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Beef CRC

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Simultaneous genetic improvement of maternal productivity, feed efficiency and end-product traits in variable environments

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Abstract

A concern in the beef industry is that genetic change in growth and carcass quality has led to cows that have compromised productivity when under limited feed supply resulting from high stocking rate or dry seasons. The project scanned 7,760 cows in 15 Angus or Hereford stud herds. There were also over 500 cows run on research centres in WA and SA with intensive measurement including feed intake over 3 calving cycles. There was large variation in cow size and body composition due to both genetic and nutrition effects. The current carcass EBVs can be used to select for changes on cow body composition if desired. However, genetic effects on mature cow productivity or efficiency were small. Heifer management targets have been produced to aid management. Genetically lean heifers did have reduced fertility and the challenge of achieving heifer fertility EBVs on young bulls remains.

Executive summary

Maternal productivity is a function of a range of traits including fertility within a specified time, calving ease, calf survival, calf growth to weaning. The weaned calf should have desirable growth and carcass characteristics for the following part of the value chain. Cow feed intake is a major cost and so should be minimised relative to output, cow salvage value is an additional output and cows need to be able to remain productive while coping with variable levels of nutrition to cope with Australia's diverse environment and the large variability of seasonal conditions. Key messages are listed with more detail added below.

1. There is a diversity of views among breeders in the importance of genetic fatness on maternal productivity;
2. Cow body composition can be genetically changed by selecting with current EBVs for rib and rump fat depth, intramuscular fat and eye muscle area;
3. Phenotypic growth and fat targets to maximise heifer pregnancy rates have been produced for current Angus cattle;
4. Genetically Low-Fat heifers had lower conception rates and slightly lower subsequent reproduction than genetically High-Fat heifers/cows;
5. Days to calving was the most important EBV affecting heifer conception rate, just as it is designed to do. However, accurate DC EBV are difficult to obtain on young bulls because it can only be measured in females and there is a large use of AI which masks some of the variation;
6. Commercial producers should focus on managing heifer growth and condition and cull dry heifers;
7. Genetically High-Fat cows were more efficient than Low-Fat cows when on Low-Nutrition but this was primarily due to differences in reproduction and so should be able to be managed;
8. Genetically Low-Fat cows were more efficient than High-Fat when on High-Nutrition;
9. Genetically High-Fat cows ate more feed and gained more fat during spring which meant they required less supplementary feed during autumn when feed is expensive;
10. Steers from Low-Fat cows met market specifications for weight and fat when finished a feedlot, but when finished on pasture more failed due to lack of fat cover compared to High-Fat steer progeny;
11. Selecting for efficiency by selecting for low net feed intake resulted in cows that were leaner, had slightly fewer calves (like low fat cows) but were still more efficient than High-NFI cows;
12. Seedstock and commercial breeders should continue selecting in a balanced manner;
13. 16 papers directly from the project plus 3 associated papers have been or will be submitted to the Animal Production Science journal and a special edition on maternal productivity will be published in 2014.

While not part of the original project, a PhD student interviewed seedstock breeders to capture additional insights that may have been too subtle to be obvious when analysing project data. It was found that there was a strong diversity of attitude about the importance of genetic fatness in their client's and own production systems. All breeders had a common breeding objective and were making similar gains for most traits, but the genetic change in fat depth was diverse.

The project was designed with two components. A large number of Angus and Hereford stud cows were scanned 4 times during their first two calvings to monitor changes in body composition and examine relationships with existing EBVs. Over 500 cows were raised on DAFWA's Vasse and SARDI's Struan research centres. This enabled extensive animal measurements, formal genetic treatments (High Fat, Low Fat, High Net Feed Intake, Low NFI), formal nutritional treatments (High and Low) and weekly feed intake measurements for 3½ years on 64 groups of cows and their calves up to weaning.

The data collected on studs demonstrated that cow body composition is heritable and closely genetically related to existing carcass EBVs. The traits after calving were strongly genetically related across time. Generally genetic variation in change in composition during lactation was lowly heritable although fat cover may be an exception. In general, if producers want genetically fatter cows, they can select for increased fat using carcass EBVs although this could lead to decreases in carcass retail beef yield of steers. In all parts of the project there have been no negative effects on maternal productivity associated with increased muscle (EMA EBV) and so it seems sensible for breeders to continue to improve muscling as part of a balanced selection program.

An early result from the research herd component was on pregnancy rates. The High Fat and Low Fat Angus heifers represented the top and bottom 10% of the breed for Rib Fat EBV. Under a 9 week joining, High Fat heifers were similar weight but had 27% greater rib fat depth than the Low Fat line heifers. They also had an 8.5% after a 9 week joining but would have had 12.3% higher pregnancy rates after a 6 week joining regime. The High NFI line had a 19% greater fat depth than the Low NFI line and differences in pregnancy rate were in the same direction as for the Fat lines but not significant (3.9% and 7.5%). There were also small differences in pregnancy rates of lactating first calvers (High Fat 4.2% greater than Low Fat, High NFI 2.5% greater than Low NFI), but these were not significant. There were no genotype effects on pregnancy rate of mature cows.

