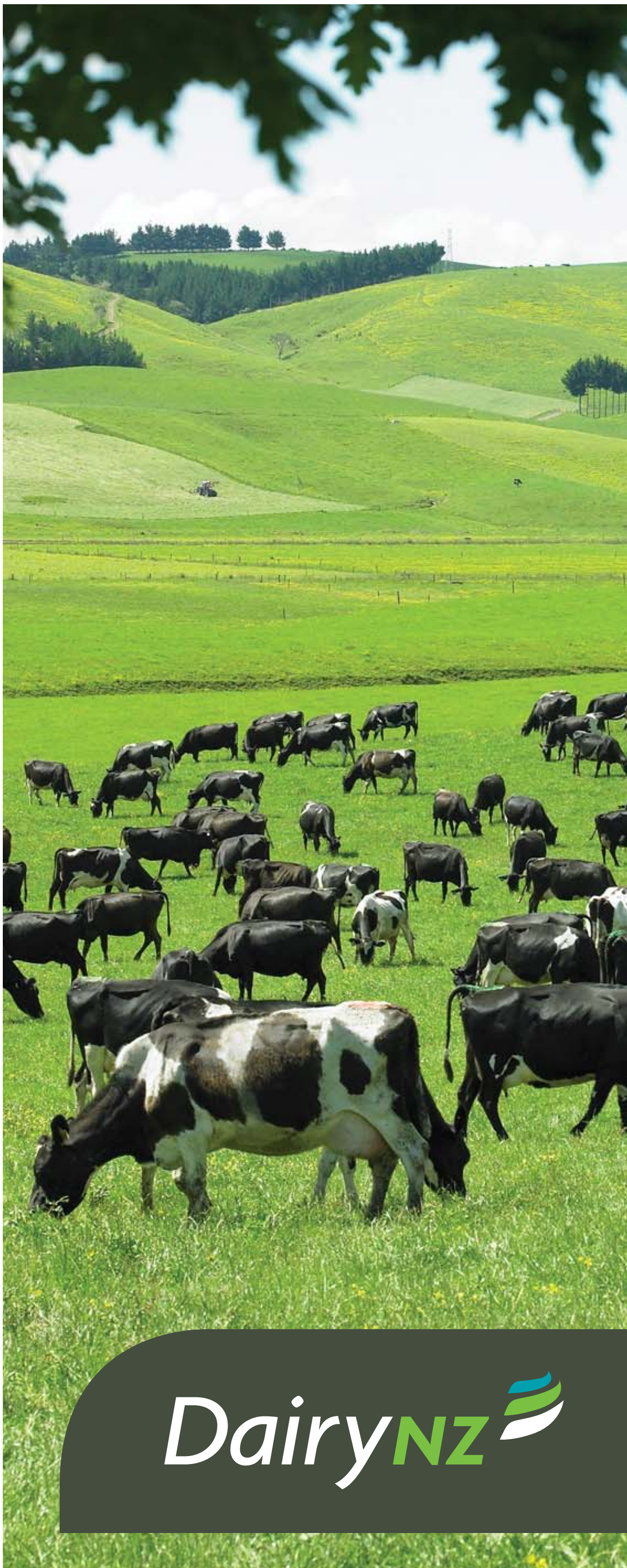
April 2013

Technical Series

Issue 15



ISSN 2230-2409

DairyNZ

0800 4 DairyNZ (0800 4 324 7969) dairynz.co.nz

Introduction

This issue of the Technical Series comprises a series of reports on a project originally called 'Genetic and farm systems technologies to improve feed conversion efficiency on dairy farms'. It is now more appropriately known as determining divergence in residual feed intake (RFI).

This work, previously known as the Feed Conversion Efficiency project (the change is described in the articles), was conceived by DairyNZ and LIC scientists about seven years ago. The project was developed and carried out by them and Australian partners.

The aim was to identify if variation in feed conversion efficiency (i.e. that some individuals eat less than others yet still produce the same), is genetically controlled. If so, can it be measured and included in a breeding programme?

The delivery of the work has included development of unique resources, melding of teams comprised of trans Tasman dairy scientists and considerable investment from a number of funders. In New Zealand, the funding has come from the Ministry of Business, Innovation and Employment (formerly the Foundation for Science, Research and Technology), New Zealand dairy farmers through DairyNZ Inc and LIC, and the New Zealand Trade and Enterprise Scheme. In Australia, the funding has come from the Geoffrey Gardiner Foundation, the Department of Primary Industries, Victoria, and Dairy Futures CRC.

The main project components and achievements have been:

- Creating a true and sustained research partnership
- Development of methodologies in dairy science and molecular genetics
- Creation of unique facilities in Taranaki (WTARS) and Ellinbank, Victoria
- Demonstration that differences in RFI in New Zealand are measurable and real in growing calves
- Confirmation in the parallel study in Victoria
- Demonstration that the RFI for growth in calves is predictive of RFI differences in lactating cows
- Validation of milk production differences in an independent population of lactating cows
- Measurement that the heritability of the trait is 0.27-0.38
- Population studies indicating that no obvious adverse effects are associated with the more efficient animals
- Identification of a sire effect that may make selection for this productivity trait easier in future
- Calculation that a real value is likely when selection is made for RFI.

These are described in this issue of the *Technical Series*. In keeping with our philosophy of doing the very best science for our dairy farmers, all the studies are being reported in leading international science journals with four papers already published. Further papers will appear in the next few months. On going validation of RFI will be needed in some form, especially to determine if this is a continuous effect. Any possibility of adverse effects, although none have been identified so far, will also be monitored.

What is residual feed intake?

A high proportion of feed energy is used for maintenance in New Zealand pasture-fed dairy cows because they have a short lactation and low annual production (about 4000 kg compared with 8,000-12,000 kg milk from cows in the northern hemisphere).

Growing animals use a high proportion of feed energy for maintenance, so animals that use energy efficiently for growth should also be efficient for lactation. Thus we can use growing heifer calves to screen for feed conversion efficiency (FCE) in lactation. FCE is the difference between the actual amount of feed eaten and the expected amount eaten, and is often referred to as residual feed intake (RFI).

Efficient feed utilisation applies to the energy required for maintenance and to synthesise milk and liveweight gain. This is the energy required to rearrange absorbed nutrients (volatile fatty acids and amino acids as well as lipids, minerals and vitamins) into the fat, protein and lactose in milk, or fat, protein and bone in growing animals.

Feed efficiency has nothing to do with the actual level of milk production. The concept of RFI is the variation of an individual from the average requirements for energy use, relative to animals of the same weight and productivity. It is about the range of efficiency in a population of animals. This is illustrated in Figure 1, representing a typical distribution of efficiency and selection of least and most efficient individuals from a population.

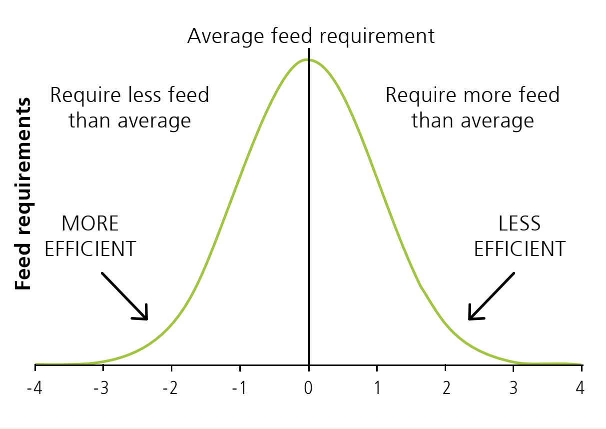


Figure 1. The distribution of feed energy requirements for animals that are similar in size and productivity, demonstrating the mean requirements and that some cows require less, and others, more feed than average.

Unique facilities

Feed intake is difficult to measure in grazing animals and it needs to be accurate to be of use in calculating total energy intake.

Commercial systems are available for measuring feed intakes of cattle, based on electronic identification (EID) and feed bins, mounted on load cells that allow access by only one animal at a time. However, none of the companies contacted seemed interested in establishing their system in New Zealand; therefore, Gallagher Group Ltd (Hamilton) were commissioned to build a unique system. The feed facility was sized to measure intakes of up to 224 calves or 56 lactating cows, automatically.

The Westpac Taranaki Agriculture Research Station (WTARS) at Hawera has a sound history of dairy research, DairyNZ manages the farm on contract and so has an established team on site. Key partner LIC also has a strong track record at Hawera. The farm is an ideal size, with access to qualified staff to undertake the experimental programme.

