daily feed intake by each steer, they also stored data from which the number of feeding sessions per day and the total duration spent feeding per day can be derived. Feeding sessions were sub-classified as brief if less than 120 seconds duration or long if of greater than 120 seconds duration. Mean values for each animal for duration spent feeding per day and the number of brief, long and total feeding sessions per day were calculated over the feed efficiency test period. Three additional traits to describe feeding behaviour were also derived: average length of time per feeding session (in seconds), the average rate of DM-intake (g/second) and the average DM-intake per feeding session (in kg).

In the first year only insufficient feedlot yards with individual feed-intake recorders were available to accommodate all the steers. The Angus portion of these steers was put into these yards and had individual feed-intakes measured. The crossbred steers were split into low and high RFI groups, each group then sub-divided into two, and the cattle put into four adjacent feedlot yards so that there were two pens of HE steers and two pens of LE steers. Group feed intakes were measured by weighing the feed augered into the feed-bunks twice-daily. The amount of feed put into each bunk was managed to achieve negligible residues each day but with sufficient feed dispensed for the steers to be consuming close to *ad libitum* requirement.

Slaughter and carcass measurements. Following the feed efficiency test the steers remained in their feedlot yard. Two days after the end of the test in year 1, after seven days in year 2 and after 14 days in year 3 the steers were trucked to a commercial abattoir near Grantham, Queensland. In years 2 and 3 the steers were weighed as they boarded the truck to obtain a "preslaughter" LW; the end-of-test LW was used in year 1. At the abattoir the steers were held in lairage for one day (water only available), and killed the following morning. Following slaughter, the weight of the “hot” carcass and depth of fat at the P8 site was recorded before going into the chiller, being the two main measurements determining the monetary value of the carcass in Australian markets. After overnight storage at 1^{o}C the left-hand side of the carcass was given a muscle score by a trained assessor and then quartered between the 12th and 13th ribs. The exposed surface scored for meat colour, fat colour and marbling, by comparison against industry-standard coloured strips and photographs. The muscularity of the carcass was scored on a scale from A: highly muscular and convex shape, to E: light and almost concave in shape. Meat colour was scored on a scale from 1: light pinkish red, to 9:dark red. Fat colour was scored from 1:white, to 9:yellow. Marbling was scored from 0:nil visible, to 5:abundent. In year 2 the carcasses were also given a USDA ossification score by a Meat Standards Australia (MSA) grader.

The carcasses were then moved to the boning room of the abattoir and the individual weights of selected primal cuts from the left side of each carcass were recorded for subsequent use in the prediction of beef yield. The cuts were trimmed to abattoir specification for fat cover where necessary: being 5mm in year 1 and 10 mm in years 2 and 3. In year 1 the LD was removed, halved and vacuum-packed in plastic; in year the LD was cut into 3 and then stored. Prior to slaughter the identities of the steers had being sorted by breed, selection line and final LW. Based on this order, the cranial end of the LD from alternate steers was assigned to either one day of ageing (ie. frozen immediately) or 14 days of ageing at 1^{o}C, then frozen (-14^{o}C), and the corresponding caudal end was stored for 14 or 1 day. The mid-section of LD collected in year 2 was aged for 14 days and then stored frozen for subsequent sensory evaluation.

Meat yield. Retail beef yield, defined as the total weight of trimmed boneless cuts trimmed to 3mm fat thickness plus the weight of manufacturing meat offcuts (Perry et al., 2001), as a percentage of carcass weight, was calculated from the weights of the hot carcass and selected, trimmed meat cuts. For the steers in year 1 of the experiment, prediction of retail beef yield used the equation of Reverter et al. (1999). For steers in years 2 and 3, the temperate feedlot cattle equation of Reverter et al. (2001) was used.

Meat testing. Sample preparation, cooking and measurements are described in detail by Perry et al. (2001). Briefly, samples were thawed (4°C) for 48 hours, a subsample removed for chemical analysis of intramuscular fat and the remaining sample trimmed into 250 g block. The blocks from samples aged for 1day were returned to the coolroom (1-4°C) for a minimum of 60minutes to enable the meat to"bloom" (development of oxymyoglobin on the exposed surface). Three colour mesurements per sample were taken on the bloomed surface and recorded in the L (lightness), a (redness) and b (yellowness) colour space. Cooking was at 70°C for one hour in a waterbath, after which samples were cooled and stored at 4°C overnight prior to measurement. Shear force and compression values were determined on LD samples following the methods of Bouton et al. (1971) and as described by Perry et al. (2001). Objective measurements of meat tenderness were determined with a Lloyd LRX instrument (Lloyd Instruments Ltd., Hampshire, England). Change in shear force and compression with days of ageing was calculated as the change from day one to day 14, divided by 13 days, with a negative value representing a decline in shear force and compression and indicative of meat becoming more tender. A subsample from the cranial end of the LD was used for determination of intramuscular fat percent (IMF%, wet weight basis). This meat sample was minced and freeze-dried to determine dry-matter content, and then ground again. Intramuscular fat content of the LD was determined in duplicate on 5g dried sample by weight lost following 20 hours extraction with chloroform in a soxhlet apparatus.

Sensory evaluation of the palatibility of the LD mid-section samples collected in year 2 and aged for 14 days was performed by Meat & Livestock Australia Limited, North Sydney NSW, within their Meat Standards Australia (MSA) program. Preparation, tasting and scoring protocols are described in Perry et al. (2001). Steaks were assessed for tenderness, juiciness, flavour and overall acceptability. These four sensory dimensions were combined into a single palatability score (MQ4) using the weightings of 0.4, 0.1, 0.2, and 0.3, respectively.

Final dataset. Over the three years 166 HE and 192 LE steers were available to this experiment. Twenty-one HE and 25 LE steers were excluded from the final dataset for the following reasons: sold due to drought (10HE:19LE), suspect pedigree (2HE:1LE), structural faults (2HE), shy feeder (6HE:8LE) and death (1HE). There was no evidence that proportionally more HE or LE steers were excluded from the experiment. There remained 145 HE steers and 167 LE steers in the final dataset. They were the progeny of 15 HE steers and 16 LE sires. One HE and one LE sire had only one progeny each in the experiment, the remainder at least five progeny, with the mean number being 9.7 per HE sire and 9.8 per LE sire. For logistical reasons, consumer sensory assessments were done for only 51 of the 54 HE steers and 51 of the 69 LE steers in year 2 of the experiment.

Measures of feed efficiency. Residual feed intake by an animal is calculated as the amount of feed consumed net of the predicted feed intake based on mid-test LW and ADG. Individual feed intakes (kg/day of 12MJ ME/kg DM), metabolic mid-test LW and ADG were used in the calculation of RFI. Metabolic mid-test LW (ie. mid-test $LW^{0.73}$) was used in recognition that differences in energy intake and expenditure increase more slowly as LW increases. They were used in a multiple-regression for each year with the residuals from the regression being the individual animal values for RFI, that is the differences between actual feed intakes and predicted feed intakes for each steer. The r-square values for these multiple regressions over the three years were 58, 81 and 81%. Feed conversion ratio (FCR) by each animal by was calculated as the ratio of its daily DM-intake to daily weight gain over the test period. Individual feed intakes were not available for the crossbred steers in year 1 so that RFIs could not be calculated for these animals.

Comparison of HE and LE progeny following a single generation of divergent selection. Differences in the means for the HE and LE steer progeny for traits across the three years of the experiment were tested within the GLM procedure of SAS (1989). Included in the GLM-models were the fixed effects of year (ie. year of birth), breed (Angus, Angus-crossbreed), age of dam at calving (54% were 2-years old; 43% were 3-years old; 3% were 4-years old), selection line (HE, LE) and the interactions of line-by-breed and line-by-year. To guard against comparisons being unduly influenced by the limited number of individual sires used, sire identity within selection line was fitted as a random effect in the GLM and selection line differences tested against the sire within selection line mean squares. Preliminary analyses showed that the age of dam, the line-by-breed and the line-by-breed interactions to be not significant (P>0.05) and they were dropped from the final GLM models. Preliminary analysis also showed there to be a consistent difference in date of birth across the three years (no year-by-line interaction; P>0.05) with the HE steers being born on average 6 days later than the LE steers. These differences in date of birth and hence age could bias comparisons of growth performance. To guard against this, age at weaning was included as a covariate in the final GLM. Since the management of animals in each line was identical, any observed differences in mean performance of the lines could be attributed to genetic selection response.

Associations with parental estimated breeding value for postweaning RFI. Differences between the HE and LE selection lines following a single generation of divergent selection might be small and difficult to demonstrate statistically. An alternate analysis was undertaken to assess whether there was a genetic association of parental postweaning RFI with variation in the traits measured on their progeny. Correlations were determined for this purpose between the mean value for the sire and dam's estimated breeding value (EBV) for postweaning RFI (EBV_{RFI}) and the traits measured on their progeny. These EBVs were determined by one of the authors (J. Archer) using the results from progeny tests for postweaning RFI conducted at the NSW Agriculture Research Centre, Trangie, and genetic parameters reported by Arthur et al. (2001). Sire EBV_{RFI} ranged from -0.65 to +1.15 kg/day and dam EBV_{RFI} from -0.63 to +0.67 kg/day. Associations were investigated using the GLM procedure of SAS (1989) with a model that included year, breed, age of steer and parental EBV_{RFI}. The direction and strength of the association was measured as the correlation coefficient, calculated as: √(type III SS for parental EBV_{RFI}/Total SS), where SS is sum-of-squares and the direction of the association is that for the regression coefficient given in the solution option within the GLM procedure. Statistically-significant correlations were presumed as evidence for a genetic association.

Phenotypic associations with feedlot RFI and FCR. Phenotypic associations between RFI and FCR in the feedlot with traits measured on the steers before feedlot entry, in the feedlot or after slaughter, were investigated using the GLM procedure of SAS (1989). Average daily gain before feedlot entry was calculated using LW's measured at weaning and at the end of grow-out on pasture. The GLM models included year, breed, age of steer, and RFI or FCR of the steer in the feedlot. The direction and strength of the association was measured as the correlation coefficient, calculated as: √(type III SS for RFI or FCR/Total SS), and the direction of the association is that for the regression coefficient given in the solution option within the GLM procedure.

Results

Performance over feedlot RFI test. There was no difference between HE and LE progeny in LW at the start of the RFI-test period, in growth rate over the test, or in LW at the end of the test (Table 1). Daily feed intake, FCR and RFI did not differ between the selection lines. However, statistically-significant correlations of mean parental postweaning EBV_{RFI} with ADG, FCR and RFI provided evidence for genetic association of postweaning RFI with these feedlot traits. Phenotypic correlations for RFI during the RFI test with size and growth rate (ie. LW at the start and end of the test, ADG) were non-significant (P>0.05), as expected given that RFI was calculated to be independent of them. Phenotypic correlations of RFI with actual feed intake (r=0.50, P<0.001) and FCR (r=0.27, P<0.001) showed that steers with lower RFIs in the feedlot also had a lower feed intake and more favourable FCR.

Table 1: Growth, feed intake and efficiency during feedlot testing for residual feed intake (RFI) of Angus and Angus-crossbreed steer progeny of parents selected for high efficiency (low postweaning RFI) or low efficiency (high RFI), and correlations with mean parental EBV for postweaning RFI

	Selection line mean[a]		Correlation with parental EBV_{RFI}
	High efficiency	**Low efficiency**	
n	103	132	
Animal performance			
Start of test weight, kg[b]	481 ± 9	489 ± 9	-0.02
Average daily gain, kg/d[b]	1.53 ± 0.03	1.49 ± 0.02	-0.10*
End of test weight, kg[b]	586 ±10	592 ± 9	-0.03
Feed intake, kg DM/d	12.4 ± 0.2	12.5 ± 0.1	0.01
Feed conversion ratio	7.6 ± 0.2	8.1 ± 0.2	0.07[†]
Residual feed intake, kg/d	-0.11 ±0.08	0.10 ± 0.07	0.15*
Preslaughter fat depth over ribs, mm	10.2 ± 0.3[f]	11.6 ± 0.3[g]	0.14***
Preslaughter fat depth over rump, mm	13.2 ± 0.4	14.8 ± 0.4	0.14***
Preslaughter eye-muscle area, cm^2	67.1 ± 0.9[f]	70.5 ± 0.9[g]	0.09**
Feeding behaviour			
Number of feeding sessions per day	18.7 ± 0.6[c]	20.9 ± 0.6[d]	0.23***
Total time spend feeding, s	5792 ± 93	6034 ± 104	0.07
Rate of feed intake, g/s	2.20 ± 0.05	2.17 ± 0.05	0.02
Mean duration of feeding sessions, s	344 ± 12	321 ± 11	-0.18**
Feed intake per feeding session, g	713 ± 20[c]	650 ± 17[d]	-0.24***

[a]Values are means (±se) for cohorts born in 1987, 1998 and 1999.
[b]Weight traits were recorded on n=145 high and 167 and low efficiency line steers.
[cd]Selection line means with different superscripts differ significantly (P<0.05).

Even though no difference in daily feed intake was observed between the HE and LE groups there were some statistically-significant differences in feeding patterns between the two selection lines. The HE steers had fewer feeding sessions per day than the LE steers: in total number of visits to the automated feeders (18.7 *v* 20.9; Table 1), in brief visits (10.3 ± 0.4 *v* 11.7 ± 0.3, P<0.05), and in long visits (8.4 ± 0.3 *v* 9.2 ± 0.2, P<0.05). The total time spent in the automated feeders each day and the mean duration of feeding sessions did not differ between HE and LE steers, nor did their rate of feed intake differ. However, the HE steers consumed more feed per feeding session (713 *v* 650grams) than the LE steers. These results describe feeding behaviour by HE steers that could be summarised as consisting of fewer feeding sessions and larger meal sizes than those by the LE steers.

Number of feeding sessions, mean duration of feeding session and intake per session were correlated with mean parental EBV_{RFI}. Correlations with RFI by the steers in the feedlot showed that at a phenotypic level variation in RFI was associated with number of feeding sessions (r=0.29, P<0.001), rate of feed intake (r=0.25, P<0.001), mean duration of feeding sessions (r=-0.24, P<0.001) and feed intake per feeding session (r=-0.12, P<0.1), but not total time per day spent in the feeders (P>0.05). There were no significant (P>0.05) line-by-year interactions for the above traits describing animal performance in the feedlot or feeding behaviour indicating that the relative performances of the selection line progeny groups were consistent across the three years of this experiment.

Without individual feed-intake data for the crossbred steers in year 1 it was not possible to calculate RFI for them. The crossbred HE steers were no heavier than the crossbred LE steers at the start of the test period (393 ± 4 *v* 382 ± 5 kg, P>0.05), grew no faster over the test period (1.21 ± 0.03 *v* 1.19 ± 0.03 kg/day, P>0.05), and were no heavier at the end of the test (473 ± 5 *v* 460 ± 5, P>0.05). The average intake per head by the group-fed HE steers was less than for the LE steers (9.7 *v* 10.3 kg/day) and the HE steers had a lower FCR (8.3 *v* 8.8). Without individual feed-intake data it was not possible to statistically compare these means but they do indicate that these crossbred HE steers were more efficient in the feedlot than the contemporary crossbred LE steers.

Body composition, carcass and meat traits. There were significant differences between the HE and LE steers in body composition traits measured ultrasonically before slaughter. The HE steers had less depth of fat over their rib (10.2 *v* 11.6 mm) and rump (13.3 *v* 14.8 mm; P=0.06) and had a smaller cross-sectional area of the eye-muscle (67.1 *v* 70.5 cm^2) than the LE steers (Table 2). There was no difference between the HE and LE steers in hot carcass weight or in fat depth at the rump site on the carcass but was there a trend toward a lower dressing percentage in the HE steers. There was no difference (P>0.05) between HE and LE steers in the visual marbling score given to their carcasses. There was no difference HE and LE steers in retail beef yield from their carcasses predicted on the basis of weights of trimmed primal cuts. There were statistically-significant correlations of parental postweaning EBV_{RFI} with carcass fatness traits, eye-muscle area and dressing percentage) providing evidence of genetic associations, even though the differences between the selection-line progeny groups for some of these traits were not statistically-significant. Correlations for all carcass traits with RFI in the feedlot were not significant (P>0.05). This indicated that there were no phenotypic associations between actual RFI and these carcass traits. There were no significant (P>0.05) line-by-year interactions for any of the above traits indicating that the relative performances of the selection line progeny groups were consistent across the three years.

Table 2: Body composition, carcass and meat quality attributes of the *M. longissimus dorsi* for Angus and Angus-crossbreed feedlot steers of parents selected for high efficiency (low postweaning RFI) or low efficiency (high RFI), and correlations with mean parental EBV for postweaning RFI

	Selection line mean[a]		Correlation with parental EBV_{RFI}
	High efficiency	Low efficiency	
Carcass[b]			
n	145	167	
Preslaughter fat depth over ribs, mm	10.2 ± 0.3[f]	11.6 ± 0.3[g]	0.14***
Preslaughter fat depth over rump, mm	13.2 ± 0.4	14.8 ± 0.4	0.14***
Preslaughter eye-muscle area, cm^2	67.1 ± 0.9[f]	70.5 ± 0.9[g]	0.09**
Hot carcass weight, kg	307 ± 6	314 ± 6	0.00
Dressing percentage	52.1 ± 0.3	52.9 ± 0.2	0.14**
Rump fat depth on hot carcass, mm	15.0 ± 0.5	16.4 ± 0.5	0.07*
Marble score	1.3 ± 0.1	1.3 ± 0.1	0.00
Retail beef yield, %	67.5 ± 0.3	67.3 ± 0.2	-0.02
Meat quality objective traits[c]			
n	109	127	
Intramuscular fat, % wet weight	6.0 ± 0.2	6.0 ± 0.2	-0.09[†]
Meat colour			
L (lightness)	39.3 ± 0.2	38.9 ± 0.2	-0.10
a (redness)	22.9 ± 0.2	23.1 ± 0.2	-0.04
b (yellowness)	12.0 ± 0.1	11.9 ± 0.1	-0.08
Shear force, kg			
Day 1 of ageing	4.3 ± 0.1	4.5 ± 0.1	0.14*
Day 14 of ageing	3.9 ± 0.1	3.9 ± 0.1	0.06
Shear force change, g/day	-32 ± 10	-48 ± 11	-0.08
Compression force, kg			
Day 1 of ageing	1.43 ± 0.02	1.42 ± 0.02	0.03
Day 14 of ageing	1.31 ± 0.02	1.32 ± 0.02	0.06
Compression force change, g/day	-9 ± 1	-8 ± 2	0.03
Meat sensory traits[d,e]			
n	51	51	
Tenderness	73 ± 1	69 ± 1	-0.23*
Juiciness	72 ± 1[f]	67 ± 1[g]	-0.27**
Flavour	73 ± 1[f]	67 ± 1[g]	-0.25**

[a]Values are means (±se).
[b]Cohorts born in 1987, 1998 and 1999.
[c]Cohorts born in 1997 and 1998.
[d]Cohort born in 1998.
[e]Higher values more tender, juicy or flavoursome.
[fg]Selection line means with different superscripts differ significantly (P<0.05).