Scrotal size and fat depth EBVs were related to heifer pregnancy rate, but the EBV that was most closely associated with heifer pregnancy rate was days to calving. The challenge for the stud industry is to be able to get reasonable accuracy EBVs for days to calving on young bulls when there is commonly oestrus synchronisation for AI and ET programs. Growth targets for heifers have been calculated but roughly match with the existing recommendation of heifer joining weights being 65% of mature cow weight. A prototype maternal model has been developed by the Beef CRC and includes a heifer management tool similar to the BeefSpecs model for reaching carcass specifications.

Between joining and calving, heifers were assigned to High or Low nutrition treatments. At the start of second mating, cows on High nutrition were 8% heavier with 11% greater EMA and 23% more rib fat depth than Low Nutrition. At start of mating for mature cows, the High Nutrition treatment were 15% heavier with 15% bigger EMA and 61% greater rib fat depth than the cows on Low Nutrition. The differences at weaning time were similar and the calves from the High Nutrition treatment were 10% heavier than the Low Nutrition. Even for first calvers, the difference between the nutrition treatments in pregnancy rate was just 0.8%.

The experiment operated under strict protocols for supplementary feeding to prevent Low nutrition cows being in a poor welfare state. There were generally no significant genotype by nutrition treatment effects on body composition or fertility. However, every time supplementary feeding was triggered by either a Low Fat or Low NFI cow on Low nutrition. This matches with some of the industry concerns that initiated the project and attempts to quantify the effects on gross margins are being pursued with ongoing economic analysis of the project.

Maternal productivity was defined as weight of calf weaned per unit of energy consumed by the cow and calf. Cow weight gain has a value and can be included as an additional output. The alternative measure is energy cost per unit of weight gain which is akin to a feed conversion ratio and is a function of the inverse of the efficiency measure. The measures have been converted to productivity per ha and cost of production to aid communication of results.

Cows on High nutrition were more costly than Low nutrition when considering just calf production as the output, but the differences were negligible when cow weight gain was included. If supplementary feed costs are accounted for, then the High Nutrition may be better. The genetic line differences in cost of production were surprisingly small. The High Fat line was more costly than Low Fat when on High Nutrition, but was better on Low nutrition. The Low NFI line was always better than the High NFI line which ate a lot more and ended up significantly fatter. That said, the greatest difference between the NFI lines in feed intake was in spring when feed is relatively cheap. The industry sourced Fat lines were bigger and later maturing type cattle than the NFI lines, but this did not have a large effect on cost of weaner production.

A major conclusion from the project is that within the constraints of the type of cattle, environments and nutrition treatments, breeders can continue selecting for growth and carcass quality traits without major impacts on breeder herd efficiency. However, significant negative effects on fertility in young cattle have been identified and there is a need to include a measure of fertility as part of a balanced breeding program. The current days to calving EBV was associated with fertility, but there may be other measures that have greater traction with seedstock and commercial breeders. Regardless of the measure, given the current use of oestrus synchronisation and poor recording of reasons for culling cows, there are significant challenges to achieving reasonable female fertility EBVs on young bulls.

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1. Background

The challenge in a beef cattle production system is to maximise production (output) from a limited and variable feed resource (input). The most obvious output from a cow herd is calf weaning weight per cow joined. As reviewed by Walmsley *et al.* (2012), a combination of cow and calf traits contribute to the maximising of weaning weight. Cow traits include conception, pre-natal growth, gestation length, calving ease, nurturing and milk production. The primary calf traits are pre- and post-natal growth potential, but the calf also influences gestation length and calving ease. An additional important output in cow/calf systems is the final salvage value and weight gain of the cow. Indeed, in some production systems, cows that fail to rear a calf can gain as much weight as they would have weaned in calf, albeit generally at a lower value in terms of price per kg.

An important part of maximising herd efficiency is the utilisation of breed(s) in either purebred or crossbred combinations. Beef cattle germ plasm evaluation trials in the USA (e.g. Cundiff *et al.* 1998) and similar trials in Australia (Upton *et al.* 2001, Pitchford *et al.* 2002, 2006, McKiernan *et al.* 2005) have demonstrated large genetic variation both between and within breeds in most traits studied. Jenkins and Ferrell (1994) utilised the information from USDA breed evaluations and demonstrated the importance of genotype by environment interactions (GxE). Specifically, breed rankings for calf production depend on feed availability.

Another important part of ongoing improvement in components of herd efficiency is genetic gain within existing breeds. During the past 20 years, there has been significant genetic change in the major breeds in southern Australia, especially in Angus where the Long-fed index increased by $4.30/cow/yr from 1998-2008 (Barwick and Henzell 2005, Angus Australia 2011, Figure 1). This change was achieved by increased growth and mature size, increased milk, muscle and intramuscular fat but slightly decreased subcutaneous (Rib and Rump) fat depth (Figure 2). Some of these changes have resulted from direct selection pressure and others as correlated responses.