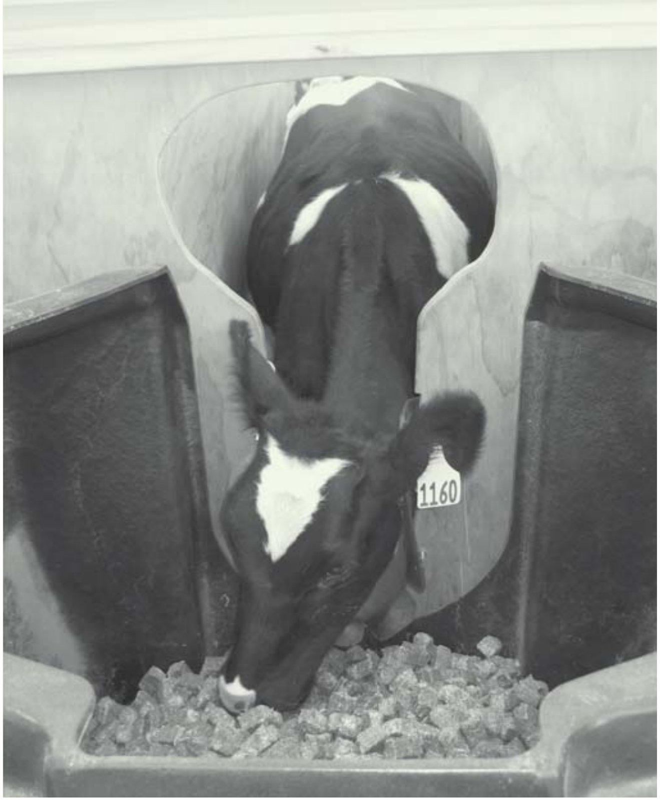
Construction started in October 2007 and the facility was operational by February 2008. The unit consists of 28 pens, each with a feed station (on load cells) enabling feed bin weights to be downloaded, with animal identification, to computers. Each pen is 42 m^2 and can accommodate eight calves or two cows, with a base of post peelings (for comfort and rest) and a concrete apron adjacent to the feeders and exit gates. The facility is well drained and effluent drains to adjacent effluent ponds. The area is somewhat sheltered by a surrounding bank and solid walls and shade cloth provides additional protection from wind and sun.

Measuring residual feed intake in heifer calves

Garry Waghorn and Kevin Macdonald, Senior Scientists, DairyNZ

Summary

- The feed intakes and daily weight gain of 1052 6-8 month old heifer calves were measured for 42 days to measure their feed conversion efficiency (FCE), being described as residual feed intake (RFI).
- All calves had similar mid-trial liveweights (196 kg), growth rates (0.88 kg/day) and breeding worth (BW; 148 LIC 2009).
- The most efficient calves ate on average 22% less feed than the least efficient animals.
- The heritability of RFI in these animals was estimated to be 0.38 (SE 0.09), suggesting good potential to select for efficiency.



The trial was designed to identify individual heifer calves that used feed either more efficiently than average, or less efficiently than average, so that future selection criteria might take this into account.

The concept of efficiency is well established in the pig, poultry and beef industries, and individuals vary considerably in the amount of feed used for similar levels of production[10]. Such work has rarely been attempted with dairy cows because it requires accurate measurement of individual feed intakes and energy use for maintenance and production. In lactating cows this is difficult because rumen fill varies greatly and they mobilise, and also deposit, body weight (condition) throughout lactation.

The work described here was undertaken because feed is a large cost to dairy farmers, and was possible because new technologies allow automatic recording from large numbers of animals, and because genomic technologies provide opportunities for future selection based on analysis of DNA from a blood or tissue sample.

The science behind the measurements

This screening for efficiency was undertaken in young growing heifer calves (6-8 months old), and assumed that divergence for efficiency in growth would apply to lactation. This was a sound, but previously untested, assumption. Most feed is used for energy needed for maintenance, as well as production, and this is provided through digestion, absorption and biochemistry. The assumption was that these are essentially the same for all physiological needs, so variations in efficiency would be equally applicable to growth or lactation; young animals were, in effect, a proxy for lactating cows.

The trial was designed to identify animals that used either less, or more feed than expected, based on requirements for an average animal of the same size and level of production. This is termed residual feed intake, or RFI. An efficient animal has a negative RFI (uses less feed that average) and an inefficient individual has a positive RFI.

To identify genetic markers for RFI the following were required:

- A customised facility accommodating a large number of calves over 50-60 days, with automatic recording of feed intake and frequent liveweight measures
- A total of 1000 suitable calves to be tested over a three year period
- A forage diet of a consistent quality
- DNA analysis to identify potential gene markers for RFI.

Measuring feed intake and daily weight gain of 1000 calves

The requirement for measurements on 1000 animals was based on the sample size estimated to obtain gene markers for the RFI trait[5], with a similar number of animals also being measured by Australian collaborators. The DairyNZ facility was built at the Westpac Taranaki Research Station (WTARS) near Hawera, with capacity for up to 224 calves housed in 28 pens, each pen having an individual, single-access feeding station. Pre-trial testing indicated that eight calves (aged 6-8 months) could utilise a single feed bin without any reduction in intake due to competition for access.

A single group of 164 calves was evaluated in the first year of the trial, with two larger groups measured in the facility in each subsequent year.

Calves were fitted with electronic identification (EID) ear tags, with an EID reader located at each feed bin which was mounted on load cells, with real-time data download using software designed by Gallagher Group Ltd. (Hamilton). This allowed individual intakes to be measured, even as the animals were eating, and daily summaries were generated giving time, duration and weight eaten at each feeding bout for each animal.

Liveweights were collected using electronic scales (Gallaghers SmartScale 500 data collector) and an EID reader (Smartreader HR1). By weighing calves three times weekly for six weeks[9], a similar level of accuracy could be obtained to weighing every 14 days for 10 weeks[1], enabling each part of the trial to be shortened without affecting the accuracy of the results.

Selecting the right calves and early rearing

It was important to select for diversity in RFI from calves of high genetic merit, so the trial represents a 'typical' herd likely to exist in 2018.

Approximately 300 farmers that were using artificial insemination (as identified from the LIC database) and operating within a 100 km radius of the rearing facility were contacted via letters outlining the intent of the project, with offers to purchase AI heifer calves born from their high breeding worth (BW) cows. About 60% of farmers accepted the offer, with 4300 contracts signed for right to purchase over the three year calf measurement period.

Because about half of the calves were male and some had uncertain parentage or poor health, about 1120 heifer calves with a BW of 148 (LIC, 2009) were collected within 4-7 days of birth, given a unique identification (ID) tag, weighed, and a tissue sample taken for DNA analysis. They were all reared to weaning at about 10 weeks old and then grazed until they entered the feeding facility.

All animals were of Holstein-Friesian parentage (15/16 or better) and this allowed New Zealand data to be combined with measurements from the parallel study in Australia.

(cont'd p6)

(cont'd from p5)

Getting the diet right

Measurements of RFI with beef cattle have used silage and/or grain-based rations because this is appropriate for that industry, and the high dry matter content of these diets enables an accurate measure of intake.

This is important because any loss of water (pasture is 80-90% water) will create errors in estimates of feed intake, and pasture quality deteriorates rapidly after cutting. It is probably important to screen animals for divergence in RFI using a similar diet to that fed during production[10] because animal performance and digestive physiology is affected by diet[8].

These considerations resulted in a decision to evaluate the heifers by feeding a dry lucerne cube diet, imported from Canada (Kapt-al, Vancouver, BC). The assumption was that a lucerne diet would be more similar to dairy pasture than a diet based on grain and silage.

Growth is equal, but some eat less

The calves grew at about 0.88 kg/day, which is similar to gain from pasture fed calves[4], and only three of the 1052 calves tested had to be removed from the trial. Monitoring indicated excellent health and, as expected, there was a substantial range in the quantity of feed required for weight gain.

Table 1 summarises the results for the most and least efficient animals and shows that feed eaten by the most efficient 10% was 0.77 kg DM less than the average, whilst the least efficient 10% ate 0.69 kg DM more than average. This range of 1.46 kg DM between the 10% most and 10% least efficient groups amounts to a 22% difference in feed requirements. Similar results have been found for beef animals[3,7] and for the dairy calves in the Australian part of the study[11] that were selected for divergence in RFI. These large differences in feed requirements for weight gain were apparent despite calves having similar average liveweight and BW for the most and least efficient groups (Table 1)

Table 1. Means of the 10% least and most efficient individuals and average values for all 1049 calves that were evaluated for age, breeding worth, liveweight at mid-trial, intake, RFI and daily gain.