Visual inspection of the data for fat colour, meat colour and carcass muscle score showed that there were no differences by the HE and LE steers in these meat quality characteristics. The majority (90%) of carcasses had fat colour 0 (white) and 8% (n=11) of HE steers and 13% (n=21) of LE steers had fat colour 1 (less white). Virtually all (98%) carcasses had meat colour 1B and 1C ("pinkish red") plus 2% (n=3) of HE steers and 1% (n=2) of LE steers had meat colour 2 (darker red). Most (84%) carcasses received a muscle score grade of C plus 2% (n=3) and 1% (n=2) of HE and LE steers being graded "B" (more muscular) and 17% (n=24) and 13% (n=21) graded "D".

Objective measurements of meat tenderness and IMF% were available for the year 1 and year 2 animals representing cattle killed at light and heavy market LWs, respectively. There were no differences detected between the HE and LE steers in IMF% nor in the L, a and b dimensions of meat colour (Table 2). Shear force and compression values for meats samples aged for one or for 14 days, and the rate of change in these measures of tenderness during ageing, did not differ between the HE and LE steers. Parental postweaning EBV_{RFI} was negatively correlated with IMF% (P=0.06) and positively correlated with shear force measured after one day of ageing indicating genetic association between postweaning NFI and these meat quality traits. Correlations for parental postweaning EBV_{RFI} with the other objective measurements were not significant (P>0.05). Correlations for steer RFI in the feedlot with objective measurements of meat quality, excluding meat colour dimension L and rate of change in shear force, were not significant (P>0.05) and provided no evidence for phenotypic associations between actual RFI and these traits. Meat colour dimension L and rate of change in shear force were both negatively correlated (r=-0.16, P<0.05 and r=-0.14, P=0.09, respectively) with actual RFI. This indicated that superior RFI in the feedlot was associated with lighter (whiter) coloured meat and a slower rate of decline in shear force during ageing.

Consumer sensory evaluation of meat from the year 2 (heavy market LW) steers rated steaks from the HE steers as more tender (P=0.07), juicy and better flavoured than steaks from LE steers (Table 2). This was reflected in higher preference for the steaks from the HE steers (overall liking: 74 ± 1 *v* 69 ± 1, P<0.05) and a superior MQ4 score (73 ± 1 *v* 68 ± 1, P<0.05) compared to steaks from the LE steers. The five sensory traits were negatively correlated with parental postweaning EBV_{RFI} (r=-0.23 to -0.27, P<0.05) but not (P>0.05) with actual RFI by the steers in the feedlot. This implied a favourable genetic association of these sensory traits with postweaning RFI but not with phenotypic variation in RFI in the feedlot. The five traits for the sensory assessments given by the taste panels were strongly negatively correlated (P<0.001) with the two objective measurements of tenderness made on the same 14-day aged LDs, with correlation coefficients with shear force from 0.33 to 0.50 and with compression from 0.39 to 0.50.

Discussion

Divergent selection for postweaning RFI was genetically associated with differences in average daily gain, FCR and RFI by steer progeny over a feedlot RFI-test conducted under conditions similar to those of commercial feedlots. Selection for reduced RFI should produce steer progeny that are more feed efficient in the feedlot than progeny of high-RFI parents and would, therefore, cost less to feed to reach comparable final preslaughter LWs.

This experiment did not demonstrate a statistically-significant correlated response in RFI in the feedlot following just a single generation of divergent selection on postweaning RFI. Postweaning RFI is heritable and responds to selection to produce direct improvement in postweaning RFI and correlated improvement in postweaning FCR (Herd et al., 1997; Arthur et al., 2002). Postweaning RFI is genetically correlated with feedlot RFI and FCR as demonstrated by the associations with parental postweaning EBV_{RFI} but the magnitude of the correlations are at present unknown although unlikely to be unity. Change in feedlot RFI and FCR was evident but this experiment lacked the statistical power to confirm these differences.

Measures of body composition (subcutaneous fat depths, eye-muscle area, dressing percentage) were genetically associated with postweaning RFI even though the differences between selection-line progeny groups for some of these traits were not statistically significant. Reduction in subcutaneous fatness accompanying selection for high efficiency (low RFI) might be expected from the genetic correlations reported for cattle at the end of postweaning testing (Herd and Bishop, 2000; Arthur et al., 2001) and feedlot testing

(Robinson et al., 1999), and demonstrated in yearling-age cattle as a correlated response to divergent selection on postweaning RFI (Arthur et al., 2002). Carcass weight and fat depth at the P8 rump site are at present major determinants of carcass value in Australia. The HE steers yielded carcasses of similar weight to the LE steers and the difference in fat depth on the hot carcass was sufficiently small that the price paid by the abattoir for carcasses from both groups of steers did not differ. There was no evidence of a reduction in the yield of retail beef from the carcasses of the HE steers. The carcasses of HE and LE steers did not differ in the other visual traits used in grading, viz meat colour, fat colour, muscle score and marbling. Therefore after a single generation of divergent selection on postweaning RFI there was no evidence for a difference in meat yield or meat quality as judged by these visual traits.

The correlations of parental postweaning EBV_{RFI} with subcutaneous fat and eye-muscle area suggest genetic association with carcass traits of monetary value and with body composition. This has at least two important implications for selection against RFI as a tool to improve efficiency and reduce the cost of beef production. Firstly, the correlation with parental EBV_{RFI} could result in reduction in subcutaneous fatness as an indirect response to selection for lower RFI. The magnitude of the correlations are quite low as that the correlated reduction in fatness of progeny following selection would be expected to be small, as was observed in the steer progeny following a single generation of selection. Ongoing selection may eventually lead to sufficient change in fatness so as to result in failure to meet market specifications for fatness, and therefore produce a change in the monetary value of carcasses. Secondly, change in body composition may be part of the underlying biological basis to genetic variation in RFI. If a major driver of this variation than selection for RFI could just be an expensive tool to select fatter or leaner cattle, for which there already exist cheaper and more convenient traits to measure. However, there were no phenotypic correlations between actual RFI in the feedlot and the carcass traits indicating that these measurements of body composition were not associated with variation in RFI between steers in this experiment. Moreover, Richardson et al (2001) have shown that variation in body composition explains only a very small portion of variation in RFI in beef steers and that most of the variation is due to differences in metabolic processes and behaviour.

McDonagh et al. (2001) reported that differences in calpastatin and MFI in LD muscle accompanied divergent selection for postweaning RFI and postulated that this could provide a mechanistic basis for differences in tenderness to also accompany such divergent selection. However, McDonagh et al. (2001) were unable to demonstrate such a difference in objective measures of meat tenderness in their study of a smaller number of steer progeny. In this experiment there was a positive correlation between parental EBV_{RFI} and shear force after one day of ageing that provides evidence for a genetic association between high efficiency (low RFI) and lower (more tender) initial shear force. At a phenotypic level, meat colour dimension L (related to composition of muscle fibres) and rate of change in shear force were both negatively correlated with actual RFI in the feedlot so that higher efficiency (lower RFI) in the feedlot was associated with darker (less white) coloured meat and a slower rate of decline in shear force during ageing. These results are consistent with the above hypothesis.

No differences were observed between HE and LE steer progeny in objective measures of IMF%, meat colour and meat tenderness following a single generation of divergent selection. Consumer sensory evaluation of LD steaks aged for 14 days showed a preference for steaks from the HE steers and the five traits used to score their preferences showed negative (favourable) genetic associations with postweaning RFI, but no phenotypic association with actual RFI by the steers in the feedlot. The five traits used in the sensory assessments were negatively correlated with objective measurements of tenderness and indicate that the consumer test panelists were giving higher scores to steaks with lower shear force and compression values. These results indicate that if any change in meat tenderness was to occur following selection for high efficiency (ie against RFI) that it is unlikely impact on consumers preferences provided the steaks have received a reasonable period of ageing. IMF% can influence consumer preferences and its visual expression as the related trait, marbling, is important to the monetary value of carcasses in some markets. Whilst no difference was detected in IMF% in LD between the HE and LE steers there was a trend towards a negative association with postweaning RFI. In contrast, Robinson et al. (1999) reported a small positive genetic correlation of IMF% with RFI of feedlot steers (r_g=0.17). The difference in direction of these associations with RFI may be due to the different ages and hence maturity of cattle when RFI was measured in the two experiments.

The feeding behaviour of the HE steers was characterised by fewer feeding sessions and larger meal size than those of the LE steers. Correlations with parental postweaning EBV_{RFI} and with RFI in the feedlot provide evidence for genetic and phenotypic associations between aspects of feeding behaviour and variation in RFI. The decrease in the number of feeding sessions accompanying lower RFI may be a factor contributing to the positive correlation between activity (as measured by pedometers) and RFI, and the lower pedometer counts by HE bulls, measured in the confinement of a postweaning RFI test by Richardson et al. (1999). The implications of these variations in feeding behaviour to digestive function and substrate supply are unknown.

In this experiment there were no strong phenoptypic correlations for traits that could be easily measured on the steers with their RFI in the feedlot. Such traits if available and measured during feedlot finishing or at slaughter could be used as a basis for a payment reward for superior feed efficiency. Although data collected on the steers before feedlot entry were not presented, neither daily weight gain at pasture nor LW or ultrasound measurements of subcutaneous fat depths or eye-muscle area made at feedlot entry were correlated (P>0.05) with subsequent RFI in the feedlot and would not be useful to identify steers that have superior RFI in the feedlot. Without a useful marker trait, measurement of feed intake will continue to be necessary to quantify differences in RFI by steers in the feedlot. A corollary is that RFI as a measure of animal performance is independent of prior growth path and growth checks, unlike growth rate and FCR (Herd and Bishop, 2000).

Implications

In this study of HE and LE steer progeny, selection for postweaning RFI had favourable genetic associations with RFI and FCR in the feedlot. Selection for low postweaning RFI (high efficiency) was associated with steers that ate less per unit gain, with no adverse effects on growth, beef yield or meat quality. Feeding HE steers for slaughter should then be more profitable than feeding LE steers. The genetic associations of RFI with subcutaneous fatness, eye-muscle area, dressing percentage and IMF% suggest that carcass weight, fatness and marble score should be monitored in association with on-going selection for RFI. There was evidence to support the hypothesis that factors other than variation in body composition appear likely to be responsible for most of the observed variation in RFI.

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APPENDIX 5a

ECONOMIC ANALYSIS OF NET FEED INTAKE IN INDUSTRY BREEDING SCHEMES INCORPORATING TWO-STAGE SELECTION

J. A. Archer and S. A. Barwick

Abstract: An evaluation of the benefit of recording net feed intake in industry breeding schemes using a model of investment and gene flow resulting from selection activities was conducted. The analysis considered breeding schemes targeting either the high quality Japanese export market (with steers fed for 210 days) or the grass fed domestic market. Net feed intake (NFI) measurement costs per bull ranging from $150 to $450 were used. Inclusion of NFI, measured on a proportion of bulls in the seedstock sector, as a selection criterion increase annual genetic gain in the breeding objective by up to 16% and 35% for breeding schemes targeting the domestic and Japanese markets respectively. Recording NFI on the top 25% of young bulls (selected based on information available at weaning) in the breeding unit produced close to optimal profit across the breeding scheme for the range of objectives, NFI measurement costs and breeding sector efficiencies considered. Additional profit per cow from one round of selection was $7.84 and $1.41 for breeding schemes targeting the Japanese and domestic markets respectively (assuming a measurement cost of $300). A premium of $153 per bull sold to the commercial sector was required to recover the costs of NFI measurement incurred by the breeding sector. The results indicate that inclusion of NFI as a selection criterion in beef cattle breeding schemes is profitable.

Background

Results from the DAN.75 research project and from research conducted by the Beef CRC have shown large variation in Net Feed Intake (NFI) of beef cattle exists, and that NFI is moderately heritable and so genetic improvement of NFI should be possible (Archer *et al.* 1998; Robinson *et al.* 1997). An analysis of the value of NFI in selecting profitable cattle found that including NFI as a selection criterion (in addition to the traits currently recorded in BREEDPLAN) can improve the accuracy of selection for the breeding objective by up to 42% (Barwick *et al.* 1999). However, NFI is expensive to measure and therefore it needs to be determined whether (and under what circumstances) the return gained from measuring NFI is sufficient to justify the investment in measuring it.

A framework for evaluating selection criteria in an economic context in industry breeding schemes has been developed as a computer program “ZPLAN” (Nitter *et al.* 1994). This approach has been used previously to assess the benefit of including reproductive traits and ultra-sound scanning as selection criteria for Australian beef cattle (Graser *et al.* 1994). The approach models the flow of genes from a breeding sector to the commercial sector, and uses selection index theory to calculate genetic gain and the discounted economic benefits accrued over a specified period. The cost of the breeding scheme is calculated and compared to the benefits obtained to determine whether the breeding scheme is profitable or not. A preliminary analysis has been described by Archer and Barwick (1999) which extended the previous model to examine the economic benefits obtained from incorporating NFI as a selection criterion in beef cattle breeding programs. Further analyses have been conducted which build on the preliminary analysis by incorporating two-stage selection structures to better model the use of NFI in industry breeding schemes and improve the cost-effectiveness of selection.

Model Description

Breeding population structure The structure of the breeding population considered was similar to that described by Graser *et al.* (1994). A self-replacing population of 200,000 breeding cows was modelled, with 10,000 cows in the closed breeding unit (where genetic gain is generated) and 190,000 cows in the commercial herd. Each year the best bulls in the breeding unit were selected (using an index including all available information) for use as sires in the breeding unit and were used for an average of 2.5 years. Replacement dams in the breeding unit were selected from first-calf heifers.

Bulls not selected as sires for the breeding unit were available for selection as sires for the commercial herd. Natural mating was used in the commercial herd with a ratio of 40 cows per bull, and bulls were used for 3 years. Ninety-nine percent of bulls used in the commercial herd were obtained from the breeding unit. The 1 % of bulls selected from the commercial herd, and all replacement dams for the commercial herd, were selected on an index not correlated with the breeding objective. No females passed from the breeding unit to the commercial herd.

Breeding objective Two breeding objectives were considered, one for production of 650 kg steers fed for 210 days for the high quality Japanese market where marbling has a high value (Japanese), and the other for production of 400 kg steers for the grass-fed domestic market where marbling is not valued (Domestic). The breeding objectives and the derivation of economic values for NFI traits were as described by Barwick *et al.* (1999), except that economic values were not discounted as ZPLAN discounts the values internally. Costs and Returns were discounted over a 25 year investment horizon.

Measurements and information sources The selection criteria used were intended to represent the criteria currently used in beef cattle selection and recorded in BREEDPLAN V4.1, plus the new criterion of NFI. Information sources used in the index included records on the individual, sire, dam, paternal half sibs of the individual, paternal half sibs of the sire and paternal half sibs of the dam. All information sources had growth traits of young animals (weight at birth, 200, 400 and 600 days) and carcase traits (fat depth at $12^{th}/13^{th}$ rib and P8 site, eye muscle area and percent intra-muscular fat, measured on live animals using ultra-sound scanning and recorded as separate traits for males and females) recorded. Days to calving and mature cow weight information was available on the dam and on paternal half sisters of the sire and of the dam. Additional records of days to calving were available on the individual and paternal half sisters when selecting replacement females for the breeding unit. Bulls from the breeding unit were selected on an index which also included scrotal circumference records on the sire and on the individual, and NFI of the individual.

Numbers of animals in the half sib groups for each trait category were calculated from herd structure parameters, and were discounted by 0.7 to account for lower effective progeny numbers from finite sized contemporary groups. As the index subroutine of ZPLAN is not able to accept multiple information sources of the same relationship but different animals (eg. male and female half sibs), it was assumed that the female carcase traits were measured on all half sibs, but the number of half sibs in the group was multiplied by 0.8 to compensate for the poorer information obtained from bulls compared with females from ultra-sound scanning data.

Genetic parameters Genetic and phenotypic parameters used were as described by Barwick *et al.* (1999), and were based around current BREEDPLAN parameters and parameters from literature (eg. Koots *et al* 1994). Genetic variance of NFI in the breeding objective traits (on young animals and mature cows) and as a criterion on post-weaning bulls was assumed to be 0.15 $kg^2.day^{-2}$, with a heritability of 0.43, based on latest parameter estimates from the DAN.75 project (Archer *et al.* 1998). Genetic correlations between the NFI criterion and NFI of young animals and mature cows was assumed to be 0.75 and 0.50 respectively. All other phenotypic and genetic correlations involving NFI were assumed to be zero, except for those with fat depth traits which were assumed to be 0.20 based on phenotypic information.

Model calculations A base situation representing the current status quo was modelled where all bulls in the breeding unit were measured for all available criteria except for NFI, and selected for the breeding unit and for the commercial sector based on this information. The number of bulls selected as sires in the breeding unit was set to 20, 50 and 100 to examine the impact of different levels of breeding unit efficiency. The corresponding number of cows mated per bull were 200, 100 and 40 respectively, with the former level corresponding to a breeding scheme using AI exclusively, and the second level approximating a scheme where only natural mating is used.

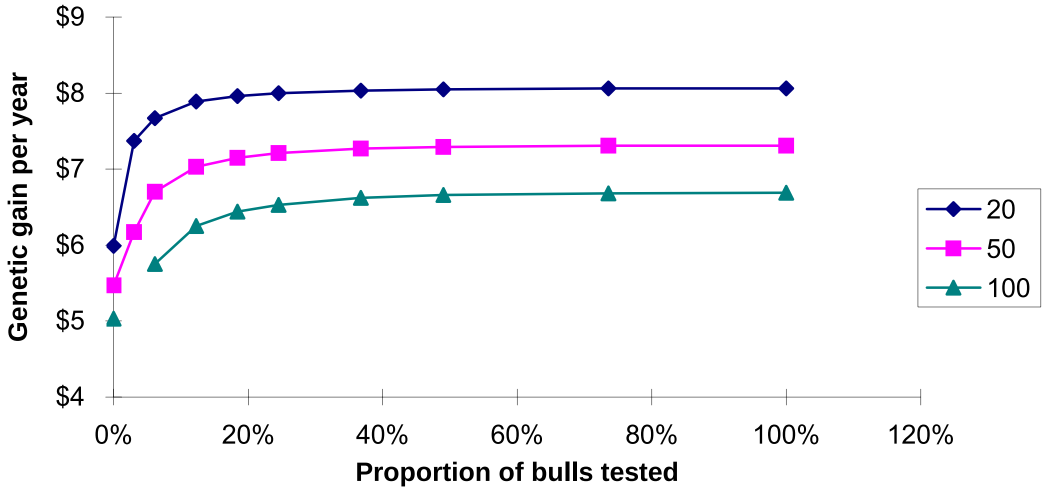
Incorporating NFI into the breeding scheme involved setting up a scenario where a proportion of bulls are selected for measurement of NFI based on information available at weaning (essentially a weight at birth and 200 days of age on the individual, plus information from relatives). Sires for the breeding unit were then selected from the group of animals tested for NFI, based on an index which incorporated all available information as described previously. To consider this two-stage selection process, a subroutine calculating gains from two-stage selection based on the formula of Cochran (1951) and using algorithms developed by Wade and James (1996) was added to the model. Bulls for the commercial unit were selected from all candidate bulls on an index incorporating all information except for NFI.