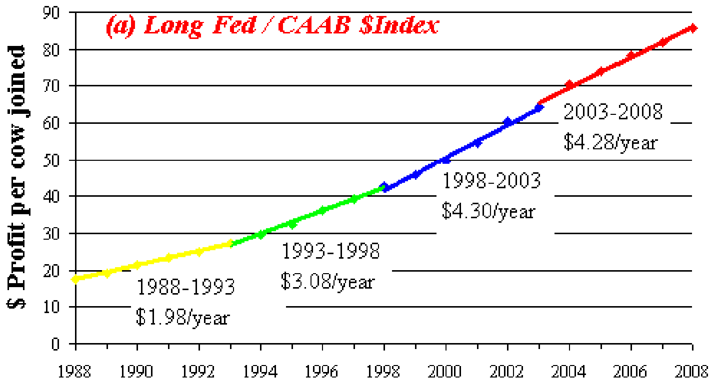

Figure 1. Genetic change in seedstock Angus cattle for the Long-Fed index over 20 years

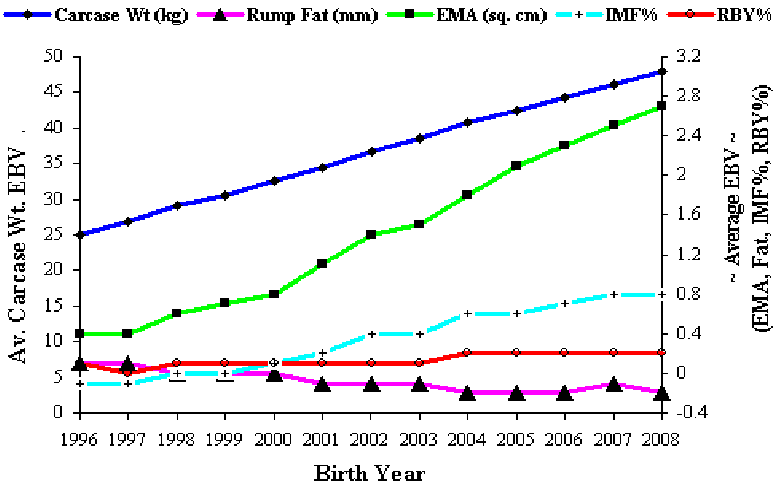

Figure 2. Genetic change in growth and body composition of seedstock Angus cattle over 12 years

The primary measure of reproductive performance of beef cows in the Australian beef cattle genetic recording system Breedplan (Graser 2005) is the number of days from bull-in (joining) date until the cow subsequently calves. This is referred to as *days-to-calving* (DTC) (Meyer *et al.* 1990, Graser 2005). This measure is a function of both post-partum anoestrus interval and gestation length. Donoghue *et al.* (2004) demonstrated the variance of natural service DTC is much greater than AI DTC, demonstrating that more of the variance in DTC is a function of post-partum anoestrus rather than gestation length. In Breedplan, cows that fail to calve are assigned a 21 day penalty from the date of the last calving (Johnston and Bunter 1996). Thus, DTC reflects weaning rate which is a trait with multiple expressions and of high economic value (Barwick and Henzell 2005). However, as outlined by Graser *et al.* (2005), the recording of DTC requires a full female inventory recording system and "correct use of disposal codes, especially for cows culled for infertility, is critical for the evaluation of this trait." Furthermore, DTC records can only currently be used from natural matings because AI mating generally requires synchronisation of oestrus. There have been recent changes in Breedplan recording to try and capture more information and Donoghue *et al.* (2004) estimated the genetic correlation between natural service and AI DTC was 0.81 which provides hope for being able to use that data in the future.

There are five reasons why genetic gain in DTC is limited and why there is a need for good selection criteria that can be measured early in life:

1. DTC is a low heritability trait.
2. Herds making the most genetic progress are probably making extensive use of artificial insemination (AI) and the most common method requires synchronisation of oestrus which masks variation in DTC. Indeed, Donoghue *et al.* (2004) reported one third of Angus seedstock calves are by AI. To achieve that, many more would have been synchronised.
3. It is common that cows that do have DTC records have actually been part of AI programs before being joined naturally but this is rarely recorded.
4. Very few herds have been submitting data on dry cows with accurate fate codes. In many breeds, there has been a financial disincentive that has prevented accurate recording dry cows (Graser personal communication, 2011).
5. Lifetime weaning rate, by definition, takes a long time to record.

To maintain an annual calving pattern, cows must be able to re-conceive soon after peak lactation and cope with seasonal variations in feed supply. This requires periods of accretion and mobilisation of the main body energy reserves, fat and muscle. Thus, calf production is intimately linked to feed intake and energy reserves which vary greatly both within and between years and is also affected by genetics.