	10% most efficient	10% least efficient	Average for all calves
Age at start (days)	217	217	217
Breeding Worth	148	148	148
Liveweight mid-trial (kg)	195	196	196
Feed intake mid-trial (kg DM/day)	6.0	7.5	6.7
Residual feed intake (kg DM)	-0.77	+0.69	0
Liveweight gain (kg/day)	0.88	0.87	0.88

The DNA from each animal was analysed by Illumina Inc. (San Diego, CA, USA) and in 2011 the DNA markers related to RFI measurements were identified by the LIC scientists. This information was used to calculate the heritability of the RFI trait, estimated at 0.38 for the New Zealand heifers and 0.22 for Australian animals, with similar values (0.44 and 0.28 respectively) for 250 day liveweight.

This means that there are excellent opportunities for selection to improve herd efficiency. However, for this to be successful, the RFI must apply to lactating animals to ensure they retain divergence for efficiency. This was tested in the same calves during their first lactation and in cows selected from the national herd using the gene markers identified by LIC. These animals were assessed during lactation in 2011/2012, and the results are presented in the report of the cow validation/gene marker study (page 8) and the report from LIC later in this publication.

Where can I find out more about this research?

The findings of the New Zealand trial[8] and the Australian trial[11] have been reported in detail, with a combined analysis to determine heritability of RFI[6]. Lactating heifers that were either efficient or inefficient during the calf trials were measured to determine efficiency during lactation in 2010/2011, and additional measurements of calf behaviour[2] have been analysed.

Summary

The benefits from this selection for farmers will be lower feed costs for heifer calves without affecting growth and production. Gene markers linked to RFI will allow efficient and inefficient individuals to be identified with minimal effort and cheaply.

Acknowledgements

This project was funded by the Ministry of Business, Industry and Employment, New Zealand dairy farmers through DairyNZ, NZ Trade and Enterprise, and LIC.

References

1. Archer, J.A., R.F. Arthur, R.M. Herd, P.F. Parnell, and W.S. Pitchford. 1997. Optimum postweaning test for measurement of growth rate, feed intake and feed efficiency in British breed cattle. Journal of Animal Science 75:2024-2032.

2. Green, T.C., J.G. Jago, K.A. Macdonald, and G.C. Waghorn. 2013. Relationships between residual feed intake, average daily gain and feeding behaviour in growing dairy heifers. Journal of Dairy Science. 96: 2012-6087

3. Lancaster, P.A., G.E. Carstens, F.R.B. Ribeiro, L.O. Tedeshi, and D.H. Crews 2009. Characterization of feed efficiency traits and relationships with feeding behaviour and ultrasound carcass traits in growing bulls. Journal of Animal Science 87:1528-1539.

4. Macdonald, K.A., McNaughton, L.R., G.A. Verkerk, J.W. Penno, L.J. Burton, D.P Berry, P.J.S. Gore, J.A.S. Lancaster, and C.W. Holmes. 2007. A comparison of three strains of Holstein-Friesian grazed on pasture: Growth, development and puberty. Journal of Dairy Science 90:3993-4003.

5. McNaughton, L.R. and J.E. Pryce. 2007. Metabolic feed efficiency-opportunities for selection in dairy cows. Proceedings of the New Zealand Society of Animal Production 67:392-398.

6. Pryce, J.E., J. Arias, P.J. Bowman, K.A. Macdonald, G.C. Waghorn, W.J. Wales, Y.J. Williams, R.J. Spelman, and B.J. Hayes. 2012. Accuracy of genomic prediction of residual feed intake and 250 day bodyweight in growing heifers using 623,000 single nucleotide polymorphism markers. Journal of Dairy Science 95: 2108-2119.

7. Shaffer, K.S., P. Turk, W.R. Wagner, and E.E.D. Felton. 2011. Residual feed intake, body composition, and fertility in yearling beef heifers. Journal of Animal Science 89:1028-1034.

8. Waghorn, G.C. 2002. Can forages match concentrate diets for dairy production? Proceedings of the New Zealand Society of Animal Production 62: 261 266.

9. Waghorn, G.C., K.A. Macdonald, Y. Williams, S.R. Davis, and R.J. Spelman. 2012. Measuring residual feed intake in dairy heifers fed an alfafa (Medicago sativa) cube diet. Journal of Dairy Science 95:1462-1471.

10. Waghorn, G.C., and R.J. Dewhurst. 2007. Feed efficiency in cattle – the contribution of rumen function. In: Meeting the challenges for pasture-based dairying. Proceedings of the Australasian Dairy Sciences Symposium. September 2007. Eds. D.F. Chapman, D.A. Clark, K.L. Macmillan, and D.P. Nation. National Dairy Alliance, Melbourne. p111-123.

11. Williams Y. J., J.E. Pryce, C. Grainger, W.J. Wales, N. Linden, M. Porker, and B.J. Hayes. 2011. Variation in residual feed intake in Holstein-Friesian dairy heifers in southern Australia. Journal of Dairy Science 94:4715-4725.

Efficient calves are efficient cows

Kevin Macdonald & Garry Waghorn, Senior Scientists, DairyNZ

Summary

- Calves identified as most or least efficient in using feed for growth (divergent residual feed intake) were re-tested to measure their efficiency during their first lactation.
- The heifers were fed grass/lucerne cubes for 35 days commencing at 75-100 days of lactation.
- Those calves identified as being most efficient were still more efficient when lactating heifers.
- The two groups had similar milk production but the efficient heifers required 0.62 kg DM/day less than the inefficient heifers.

The main aim of this study was to take the 10% most and 10% least efficient growing calves in converting feed to liveweight and examine if this divergence still occurred when lactating.

DM production and nutritive value

Forty Holstein-Friesian cows classified as "most efficient" and another 40 cows classified as "least inefficient" as growing calves[3] were raised on pasture, inseminated at 15 months, and evaluated for feed conversion efficiency early in their first lactation. The two year-old heifers were tested in the Westpac Trust Agricultural Research Station (WTARS) feeding facility at Hawera, with half the cows tested in September (~75 days in milk) and the other half in November (~100 days in milk). The feed intakes, milk production and liveweights were measured over 35 days.

Four groups of 10 cows each had access to seven feeding stations with each cow having electronic identification (EID). Their intakes were measured as the disappearance of cubes from feed bins i.e. reduction in total weight of the bin. The bins were mounted on load cells attached to software able to accumulate and integrate weight measurements while animals are eating.

During each measurement period, cows were given *ad libitum* access to cubes made of grass and lucerne. The lucerne was added to raise the crude protein concentrations to about 17.5% of the dry matter (DM) to ensure requirements for lactation were met. Cubes are not manufactured in New Zealand and were sourced from Australia.

The evaluation

For each cow, average milk production over the experimental period was calculated as well as feed intake, liveweight at the mid-point of the trial, and liveweight change (kg/day).

Efficiency relates only to energy used for maintenance and synthesis of products (milk and liveweight). The evaluation of efficiency required the energy in feed and production to be considered. The feed energy came from its technical specification.

Energy in milk (megajoules) produced was calculated (average/day) as

*(fat yield*38.1) + (protein yield*24.5) + (lactose yield *16.5)*

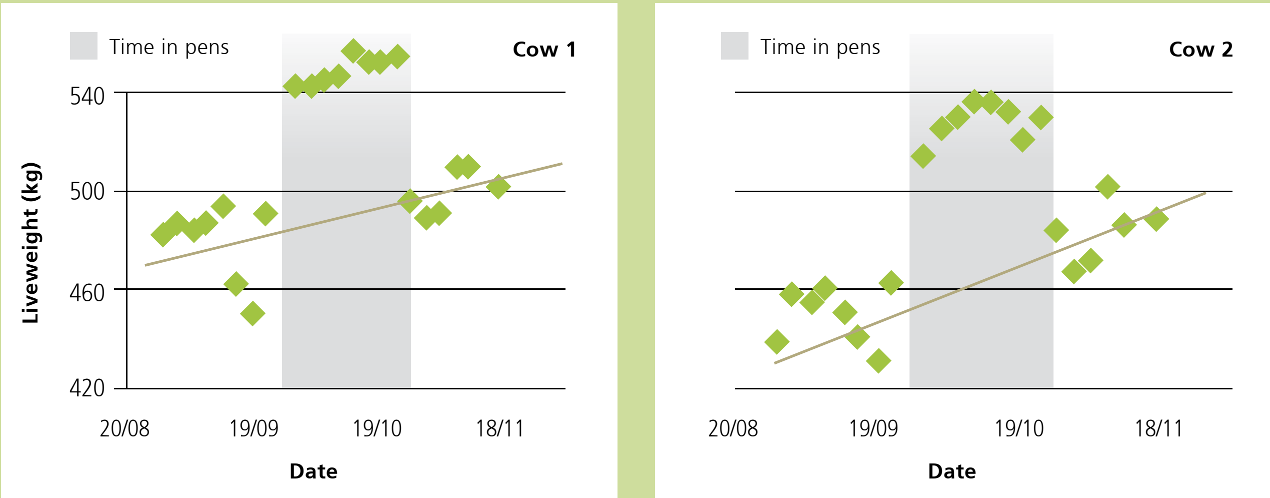
The different multipliers for each milk component reflect the differences in energy content of fat, protein and lactose.