For each breeding objective (Japanese and Domestic) and for each number of bulls selected per year for the breeding unit (20, 50 and 100), two parameters were varied. Firstly, the number of bulls selected for NFI testing was varied from 100 to 3263 (out of 3264 available candidates). When 100 bulls were used for the breeding unit, results where only 100 bulls were tested for NFI were discarded. The second parameter varied was the cost of measuring NFI, which ranged from $150 to $450 per animal. The current cost of testing cattle in central test stations is up to $500 per animal, including cost of feed (approximately $200), of which at least part should not be counted as a measurement cost. On-farm tests might be considerably cheaper.

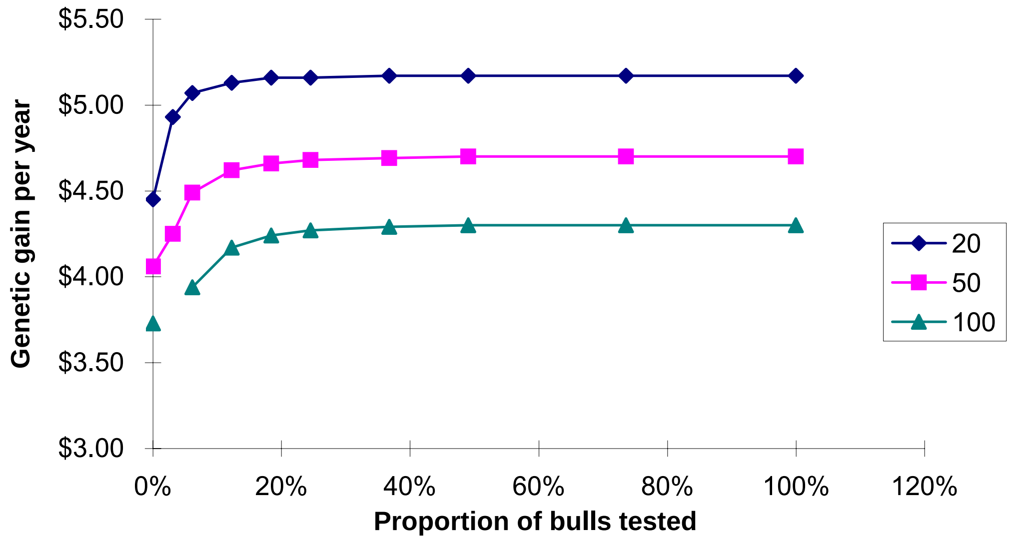
Analysis Outcomes

Figures 1 and 2 show the annual genetic gain in the aggregate breeding value achieved by measuring NFI on varying proportions of bulls in the seedstock sector for the Japanese and Domestic objectives respectively. Inclusion of NFI as a selection criterion was able to increase annual genetic gain in the breeding objective by up to 16% for the Domestic objective and 35% for the Japanese objective. As the proportion of bulls tested rises, annual genetic gain increases, but the trend follows the law of diminishing returns with very little increase in genetic gain occurring when the proportion of bulls tested for NFI increases past 40%.

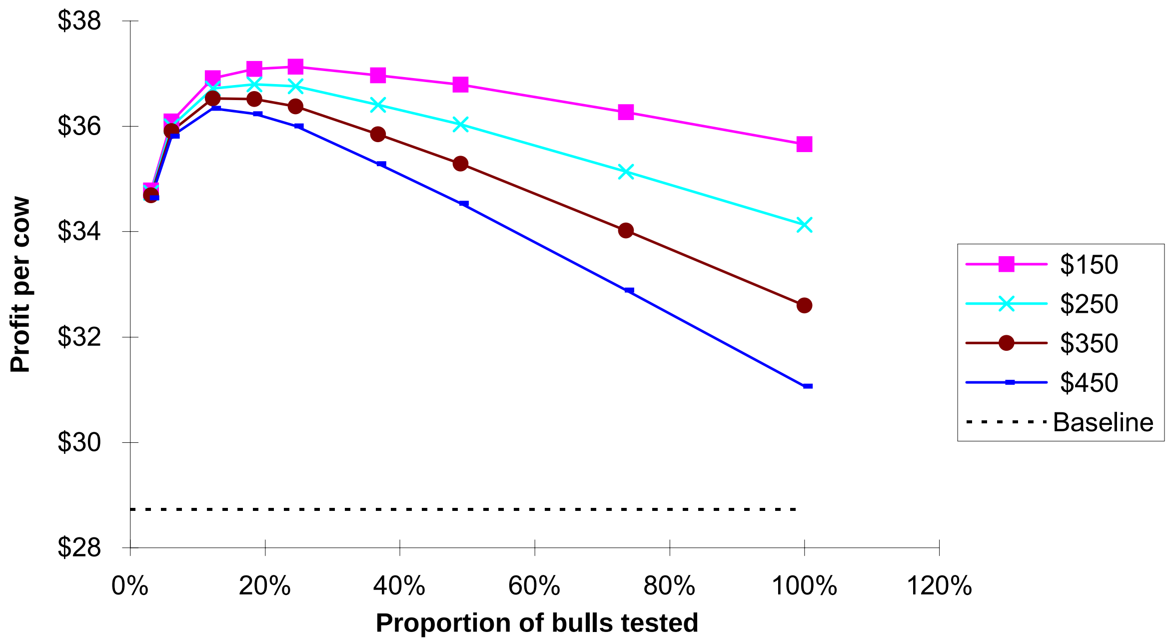
Profit per cow from one round of selection is calculated as the total returns generated by the breeding activity over the whole population (ie. 200,000 cows) minus the costs incurred by the breeding program, and divided by the number of cows in the population. Figures 3 and 4 show the profit per cow from the breeding program targeting the Japanese objective, for different NFI measurement costs and for 20 or 100 bulls selected per year. The baseline represents the breeding program where NFI is not measured (ie. the status quo). The results show that measurement of NFI on all bulls in the breeding unit is profitable (ie. profit per cow is higher than the baseline situation) for the Japanese objective, even when measurement cost is as high as $450 per bull. However, profit was optimised when approximately 20 to 30% of bulls were selected for NFI testing (depending on measurement cost).



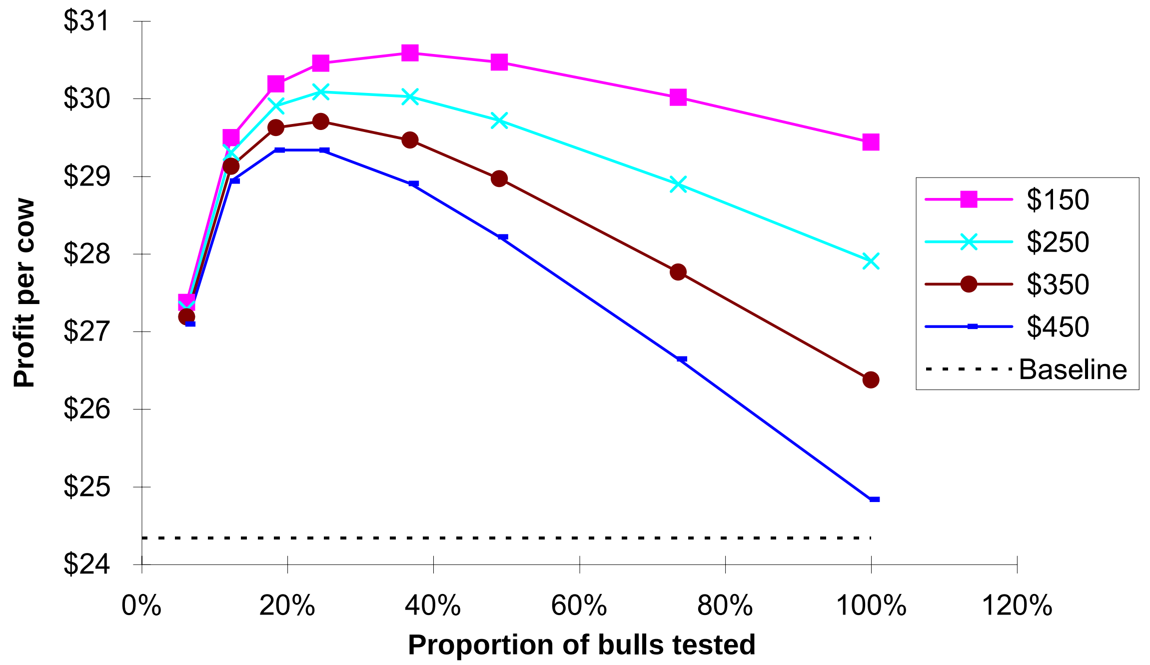
Appendix I - Figure 1: Relationship between genetic gain per year and proportion of bulls tested, when targeting the Japanese export market, for different numbers of bulls selected for use in the seedstock sector (20, 50 & 100).



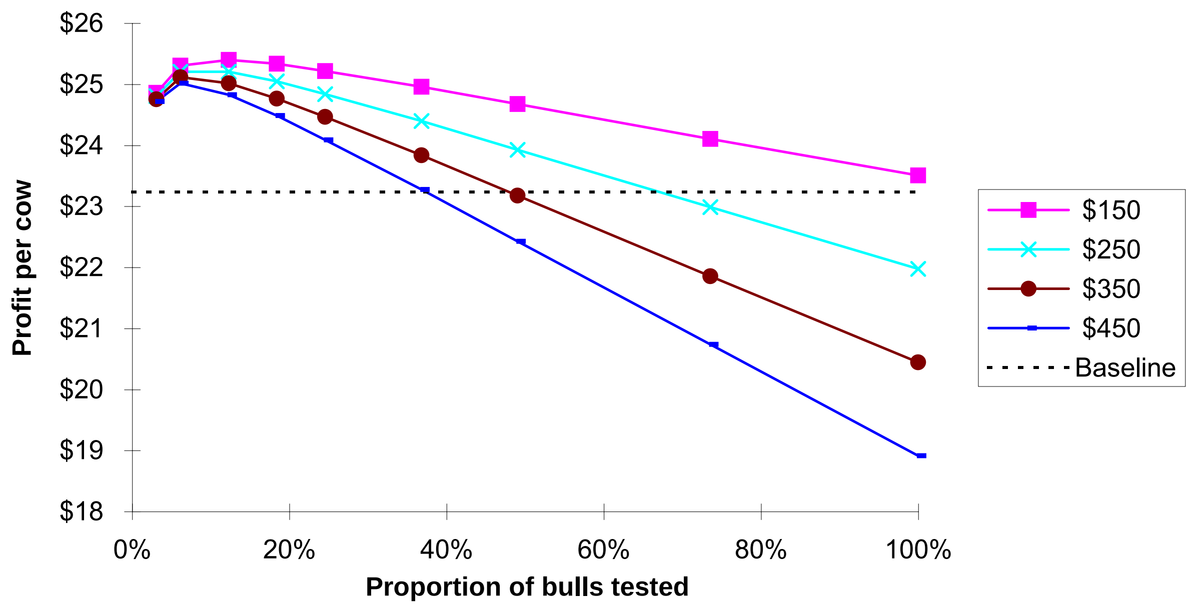
Appendix I - Figure 2: Relationship between genetic gain per year and proportion of bulls tested, when targeting the Domestic market, for different numbers of bulls selected for use in the seedstock sector (20, 50 & 100).



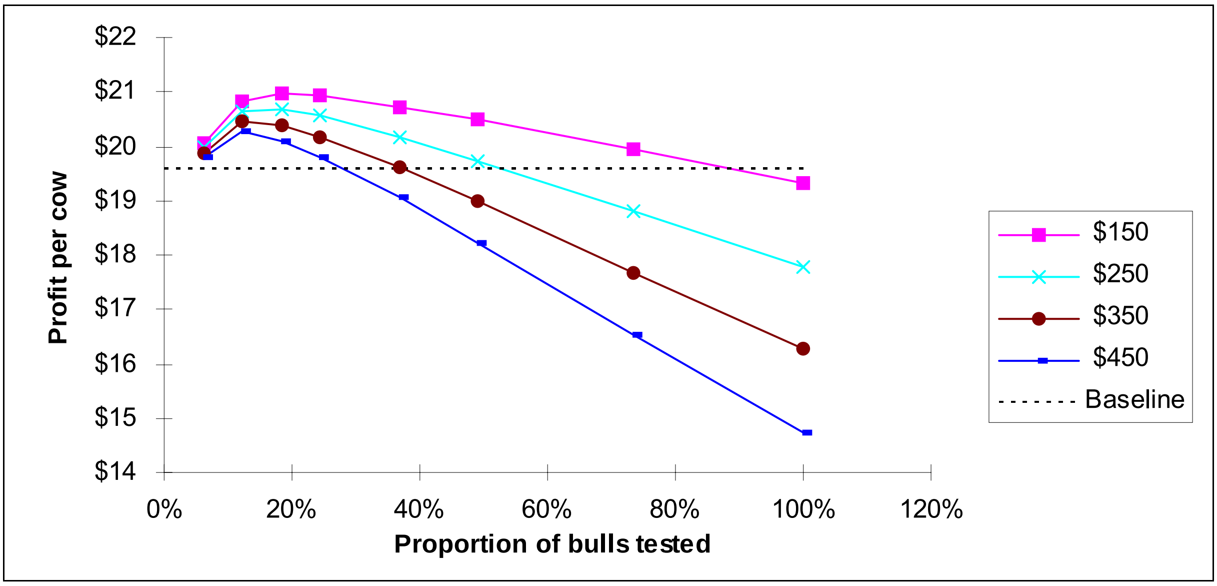
Appendix I - Figure 3: Relationship between profit per cow from the breeding program and proportion of bulls tested for different NFI measurement costs. The objective targets the Japanese market, and 20 bulls are selected for use in the breeding sector per year. The baseline represents a breeding program with no measurement of NFI.



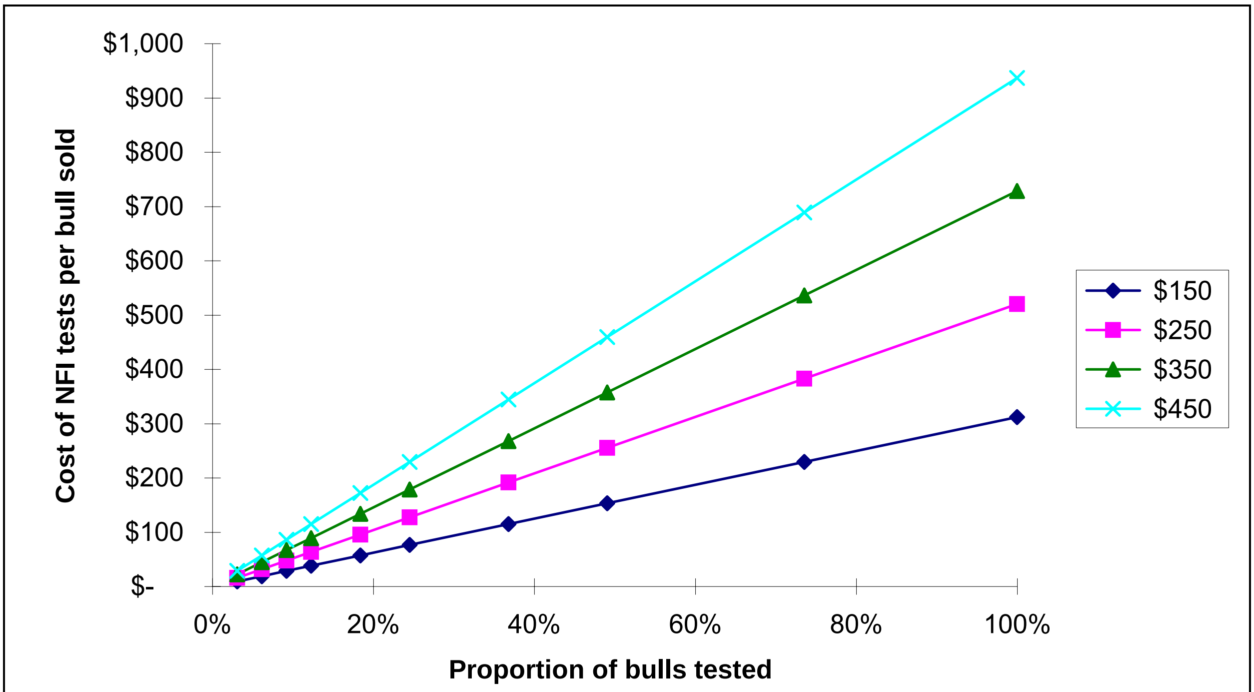
Appendix I - Figure 4: Relationship between profit per cow from the breeding program and proportion of bulls tested for different NFI measurement costs. The objective targets the Japanese market, and 100 bulls are selected for use in the breeding sector per year. The baseline represents a breeding program with no measurement of NFI.



Appendix I - Figure 5: Relationship between profit per cow from the breeding program and proportion of bulls tested for different NFI measurement costs. The objective targets the Domestic market, and 20 bulls are selected for use in the breeding sector per year. The baseline represents a breeding program with no measurement of NFI.



Appendix I - Figure 6: Relationship between profit per cow from the breeding program and proportion of bulls tested for different NFI measurement costs. The objective targets the Domestic market, and 100 bulls are selected for use in the breeding sector per year. The baseline represents a breeding program with no measurement of NFI.



Appendix I - Figure 7: Relationship between proportion of bulls tested for NFI and the premium per bull sold to the commercial sector required to recover the investment in measuring NFI by the seedstock sector. Different costs of NFI measurement ranging from $150 to $450 are assumed.

Figures 5 and 6 show the profit per cow from the breeding program targeting the Domestic objective (for different NFI measurement costs and for 20 or 100 bulls selected per year). When all bulls are tested for NFI, profit is equivalent to the profit for the base situation when measurement cost is $150, and measuring NFI is not profitable for all measurement costs greater than $150. However when only a proportion of bulls are tested, inclusion of NFI becomes profitable even where cost is as high as $450. Profit is optimised, or very close to optimal when between 10 and 25% of bulls are measured. For the Domestic objective, increases in profit per cow are generally in the range of $1-$2 where proportion of bulls tested is close to optimal. Profit from the breeding scheme is also influenced by the number of bulls selected per year for the breeding unit, emphasising that it is important that breeding schemes are operating efficiently and identified elite sires are used widely to maximise returns on investment.

In practice, very few breeders target only the Japanese market, and so recommendations must be able to be applied in situations where multiple breeding objectives are considered. From these graphs it is apparent that measurement of NFI on a proportion of bulls is profitable when elite bulls are selected and used widely in the breeding unit to maximise the impact of the superior genetics in the breeding scheme. Moreover, while differences in profit due to breeding objective, cost of NFI measurement and number of bulls selected exist, profit from the breeding scheme is generally optimised (and is always positive) when around 20 to 25% of bulls are tested. Thus it seems appropriate to recommend testing bulls for NFI when a bull is in the top 25% of the breed based on information available at weaning, and is a potential seedstock sire. While the returns from measuring NFI for the Domestic market are positive, largest gains are made when the objective targets the Japanese market.