Feed requirement of cows is the largest cost in a breeder herd and a large proportion of this cost is maintenance requirements of cows (Arthur 2004). There is variation between animals in various measures of efficiency and this is moderately heritable in a range of species (Pitchford 2004). It has been known for some time that selection for gross efficiency or feed conversion will result in bigger animals (Arthur *et al.* 2001). While this is ideal for the feedlot sector, larger cows are likely to have higher feed requirements resulting in increased costs in the breeder herd. A measure of efficiency that may be better is residual feed intake as originally defined by Koch (1963). However, it is still not clear if selection for residual feed intake in young animals on high quality feed will lead to improved efficiency of the pasture fed breeder herd.

Most cattle production systems experience seasonal variation in feed supply which is determined by rainfall, temperature and day length. In addition, Australia's environment has large variation between years in feed production. Thus, it is possible that genotypes that perform relatively well in good years may not in poor years. This certainly is the case when comparing breeds as quantified by Jenkins and Ferrell (1994).

The project described herein was initiated following concerns expressed by seedstock cattle breeders that while there was genetic improvement in feedlot and abattoir performance of cows, it could lead to declines in cow herd efficiency, especially under variable nutritional conditions. Among the seedstock breeders and scientists, it was felt that these concerns were limiting the adoption of genetic technologies that increase the rate of genetic progress. Specifically, this could be the reason the rate of gain in Angus did not accelerate in 2003-2008 as it had done in the previous 5 year period (Figures 1 and 2, Angus Australia 2011). Indeed, the rate of genetic progress during the period 2008-10 had dropped to just $2.79/cow/year (Dr Peter Parnell, personal communication 2012, Angus Australia).

The aim of this project was to provide information to improve efficiency of cow/calf systems (maternal efficiency) by quantifying relationships between calf production, body composition and feed efficiency in variable nutritional environments. One output from the project will be a series of new genetic parameters for early-in-life selection criteria for maternal efficiency and new knowledge as to whether there is a need for additional estimated breeding values (EBVs) for cow body composition in addition to the steer body composition EBVs already available. Two approaches were taken: additional measurements in large, performance-recorded seedstock herds, and a designed project on research centres to enable detailed measurement of cow reproductive performance, change in body composition and measurement of feed intake in cows grazing pasture.

2. Industry herds

Seedstock cattle herds with large cohorts of heifers that were well recorded on Breedplan, including ultrasound scanning of body composition, were identified and additional sequential measurements of body composition collected on the heifers over two years. While many seedstock herds scan bulls, far fewer scan heifers and the number of available herds with large cohorts of scanned heifers was not large.

The project used data for 7,760 cows in 15 herds and two breeds (77% Angus and 23% Hereford or Poll Hereford, Table 1). When the research herd animals from Fat, NFI and Muscle lines (MLA project BFG.0049) are added, there will be close to 9,000 cows. This analysis will be done at a later date.

The aim in monitoring changes in body composition was to scan at key times to detect peaks and troughs in condition. The measurement times chosen were pre-calving and at weaning for the first two parities. In the first year, 2006, the season was particularly bad and herds adopted a range of drought strategies. Some retained heifers that were not in calf, others sold whole cohorts and two studs were completely dispersed. Thus, the total number of measurements (20,024) was less than the desired 8,000 x 4 = 32,000 (Table 1). While the numbers of records collected at individual measurement time-points are quite high, the number of animals with complete information (all four scans) is quite low (2,270).

As outlined in the introduction, the majority of heifers and cows were synchronised for AI programs so the number of DTC records was greatly reduced. Of these, it is likely a number were part of an AI program before being mated to back up bulls. This means the bulk of the DTC information in the project actually comes from the research herds despite them being much smaller.

Table 1. Number of cattle measured by breed and time

	Angus	Hereford	Total
Parity 1			
Pre-calving	4,841	1,273	6,114
Weaning	3,767	939	4,706
Parity 2	3,618		
Pre-calving	3,618	1,204	4,822
Weaning	2,740	942	3,682
Total herds	11	4	15
Total cows	5,975	1,785	7,760
Min cows per herd	47	154	
Max cows per herd	1,630	696	
Total scans	15,547	4,477	20,024
All 4 scans	1,773	497	2,270

The measurements at the four time points include weight (Wt, kg), height (Ht, cm, PC1 and PC2 only), condition score (CS), P8 rump fat depth (P8, mm), rib fat depth (Rib, mm), intramuscular fat (IMF, %) and eye muscle area (EMA, cm^2). Scanning in the industry herds was conducted by 3 accredited scanners. Summary statistics and breeding values are presented in Tables 2 and 3 respectively. Other measurements recorded routinely are bull-in or AI date, calving and weaning date, calf birth and weaning weight, calving difficulty, mature cow weight (at weaning) and many have structural assessment scores. Fate codes of cull cows are currently being collected but with significant difficulty. Unfortunately the reproduction information from the industry herds is nowhere near what was aimed for. This means that the primary information from industry herds is on body composition. Information on relationships between composition and reproduction must be drawn from the research centre herds.