Liveweight change was determined by regression analysis of liveweights of the cows at pasture over three weeks before and three weeks after cube feeding in the feed facility. This was because the cube diet was less digestible than pasture, so feed intakes were high, and cow liveweight increased by 20-40 kg within 1-3 days of entering the feeding facility, and decreased by similar amounts upon release to pasture, as indicated in Figure 1.

A linear statistical model was used to fit dry matter intakes of individuals to their metabolic liveweight ($kg^{0.75}$) at the midpoint of the trial, mean liveweight gain (kg/day), and energy content associated with daily yields in milk of fat, protein and lactose. The difference between actual and predicted intake was fitted to data from all animals, and intakes of individuals were calculated to determine individual RFI. The regressions for both groups of 40 cows were combined to determine if differences between the most and least efficient groups for growth also applied to lactation. Predictions were checked by cross-validation, using the model (excluding inputs from the cow under test) to predict individual intakes.

(cont'd p10)

Figure 1 Examples of regressions based on liveweights measured in two cows grazing pasture to calculate daily gain when fed cubes in pens. The cubes increased weights by 40-50 kg, although this was temporary.



(cont'd from p9)

Results

Feed efficiencies of the two groups differed during lactation. The least efficient cows had, on average, a greater feed intake than predicted, and the most efficient had, on average, a smaller feed intake than predicted (Table 1).

Table 1. Milksolids production, feed intakes and divergence for dry matter (DM) intakes of first lactation cows selected for low and high feed efficiency as 6-8 month old calves. There were 40 most efficient and 40 least efficient heifers evaluated.

Item	Most efficient	Least efficient	SED	P
Milksolids (kg/cow/day)	1.05	1.04	0.01	0.82
Mean liveweight (kg)	407	401	6.0	0.31
Feed intake (kg DM/cow/ day)	18.9	19.1	0.32	0.39
Divergence[#] (kg DM/cow)	-0.31	+0.31	0.22	0.007

[#]Divergence is the difference between the high and low efficiency groups

Milksolids production was similar for cows identified as either efficient or inefficient for growth as calves. This was important because it would not be acceptable to select efficient cows that produced less milk.

The most important finding from this work was the difference in efficiency of feed utilisation for the two groups, which correlated with their divergence as calves. The difference of 0.62 kg DM/cow (the most efficient cows ate 0.31 kg DM less than expected and the least efficient 0.31 kg DM more than expected) might not seem a lot, but it is equivalent to the more efficient animals requiring 3- 4% less feed to produce the same amount of milk; alternatively, 3-4% more cows could be managed on the same amount of feed, or the cows fed better to produce more milk.

Associated trials

In a sub-group of eight high and eight low efficiency animals it was demonstrated that feed digestibility was slightly greater in the efficient animals, but the rumen microbial composition and methane emissions (g/kg DM intake) were similar for both groups[2]. In the study on calf feeding[1] it was reported that feeding behaviour explained only a small proportion of the variation in RFI in dairy heifers. No differences in grazing behaviour have been identified between the high and low efficiency cows when lactating.

Conclusion

The divergence in RFI measured in growing calves was confirmed when they were lactating. Efficient cows ate 3-4% less feed for the same level of production, and these results suggest the gains in efficiency probably have a biochemical basis.

Acknowledgements

This project was funded by the Ministry of Business, Industry and Employment, New Zealand dairy farmers through DairyNZ, NZ Trade and Enterprise, and LIC.

References

1. Green, T.C., J.G. Jago, K.A. Macdonald, and G.C. Waghorn. 2013. Relationships between residual feed intake, average daily gain and feeding behaviour in growing dairy heifers. Journal of Dairy Science. 96: 20132-6087

2. Rius, A.G., S. Kittleman, K.A. Macdonald, G.C. Waghorn, P.H. Janssen, and E. Sikkema 2012. Nitrogen metabolism and rumen microbial enumeration in lactating cows with divergent residual feed intake fed high-quality pasture. Journal of Dairy Science 95: 5024-5034.

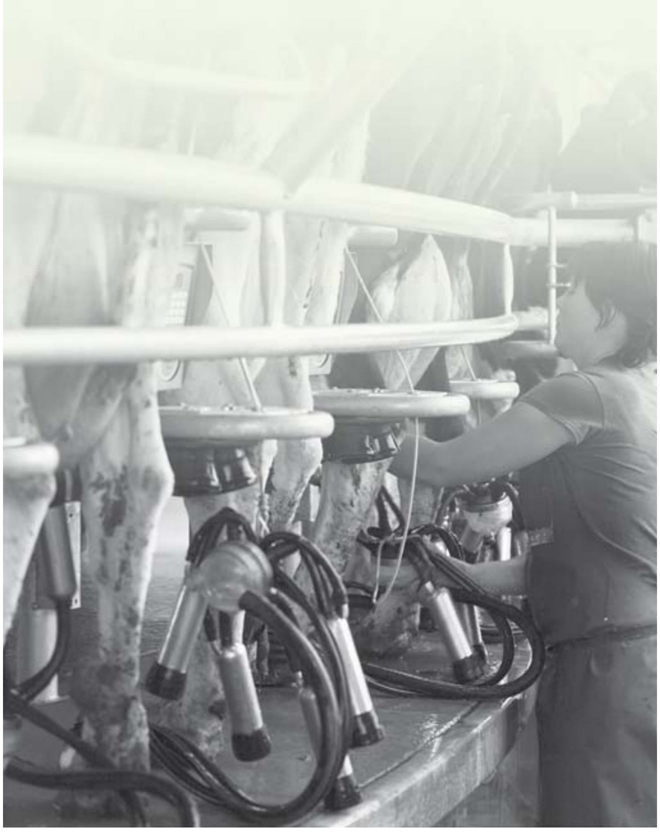
3. Waghorn, G.C., K.A. Macdonald, Y. Williams, S.R. Davis, and R.J. Spelman. 2012. Measuring residual feed intake in dairy heifers fed an alfafa (Medicago sativa) cube diet. Journal of Dairy Science 95: 1462-1471.

Predicting residual feed intake of lactating cows

Steve Davis, Senior Scientist, LIC & Richard Spelman, GM Research and Development, LIC

Summary

- Variation in RFI (residual feed intake, a measure of feed conversion efficiency) among lactating cows contributes to efficiency of feed utilisation for growth and lactation.
- Genomic prediction of RFI during growth can discriminate for RFI among lactating cows, although accuracy needs to be improved.
- A strong sire effect appears to exist for RFI.
- Further work will improve the accuracy of RFI prediction and explore the possibility of sire testing to identify efficient extremes.



This trial was designed to validate that a likely set of gene marks for RFI accurately predicts cows that are divergent for RFI in lactation.

Residual feed intake (RFI; defined as actual minus predicted feed intake) has been widely studied in growing beef animals but there are few reports on measurements in dairy animals. Nevertheless, RFI has been identified as a heritable trait in lactating dairy cows[4], and in growing beef[1] and dairy animals[2]. Furthermore, the trait appears to be repeatable between growth and finishing phases in beef animals[1] and between growth and lactation in dairy cattle[2].

Recent development of rapid and inexpensive genotyping methodologies has enabled the prediction of breeding values based on the profile of genotypes across the whole genome. This approach has been implemented for dairy animals, enabling genomic prediction of genetic merit and acceleration of genetic gain across a range of economically important dairy traits. Prediction of RFI based on a genomic profile will facilitate incorporation of this efficiency trait into a selection index. The main issues are the size of the trait (variance) and if the trait can be predicted with sufficient accuracy to make selection worthwhile.

Experiments outlined elsewhere in this publication have shown that there is variation in RFI in growing Holstein-Friesian heifers in New Zealand and Australia[3] and that this trait is retained in lactating animals. The experiment reported here extends these observations to the genomic prediction of RFI (from the calf trial) in an independent group of lactating cows, this prediction being based on the results of the first study[3] with RFI measurements in growing heifers.