In a segmented industry where seedstock herds and commercial herds are owned by different individuals or companies, the seedstock sector must be able to recoup their investment in measuring NFI in the form of premiums obtained for bulls sold to the commercial sector. Figure 7 shows the average premium required per bull used in the commercial sector to cover the extra costs of measuring NFI in the breeding unit, for different NFI measurement costs. In the range where breeding scheme profit is optimised (20 to 25 % of bulls tested) it is apparent that the premium required for bulls sold to commercial breeders is between $100 and $200 dollars. This relatively small premium required to cover costs suggests that commercial implementation of NFI technology will be feasible. This analysis is based on an industry-wide scenario, and does not consider the increase in market share that individuals selling bulls with superior NFI EBVs might achieve.

Recommendations

Recording NFI on a proportion of bulls, selected based on information available at weaning, is economically profitable on an industry-wide basis, for breeding objectives targeting the Japanese grain-fed market and the Domestic grass-fed market. Bulls identified as superior based on an index incorporating NFI and other traits should be used widely in the seedstock sector to maximise the return from the investment in identifying such animals. Bulls to be tested for NFI should be potential seedstock sires and in the top 25% of the breed based on information available at weaning.

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APPENDIX 5B

The Economic Benefits to the Southern Australian Beef Industry from Investment in Genetic Improvement in Net Feed Efficiency

R. M. Herd and L. Davis

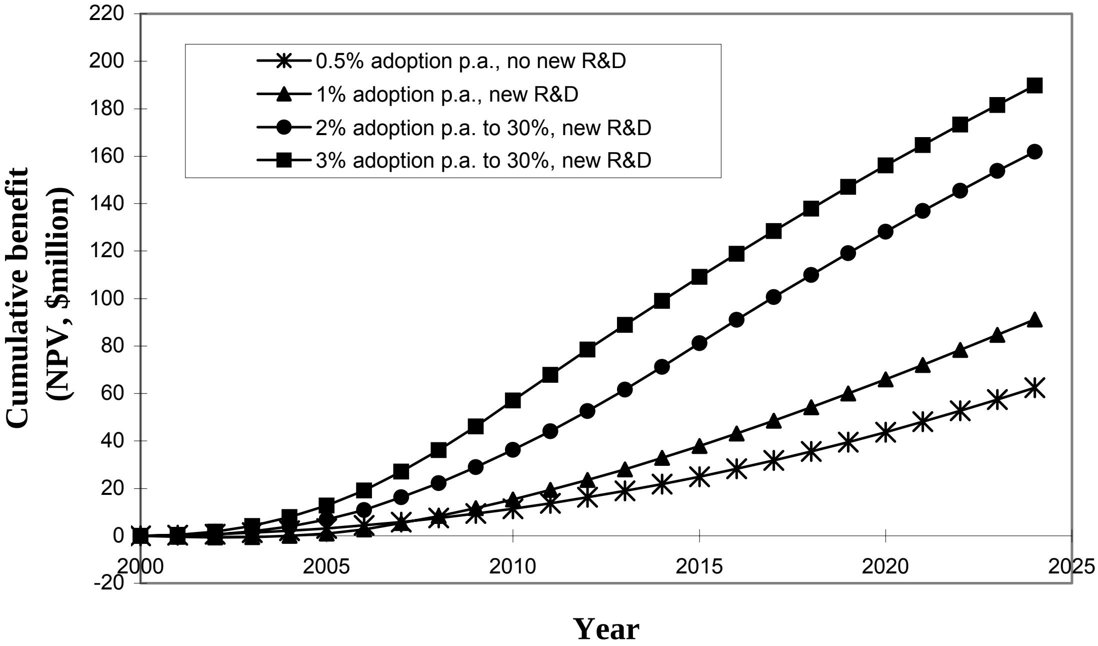
Abstract: The southern Australian beef cattle industry is based on about 5 million cows which are predominantly from British breeds, and it is to this sector of the National industry that the current research findings on net feed efficiency are immediately applicable. The commercial cattle enterprise modelled was based on a 100-cow herd run on native pasture, with progeny being grown on improved pastures. In the production system modelled, surplus heifers were sold at 18 months of age into the domestic market and 80% of the steers were sold for feedlot finishing and subsequent sale as heavy export steers.

For this typical production system the benefits from improvements in efficiency in calves and in the cow herd accrue slowly but are cumulative. Gross margin budget and cashflow analyses for the 100-cow herd showed that, despite the initial cost of purchasing bulls genetically superior for efficiency, over a 25-year investment period the internal rate of return was a healthy 61% and the net present value (NPV) of surplus income over expenses was $21,907. This equates to an annual benefit per cow of $8.76.

The estimated NPV of the benefit from genetic improvement in NFE to the commercial cattle sector of the southern beef cattle industry from research to date, based on an expected rate of adoption 0.5%p.a., is $52million over 25 years. The additional benefit in savings in feed costs in feedlots is $5million to be shared between the producers of more efficient feeder steers, feedlots and other industry sectors. The total NPV of the benefit to the southern beef cattle industry is $62million.

However, without ongoing R&D to continue to demonstrate the value of genetic improvement in NFE to a conservative industry there is a risk of low adoption and failure to capture more of the potential benefit from improvement in feed efficiency. The benefit:cost analysis was redone to include 5 further years of new R&D designed to encourage an industry adoption rate of at least 2%p.a., to achieve 30% adoption after 16years. The NPV of the benefit to industry from this increase in adoption is $162million over 25 years. This is equivalent to an internal rate of return of 291% and has a benefit:cost ratio of 41:1. As shown in the following figure, new R&D that increases industry adoption will greater increase the potential benefit to the beef industry of genetic improvement in efficiency.

The cumulative industry benefit of research on genetic improvement in NFE with a low rate of adoption, and with new R&D to improve the rate of adoption



Industry adoption	Cumulative benefit over 25 years (NPV; $million)	Internal rate of return	Benefit to cost ratio
0.5% adoption p.a., no new R&D	62	n/a	n/a
1% adoption p.a., new R&D	91	81%	23 :1
2% adoption p.a., new R&D	162	291%	41 :1
3% adoption p.a., new R&D	190	685%	48 :1

Introduction

Research conducted at Trangie, and elsewhere, is showing that there is considerable genetic variation in net feed efficiency (NFE) in beef cattle. Selection of sires based on NFI will reduce the feed requirements of their steer and heifer progeny when fed for slaughter and that of their daughters that enter the cow herd, without compromising growth performance or increasing cow size.

Cows are predominantly run on native pastures. Their progeny are generally run on improved pastures until they reach specified liveweights after which they are either sold direct for slaughter or as store cattle for subsequent feeding on pasture or in feedlots until they attain specified market liveweights and fatness. Supplementary feeding with hay, grain and silage is often necessary to fill feedgaps for cows on pasture and to ensure young cattle grow to specification.

The benefits from buying bulls genetically superior for efficiency are expected to be progeny that require less feed without compromise in growth performance. As genes for superior feed efficiency spread through the herd, a commercial cattle producer should be able to run more cows and calves on the same area of pasture and with the same inputs of supplementary feed as previously required for the unimproved herd.

The rate of improvement in efficiency within a herd depends upon the flow of superior genes for efficiency from the sire to his progeny, the rate of replacement of old cows by his heifer progeny, and the rate of genetic improvement in the seedstock herds from which the sire is purchased. This leads to faster rates of improvement in efficiency in young cattle for slaughter compared to that in the cow herd. The economic benefit following the purchase of the first bulls that are genetically superior for efficiency, and their subsequent replacements, will be cumulative over time and its evaluation must the include realistic estimates for the different rates of genetic improvement within the seedstock industry and within the commercial herd over time.

The aim of this paper is to investigate the economic benefits to a commercial cattle producer, and to the southern Australian beef cattle industry, of past and proposed future investment in genetic improvement of NFE.

Analyses

The Australian Cattle Industry can be roughly split into a southern and a northern industry. The southern industry is based on about 5 million cows (calculated assuming 40% of 12million head in southern States are cows; “Beef Industry Situation Statement for New South Wales 1997” - NSW Agriculture Animal Industries Report No.4 by J. Graham). These are predominantly from British breeds and it is to this sector of the National industry that the current research findings on net feed efficiency are immediately applicable.

The commercial cattle enterprise modelled was based on a 100-cow herd run on native pasture, with progeny being grown on improved pastures. It was assumed that all progeny were retained to 18 months of age, with some heifers being retained as replacements for the cow-herd. In the production system modelled, surplus heifers and steers were sold either as grassfed cattle into the domestic market or most of the steers were sold for feedlot finishing and subsequent sale as heavy export (164 days on feed). Approximately 75% of steers of the 500,000 head in feedlots at any time are grown to this specification (Graham 1997).

A standard NSW Agriculture gross margin budget for a commercial herd buying annually one replacement bull for $2500 and selling 18 month-old grassfed heifers and steers for the domestic market was calculated. This enterprise has a gross margin of $354.37/cow. The economic benefit following the decision to invest in (ie. buy) bulls that are genetically superior for efficiency was first examined by looking at the change in cashflow model for a base herd of 100 cows. The initial change in cashflow was calculated for a commercial herd turning off 18 month-old grassfed steers and heifers. The cashflow was then augmented by assuming 80% of steers were sold for feedlot finishing and that the producer received a premium for these steers equal to half the value of feed saved in the feedlot. The following assumptions were made:

1. Having made the decision to invest in genetic improvement in efficiency, the cattle manager would initially buy 3 bulls that are genetically superior for efficiency, and replace them every 3 years, with even more efficient bulls.

2. A bull that known to be genetically superior for efficiency would cost $153 more than the $2500 usually paid for a standard bull. This amount is equivalent to the premium required by the seedstock bull seller to recoup the cost of testing elite

candidate bulls in a two-stage selection program and paying $300 for the cost of measuring feed intake on each bull tested for efficiency (see separate document by Jason Archer for detail).

3. In year 1 it would be possible to buy bulls that are 4% superior in NFE, and then immediately join these bulls to the existing 100 unimproved cows.

4. In year 2, progeny 2% superior for NFE would be born and the benefits in feed savings start to accrue.

5. In year 3, 20 female progeny replace 20 unimproved cows in the 100-cow herd, giving only a 20/100 * 2% (ie. 0.4%) improvement in NFE. Improvement in postweaning NFE is unlikely to have a genetic correlation of unity with cow NFE and a initial value of 0.3% is used in the cashflow model.

6. Annual improvement of 0.6% in NFE is achieved in seedstock herds, resulting in cumulative annual improvement of 0.3% in calves and in the cow herd.

7. As calves and the cow herd becomes more efficient over years, extra cows are purchased such that the annual feed requirements of the new, bigger improved herd are the same as the old unimproved 100-cow herd.

8. Unimproved steers fed in a feedlot ate $404 worth of feed over a 164 day period. This was calculated assuming these steers ate the equivalent of 3%/day of their average liveweight (586kg) whilst in the feedlot of a ration costing $140/tonne. Over years, as steer progeny became more efficient there is a saving in cost of feed fed and this benefit was shared equally between the feedlot operator and the commercial steer producer.

9. Investing in genetic improvement in efficiency is a long term investment and the cashflow model was therefore run over 25 years.

10. At the end of the investment period (ie. 25 years), there will have been an increase in equity in the cow herd equal to the number of extra cows above the original 100 (@ $425 each), plus an additional (say) $2 per cow per year due to their higher genetic merit.

Results and Conclusions

The cashflow for the commercial cow/calf operation was slightly reduced for the first 5 years as a consequence of the initial purchase cost of the more efficient bulls. Benefits from improvements in efficiency in calves and in the cow herd accrue slowly but are cumulative so that over the life of the investment period the internal rate of return was a healthy 42% and the net present value (NPV) of surplus income over expenses was $17,363. This equates to an annual benefit per cow of $6.95.

If 80% of steers were sold for feedlot finishing and a premium paid for them equal to half the cost of feed saved by the feedlot operator, this premium to the commercial cattle producer had an additional NPV of $4,771, or $1.91 per cow annually. This premium for more feed-efficient steers is almost equivalent to a third of the benefit from improvements in efficiency in the entire cow/calf operation, comes at no additional cost, and reduces the initial period of slight reduction in cashflow. For the combined cow/calf and feeder steer operation the NPV of surplus income over expenses was $21,907, the internal rate of return of investing in NFE was 61%, and the net present benefit per cow was $8.76.

The estimated NPV of the benefit from genetic improvement in NFE to the southern beef cattle industry from research to date (DAN.75), based on 5million cows and an expected rate of adoption 0.5%p.a., is $52million over 25 years. The additional benefit in savings in feed costs in feedlots is $5million to be shared between the producers of more efficient feeder steers, feedlots and other industry sectors. The total NPV of the benefit to the southern beef cattle industry is $62million.

However, without ongoing R&D to continue to demonstrate the value of genetic improvement in NFE to a conservative industry there is a risk of low adoption and failure to capture more of the potential benefit from improvement in feed efficiency. The benefit: cost analysis was redone to include 5 further years of new R&D designed to encourage an industry adoption rate of at least 2%p.a., to achieve 30% adoption after 16years. The NPV of the benefit to industry from this increase in adoption is $162million over 25 years. This is equivalent is an internal rate of return of 291% and has a benefit: cost ratio of 41:1.

The importance of improving rates of adoption to maximising the potential benefit to the beef industry from genetic improvement in NFE is demonstrated in the figure above. Clearly, new R&D that increases industry adoption will greater increase the potential benefit to the beef industry of genetic improvement in efficiency.

APPENDIX 6

Industry Implementation Program

S.C. Exton

The ultimate focus of the project in terms of industry implementation was to provide the means by which a BREEDPLAN Estimated Breeding Value (EBV) for net feed intake (NFI) can be calculated. This will allow the Australian beef industry to implement genetic improvement in feed efficiency in breeding programs. In the interim, breeders testing bulls have been provided with either a within-herd ranking, or a trial EBV for their bulls. Trial EBVs for Angus bulls tested to that date were calculated and published in the 1999 Autumn Angus GROUP BREEDPLAN Genetic Evaluation Report (Sire summary) and is attached as Appendix 10.

Individual rankings or trial EBVs for bulls tested have also been presented at bull sales of Ythanbrae Angus, (Yea, Vic.); Te Mania Angus, (Coolac, Vic.); Noonee Angus, (Wellington, NSW); High Spa Angus (Daylesford, Vic.); The Rock Poll Herefords, (Coolah, NSW) and Coota Park Poll Herefords (Woodstock, NSW).

Adoption rates within the beef industry.
Industry testing of bulls for NFI began in 1997, and there has been a steady increase in the number of bulls tested each year since (Figure 1).

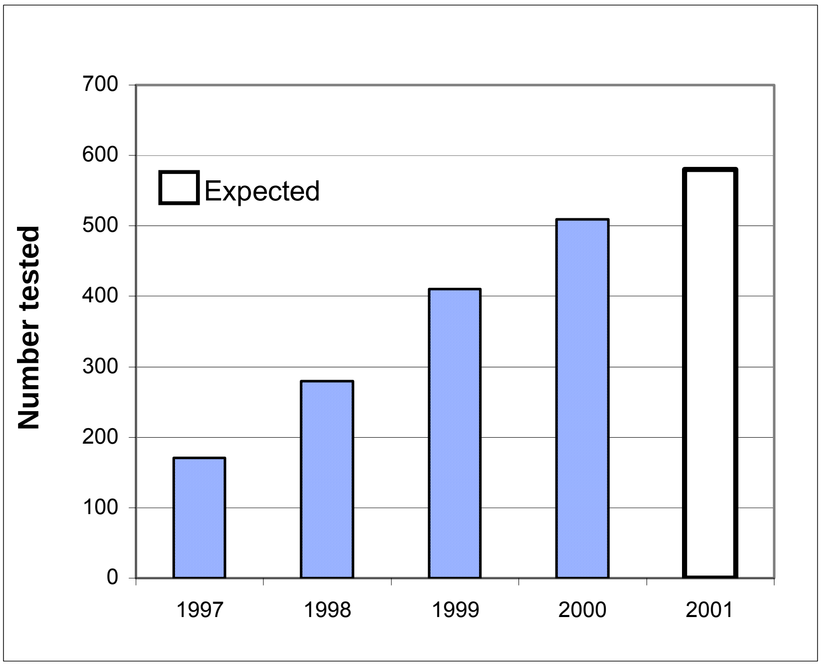


Figure 1: Number of bulls tested each year from 1997.

Industry standards and accreditation of test facilities

To ensure the integrity of data generated across tests and test facilities, and that all data are standardised and accurate to maintain suitability for inclusion in BREEDPLAN analyses, strict protocols for industry testing have been developed and published. The first of these, "Recommended guidelines for Net Feed Efficiency testing in Beef Cattle" was published in July 1998, following two development workshops.

The first workshop, designated an Industry Adoption Workshop, included representatives from NSW Agriculture, Queensland Department of Primary Industry, Agriculture Victoria, University of Adelaide, SARDI, AGBU, Beef CRC, Breed Societies, Consultants, the feedlot industry and the seedstock sector. The second workshop, designated a scientific Adoption Workshop, and including scientists involved in animal breeding and genetics from NSW Agriculture, Agriculture Victoria, Agriculture Western Australia, Beef CRC, AGBU, Adelaide University, SARDI and the Angus Society.

Following further research and industry consultation these guidelines were developed into a draft Standards Manual – testing Beef Cattle for Net Feed Efficiency in March 1999, which was published as the 1st edition in July 1999 and the 2nd edition in March 2001. The second edition is attached as Appendix 11.

An accreditation process for all industry testing facilities has been developed and it is administered by the Performance Beef Breeders Association (PBBA), representing all breeds submitting data for annual BREEDPLAN analyses. Once accredited, PBBA assign facilities a unique code to be used when submitting data for calculation of EBVs.

Established testing facilities

As a result of industry recognition of the relevance of testing for NFI, and select seedstock breeders willingness to pay to have bulls tested, a number of central testing facilities have been established. The following list provides these facilities and contact details for each.

- Vasse Research Station, Vasse, WA.
  Agriculture Western Australia
  (contact Richard Morris)
  ph 0897 806282

- Rutherglen Research Institute, Rutherglen, Vic.
  Agriculture Victoria
  (contact Duncan Rowland)
  ph 0360 304587

- Pastoral and Veterinary Institute, Hamilton, Vic.
  Agriculture Victoria
  (contact Mr Bruce Knee)
  ph 0355 730900

- Coota Park, Woodstock via Cowra, NSW
  (contact Mr Jonathan Wright)
  ph 0263 450326

- Beef CRC Tullimba Research Feedlot, Armidale, NSW
  (contact Mr Matt Wolcott)
  ph 0267 780140 (Available when research requirements allow)

Commercially available testing units

Two companies have developed feed intake recording units for commercial production, that will facilitate the uptake of on-farm testing by seedstock breeders. International Scale Company (Guyra) are manufacturing under licence the units developed by the Cattle and Beef Quality CRC at Tullimba, and Bunge Meats are manufacturing a unit in Gatton, Queensland.