Table 2. Average and range of Estimated Breeding Values[1] for recorded females

	200 Day Wt. (kg)	200 Day Milk (kg)	Cow Wt. (kg)	Days To Calving	Carcass Wt. (kg)	EMA (cm^2)	Rib Fat (mm)	P8 Fat (mm)	RBY[#] %	IMF %
Angus										
Average	+40	+14	+85	-3.7	+54.4	+3.7	+0.1	+0.1	0.2	+1.4
Min	+7	-1	+2	-14.3	+1.2	-2.9	-4.0	-5.2	-2.8	-1.5
Max	+62	+26	+152	+6.2	+81.6	+11.1	+6.4	+6.9	+3.2	+4.1
Breed avg	+37	+12	+81	-2.7	+49	+3.0	-0.1	-0.1	+0.2	+0.9
Hereford/Poll Hereford										
Average	+31	+11	+68	-1.2	+39	+2.4	-0.2	-0.3	+0.8	+0.0
Min	+10	0	+8	-5.7	+7	-0.9	-3.6	-5.0	-2.6	-2.0
Max	+51	+24	+125	+3.2	+66	+6.7	+3.3	+4.6	+4.4	+2.5
Breed avg	+26	+12	+59	-1.7	+36	+2.3	+0.1	+0.1	+0.7	+0.0

[1] GROUP BREEDPLAN EBVs published in August 2011

[#]RBY = Retail Beef Yield

The number of progeny per sire was not normally distributed so while the mean was 14, the median was 5 in Angus, with a similar pattern in Hereford with a mean of 9 and a median of 6. Calculated a different way, on average, cows came from sires with 46 progeny in the project. Thus, while there were many sires with few progeny, there were numerous cows with good genetic relationships.

A common belief among commercial cow/calf producers is that seedstock cattle herds are well fed and run “soft” (that is, at lower stocking rates). Thus, an initial concern in the design of the project was that there would be insufficient variation between herds to allow detection of GxE effects. The herds were located in eastern Australia, mostly around the New England tablelands and eastern Riverina of New South Wales, in southern Victoria, and one in South Australia. After the first year it was evident that there was both large variation within and between herds in the condition of their cattle (Figure 3) and that some seedstock herds are managed at relatively high stocking rates as indicated by low condition of their cows.

Another concern in the design of the project was that negative genetic relationships between cow body composition and maternal productivity would be masked by good management by seedstock cattle breeders. A social science study was initiated to capture additional information from seedstock cattle breeders regarding management and selection of their breeding females and sires. The study comprised in-depth interviews with the breeders from the 15 contributing and 10 additional herds recognised as industry leaders. Content analysis was conducted and hypotheses posed by the seedstock cattle breeders were tested in the industry herd and research herd data sets. The final step included “member checking” where results from the content analysis and quantitative analyses were presented to the seedstock breeders and their reactions were documented as reported by Lee *et al.* (2012).

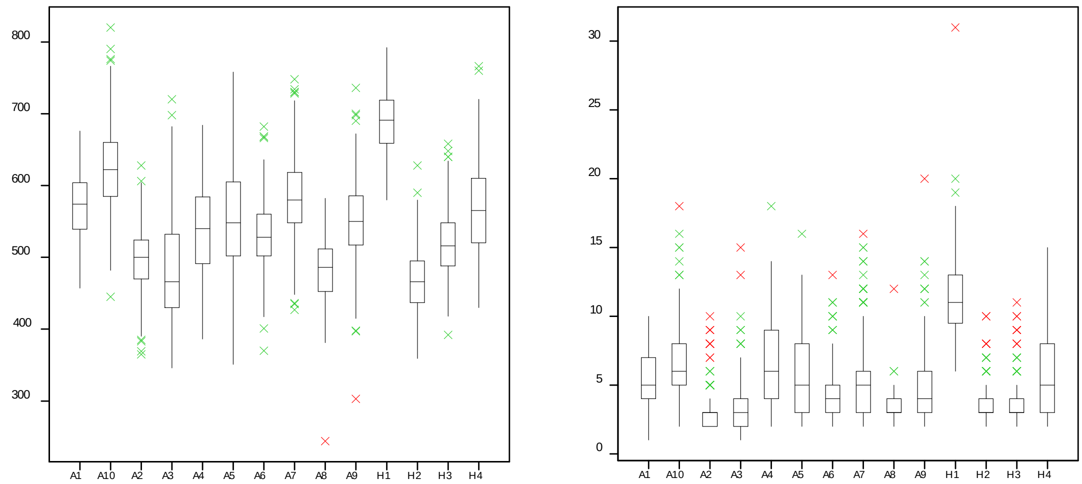

Figure 3. Variation in weight (kg) and rib fat (mm) between and within herds at pre-calving parity 2 (cows approximately 3 years of age). There were 10 Angus (A) and 4 Hereford (H) herds

An outcome of the social science study was that breeders tended to diverge into two groups which reflected their management approach, or at least the perceived approach their clients were taking. One approach is the controlled input approach (Figure 4) where inputs are carefully managed and closely aligned to cow feed requirements. By doing this, breeders closely manage cow body condition and minimise fluctuation. This enables a strong focus on production traits, which is believed to be the most efficient for the whole system, thus leading to greater profitability. The alternative is the variable input approach where cows must adapt to variable pasture feed supply in terms of quantity and quality. Cows gain more condition in spring and mobilise more in autumn and winter. Since feed requirements of cows is a large cost, it is believed the system is more profitable by having an adaptable cow. Selection in this system is greater for fat reserves which may be perceived as resilience and may mean slightly less pressure is placed on production traits such as growth and meat yield.