Prediction of RFI

Animals

A group of 3359 cows, born in 2005 or 2006 and identified as at least 15/16ths Holstein-Friesian breed were selected from

(cont'd p12)

(cont'd from p11)

commercial dairy herds in the South Auckland and Taranaki regions of New Zealand. Ear tissue samples were taken by an ear-punch and DNA was extracted for genotyping.

Genotyping was undertaken using the Bovine SNP50 BeadChip (Illumina Inc., San Diego, CA) and the genotyping extended to the 624,930 SNPs (SNP = single nucleotide polymorphism) that were used[3]. (note that an SNP is a base at a defined point in the DNA sequence that can have one of four alternative bases at that position). These changes can be linked to changes in genetic merit for many traits. In this instance, the SNP profile across the full DNA sequence is being used to predict RFI. Using the 'extended' genotype data, genomically-estimated breeding values (GEBV) were calculated for RFI based on the SNP estimates that were generated from the statistical model for growing New Zealand and Australian heifers[3].

After health checks, a total of 214 of the genotyped cows, ranked in the top or bottom 10% for GEBV for RFI, were purchased. They were relocated to the DairyNZ managed Westpac Taranaki Agricultural Research Station (WTARS) near Hawera in May 2011, at the end of their third or fourth lactation. Genetic merit for lactation traits (Breeding Worth) was 95 (±3) and 99 (±4) for the low and high RFI cows, respectively. This compares with the New Zealand average of 72 for Holstein-Friesian cows in 2010. These cows were tested for RFI during lactation (2011-12).

After calving, the cows were managed under commercial conditions, milked twice daily and grazed on ryegrass/white clover pasture. They were transferred to the feed intake facility[5] for one of four trials during the lactation.

Measurement of RFI

A total of 204 cows were evaluated in groups of 52, 52, 52 and 48, over the periods 19 September to 24 October 2011 (Group 1), 7 November to 12 December 2011 (Group 2), 10 January to 20 February 2012 (Group 3), and 29 February to 9 April 2012 (Group 4). Mean days-in-milk were 62, 97, 152 and 197 at the start of each trial for Groups 1-4 respectively. All cows in the first group completed the study period, but from subsequent groups, seven animals were removed because of mastitis or low milk production. In total, 197 cows completed the study.

Cows were fed cubes made from grass and lucerne (40:60 ratio; 90% DM) supplied by MultiCube Stockfeed, (Yarrawinga, Victoria, Australia). These contained 214 g CP/kg DM and predicted digestibility was about 63%. Cows were introduced to cubes when grazing pasture over four days prior to entering the facilities. The cows were in the facilities for 35 days and after a three day acclimatisation period intakes were measured for RFI calculation, along with milk production, composition and liveweight change,

Liveweight was recorded once a week pre and post-trial and twice-weekly during the trial, using a commercial weigher (Gallagher SmartScale 500, Hamilton, NZ).

Milk yields were measured using in-line milk meters (GEA Farm Technology) at morning and afternoon milkings each day. Composite am/pm milk samples were taken three times weekly and analysed for fat, protein and lactose by FTIR spectroscopy (FT120, Foss Electric, Hillerød, Denmark).

Calculation of RFI

Residual feed intake was calculated within each trial as the residual term from a linear statistical model that fitted dry matter intake (DMI; kg/d) to the energy content in daily fat, lactose and protein yields (kg/d), liveweight (LW; kg), and liveweight change (LWΔ), thus;

$DMI = \mu + fat + protein + lactose + LW + LW\Delta + RFI$
(μ is the overall mean)

Analysis of variance was used to test differences between high and low RFI groups. Data were analysed with trial number, efficiency group and interactions included as fixed effects.

Results

Cows that are more efficient have a low (negative) RFI (consume less than predicted) and cows that are relatively inefficient have a high (positive) RFI and eat more than predicted. Table 1 shows that cows selected for low and high RFI had a statistically significant difference for RFI averaging 0.71 kg DM/d over the season. There were no statistically significant differences in milk or milksolids yields between the RFI groups. This means that the efficient (low RFI) cows produced similar amounts of milksolids to inefficient (high RFI) cows, at a similar liveweight, but, on average, ate 0.71 kg DM less feed per day. This compares well with the differences of 0.62 kg DM less feed per day (on a different group of cows) reported for first lactation animals earlier in this publication.

Furthermore, the differences between groups were evident at each measurement period, suggesting a relatively consistent difference in RFI (Table 2) over lactation.

Table 1. Pooled means for the major traits measured during in the four study groups.

RFI Group	Low	High	SED
Efficiency	**(efficient)**	**(inefficient)**	
N	99	98	
Milksolids kg/day	1.38	1.34	0.03 ns
Milk yield kg/day	16.8	16.0	0.5 ns
LW kg	514	511	5.6 ns
LW∆ kg/day	0.24	0.27	0.02 ns
DM intake kg/day	25.0	25.6	0.27 ns
RFI kg DM/day	-0.35	0.36	0.22 ***

(LW liveweight, ns not significant; *** P<0.001)

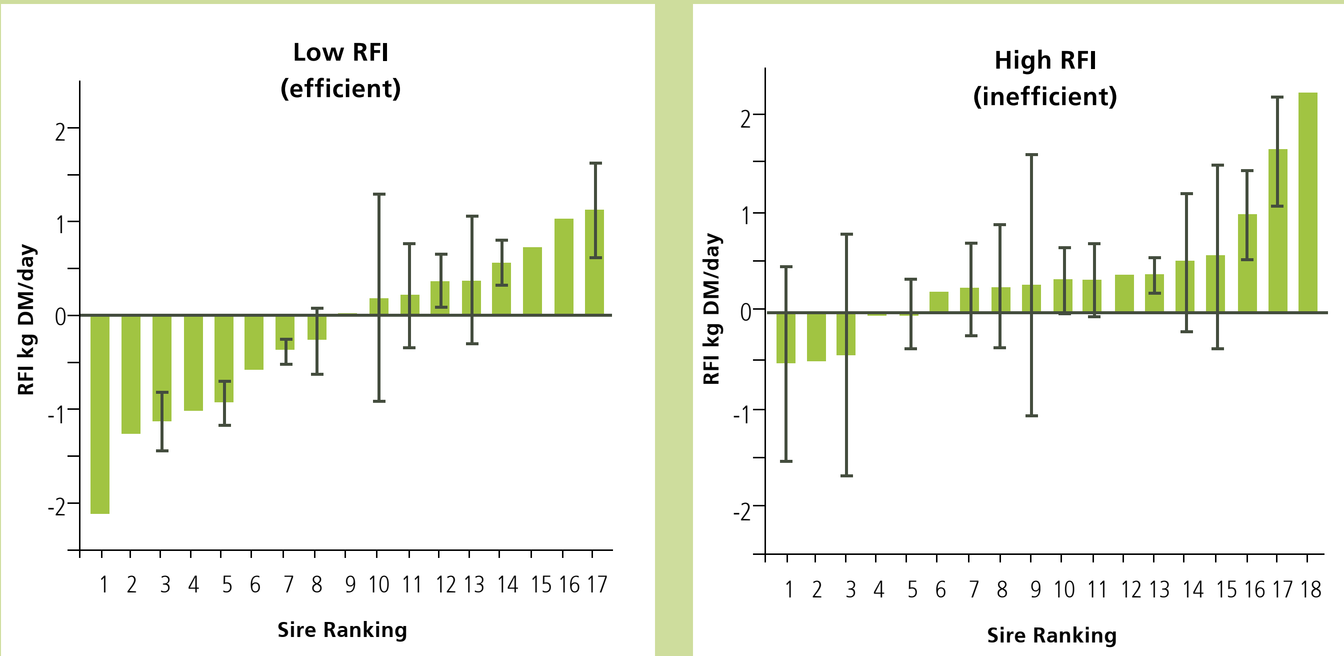
Table 2. Mean RFI of selected groups in each trial; data are kg DM/cow/d with standard errors in parentheses.

	Low RFI	High RFI	Difference
Efficiency	**(efficient)**	**(inefficient)**	
September	-0.37 (0.24)	0.37 (0.31)	0.74
November	-0.24 (0.25)	0.27 (0.29)	0.61
January	-0.55 (0.33)	0.59 (0.37)	1.14
April	-0.24 (0.39)	0.20 (0.22)	0.46

There were 31 sires represented in the 197 cows that completed the trial. While the numbers of daughters were relatively small for most sires, sire 5 in the low RFI group had 47 daughters with an average RFI of -0.92 ± 0.25 kg DM/d (Figure 1). While the dataset is not strong numerically, there appear to be differences in RFI among sires that are worthy of further investigation.