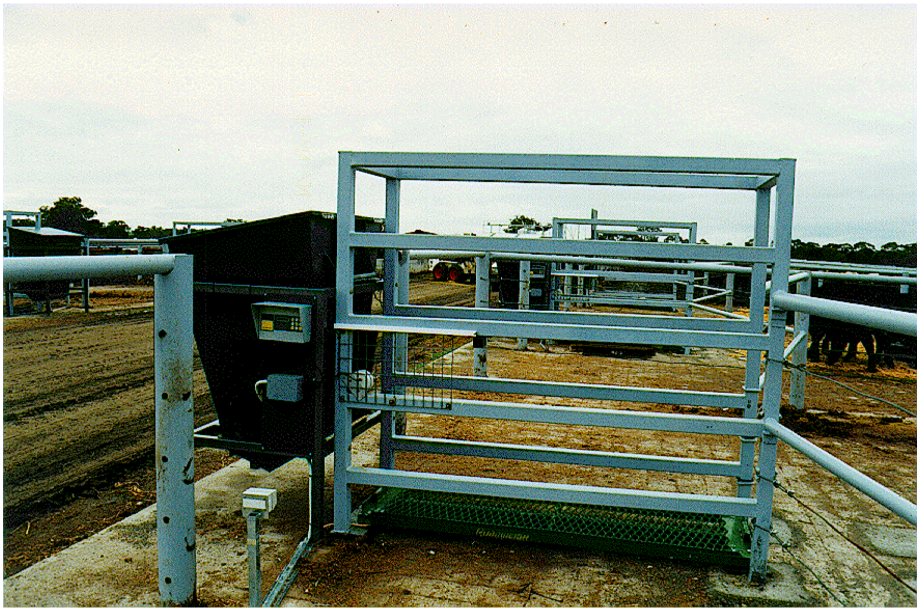


Plate 1: Ruddweigh Feed Intake Recorder by International Scale Company, Guyra

Database development and management.

A database suitable for loading all industry data for eventual calculation of BREEDPLAN EBVs has been developed jointly through collaboration of staff from NSW Agriculture Trangie, ABRI, AGBU and CRC for Cattle and Beef Quality. Handling of data is a two-stage process.

1. Detailed data from a feed intake test will be loaded onto a database maintained by NSW Agriculture at Trangie. The data will be checked for compliance to test requirements, and will be processed into a summarised form. Reports of results from individual animals will be produced and sent to the test station submitting the data.

2. A summarised form of the feed intake result will be sent to ABRI for loading onto the NBRS database. This data will be used to calculate BREEDPLAN EBVs for NFI when these become available.

Major extension activities

Each year, a number of field days, workshops, presentations and seminars have been conducted in order to increase awareness, understanding and potential benefits from adoption of techniques to lower NFI in beef cattle (Table 1).

Table 1: Major events in which presentations have been made.

	Field Days &/or other presentations	Workshops or Seminars
1994	Trangie Beef Industry Technology Day	CRC Program Leaders and Breed Societies
	Trangie Open Day	
1995	Trangie Beef Industry Technology Day	
	Trangie Open Day	
	Beef Improvement Association Conference, Wagga Wagga	
	ALFA Conference, Armidale	
	Orange Meat profit Day	
	Hungerford (Qld) Field Day	
	Mudgee Field Days	
	National Field Days, Orange	
1996	Trangie Beef Industry Technology Day	QDPI and CRC staff, Gatton (Qld)
	Trangie Open Day	
	Millicent (SA) Meat Profit Day	
	Duck Ponds (Qld) Open Day	
	Tropical Beef Centre, Rockhampton (Qld) Open Day	
	North West Ag Expo, Coonabarabran	
	JS Davies beef Forum, Glen Osmond (SA)	
	Wodonga (Vic) Meat Profit Day	
	Chinchilla (Qld) Meat Profit Day	
	Beef-ex, Gold Coast (Qld)	
1997	Trangie Beef Industry Technology Day	UNE Feedlot Management
	Deloraine (Tas) Meat Profit Day	
	Coota Park Efficiency Testing Field Day	
	Armidale Meat Profit Day	
1998	Trangie Beef Industry Technology Day	ALFA Busselton (WA)
	Melbourne (Vic) Meat Profit Day	Cooma Feeder Steer School
	Royal Agricultural Society Show, Sydney	UNE Feedlot Management
	Vasse (WA) Feed Efficiency Field Day	
	Trangie Centre of Excellence Open Day	
	Coota Park Efficiency Testing Field Day	
	Esperance (WA) Meat Profit Day	
	Wagga Wagga Agricultural Research Institute Open day	
1999	Angus National Show and Sale, Wodonga	Angus Advanced Breedplan Workshop, Wodonga
	Coota Park Efficiency Testing Field Day	Murray Grey Beef School, Wodonga
	Vasse (WA) Feed Efficiency Field Day	BREEDPLAN Expo, Armidale
	CRC Tullimba Technology Day	ALFA Council, Sydney
	"The Rock" Feed Efficiency Day, Coolah	UNE Feedlot Management
	Murray Grey National Show and Sale, Wodonga	
2000	Royal Agricultural Society Show, Sydney	NSW Farmers Cattle Committee, RAS
	Vasse (WA) Feed Efficiency Field Day	UNE Feedlot Management
	Ythanbrae Sale and Open Day, Yea (Vic)	
	NSW Ag/BIA/CRC Field Day, Wagga	
	Coota Park Efficiency Testing Field Day	
	National Field Days, Orange	
2001	Adelaide (SA) Meat Profit Day	UNE Feedlot Management
	Vasse (WA) Feed Efficiency Field Day	
	Ythanbrae Sale and Open Day, Yea (Vic)	

APPENDIX 9

Correlated Improvement in Efficiency of Cows and Steers on Pasture following Selection to Improve Postweaning Net Feed Efficiency

R. M. Herd

PRECIS

Feed consumed by the cow herd typically represents 70% of the total feed consumed annually on beef production enterprises in southern Australia. However previous attempts at genetic improvement of feed use have focused on growth rate and feed conversion ratio (FCR) in young cattle. Selection on these measures to improve for feed efficiency has indicated a high correlated response in growth rate and size (Arthur et al., 2002) which is not always desirable in beef cattle.

Net (or residual) feed intake (NFI) was proposed by Koch et al. (1963) as an alternate measure of feed efficiency that would be independent or net of size and growth rate. It is calculated as the amount of feed consumed net of that predicted based on liveweight (LW) and ADG. Cattle with negative NFI eat less than expected for their size and growth rate and are therefore more efficient. Postweaning tests of young bulls and heifers from a number of beef breeds have shown NFI to be heritable (Arthur et al., 2001) and to respond to selection (Renand et al., 1998; Arthur et al., 2002). Genetic variation in NFI in feedlot steers being fed for slaughter has also being shown (Robinson et al., 1999). More recently, divergent selection for postweaning NFI has been shown to be genetically associated with differences in average daily gain, feed conversion ratio and NFI in feedlot steer progeny (Herd et al., 2002). Selection for reduced NFI should produce steers that are more feed efficient in the feedlot and hence more profitable.

Australian beef cows are predominantly run on pasture. Their progeny are generally run on improved pastures until they reach a specified liveweight after which they are either sold direct for slaughter or as store cattle for subsequent feeding on pasture, or in feedlots, to a specified market liveweight and fatness. The benefits to a commercial cattle producer from buying bulls genetically-superior for NFI accrue as genes for superior feed efficiency spread through the herd and enable more cows and steers to be run on the same area of pasture (Exton et al., 2000). However potential young sires are evaluated for NFI on a medium to high-quality ration. The relevance of this measure of efficiency to the efficiency of cows and steers grazing extensive pastures needs to be known.

This key assumption of improved efficiency on pasture following selection for superior postweaning NFI was examined in three experiments. The first was on cows with calves at foot; the second in yearling-age steers growing on improved pastures, and the third was a modelling study on steers raised on improved phalaris/sub clover pasture on the NW slopes and Upper Hunter in NSW. Detailed reports on the experiments follow.

Briefly, the first experiment showed a phenotypic association between the postweaning NFI of the young heifer and her subsequent feed efficiency as a lactating cow on pasture, viz-heifers assessed as being efficiency immediately postweaning are also efficient as lactating cows on pasture. The second experiment showed that selection for low postweaning NFI (high efficiency) was genetically associated with improved feed conversion by steers growing on pasture. Together these results support the assumption that selection for postweaning

NFI will bring correlated improvement in feed efficiency in cows and steers at pasture. The results of the third study indicate that grazing an additional eight high efficiency steers would result in monthly pasture availability being unchanged to that of the unimproved (not selected for NFI) herd.

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EXPERIMENT ONE

(Published in Animal Production in Australia 1998 vol. 22:137-140)

PASTURE INTAKE BY HIGH VERSUS LOW NET FEED EFFICIENT ANGUS COWS

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Abstract: Pasture intake was measured in 41 lactating cows that had previously been ranked as either above average for postweaning net feed efficiency (HE), or below average (LE), when tested as young heifers on a pelleted ration. The study demonstrated a phenotypic association between the net feed efficiency of the young female and her later efficiency at pasture. High net efficient cows were 7% heavier (P<0.05), had similar subcutaneous fat stores and reared calves of similar weight to LE cows, but consumed no more feed than the LE cows. The advantage in efficiency of HE cows, when expressed as a ratio of calf weight to cow feed intake, whilst numerically large (15%), was statistically non-significant (P=0.07). That the HE cows were heavier, but no fatter than the LE cows, could imply an association of efficiency with maturity pattern.

Keywords: cow efficiency, pasture intake, alkanes

Introduction

Feed consumed by the cow herd typically represents 70% of the total feed consumed annually on beef production enterprises in southern Australia. Recent research has shown large variation in feed intake by young cattle that is independent (net) of their size and growth rate (Herd *et al*. 1997). This measure of efficiency has been termed net feed efficiency, is heritable and responds to selection (Herd *et al*. 1997). Should this variation in efficiency in young cattle also be associated with variation in efficiency when they are older, then breeding for superior net feed efficiency could reduce the feed cost for the cow herd.

However, postweaning net feed efficiency is currently assessed in confined young cattle individually fed a medium-quality pelleted ration (Herd *et al*. 1997). The relevance of this measure of efficiency to the efficiency of cows grazing extensive pasture needs to be determined. The aim of this study was to evaluate whether heifers previously tested and ranked for postweaning net feed efficiency were more or less efficient as lactating cows consuming pasture.

Materials and Methods

Animals

The study was conducted at the NSW Agriculture Research Centre at Trangie. Fifty-six cows (three years old; second lactation) that had previously been tested and ranked for postweaning net feed efficiency were available. The 22 most efficient and 22 least efficient were selected to have their pasture intakes measured. Details of the postweaning net feed efficiency-test procedure are available in Herd *et al*. (1997). The cows and calves had been grazing an irrigated oat crop and were moved onto an ungrazed oat crop adjacent to the cattle yards, two days before insertion of intraruminal alkane capsules. The cows were in the third month of their lactation when tested in October 1996.

The cows and calves were weighed immediately off pasture, at the start of the measurement period, and again after 11, 14 and 18 days. The mean liveweight (LW) of each animal was calculated for the period. Subcutaneous fat thickness at the 12/13th rib and P8 rump site was measured by ultrasound on the cows at the start of the measurement period.

Measurement of intake and diet composition

Cows were dosed (on day=0) with an intraruminal controlled-release device (CRD) containing 7.53 g of C32 and C36 alkane. The CRDs were supplied in two batches by Captec (NZ) Ltd, and manufactured and tested to deliver either 355 (batch 1) or 410 mg/day (batch 2) of each alkane. The expected duration of payout of alkane by the CRDs was 21 and 18 days, respectively, assuming no delay in start of release of alkane after dosing. On day 0, six cows had faecal samples taken for measurement of pre-dosing or background levels of C32 and C36 alkanes. All the cows were faecal sampled once only on each of three days (7, 11, 14). If a faecal sample could not be easily obtained from a cow, she was mustered the next day and a sample obtained. Faecal samples were taken mid-morning. Diurnal variation in the faecal alkane ratios used in calculating intake were presumed to be negligible with the synthetic alkanes being administered by CRD (Dove and Mayes 1996).

The diet consumed by the cows during the feed-intake measurement period was determined on day 11. Samples of the pasture that the cows were observed to be grazing were cut and the least-squares combination of alkane profile of the pasture species which best explained the alkane profile of the faeces calculated (Dove and Moore 1995). The concentrations of plant alkanes were adjusted for differential recoveries in faeces using assumed recoveries for C33=84% and C31=80% (Dicker *et al*. 1996), and for C29=75% and C27=70% (assuming recoveries declined by 5% units for each 2-carbon reduction in alkane chain length, extrapolated from Figure 2b in Dove and Mayes 1991).

Intake of dry matter (DM) was calculated using the formula of Dove and Mayes (1991), assuming equal recovery of the C32:C33 and C31:C32 pairs, and after adjusting faecal alkane concentrations for assumed differences in recovery. The recoveries used for dosed synthetic alkanes were 96% for C32 and C36 (Dicker et al. 1996). Faecal output was calculated as (C36 dose rate x C36 recovery)/faecal C36 concentration, and digestibility of DM as (intake minus faecal output)/intake.

The nitrogen and digestible-DM content of dried (60^{o}C) pasture components was measured *in vitro* by the Feeds Evaluation Service of the University of New England, Armidale. The alkane compositions of dried pasture samples and faeces were analysed by gas chromatography. Excessively large variation (c.v.>50%; equivalent to exceeding a 95% confidence level that is ±100% of the mean) in dosed C36 alkane for the three faecal samples collected from each cows was taken as evidence of malfunction their CRD or interruption to normal intake. On this basis, data for three cows were excluded from the results. Differences between means for the HE and LE groups were tested using the t-statistic, computed assuming unequal variances.

Results

Diet composition

The cows were observed to be eating mostly the grained-filled heads of the immature oat plants, a little of the regrowing green tops of previously grazed plants and, perhaps, a small quantity of the sparse ryegrass at ground level that was regrowing from the previous year. However, comparison of the alkane composition of these feeds with the alkane profile in faeces revealed that about one-quarter of the herbage being consumed was ryegrass, with the remainder being the grain-filled heads, and no evidence for consumption of the regrowing shoots from previously grazed oat plants.

Table 1: Nitrogen and digestible DM content, and alkane composition, of the main components of the grazed oat pasture

	Grain-filled heads	Regrowing oat tops	Ryegrass
Nitrogen (% DM)	1.6	3.6	1.1
Digestible DM (%)	64	69	44
C27 (mg/kg DM)	11	52	57
C29 (mg/kg DM)	42	62	144
C31 (mg/kg DM)	90	64	248
C32 (mg/kg DM)	3	7	7
C33 (mg/kg DM)	12	31	50

There was no difference between the HE and LE cow groups in the proportion of grain-filled heads in the diet consumed (mean $\pm$ s.e. = 71 $\pm$ 4 % and 76 $\pm$ 2 % respectively; P=0.19). From the amounts of each pasture component being consumed, the alkane composition of the diet for each cow was calculated for subsequent use in computing each cow's intake of DM. The nitrogen, digestible DM and alkane content of the pasture components is shown in Table 1.

Performance of the alkane CRDs

The mean intake of DM by all cows was 10.1 and 12.9 kg/day calculated using the C31:C32 and C33:C32 ratios respectively, and assuming similar recoveries in faeces for the alkanes in each ratio. Failure to adjust for differences in recovery can result in erroneous estimates of intake (Dicker *et al*. 1996). Intakes were recalculated using the recoveries assumed above. Mean DM intake estimated by the adjusted C31:C32 and C33:C32 ratios increased by 23 and 16%, to 12.4 and 15.0 kg/day respectively. This is in close agreement with the 20 and 15% increases predicted by Dove and Moore (1995) for the 12 and 16 percentage-unit differences in assumed alkane recoveries. The discrepancy in intake estimates between the two alkane pairs suggested imperfect adjustment for differences in recovery; the ratio of the mean of the adjusted faecal C31 and C33 values, to the adjusted C32 content, was used to recalculate intakes. The resultant mean intake by all the cows was 12.9 kg DM/day. This is close to the intake of 12.6 kg DM/day predicted by SCA (1990) for 600 kg Angus cows eating a 75% oat/25% ryegrass diet (assumed metabolisable energy content 8.8 MJ/kg DM) and gaining 0.4 kg/day (as in this study), and producing 7.5 kg/day of 3.2% fat and 8.9% solids-not-fat milk (unpublished results for similar Trangie cows).

Liveweights, DM intakes and efficiency

The HE cows were heavier than the LE cows during the intake measurement period, but no fatter (Table 2). Calves from both cow groups were, on average, the same weight and age.

Although 7% heavier, the HE cows consumed no more feed DM per day than the LE cows (Table 2), and on this basis were more efficient. Efficiency is often expressed as a ratio of output/input. In this study the ratio of calf weight sustained by the cow divided by the feed intake of the cow, was calculated. During the measurement period, the HE cows sustained 15% more weight of calf per kilogram of feed eaten than did the LE cows, but this difference was not significant (P=0.07). There was no evidence that either group of cows were more able to digest the DM in their diet.

Table 2: Cow and calf liveweights, pasture intake and efficiency for lactating cows that had previously being tested for postweaning net feed efficiency and ranked as high (HE) or low (LE) net feed efficient. Values are means ± s.e.

	HE cows	LE cows	Significance[a]
Number of cows	20	21	
Cow LW (kg)	618 ± 16	577 ± 11	*
Cow rib fat (mm)	12.0 ± 0.7	11.7 ± 0.8	n.s.
Cow rump fat (mm)	15.8 ± 0.8	15.6 ± 0.8	n.s.
Calf LW (kg)	111 ± 4	104 ± 4	n.s.
Calf age at start (days)	69 ± 2	63 ± 3	n.s.
Cow DM-intake (kg/day)	12.5 ± 0.7	13.2 ± 0.7	n.s.
Calf LW / cow DM-intake (kg/kg.day)	9.3 ± 0.5	8.1 ± 0.4	n.s. (P=0.07)
DM digestibility by cow (%)	60 ± 2	62 ± 1	n.s.

[a] * Means are significantly different (P<0.05); n.s. means are not significantly different (P>0.05)

Discussion

This study was in response to the question: do young heifers that rank highly for net feed efficiency in postweaning tests conducted at the Trangie Research Centre grow to become more efficient cows at pasture? The results show that this sample of phenotypically-selected HE cows were more efficient at pasture than the LE cows. The HE cows were 7% heavier, had similar subcutaneous fat stores and reared calves of similar weight to LE cows, but consumed no more feed DM than the LE cows. If the HE cows are still heavier at cull age then there would be a small economic advantage to the HE cows from the increased value of the heavier cull cow. That the HE cows were heavier, but no fatter than the LE cows, could imply an association of efficiency with maturity pattern.