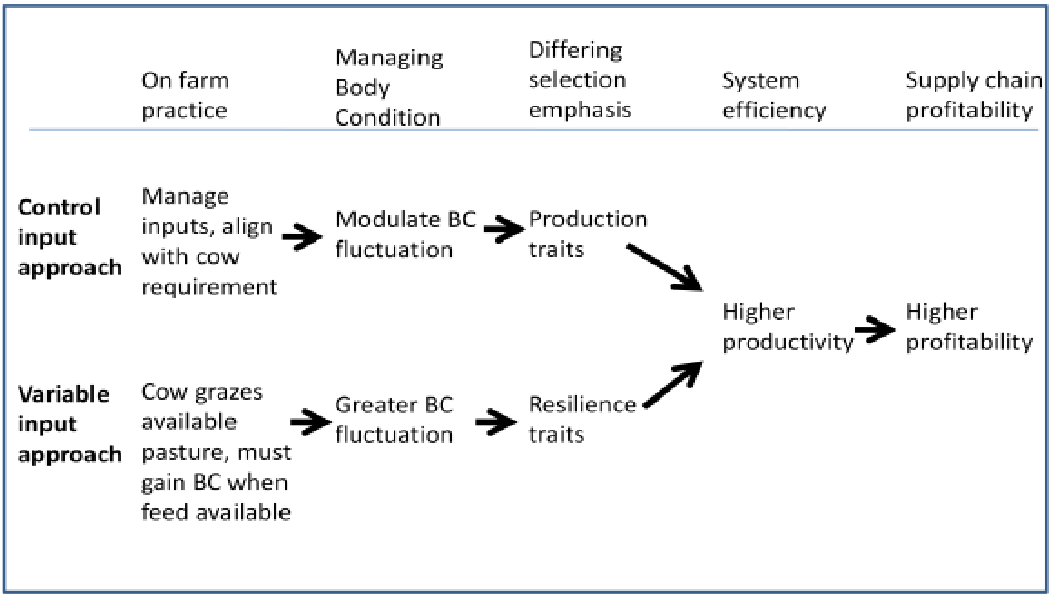

Figure 4. Diversity in breeder logic pattern

An obvious question that arises from the stated diverse attitudes to the importance of selection for fat or resilience in cows is whether breeders are actually selecting for different traits, i.e. do they walk the walk and not just talk the talk. To address this, for the 10 Angus herds in the project, their genetic progress from 2000-2009 was examined (Figure 5). Individual traits (Wt, EMA, IMF and P8) were plotted against the Long Fed index. All breeders had made approximately $50 gain in the index, increased 600d weight by 60kg, eye muscle area by 3cm^2 and intramuscular fat by 1.5%. However, there was large variation in the genetic trend for P8 fat depth which did reflect a diversity of opinion of the importance of fat depth.