(cont'd p14)

Figure 1. Residual feed intake (RFI) by sire within high and low RFI selection groups. 31 sires were represented in the overall trial, with 17 sires in the "low" group and 18 in the "high" group. Sires ranked 5 and 12 in the 'low' group had 47 and 17 daughters respectively. In the 'high' RFI group, sires ranked 5, 7, and 10 had 10, 15, 21, daughters respectively. All remaining sires are represented by 7 daughters or fewer within an RFI group so the reliability of the ranking is weak. Sire 5 (low RFI) with 47 daughters gives the most reliable estimate of RFI in this dataset at a mean of -0.92 kg DM/d. Four sires had daughters in both RFI groups but numbers were too low for any meaningful interpretation.



(cont'd from p13)

Conclusions

This study has made a major step forward towards being able to capture productivity benefits associated with residual feed intake in dairy cattle. Genomic predictions for RFI, that were developed from feed intake measurements in young growing dairy heifers, successfully predicted dairy cows in the industry that were divergent for RFI in lactation. While differences between RFI groups were relatively small, these quantities are significant at farm level and over the lifetime of a dairy cow.

Further, there is evidence that some sires produce daughters that are more efficient than other sires. Accurate sire ranking for RFI will help improve feed conversion efficiency in dairy cattle. Improvement in the accuracy of prediction will be the focus of future work.

There do not appear to be any negative genetic correlations of RFI with production and reproduction traits, although more data are required for confirmation.

Acknowledgements

This project was funded by the Ministry of Business, Industry and Employment, New Zealand dairy farmers through DairyNZ, NZ Trade and Enterprise, and LIC.

References

1. Herd, R.M., J.A. Archer, and P. F. Arthur, 2003. Reducing the cost of beef production through genetic improvement in residual feed intake: opportunities and challenges to application. Journal of Animal Science 81(E. Suppl. 1): E9-E17.

2. Nieuwhof, G. J., J. A. M. van Arendonk, H. Vos, and S. Korver. 1992. Genetic relationships between feed intake, efficiency and production traits in growing bulls, growing heifers and lactating heifers. Livestock Production Science 32:189–202.

3. Pryce, J E., J.Arias, P. J. Bowman, S. R. Davis, K. A. Macdonald, G. C. Waghorn, W. J. Wales., Y. J. Williams, R. J. Spelman, and B. J. Hayes. 2012. Accuracy of genomic predictions of residual feed intake and 250-day body weight in growing heifers using 625,000 single nucleotide polymorphism markers. Journal of Dairy Science 95: 2108-2119.

4. Van Arendonk, J. A. M., G. J. Nieuwhof, H. Vos, and S. Korver. 1991. Genetic aspects of feed intake and efficiency in lactating dairy heifers. Livestock Production Science 29:263–275.

5. Waghorn, G. C., K. A. Macdonald, Y. Williams, S. R. Davis, and R. J. Spelman. 2012. Measuring residual feed intake in dairy heifers fed an alfalfa (Medicago sativa) cube diet. Journal of Dairy Science. 95:1462–1471.

Advances in identifying cows with superior feed conversion efficiency – the Australian story

Bill Wales, Jennie Pryce, Ben Hayes; Senior Research Scientists, Department of Primary Industries, Victoria, Australia

Summary

Growing calves vary in their feed efficiency.

- Residual feed intake (RFI) was calculated for 903 six month old Holstein-Friesian heifer calves by measuring dry matter intake of cubed lucerne hay and liveweight gain over 70 days.
- On average, the calves ate 8.3 kg dry matter (DM) per day and gained 1.1 kg liveweight per day.
- The most efficient calves (lowest RFI) ate 3.0 kg DM less each day than the least efficient calves (highest RFI) for the same rate of growth.
- The heritability of RFI was 0.27

Feed efficient calves go on to be highly feed efficient cows.

- Residual feed intake was determined on 50 first lactation cows identified as efficient and 58 identified as inefficient (as above) by measuring DM intake of cubed lucerne hay and grain, milk production and liveweight change over 32 days.
- This analysis indicates that, on average, highly feed efficient calves go on to be highly feed efficient cows.

In Australia and New Zealand, feed conversion efficiency of dairy cattle is an important component of the profitability of dairying, given that the cost of feed accounts for much of total farm expenses[1]. Residual feed intake (RFI) is a measure of feed efficiency and is the difference between actual and predicted feed intake. RFI is a useful measure of feed conversion efficiency as it can be used to compare individuals with different levels of production during the period of measurement.

Nine hundred and three Holstein-Friesian heifer calves, aged between 5 and 7 months old, were sourced from commercial herds from across Victoria, Australia and measured for RFI[4] under feedlot style conditions with *ad libitum* access to cubed lucerne hay. Intakes of individual animals were recorded using an electronic feed recording system and liveweight gain was determined by weighing animals once weekly, over a period of 70 days. Calves had a dry matter intake (mean ± SEM) of 8.30 ± 0.05 kg DM/day over the measurement period with liveweight gains of 1.10 kg/day[2]. In terms of converting feed energy to maintenance and growth, the most efficient calves (lowest RFI) ate 3.0 kg DM less each day than the least efficient calves (highest RFI) for a similar rate of growth. The heritability estimate of RFI was 0.27 (± 0.12).

These results show substantial genetic variation in RFI, and that the magnitude of the variation is large enough for this trait to be considered as a candidate component in future dairy breeding goals.

The next phase of the research tested if calves which were efficient at converting feed energy to maintenance and growth were also efficient as cows in converting feed energy to milk.

The lactating experiment consisted of 50 first lactation cows identified as feed efficient and 58 identified as feed inefficient, as growing calves. RFI for lactation was determined by measuring dry matter intake of cubed lucerne hay and grain,

(cont'd p16)

(cont'd from p15)

milk production and liveweight change in two cohort studies, each over 32 days, when the cows were approximately 90 and 197 days into their first lactation[3]. The cows were producing 19.7 and 16.3 kg milk/day in the respective cohorts.

Divergence for RFI between the two groups is shown in Figure 1 and correlations between calf and lactating cow RFI were r=0.34 for the efficient group (n=47; P<0.01) and r=0.17 for the inefficient group (n=57; P=0.10).

This analysis indicates that selection for RFI derived from measurements made in young, growing heifers will, on average, lead to improvements in RFI in primiparous cows. These data are from relatively small numbers of cows and more data are required to understand the genetic relationship between growing heifer and lactating cow RFI. The response to selection, that is expected in lactating cow RFI from selection based on the RFI of growing heifers, can then be calculated. Before this trait becomes a selection objective, relationships with other traits of economic importance are required, most notably fertility.

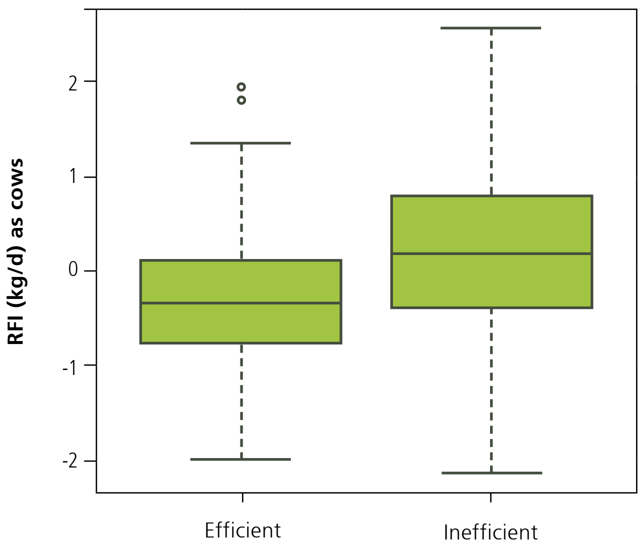
As feed intake is expensive to measure accurately on large numbers of animals, feed efficiency is an obvious candidate for genomic selection. The idea is that a genomic prediction equation can be calculated using data from a subset of animals that are genotyped and have measurements on the trait of interest (in this case RFI). The genomic prediction equation could then be applied to animals that have genotypes but no phenotypes. So, in principle, genomic breeding values could be calculated for any animal that is genotyped.

A genomic prediction equation has been derived from the combined growing heifer data and scientists in Australia and New Zealand are now working towards launching genomic breeding values for feed efficiency.

Acknowledgements

This project was funded by the Geoffrey Gardiner Foundation, Department of Primary Industries (Victoria), and Dairy Futures CRC.