The advantage in efficiency of HE cows, when expressed as a ratio of calf weight to cow feed intake, whilst numerically large (15%), was statistically non-significant (P=0.07). Strictly, this means there was no conclusive demonstration of an advantage in this important production ratio. However, the combination of errors incurred using an indirect measure of intake, measurement of intake and LWs over a short period of time (8 and 28 days respectively) and their combination into a ratio, probably increased variation in this measure of efficiency such that a difference in efficiency of this magnitude could not be demonstrated statistically without measuring a larger sample of cows. There was certainly no evidence that the HE cows and calves were less efficient than the LE cows and calves.

The use of alkane technology to estimate diet composition revealed that the cows were consuming a diet different to the one judged by simple observation. Failure to recognise this in studies at pasture, and to account for the individual diet selection of each cow, could result in erroneous values for herbage alkane concentration being used for calculation of intake. The discrepancy in intake estimates between the adjusted C31:C32 and C33:C32 ratios suggested imperfect adjustment for differences in recovery. The ability by the cows to digest

DM, as calculated from the alkane data, was slightly lower than the digestible DM content reported for the oat pasture, but not as low as might be expected for a diet apparently with one-quarter as low-digestible ryegrass. The assumed values used for recoveries came from other experiments. Their determination for the diets under study is important to both determination of diet composition and to measurement of intake. These considerations, plus the c.v. of the release rate for each batch of CRDs (6 and 9% for those used here), add to the error in measurement of intake by individual animals. They are unlikely to be a source of bias so that alkanes and CRDs remain a useful tool to compare the intake by groups of cattle.

This study has demonstrated a phenotypic association between the postweaning net feed efficiency of the young female and her later efficiency at pasture. The advantage may be as small as an improvement in the cull value of the heavier HE cow with no increase in feed eaten, but could include increased weight of calf per unit of feed eaten by the HE cow, although the evidence for the latter was inconclusive. Breeding young cattle for improved net feed efficiency has been shown to produce improvements in feed conversion ratio, and perhaps yield, in yearling steers being fed in a feedlot for slaughter (Richardson *et al*. 1998). Demonstration that selection for improved postweaning net feed efficiency will improve the efficiency of cows, and measurement of the phenotypic and genetic correlation with other important production traits continues at Trangie.

Acknowledgments

We thank S. Sinclair for the alkane analyses and J. Wright, T. Snelgar, D. Mula and S. George for their assistance. This work was funded by NSW Agriculture and the Meat Research Corporation.

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EXPERIMENT TWO

(Published in "The Beef Program-Challenges and Future Directions", NSW Agriculture Beef Products Program Conference, Dubbo, 2001, page 19.)

SELECTION FOR POSTWEANING NET FEED EFFICIENCY IMPROVES FEED CONVERSION IN STEERS ON PASTURE.

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Feed is a major cost of beef production. Net feed efficiency describes variation in feed intake that is independent (net) of size and growth rate. It is measured as residual (NFI) feed intake (NFI), calculated as the amount of feed consumed by an animal, net of its expected requirements for maintenance and production. Postweaning results from British breed cattle fed a medium quality ration have demonstrated that variation in NFI exists, and that the trait is moderately heritable (Archer *et al.,* 1998). The aim of this experiment was to determine whether selection on postweaning NFI produced differences in feed efficiency in steer progeny on pasture.

The Angus steers were born in July/August 1997 at the NSW Agriculture Research Centre, Trangie NSW, of high efficiency (HE) or low efficiency (LE) parents selected on postweaning NFI (details of selection procedure described in Herd *et al.,* 1997). The steers were weaned in March 1998 and then transported to the "Shannonvale" Research Station, near Glen Innes in northern NSW. They were grown on improved pastures. Pasture intake by 26 HE and 27 LE steers was measured during December (Spring) 1998 using the alkane technique previously described by Herd *et al*. (1998).

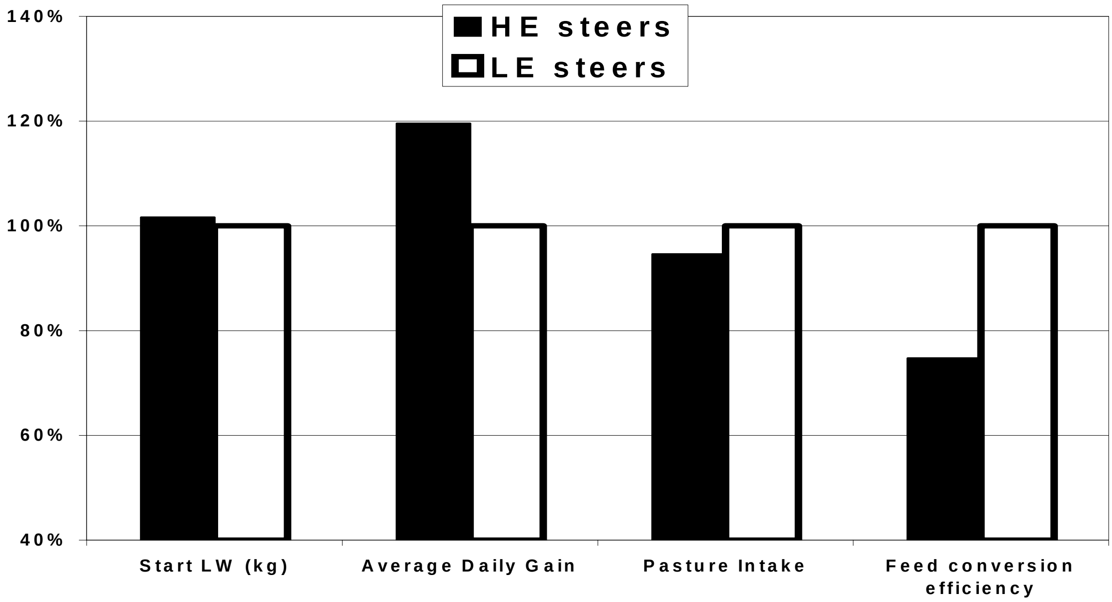

Figure 1: Mean liveweight (kg), gain (kg/day), pasture intake (kg DM/day) and feed conversion ratio (feed/gain) of Angus steers on pasture following a single generation of divergent selection for postweaning NFI.

Alkane profiles in faeces indicated that both efficiency classes of steers were consuming a similar diet with 69% ryegrass (drymatter (DM) basis). There was little difference in liveweight at the start of the measurement period (HE steers 371kg:LE steers 365kg) but the HE steers grew faster than the LE steers (0.49 *v* 0.41kg/day;P<0.05) without eating more (3.5 *v* 3.7kg DM/day), and as a result the HE steers had a superior feed conversion ratio (7.4 *v* 9.9;P<0.05; Figure 1).

Selection against postweaning NFI has being shown to improve the efficiency of progeny in postweaning tests for NFI (Herd *et al.,* 1997) and when fed in a feedlot (Richardson *et al.,* 1998). There is also evidence for a favourable phenotypic association between postweaning NFI, and cow/calf efficiency on pasture (Herd *et al*., 1998) and mature cow NFI on a pelleted ration (Arthur *et al*., 1999). This experiment has demonstrated a favourable response in efficiency of steers on pasture following selection of their parents against postweaning NFI. Together these results suggest that it is possible to genetically reduce the amount of feed required without compromise to production (*ie*. to liveweight and growth rate). Assuming no change in carcase quality or reproductive performance, an improvement in the profitability of beef production should follow.

Financial support came from the Cooperative Research Centre for Cattle and Beef Quality, Meat & Livestock Australia, and NSW Agriculture. We thank P. Kamphorst, K. Dunbar and J. Nelson for their skilled technical assistance.

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EXPERIMENT THREE

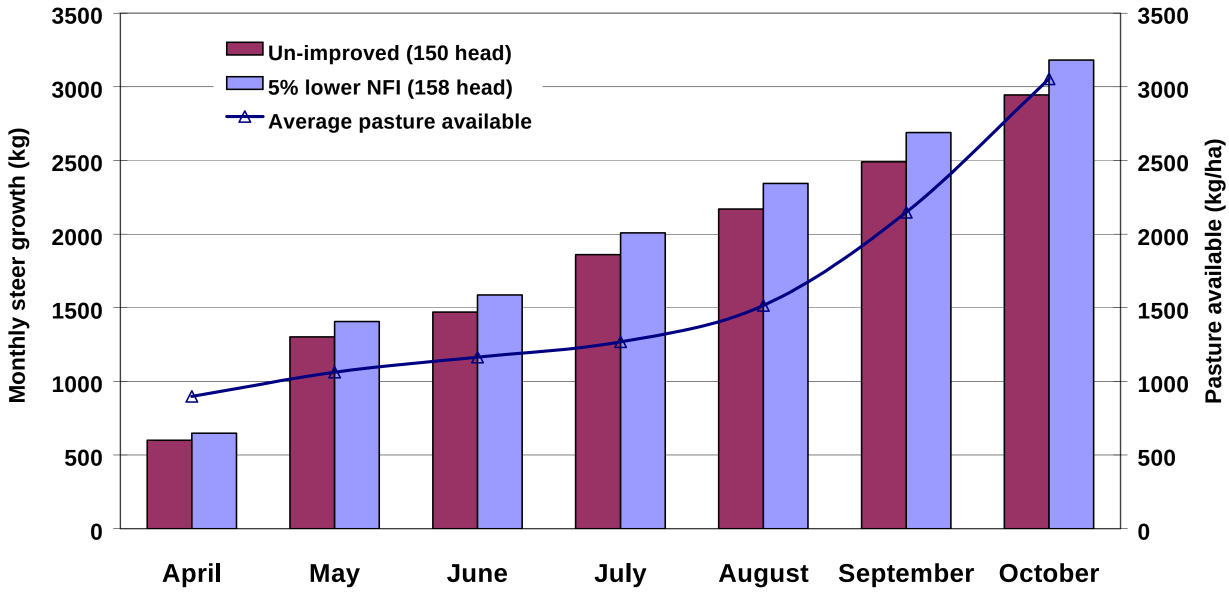
Modelling potential benefits to the beef industry from selecting for improved NFI when steers are grown on pasture

S. C. Exton

In order to assess and demonstrate potential benefits that could be obtained by commercial breeders selecting for lower NFI, a model of two groups of steers grazing a paddock of 100 hectares of improved phalaris/sub clover in the NW Slopes and Upper Hunter was evaluated, using Prograze version 4. Pasture legume content of 15% and digestibility of 70% were assumed. Steers are British-breed, dam mature weight 500 kg. Estimates for animal intake and liveweight gain are provided by Grazfeed.

Total animal growth from an un-improved herd of 150 steers is compared with total animal growth from a herd with 5% lower NFI maintained at a stocking rate that provides monthly pasture availability not different to that of the unimproved herd. Steers are weaned at 240 kg at 1st April and are grown to 367 kg at 30th October. Pasture available at 1st April is 600 kg/ha, and average growth (Prograze) is:

April	17 kg/ha/day	August	20 kg/ha/day
May	14 "	September	34 "
June	13 "	October	43 "
July	14 "	.	



Modelling of pasture availability is by Proplus version 1.1.11.

Figure 1: Additional growth from grazing high-efficient steers (5% lower NFI) at a stocking rate that resulted in the same monthly pasture availability as that from an un-improved group.

Results show that grazing an additional 8 high-efficiency steers would result in monthly pasture availability being unchanged to that of the unimproved herd. Additional liveweight gain from the high-efficiency herd under these conditions is 8%, or 1,027 kg in 7 months.

APPENDIX 10

APPENDIX 11

Testing Beef Cattle for NET FEED EFFICIENCY

- Standards Manual -

Steve Exton
NSW Agriculture, Trangie

This manual has been developed in conjunction with research project DAN.75, funded jointly by NSW Agriculture and Meat and Livestock Australia and conducted at Trangie Agricultural Research Centre; Research conducted by the Co-operative Research Centre for the Cattle and Beef Industry (Meat Quality) at Armidale; and a series of workshops involving key representatives from the Australian beef cattle industry.

These workshops, held at Armidale and Trangie, included representatives from:

NSW Agriculture
Performance Beef Breeders Association
Animal Genetics and Breeding Unit
Agricultural Business Research Institute
CRC for the Cattle and Beef Industry
Meat Research Corporation
Agriculture Victoria
Agriculture Western Australia
Queensland Dept. of Primary Industries
University of New England
University of Adelaide

South Australian Research & Development Institute
Angus Society of Australia
Australian Hereford Society Ltd.
Australian Poll Hereford Society Ltd.
Australian Limousin Breeders Society Ltd.
Murray Grey Beef Cattle Society Inc.
Santa Gertrudis Breeders Association
Shorthorn Society of Australia
Seedstock sector of industry
Lotfeeding sector of industry
Commercial sector of industry

Performance Beef Breeders Association

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ISBN 0 7347 1084 4

First printed July 1999
Revised March 2001

of the information with the appropriate representative of their State Department of Agriculture, the Performance Beef Breeders Association or Breed Society.

Testing Beef Cattle for
NET FEED EFFICIENCY

- Standards Manual -

FOREWORD

This manual outlines the standards required for accreditation by the Performance Beef Breeders Association (PBBA) as a testing facility eligible to submit data to breed society databases for the purpose of generating BREEDPLAN Estimated Breeding Values (EBVs) for Net Feed Efficiency (NFE).

Testing animals for NFE allows for comparison of individual animals within a test group. The main objective, however, is to generate EBVs of potential sires by removing non-genetic variation as much as possible. Ideally, data from all NFE tests within and between locations should be able to be pooled for the estimation of EBVs for as many sires as possible. Standardising the test procedures within and between locations reduces non-genetic variation, and with adequate genetic linkages between tests, data from different tests can be used for estimating EBVs.

This manual contains descriptions of the various components of testing for NFE, and in many cases outlines recommendations or alternatives to the systems available. Each of the points listed as the Code of Practice for that particular section is mandatory, and must be included in the testing procedures.

It is expected that NFE tests will be conducted either “on-farm”, where all animals originate from the same property, or at a “central-test” facility where animals from a number of origins are assembled at a designated location for testing under uniform conditions. The recommendations and requirements provided apply to both types of testing unless otherwise stated.

GLOSSARY OF TERMS

Accreditation	Following a successful audit in accordance with this manual, data submitted to BREEDPLAN will be accepted for calculation of EBVs.
ABRI	Agricultural Business Research Institute at University of New England (UNE) Armidale. Is responsible for data processing and commercial operation of BREEDPLAN.
AGBU	Animal Genetics and Breeding Unit at joint institute of NSW Agriculture and UNE. Is responsible for research, development and management of BREEDPLAN.
Application for accreditation	Application to PBBA to be accredited as a testing facility, accepting the requirements of the Standards Manual and outlining the procedures adopted to meet those requirements.

BREEDPLAN	The Australian genetic evaluation system for Beef Cattle. BREEDPLAN is overseen by a management committee representing Breed Societies, State Government and research bodies.
Code of Practice	The minimum requirements that have to be met in each case to achieve accreditation.
CRC	Co-operative Research Centre for the Cattle and Beef Industry (Meat Quality) with head office based at UNE and the Tropical Beef Centre at Rockhampton Queensland.
EBV	Estimated Breeding Value. A measure of an animals genetic merit for a given trait provided by BREEDPLAN.
GROUP BREEDPLAN	System providing genetic analysis and comparison across herds within a breed.
NFE	Net Feed Efficiency. Refers to the difference in animals feed intake independent of requirements for growth rate and body weight.
NFI	Net Feed Intake. The trait calculated by phenotypic adjustment of feed intake for body weight and growth as a measure of NFE.
PBBA	Performance Beef Breeders Association. A technical committee representing each of the Breed Societies that conduct annual GROUP BREEDPLAN analyses.
Test	Measurement and recording of individual animals feed intake and body weight over a specified period for the purpose of determining NFI.

1. ACCREDITATION OF TESTING FACILITIES

Persons or companies wishing to gain accreditation as either an “on-farm” or “central” test facility should:

(a) Notify the PBBA and the relevant Breed society or societies of their intent.

(b) Complete and submit to PBBA an “Application for Accreditation” (available from PBBA or breed societies), agreeing to abide by the requirements of this manual, and outlining intended procedures in accordance with these requirements.

Acceptance of this application and subsequent accreditation as a testing facility will be at the discretion of the PBBA.

The PBBA Secretariat is currently care of the Australian Limousin Breeders Society Ltd, PO Box 262, Armidale, NSW 2350. Ph: (02) 67711648, fax: (02) 67729364. E-mail: limo@northnet.com.au.

With ongoing development of testing procedures and NFE research, periodic changes to the Standards Manual may be made. In the case of significant changes being made, an amended edition of the Standards manual will be issued to all accredited facilities. In the case of minor changes, all accredited facilities will be notified of that change. It remains the responsibility of individual managers of testing facilities to ensure that the current edition of the Standards Manual is addressed in their application for accreditation.

The purpose of the application for accreditation is to describe the system developed at that testing facility to satisfy the requirements of the Standards Manual to achieve accreditation. It is expected that the application will address the procedures, systems, resources and responsibilities that are, or will be, utilised to satisfy the accreditation requirements.

Once a facility is accredited, if changes to the testing procedures are proposed, an amended application for accreditation must be submitted to the PBBA for approval before data generated from the modified system can be accepted for BREEDPLAN analysis.

Code of Practice:

Each testing facility will submit an application for accreditation that acknowledges the requirements of this manual and outlines procedures or systems in place to satisfy each of the requirements of the Standards Manual, and which must be approved by the PBBA prior to accreditation.

The relevant sections of the application for accreditation must be assessed following notification of any changes to the Standards manual, and appropriate modifications made to the application and to testing procedures. Each modification to the application shall be recorded and an amended copy submitted to the PBBA.

2. ENVIRONMENTAL AND LEGAL RESPONSIBILITIES

Development and establishment of testing facilities may require development consent under the particular State Environmental Planning and Assessment (EP&A) Acts. Each State has different requirements and different consent authorities for different levels of development. These requirements should be available through that States Department of Agriculture or Primary Industries.

Testing facilities may be regarded as legally constituting feedlots. The National Guidelines for Beef Cattle Feedlots in Australia define a feedlot as “a confined yard area with watering and feeding facilities where cattle are completely hand or mechanically fed for the purpose of production”.

Further requirements for feedlots, such as environmental protection and animal welfare are detailed in the National Guidelines for Beef Cattle Feedlots in Australia, published by the Standing Committee on Agriculture and Resource Management. Specific requirements regarding animal welfare, the Australian Code of Practice for Welfare of Cattle in Beef Feedlots, are outlined as an appendix in this document, which is available from CSIRO Publishing, PO Box 1139, Collingwood, Vic. 3066.