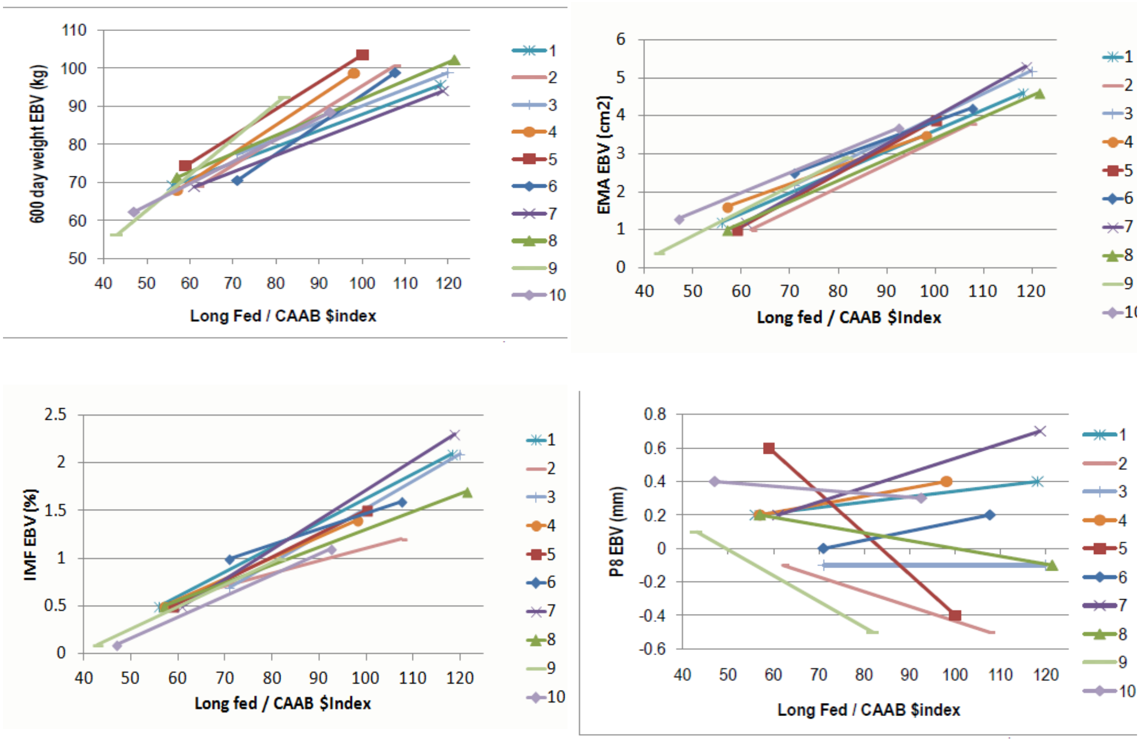

Figure 5. Diversity in genetic progress between 10 Angus herds from 2000-2009. Note that the stud numbers do not relate to those in Figure 3

As stated above, cows were scanned pre-calving and at weaning of their first two calves. Means and standard deviations are presented (Table 3). While the project is not a breed comparison because the breeds were run on separate properties, it is clear that the only major difference between the breeds in the traits measured is in intramuscular fat. The Angus had approximately 2.5% more intramuscular fat than the Hereford.

Table 3. Raw means (standard deviations) for traits and breeds.

	Pre-calving Parity 1	Weaning Parity 1	Pre-calving Parity 2	Weaning Parity 2
WT (kg)	487[A] (70) 458 (74)	514 (64) 487 (91)	554 (68) 523 (75)	579 (73) 564 (80)
P8 (mm)	5.8 (3.1) 6.5 (4.3)	5.8 (2.9) 6.3 (4.3)	6.3 (3.5) 7.0 (5.6)	7.8 (4.4) 9.1 (6.1)
Rib (mm)	4.6 (2.2) 4.4 (2.2)	5.0 (2.2) 4.6 (2.6)	5.0 (2.5) 4.7 (2.9)	6.5 (3.2) 5.9 (3.3)
EMA (cm^2)	57 (10) 51 (11)	59 (9) 55 (9)	61 (10) 54 (11)	63 (10) 60 (9)
IMF (%)	5.2 (2.0) 3.0 (1.9)	5.5 (1.9) 3.0 (1.8)	5.5 (2.1) 3.1 (2.2)	5.9 (1.9) 3.6 (1.8)
HT (cm)	132 (4.4) 131 (5.2)		134 (4.5) 134 (4.8)	

[A] Angus values on top, Hereford below

For consistency, heritability is the present study is defined as low (0-0.2), moderate (0.2-0.4) or high (>0.4). While it is well known that body composition traits in young steers and heifers are moderately heritable, there are very few estimates for cow composition. All traits at all time points in both breeds were moderate to highly heritable. Eye muscle area was the least heritable trait and height, as expected, the most highly heritable. The fat cover traits (P8 and Rib) were highly heritable demonstrating that if breeders wanted to select for fatter or leaner cows, it is quite achievable.

Table 4. Heritability estimates (%[A]) for traits and breeds

	Breed	Pre-calving Parity 1	Weaning Parity 1	Pre-calving Parity 2	Weaning Parity 2
WT (kg)	Angus Hereford	45 53	30 40	38 30	53 30
P8 (mm)	Angus Hereford	44 64	56 57	46 26	52 29
Rib (mm)	Angus Hereford	46 61	59 36	42 45	48 27
EMA (cm^2)	Angus Hereford	26 14	28 33	22 24	41 17
IMF (%)	Angus Hereford	32 47	42 51	33 47	31 32
HT (cm)	Angus Hereford	57 51		58 37	

[A] Standard errors approximately 0.05 for Angus and 0.08 for Hereford.

While body composition is highly heritable at a given time, at the start of the project it was not clear whether there was a need for new breeding values for traits like "ability to mobilise body condition". This can be addressed in two ways: first by estimating the heritability of traits as change in weight or composition; and second by estimating genetic correlations between the traits at given times.

There was very large variation in all traits when expressed as changes between time points. For example, weight change during the first lactation varied by over 300kg (Figure 6). While these "change traits" were highly variable, they were far less heritable than the measurements at a given time point (Table 5). Generally the heritabilities could be regarded as low although it appears change in fat depth may be moderately heritable. Fat depth is the trait of greatest concern to breeders because of its relationship with calving rate and animal welfare (maintenance of body condition). Thus, while it could just be a function of such high heritabilities at specific times, change in fat depth being of moderate heritability warrants further investigation.