Figure 1: A box-plot of residual feed intake (RFI) in lactating primiparous cows, grouped by their RFI as growing heifers across both cohorts.



References

1. Ho, C., R. Nessler, P.T. Doyle, and B. Malcolm. 2005 Future dairy farming systems in irrigation regions. Australian Farm Business Management Journal 2:65-74.

2. Pryce, J.E., J. Arias, P.J. Bowman, S.R. Davis,, K.A. Macdonald, G.C. Waghorn, W.J. Wales, Y.J. Williams,, R. Spelman and B.J. Hayes. 2012a. Accuracy of genomic predictions of residual feed intake and 250 day bodyweight in growing heifers using 625,000 SNP markers. Journal of Dairy Science 95:2108-2119.

3. Pryce, J.E., L. Marett, W.J. Wales, Y.J. Williams, and B.J. Hayes. 2012b. Calves selected for divergence in feed conversion efficiency for growth also exhibit divergence in feed conversion efficiency in lactation. Proceedings of the 5th Australasian Dairy Science Symposium, Melbourne Australia, p45-46.

4. Williams, Y.J., J.E. Pryce, C. Grainger, W.J. Wales, N. Linden, M. Porker, and B.J. Hayes. 2011. Variation in residual feed intake in Holstein Friesian dairy heifers in southern Australia. Journal of Dairy Science 94: 4715-4725.

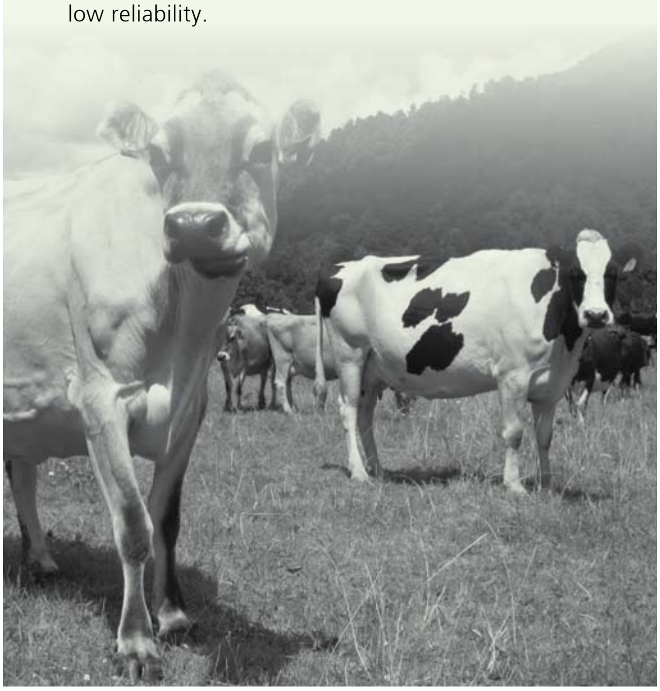
Residual feed intake brings potential to lift feed conversion efficiency

Jeremy Bryant – NZAEL Manager

Summary

How residual feed intake fits into breeding

- Residual feed intake (RFI) provides a measure of 'component feed conversion efficiency'.
- Breeding worth (BW) by comparison is a measure of 'gross lifetime feed efficiency' passed on to progeny.
- BW gives an all-round picture of genetic merit.
- Farmers should choose bulls firstly on BW.
- RFI has a separate economic value.
- The genomic RFI breeding value is not based on information from actual daughters of a sire and has low reliability.



Since 1996, the dairy industry as a whole has been actively selecting dairy cattle for improvements in gross lifetime feed efficiency.

This is thanks to the introduction of breeding worth (BW) in 1996 and continuing through the industry's national breeding objective to 'identify animals whose progeny will be the most efficient converters of feed into farm profit'.

The particular feed conversion efficiency measure, as described in this publication, is a distinct and exciting form called residual feed intake (RFI).

BW and RFI are not the same

BW provides a measure of 'gross lifetime feed efficiency' passed on to progeny.

For BW, we want to ensure animals are retained in the herd as long as possible, with high levels of milksolids production per unit liveweight and per unit of total feed eaten.

This is achieved by including seven traits in BW – milk volume, fat, protein, liveweight, fertility, somatic cell score and residual survival. These are all known to influence gross feed efficiency.

RFI provides a measure of 'component feed conversion efficiency'. For example, the difference between actual intake and expected intake, based on feed requirement equations for production, liveweight, change in body condition, growth and pregnancy.

A negative RFI is best – this minimises the amount of feed eaten per unit of product e.g. milk.

Early indications are that BW and RFI are not directly related but that RFI is a distinct trait. Based on the New Zealand studies, high BW cows were not necessarily the best for RFI.

(cont'd p18)

(cont'd from p17)

Economic value of RFI

The economic value of RFI comes from savings in feed consumed.

Feed saved is feed freed up for another cow to produce more milk or to support an increase in stocking rate. This ultimately leads to more milksolids per hectare.

A negative RFI cow must still get pregnant, have an udder that lasts and have a low somatic cell count, while producing high volumes of milksolids per unit of liveweight.

BW gives the best all-round picture of her genetic merit. RFI has a separate economic value.

Genomic estimate

The current estimate of RFI in New Zealand is derived only for LIC Holstein-Friesian sires and has low reliability.

It is a genome-based breeding value using a reference population of dairy cattle from foundation studies carried out by DairyNZ and LIC.

The genomic RFI breeding value, as opposed to traditional breeding values or BW, is not based on information from actual daughters of a sire. It is far less accurate than daughter proven estimates.

The complementary Australian studies, showing very similar results, support that this is a real effect.

Currently, genomic estimates of breeding values for RFI are the only option. It is expensive and difficult to measure the actual feed intake of dairy cattle in progeny testing schemes and consequently there will be no immediate validation of the RFI trait through progeny testing.

The current estimates are based on growing heifers and lactating cows fed a highly controlled, dry roughage diet of lucerne cubes, or grass and lucerne cubes.

Improving the accuracy and scope of the genomic RFI prediction is dependent on obtaining more information across different breeds.

It also requires building up a larger reference population across all breeds, verifying that the estimate using lucerne cubes is valid for a pasture-based diet, and exploring novel ways of obtaining feed intake information.

Using RFI information

There are a number of potential ways of using current genomic RFI information.

1. **Pre-selection of sires for use in progeny testing**
   Under this option, breeding companies might select sires based on a good genomic breeding value for RFI or, after first selecting for BW, might select other sires based on excellent RFI to enter into progeny testing regimes.

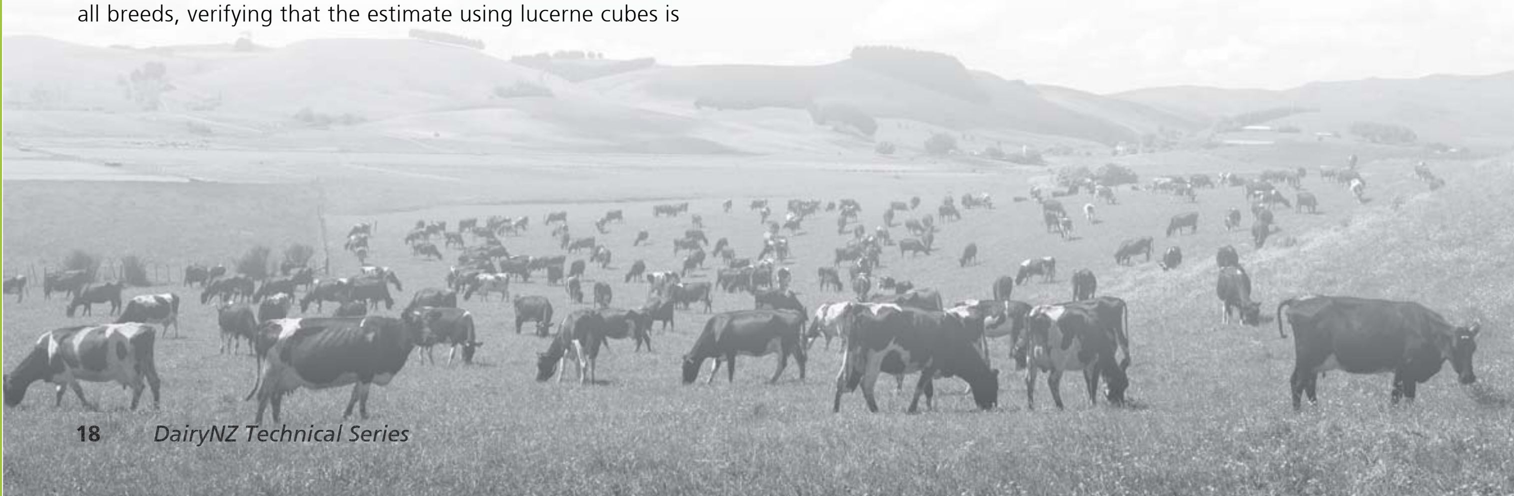
   This option is preferable to selecting sires based solely on their genomic breeding values for RFI. Progeny testing provides a layer of security to ensure the sires stack up on BW and to ensure their daughters have acceptable functional traits (e.g. udder, temperament, milking speed, fertility).