3. ELIGIBILITY OF ANIMALS FOR TESTING

3.1 Age

Animals can be tested from immediately post weaning until the later stages of their growth phase, usually less than two years of age. It is strongly recommended that during the initial years, tests should be conducted post-weaning, as more data is currently available and the development of EBVs will be more rapid. The range in age within a contemporary group must not exceed 60 days. (see 3.3)

3.2 Sex

Bulls, steers or heifers can be tested. Due to management difficulties with testing of mixed sex groups, and the fact that genetic improvement can be achieved faster through appropriate bull selection, it is recommended that bulls only should be tested, especially at Central Test facilities.

3.3 Contemporary Groups

Animals must be tested in contemporary groups to ensure that comparisons are made between animals which have been run under identical conditions, both for traits measured before and during the NFE test. The largest practical number of animals in a contemporary group is recommended as it will provide more comparative information per animal. In the event of an animal being withdrawn from a contemporary group after commencement of the test, data from the remaining animals should still be submitted.

Code of Practice:

A contemporary group shall consist of a minimum of four animals bred from a minimum of two sires with a minimum of two progeny per sire.

The contemporary group must adhere to the BREEDPLAN specifications provided for the trait of 400 day weight, ie: the maximum range in age is 60 days, same herd, same sex and same management since birth.

3.4 Genetic Links

Comparison between contemporary groups is based on genetic links. To ensure that adequate linkage is available between contemporary groups it is recommended that each contemporary group should include the progeny of at least one link sire. A link sire is defined as any sire which has had progeny tested for NFE in another contemporary group.

Central test facilities and/or Breed Societies should provide a list of all previously represented sires at all test stations which can be used to create linkages.

For breeds where no sires have been previously represented in a test, it is recommended that a sire represented in the CRC project be used. It is also recommended that bulls selected for testing have well balanced EBVs to increase the desirability of usage in AI programs and to therefore increase and improve linkages.

3.5 Animal Health

Health requirements are the responsibility of individual test managers and shall be specified for entry to each location in the case of Central Test facilities.

The purpose of specifying mandatory health treatments is to ensure that all animals have the ability to achieve their potential growth performance, and all animals are assessed on an equal basis.

Code of Practice:

Within a test all animals shall be subjected to identical health treatments.

All animals entering a test will have received standard health treatments that allow each animal to achieve potential growth performance in that environment.

Records of any remedial health treatments administered to individual animals must be maintained.

3.6 Mandatory Background Information

Specific background information must be recorded for all animals entering a test for data to be accepted by BREEDPLAN.

It is recommended that twins not be tested, as they must form a separate contemporary group from single born animals, as specified for BREEDPLAN contemporary groups.

Within one week of beginning testing, and before removing test animals from existing contemporary groups, the weights of all animals in that group should be recorded.

Code of Practice:

The following information will be recorded for all animals entering a test:

- Individual animal identification
- Sire and Dam identification
- Date of Birth
- Whether single or twin birth
- Breed
- Sex
- Property of birth identification
- Weights of all animals from contemporary group test animal originated from.

All animals must be recorded on BREEDPLAN, with at least a 200 day weight record available. Performance data on all animals from the same herd as the tested animals must be available so as to account for effects of prior selection of animals entering the test.

4. CONDUCT OF TEST

4.1 Allocation of Animals to Groups

A “group” may consist of any number of animals in individual pens, providing those pens are adjacent to each other and are of a similar structure, size and physical environment. In the case of the use of semi or fully automatic feeding systems, large groups may need to be sub-divided into smaller groups and placed in group pens. The allocation of individuals to group pens should be random and must be recorded.

Code of Practice:

All animals in the same group must be fed and maintained under similar physical conditions, and must be fed a ration containing ingredients from the same batch.

Bulls must be tested separately to steers and heifers. Where animals need to be fed in more than one group, they must be allocated to groups at random within age and/or weight classes, to minimise bullying when randomising animals. Contemporary groups existing prior to the test must be maintained.

4.2 Feeding System

The greatest variation across testing facilities will be in the use of alternate feeding systems. The simplest and cheapest system to develop and use is to hand feed a manually weighed ration to animals in individual pens. Alternately, different levels of automation may be incorporated, up to fully automatic and computer recorded weighing and dispensing of feed to electronically identified animals run in group pens.

Commercial feeding units that automatically weigh, dispense and record intake of individually electronically identified animals are currently being developed for purchase for “on-farm” testing. Details on availability and suitability of these units can be obtained from Breed Societies or State Departments of Agriculture or Primary Industries Extension staff.

Cattle should have constant access to feed. In the event of a mechanical breakdown or disruption to the feeding system, strategies must be in place to enable all cattle to have access to their normal ration within 24 hours. If this feed cannot be accurately weighed or recorded to each individual animal, that days data must be excluded from the weekly feed intake summary, and this event recorded.

Code of Practice

The feeding system used must incorporate accurate measurement and recording of daily individual animal feed intake. Provision must be made to have available sufficient back-up facilities, resources, equipment and personnel to ensure that interruptions to feeding systems are minimised.

Feeding must be ad libitum throughout the test, with animals having constant 24 hour access to feed.

If changes to the feeding system prevent accurate measurement of individual feed intake for any period, for the duration of that period any data generated must be excluded from weekly feed intake summaries, and this event recorded.

4.3 Animal Identification

The animal identification system adopted must be appropriate for the feeding system used. An adequate identification system is essential to allow individual animal feed intake to be recorded and data submitted to BREEDPLAN.

Commercially available automatic feeding systems require the use of a compatible electronic animal identification system, with details available from the manufacturer.

Code of Practice

Individual animal identification in accordance with BREEDPLAN requirements must be utilised.

4.4 Ration

The ration offered must be balanced for all essential nutrients and be of suitable energy and protein levels so as not to inhibit potential animal performance and must be delivered in a format that minimises ingredient selection.

Feeding of a supplementary roughage such as straw is not a requirement, but may be provided to aid rumen function. If it is used, it must be available to all animals (free choice) at an average of not more than 0.5 kg per day per head.

Commercially available feed additives or supplements may be included in a ration to minimise health risks, to provide essential nutrients lacking in the base ration, or to ensure that the ration meets the minimum standards for metabolisable energy and crude protein, provided they are included within the manufacturers recommendations or to accepted industry standards.

Code of Practice:

The ration must be analysed for level of metabolisable energy (MJ ME/kg dry matter) and crude protein (%) by a licensed feed analysis service prior to testing and whenever there are major changes in ingredient source to ensure it falls within the acceptable range. During the test, a sample of the feed must be taken at least weekly and weekly samples bulked. The bulked samples must be analysed following the test to determine average feed composition.

Feed additives or supplements included in the ration must be recorded.

If supplementary straw is provided, it must be analysed prior to and following the test.

The ration must consist of a minimum of 9.0 MJ metabolisable energy (ME) per kg dry matter (DM), and a minimum of 14% crude protein (CP) per kg dry matter (DM).

Minimum levels for ME and CP are stipulated in the Code of Practice to ensure that potential growth rates are not restricted. It is recommended that for a postweaning test operators aim to provide a ration as close to 10 MJ ME/kg DM as possible, and for progeny tests or animals during the finishing phase, as close to 12 MJ/kg DM as possible. This will help to ensure rations used in different tests are as similar as possible, and non-genetic variation is minimised.

Care should be taken to ensure the ration is suitable for the class of stock. Young growing animals should not be fed rations containing excessive levels of energy. If a high energy finishing ration is fed for a specific test, and is achieved by inclusion of a substantial grain component (>40%), it is recommended that buffers be included in the ration and progressive increases from low to high grain content during the pre-test period be adopted.

It is strongly recommended that feed analyses performed before the commencement of test are conducted in sufficient time to modify the intended ration if there is a risk that the ration could fall outside the stipulated levels and cause data generated to be rejected.

4.5 Pre-test Adjustment Period

An adjustment period is necessary to allow all animals in the test to adjust to the ration and the environment prior to commencement of the test. Assessments should be made during this period to monitor individual feed intakes and acceptance of the diet.

If shy feeders are detected during this phase, it is recommended that they be separated from the rest of the group during the pre-test adjustment period. If substantially more than 21 days is required to ensure all animals have achieved satisfactory levels of feed intake, caution must be used to ensure that no animals reach an age unacceptable for the intended test prior to commencement of the test.

Shy feeders or poor performers may have to be excluded before the test commences.

Code of Practice:

A minimum of 21 days adjustment period will be adopted.

4.6 Test Protocol

Net Feed Intake is the trait which will be calculated by phenotypically adjusting feed intake for liveweight and gain. As such, within the duration of the test, each animal is weighed at regular intervals to provide an average liveweight for the test and liveweight gain during the test, and the total feed intake by each animal is measured for the duration of the test.

Animals may be removed in groups from the pens where they are maintained for the purpose of conducting fortnightly weighing. All animals must be treated in a similar manner and denied access to any feed during this time.

Automatic feeding systems may incorporate automatic (continuous) weighing procedures. If these are employed, an average daily weight for the first, and each subsequent 14th day is recorded and submitted following the test. Weight records for all days should be retained for the possibility of further analysis being required.

During the test period, it is strongly recommended that animal performance be monitored by way of regular checks. Sick animals may have to be removed from the test.

Faulty equipment, causing loss of reliable data, such as feeding units, scales or identification systems may also be detected in time to allow repairs before the test is invalidated. It is strongly recommended that a back-up power source and spare or reserve weighing, recording and computing requirements are available for emergency use.

Code of Practice:

The duration of the test must be for a minimum of 70 days on a constant ration. A maximum total of 7 days when data is not recorded within a maximum 77 day period is allowable for the duration of the test.

Animals must be weighed at the start of the test and at least every fortnight thereafter. Animals must not be fasted before weighing.

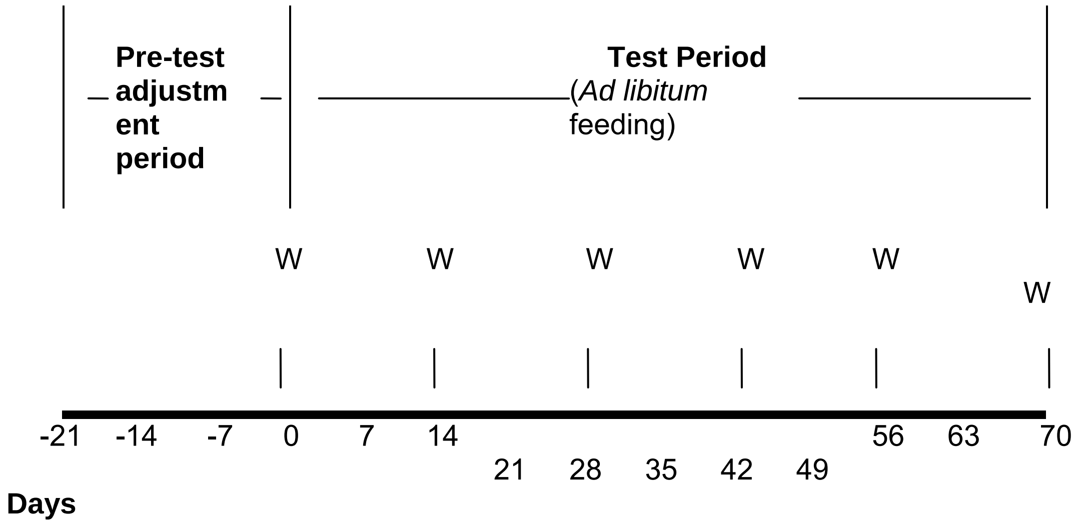


Figure 1: **Time Scale for NFE Test**
*(**W** represents days on which animals are weighed)*

4.7 Data Collection and Recording

Records must be taken and stored in a format appropriate to the individual tests.

Code of Practice:

Provision must be made to have available adequate back-up facilities or resources to ensure that interruptions to data collection or recording are minimised.

The following records are required for each animal:

- Mandatory background information specified previously.
- Weighing dates and individual animal weights as specified. If automatic (continuous) weighing is used, an average daily weight for each of the fortnightly weight dates (section 5.6) need to be recorded.
- Feed intake data (including supplementary roughage where applicable). Minimum requirement is total feed intake per animal per week.
- Feed analysis results - including date of analysis, laboratory, ME, CP and roughage as specified previously.
- Feed additives or supplements included in the ration.
- Details of interruptions to data collection or recording.
- All health treatments administered, and details of sick animals.
- Individual pen or group pen for each animal.

5. DATA INPUT SPECIFICATIONS

To calculate NFI, and ultimately BREEDPLAN EBVs for NFI, data must be loaded onto centralised databases. This will happen in a two-step process.

1. Detailed data from a feed intake test will be loaded onto a database maintained by NSW Agriculture at Trangie. The data will be checked for compliance to test requirements, and will be processed into a summarised form. Reports of results from individual animals will be produced, and sent to the test station submitting the data.

2. A summarised form of the feed intake result will be sent to ABRI for loading onto the NBRS database. This data will be used to calculate BREEDPLAN EBVs for NFI when these become available.

Code of Practice:

Only data submitted electronically in a specified format will be accepted for loading onto the Trangie database. Files should be submitted in a spreadsheet format compatible with Microsoft Excel 97. Most spreadsheet packages are able to save files in a format able to be read by Excel. If this is not possible, data should be saved in a “comma separated variable” format (filename.csv), where columns are delimited by commas. Four sheets must be submitted, named “test”, “animal”, “intake” and “weight”. Where possible, these sheets should be contained within a single workbook, and the file should be named by the test station code - year - test number combination (ie. the first 3 fields of the test sheet).

Once in the correct format, the data file should be sent on disc (PC format) to NFI Testing, NSW Agriculture, PMB 19, Trangie NSW 2823 or e-mailed to nfi@agric.nsw.gov.au with subject heading “NFI data”. A copy of the ration analysis report should be sent or faxed to 02 6888 7201. Data will not be processed until the ration analysis report is received. Contact details should be supplied so that receipt of the data and ration analysis report can be acknowledged.

The formats for the four sheets are described below. Example sheets containing data in the correct format for submission are also given. The data used in the example have been altered for demonstration purposes in some instances.

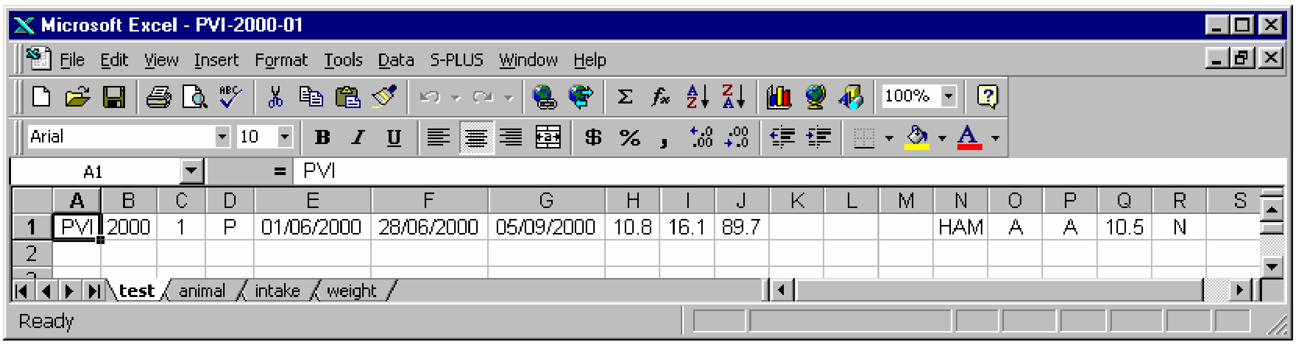
NSW Agriculture will endeavour to process the data within a maximum of 10 working days of receiving the data in the correct format. The processed data will be forwarded to ABRI for loading on the NBRS database. As with other data submitted to BREEDPLAN, a charge will apply for loading onto the NBRS database, and ABRI will invoice the breeder or test station manager for this work. NSW Agriculture will notify the test station manager once the data has been sent to ABRI, and a report on phenotypic performance of the animals will be sent.

5.1 Test Sheet

This sheet contains information specific to each test (defined as a group of animals fed using the same ration and feeding system at the same time). The sheet should contain one row of information laid out as follows.

Column	Field Name	Format	Description
A	Test Station	3 Character code (Upper Case). Eg "PVI"	Code assigned to the test station at which the test was conducted. This code will be supplied when accreditation is gained.
B	Test Year	Integer. Eg. "2000"	Year in which the test started.
C	Test Number	Integer. Eg. "1"	Number of the test started that year (1 to 99, assigned by station manager). The columns Test Station, Year and Number combined must define a unique test.
D	Test Type	1 Character. Eg. "P"	P = post-weaning (generally used for bulls on lower energy diets); or F = finishing (generally used for steers measured on feed-lot rations).
E	Pre-test Date	dd/mm/yyyy Eg. 01/06/2000	Date animals entered test facility and started pre-test adjustment period.
F	Start Date	dd/mm/yyyy	Date the test period started.
G	End Date	dd/mm/yyyy	Date the test period finished.
H	Ration ME	Number rounded to 1 decimal place. Eg. "10.8"	Metabolisable Energy content of the test ration (in MJ ME/kg Dry Matter).
I	Ration Protein	Number rounded to 1 decimal place. Eg "16.1"	Protein content of the test ration (in %)
J	Ration Dry Matter	Number rounded to 1 decimal place. Eg "89.7"	Dry Matter content of the ration (in %)
K	Supplement Quantity	Optional. Number rounded to 1 decimal place. Eg "0.5"	Quantity of supplement (eg. straw) fed to maintain rumen function (kg per head per day). Can be left blank if no supplement fed.
L	Supplement ME	Optional. Number rounded to 1 decimal place. Eg. "5.1"	Metabolisable energy content of the supplement (MJ ME/kg DM). Can be left blank if no supplement fed.
M	Supplement Dry Matter	Optional. Number rounded to 1 decimal place. Eg "98.7"	Dry Matter of the supplement (%). Can be left blank if no supplement fed.
N	Laboratory Code	3 Character code (Upper Case). Eg "HAM"	Code for laboratory providing ration analysis. HAM = Feedtest, Hamilton, Victoria; AGT = Agritech, Toowoomba, Queensland.
O	Method for Intakes	1 Character. Eg "A"	A = Automated measurement; M = Manual Measurement.
P	Method for weights	1 Character. Eg "A"	A = Automated measurement; M = Manual Measurement.
Q	Animals per pen	Number to 1 decimal place. Eg "10.5"	Average number of animals per pen.
R	Combine Pens for analysis	1 Character. Eg "Y"	Whether test manager believes that animals can be compared across pens (Y=Yes; N=No).

The *test* sheet should look something like this:



Note that where optional data is not given (eg. For fields describing the supplementary ration, where no supplementary ration was fed), the relevant column is left empty.