2. **Publish genomic breeding values for RFI**
   This will give farmers the opportunity to utilise this additional source of genomic information, but it should be used secondarily to BW information.

3. **Inclusion in BW**
   RFI is being considered as a new trait in BW. NZAEL (a subsidiary of DairyNZ), LIC and Abacus Bio Ltd are currently investigating the economic value of RFI.

   There are still very large challenges surrounding the accuracy of routine estimation of breeding values for RFI across dairy cattle breeds. A high economic value might accelerate efforts, but there are still logistical and technical challenges to overcome in regards to measuring RFI in progeny testing schemes or the wider commercial population.

The initial RFI results are exciting and promise to add an additional tool in sire and cow selection decisions. Further investigation is required before the full and true, across-breed, benefits of this trait can be realised on-farm.



Recently published by DairyNZ

DairyNZ researchers publish their findings in high calibre national and international journals, so they remain at the leading edge of dairy industry research.

Science conference publications

Chrystal, J.M., R.M. Monaghan, D. Dalley and T. Styles. 2012. Assessments of N leaching losses from six case study dairy farms using contrasting approaches to cow wintering. Proceedings of the New Zealand Grassland Association 74:51-54.

Grala, T.M., C.V.C Phyn, J.K Kay, A.G. Rius, M.D. Littlejohn, R.G. Snell and J.R Roche. 2012. Glucose and lipid metabolism are modified by short-term alterations to milking frequency in grazing dairy cows. Journal of the Federation of American Societies for Experimental Biology 26 (Suppl.):716.6.

Gregorini, P., A.J. Romera, J.R. Galli, P.C. Beukes, and H.H. Fernandez. 2012. Simulation of the effect of stocking rate on forage harvest efficiency under New Zealand intensive grazing systems. Journal of Dairy Science 95(Suppl.2):30.

Kamphuis, C., B. Dela Rue, and J. Jago. 2012. Two on-farm tests to evaluate in-line sensors for mastitis detection. Proceedings of the 11th International Conference on Precision Agriculture, Indianapolis, Indiana USA p1160.

Kerr, G.A., D.F. Chapman, E.R. Thom, C. Matthew, A. Van Der Linden, D.B. Baird, E. Johnston and J.R. Corkran. 2012. Evaluating perennial ryegrass cultivars: improving testing. Proceedings of the New Zealand Grassland Association 74:127-136.

Rius, A.G., C.V.C. Phyn, J.K. Kay and J.R. Roche. 2012. Effect of milking frequency and nutrition in pasture-based dairy cows during an extended lactation. 63rd Annual Meeting of the European Federation of Animal Science, Bratislava, Slovakia, p4.

Peer reviewed (journal) publications

Chapman, D., J. Lee, C. Matthew, E. Thom and J. Bryant. 2011. Perennial ryegrass is the king – breeding and evaluating the generation of ryegrass royalty. New Zealand Primary Industries Management Journal 15:12-14.

Finch, S.C.,E.R. Thom, J.V. Babu, A.D. Hawkes, and C.D. Waugh. 2013. The evaluation of fungal endophyte toxin residues in milk. New Zealand Journal of Veterinary Science 61:11-17.

Sutherland, M.A., A.R.Rogers and G.A. Verkerk. 2012. The effect of temperament and responsiveness towards humans on the behaviour, physiology and milk production of multi-parous dairy cows in a familiar and novel milking environment. Physiology & Behavior 107:329-337.

Thom, E.R., A.J. Popay, D.E. Hume and L.R. Fletcher. 2012. Evaluating the performance of endophytes in farm systems to improve farmer outcomes – a review. Crop & Pasture Science 63:927–943.

For the full list of DairyNZ publications visit the news and media section of **dairynz.co.nz**

Focus on international research

The following is a brief summary of some key science papers recently published.

Wright and others (2012) Effects of increased milking frequency during early lactation on milk yield and udder health of primiparous Holstein heifers.

Journal of Animal Science jas.2012-5692; published ahead of print October 16, 2012, doi:10.2527/jas.2012-5692

In mature Holstein-Friesian cows fed a total mixed ration, a temporary increase in milking frequency at the start of lactation stimulates an increase in milk production that persists when cows are switched to twice-daily (2x) milking for the remainder of lactation. This US study determined if this positive carry-over effect occurs in first-lactation heifers using a half-udder model. The left udder half of each heifer was milked 4 times daily (4x) for three weeks post-calving, and the right udder half was milked 2x as a control. During the first three weeks post-calving, udder halves milked 4x produced 13% more milk and milk protein than those milked 2x. Thereafter, when both udder halves were milked 2x, those previously milked 4x produced 9% more milk and 7% more milk fat and protein (i.e. milksolids). These immediate and carry-over responses resulted in greater total lactation yields of milk, fat and protein in udder halves milked 4x relative to 2x. Therefore, a short period of increased milking frequency during early lactation may lead to a persistent increase in milk production in first-lactation heifers.

DairyNZ comment: DairyNZ research indicates that increased milking frequency during early lactation does not increase lactation-long milksolids production in multiparous grazing cows fed concentrate. Milking cows thrice daily (3x) for up to six weeks post-calving increased milk volume yield by 7% relative to 2x, but fat and protein yield (i.e. milksolids) were not increased. When cows were switched to 2x, milk volumes remained slightly elevated but again milksolids yield did not increase. Milking cows 3x post-calving also induced a more severe negative energy balance, which increased body condition loss and the risk of metabolic disorders and poor fertility. Dairy breed and diet could be contributing factors to the contrasting results.

Kolbach and others (2013) The effect of premilking with a teat cup-like device, in a novel robotic rotary, on attachment accuracy and milk removal.

Journal of Dairy Science 96: 360-365.

Future automated milking systems (robotic rotaries) will have the option of installing a teat preparation module (TPM) for pre-milking stimulation and teat cleaning. This Australian study investigated milk harvesting efficiency; average and peak milk flow rates and cup attachment in response to pre-milking cleaning stimulation using the TPM. Washing increased the probability of successful cup attachment and attachment was also faster (70.7 v 75.0 s). However, milk harvesting efficiency was not increased with there being no effect of pre-milking preparation on average milk flow rate.

DairyNZ comment: DairyNZ data indicate that pre-milking preparation in the form of teat stripping influence milking characteristics with a small decrease in milking duration (10-20 s); however, this benefit is significantly less than the time cost of preparation. Adoption of teat preparation will negatively impact on number of cows milked per hour in a conventional dairy and limit the capacity of an automated milking system. DairyNZ data are consistent with results from this Australian study and any decision to invest in emerging new technologies need to be considered carefully in terms of overall system performance, including capital investment.

Yan, M. J. and others (2013) The carbon footprint of pasture-based milk production: Can white clover make a difference?

Journal of Dairy Science 96: 857-865.

Using a life cycle assessment, researchers from Ireland calculated the carbon footprint of milk production from pasture-based dairy systems relying on nitrogen (N) inputs from synthetic fertiliser or biological N fixation from white clover. The life cycle assessment considered all farm inputs as defined under the cradle to farm gate system boundary. Data were obtained from studies conducted in Ireland over a 6 year period (2001-2006) with a range of stocking rates, fertiliser N inputs and pasture white clover content. The study demonstrated that systems relying on N inputs, from white clover could reduce the carbon footprint of milk (environmental impact) by up to 23% (per kg of energy corrected milk) compared with systems dependent on N fertiliser inputs, without reducing milk production per cow. The three largest contributing factors to the carbon footprint were, in order of importance, methane production, nitrous oxide from N deposition on pasture, and nitrous oxide from fertiliser applications of N. The authors concluded that introducing (and increasing) white clover in pastures can reduce the environmental impact at the experimental systems scale.

DairyNZ comment: To support both current and future industry growth, profitable and sustainable farming systems are an important focus area at DairyNZ. This Irish study supports and complements current New Zealand research programmes targeted at environmental responsibility, and includes the evaluation of alternative diverse species pasture mixtures with legumes, pasture persistence and thus grass:legume balance, improved nitrogen efficiency with high genetic merit cows, and strategic management decisions.