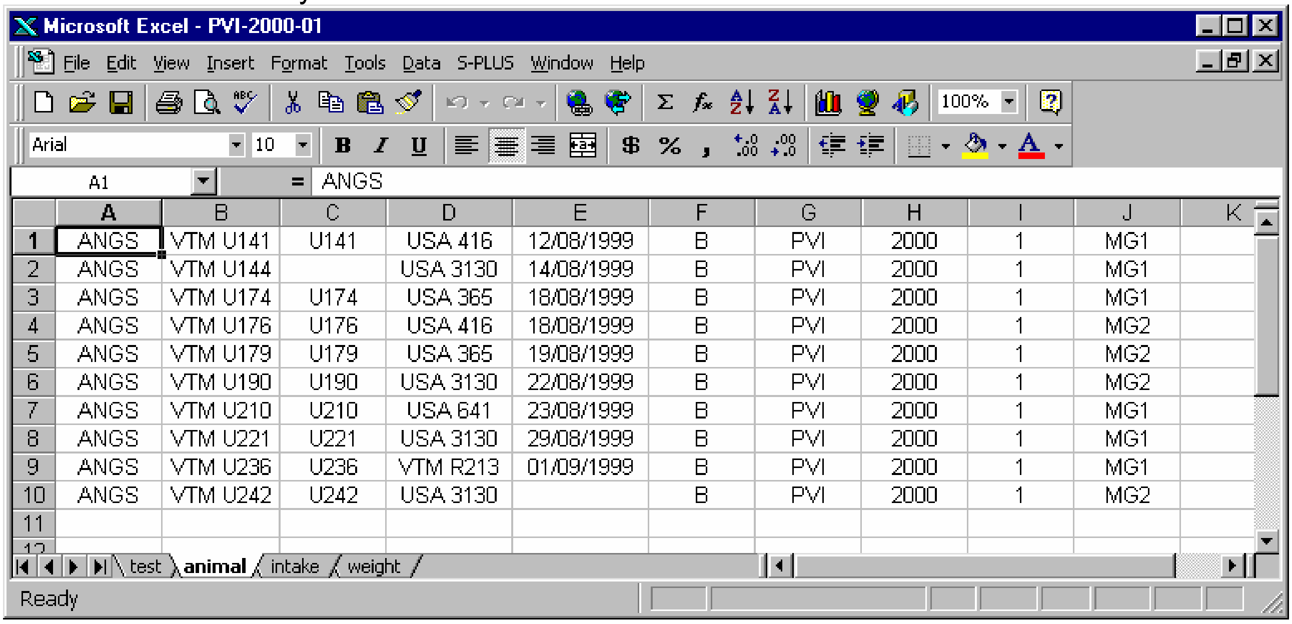
5.2 Animal Sheet

This sheet contains information specific to each animal within the test. Each animal should be represented by one row.

Column	Information	Format	Description
A	Breed	Up to 5 Characters (upper case). Eg "ANGS"	Code to describe breed society the animal is registered by. The code must match codes used by the NBRS database (see table below).
B	Ident	Up to 19 characters (upper case). Eg "VTM U141"	The Breed Society ident of the animal. This *must match exactly* the ident of the animal on the NBRS database (including spaces) if present, so that BREEDPLAN can match the record with other performance and pedigree information. Breed and Ident columns together define a unique animal.
C	Tag	Optional. Up to 20 characters. Eg "U141"	A tag or name to refer to the animal – useful for telephone queries regarding animal where Breed Society uses a numerical ident system.
D	Sire Ident	Optional. Up to 19 characters (upper case). Eg "USA 416"	The Breed Society ident of the animal's sire (used to verify animal identification on NBRS database).
E	Birthdate	Optional. dd/mm/yyyy Eg "12/08/1999"	Date of birth of the animal (Optional – used to verify animal identification on NBRS database).
F	Sex	1 Character. Eg "B"	B=Bull; H=Heifer; S=Steer
G	Test Station	3 Character code (Upper Case). Eg "PVI"	3 Character test station code, matches to test station field in *test* information.
H	Test Year	Integer. Eg. "2000"	Year at start of test, matches to year field in *test* information.
I	Test Number	Integer. Eg. "1"	Number of test, matches to test number field in *test* information.
J	Management Group	3 Character description of management groups. Eg "MG1"	Field used by test station manager to identify separate management groups *during* the test which are treated differently and shouldn't be directly compared. Management groups imposed prior to the test will be determined by BREEDPLAN using contemporary group information on the most recent weight prior to entering the test.

The *animal* sheet should look something like:

Table 1: Breed Society Codes



	A	B	C	D	E	F	G	H	I	J	K
1	ANGS	VTM U141	U141	USA 416	12/08/1999	B	PVI	2000	1	MG1	
2	ANGS	VTM U144		USA 3130	14/08/1999	B	PVI	2000	1	MG1	
3	ANGS	VTM U174	U174	USA 365	18/08/1999	B	PVI	2000	1	MG1	
4	ANGS	VTM U176	U176	USA 416	18/08/1999	B	PVI	2000	1	MG2	
5	ANGS	VTM U179	U179	USA 365	19/08/1999	B	PVI	2000	1	MG2	
6	ANGS	VTM U190	U190	USA 3130	22/08/1999	B	PVI	2000	1	MG2	
7	ANGS	VTM U210	U210	USA 641	23/08/1999	B	PVI	2000	1	MG1	
8	ANGS	VTM U221	U221	USA 3130	29/08/1999	B	PVI	2000	1	MG1	
9	ANGS	VTM U236	U236	VTM R213	01/09/1999	B	PVI	2000	1	MG1	
10	ANGS	VTM U242	U242	USA 3130		B	PVI	2000	1	MG2	

Australian Societies

ABBA	Brahman	ABS	Braford
ADA	Dexter	AHS	Hereford
ANGS	Angus	APHS	Poll Hereford
ARPS	Red Poll	ASBA	Simmental
BDAQ	Blonde d'Aquitaine	BELG	Belgian Blue
BORA	Boran	BR	Belmont Red
BSSA	Beef Shorthorn	CHAR	Charolais
CHIA	Chianina	DEVN	Devon
DSBS	Droughtmaster	GCSA	Galloway
GELB	Gelbvieh	LIMO	Limousin
LOWL	Lowline	MA	Maine Anjou
MG	Murray Grey	OSBA	Braunvieh
PIED	Piedmontese	QBRA	Brangus
RANG	Red Angus	RBS	Romagnola
SALR	Salers	SANTA	Santa Gertrudis
SDEV	South Devon	SSA	Shorthorn
TULI	Tuli	WAGY	Wagyu

New Zealand Societies

NZAA	Angus	NZHA	Hereford
NZLM	Limousin	NZMA	Maine Anjou
NZMG	Murray Grey	NSAL	Salers
NZSD	South Devon	NZSH	Shorthorn
NZSM	Simmental		

Contact ABRI (02 6773 3555) if you need a code for a Society that is not listed.

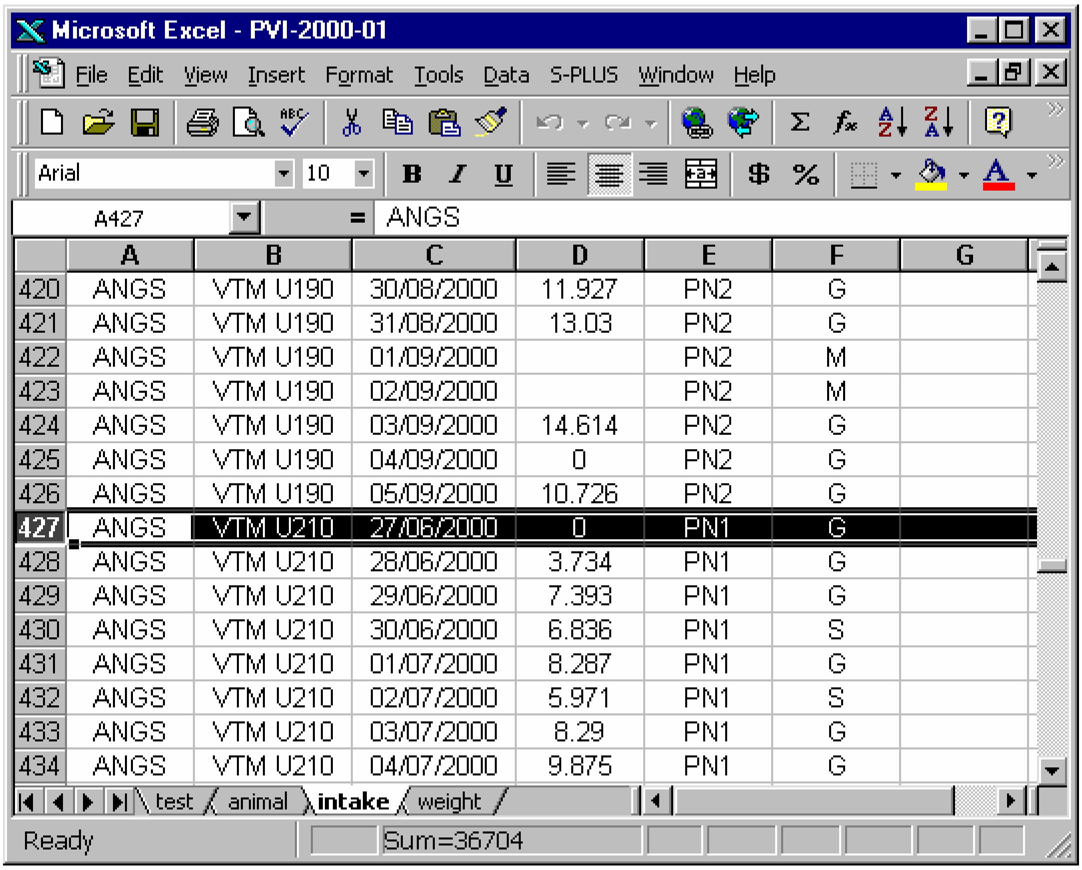
5.3 Intake Sheet

This sheet contains information on intake of animals over periods during the test. Each row represents the intake of the animal since the previous intake information. To define the start of the first intake measurement period, a row representing the day prior to the test starting should be included for each animal, with intake set to zero. A code accompanying each intake must be submitted to indicate whether the data is good, suspect or missing (due to problems with data collection). Only periods where information is "good" will be analysed. However it is important that a row is submitted even for instances where the information is suspect or missing, so that this period of time can be excluded when average daily intake of the animal is calculated. Zero intakes should be examined and given a code for "good" if the animal genuinely did not eat for that period, or a code for "missing" should be assigned if the animal did eat but data was lost.

Intakes can be submitted as frequently as daily (1 day periods), or as infrequently as fortnightly (14 day periods). Where possible, data should be submitted in shorter periods (ideally daily), so that suspect or missing data for an animal on one day does not lead to unusable data for the animal for a whole fortnight.

Column	Information	Format	Description
A	Breed	Up to 5 Characters (upper case). Eg "ANGS"	Code to describe breed society the animal is registered by.
B	Ident	Up to 19 characters (upper case). Eg "VTM U210"	The Breed Society ident of the animal.
C	Date	dd/mm/yyyy Eg 28/06/2000	Date at the end of the intake period.
D	Intake	Number to 3 decimals. Eg "3.734"	Intake of the animal (kg feed freshweight). Can be set to zero or left blank if data is missing for a period, but a row should still be loaded for the period.
E	Pen Number	3 Characters. Eg "PN1"	Optional. Number of the pen the animal was in.
F	Data Quality	1 Character. Eg "G"	Code to describe data quality. G = Good data; S = Suspect data; M = Missing data.

The *Intake* sheet should look something like:


Microsoft Excel - PVI-2000-01

A427 = ANGS

	A	B	C	D	E	F	G
420	ANGS	VTM U190	30/08/2000	11.927	PN2	G	
421	ANGS	VTM U190	31/08/2000	13.03	PN2	G	
422	ANGS	VTM U190	01/09/2000		PN2	M	
423	ANGS	VTM U190	02/09/2000		PN2	M	
424	ANGS	VTM U190	03/09/2000	14.614	PN2	G	
425	ANGS	VTM U190	04/09/2000	0	PN2	G	
426	ANGS	VTM U190	05/09/2000	10.726	PN2	G	
427	ANGS	VTM U210	27/06/2000	0	PN1	G	
428	ANGS	VTM U210	28/06/2000	3.734	PN1	G	
429	ANGS	VTM U210	29/06/2000	7.393	PN1	G	
430	ANGS	VTM U210	30/06/2000	6.836	PN1	S	
431	ANGS	VTM U210	01/07/2000	8.287	PN1	G	
432	ANGS	VTM U210	02/07/2000	5.971	PN1	S	
433	ANGS	VTM U210	03/07/2000	8.29	PN1	G	
434	ANGS	VTM U210	04/07/2000	9.875	PN1	G	

Note that intake on day before the first test day is set to zero. This will be interpreted as stating that the first data collection period started at the end of 27/06/2000. The next row (row 428) therefore is interpreted as stating that the intake of VTM U210 from 27/06/2000 to 28/06/2000 (ie. one day) was 3.734 kg.

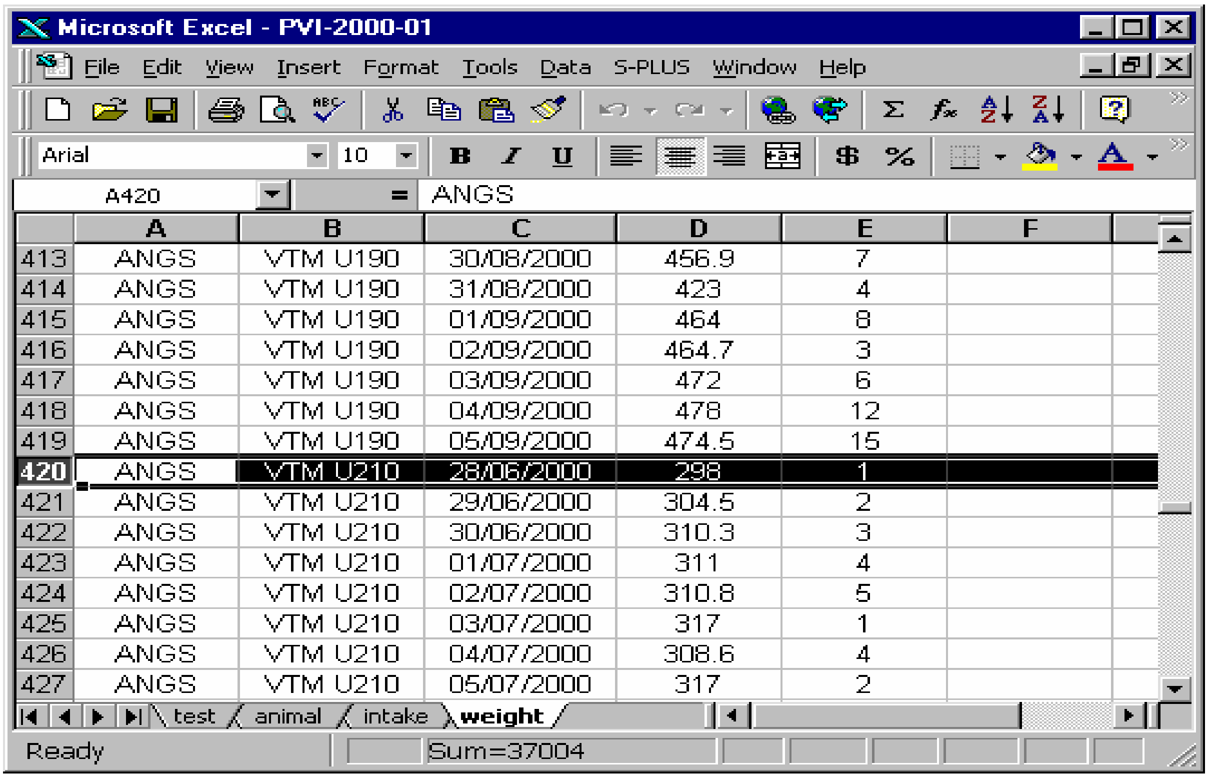
Data from periods where the quality code (column F) is “S” or “M” will not be used when the overall intake is calculated, but must still be included so that the correct daily intake can be calculated. For example, the data from VTM U210 on 30/06/2000 (row 430) will not be used to calculate intake, but must still be included so that the period for the subsequent row of data will be correctly calculated as 1 day. If row 430 was omitted, the calculation would (incorrectly) assume that the next intake (8.287 kg) was the intake from 29.06/2000 to 01/07/2000, a period of 2 days.
For days where an animal genuinely had zero intake, this should be recorded as zero (not left blank), and the data quality code set to “G” to indicate that the zero is the correct intake. For example, see the intake for VTM U190 on 04/09/2000 (row 425) in the sheet above.

5.4 Weight Sheet

This sheet contains information on liveweight of the animal. Daily. weekly or fortnightly weights can be submitted. Where weights are collected automatically and several weights are available for each day, the mean weight for each day should be submitted, along with how many individual weights the mean represents. If a weight is missing, no row should be submitted for that animal on that day.

Column	Information	Format	Description
A	Breed	Up to 5 Characters (upper case). Eg “ANGS”	Code to describe breed society the animal is registered by.
B	Ident	Up to 19 characters (upper case). Eg “VTM 210”	The Breed Society ident of the animal.
C	Date	dd/mm/yyyy Eg 29/06/2000	Date on which the weight was collected.
D	Weight	Number to 1 decimal place. Eg “304.5”	Mean weight of animal on that date.
E	Number of Records	Integer. Eg “2”	Number of individual weights used to calculate mean weight. Set to “1” where animals are weighed once manually.

The *weight* sheet should look something like:



	A	B	C	D	E	F
413	ANGS	VTM U190	30/08/2000	456.9	7	
414	ANGS	VTM U190	31/08/2000	423	4	
415	ANGS	VTM U190	01/09/2000	464	8	
416	ANGS	VTM U190	02/09/2000	464.7	3	
417	ANGS	VTM U190	03/09/2000	472	6	
418	ANGS	VTM U190	04/09/2000	478	12	
419	ANGS	VTM U190	05/09/2000	474.5	15	
420	ANGS	VTM U210	28/06/2000	298	1	
421	ANGS	VTM U210	29/06/2000	304.5	2	
422	ANGS	VTM U210	30/06/2000	310.3	3	
423	ANGS	VTM U210	01/07/2000	311	4	
424	ANGS	VTM U210	02/07/2000	310.8	5	
425	ANGS	VTM U210	03/07/2000	317	1	
426	ANGS	VTM U210	04/07/2000	308.6	4	
427	ANGS	VTM U210	05/07/2000	317	2	

APPENDIX 12

Samples of Newspaper and Magazine Articles

Western Magazine	**30th October 1995**
Beef Improvement News	**February 1995**
Milne's Prime Beef	**January 1995**
NSW Agriculture Today	**June 1996**
Australian Farm Journal "BEEF"	**November 1997**
Queensland Country Life	**24th December 1995**
Countryman	**14th May 1998**
Queensland Country Life	**16th July 1998**
Farming Ahead	**June 1998**
Lotfeeding	**April 1998**
The Land	**7th May 1998**
BREEDPLAN News	**May 1999**
Western Magazine	**9th August 1999**
NSW Agriculture Today	**April 2000**
Feedback	**March 2001**
Murray Grey World	**April 2001**
The Land	**19th July 2001**
NSW Agriculture Today	**April 2001**