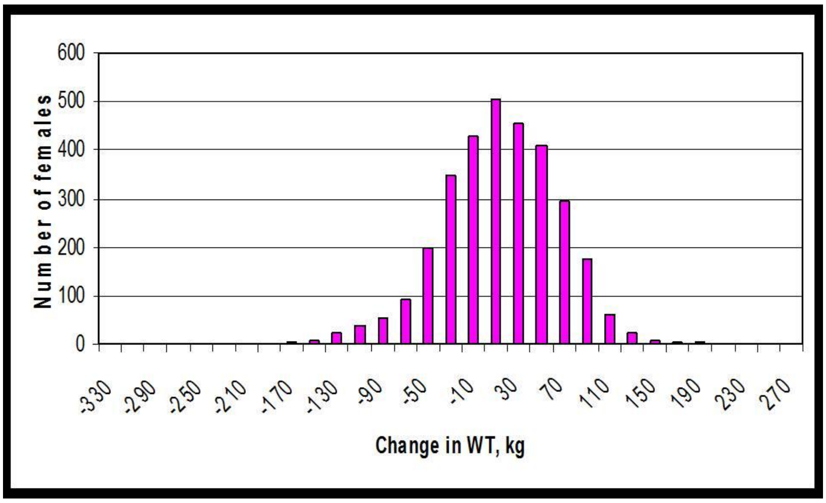

Figure 6. Change in weight during first lactation (PC1 to W1) showing large variation

Table 5. Heritability (%[A]) of change traits for Angus cows

	1st Lactation PC1-W1	Dry gain W1-PC2	2nd Lactation PC2-W2
WT (kg)	15	16	22
P8 (mm)	33	20	35
EMA (cm^2)	18	10	7
IMF (%)	16	10	4

[A] Standard errors approximately 0.06.

All bivariate genetic correlations have been estimated between the traits measured in the current project and those already recorded on heifers at approximately 500 days of age by the breeders. There are a total of 27 traits: 5 traits (Wt, EMA, P8, Rib, IMF) x 5 times (500d, PC1, W1, PC2, W2) plus height measured at PC1 and PC2. All 351 bivariate genetic correlations have been estimated to examine genetic relationships between traits and times (Table 6).

Table 6. Genetic correlations (251) between all 27 traits (Wt, EMA, P8, Rib, IMF at 500d, PC1, W1, PC2, W2; Ht at PC1 and PC2)

	e500	ePC1	ePC2	eW1	eW2	hPC1	hPC2	l500	lPC1	lPC2	lW1	lW2	lp8500	lp8PC1	lp8PC2	lp8W1	lp8W2	lrib500	lribPC1	lribPC2	lribW1	lribW2	w500	wPC1	wPC2	wW1	wW2
e500	1	0.848	0.785	0.615	0.478	0.249	0.136	0.134	0.099	0.025	0.126	-0.035	0.044	0.071	-0.013	0.028	-0.012	0.184	0.068	0.082	0.049	-0.002	0.346	0.339	0.300	0.113	0.168
ePC1	0.848	1	0.920	0.639	0.625	0.256	0.148	0.149	0.253	0.098	0.103	0.061	0.108	0.289	0.067	-0.019	0.013	0.230	0.288	0.121	-0.033	0.011	0.305	0.460	0.322	0.054	0.174
ePC2	0.785	0.920	1	0.903	0.877	0.306	0.332	0.107	0.074	0.404	0.426	0.301	0.044	0.114	0.447	0.443	0.376	0.109	0.091	0.488	0.435	0.377	0.203	0.445	0.656	0.542	0.536
eW1	0.615	0.639	0.903	1	0.867	0.134	0.304	-0.069	0.007	0.180	0.435	0.229	-0.016	0.159	0.398	0.525	0.364	0.072	0.104	0.400	0.510	0.405	0.100	0.224	0.469	0.571	0.411
eW2	0.478	0.625	0.877	0.867	1	0.172	0.254	-0.156	-0.138	0.390	0.297	0.510	-0.021	-0.083	0.378	0.320	0.665	0.001	-0.111	0.424	0.326	0.603	-0.046	0.172	0.471	0.452	0.725
hPC1	0.249	0.256	0.306	0.134	0.172	1	0.983	-0.066	0.043	-0.106	0.043	0.077	-0.226	-0.151	-0.191	-0.207	-0.038	-0.157	-0.103	-0.131	-0.176	0.021	0.730	0.788	0.720	0.685	0.661
hPC2	0.136	0.148	0.332	0.304	0.254	0.983	1	-0.188	-0.138	0.029	0.017	0.057	-0.268	-0.217	0.027	-0.066	0.102	-0.270	-0.153	-0.007	-0.032	0.125	0.616	0.754	0.778	0.729	0.725
l500	0.134	0.149	0.107	-0.069	-0.156	-0.066	-0.188	1	0.905	0.662	0.696	0.526	0.499	0.558	0.348	0.356	0.184	0.521	0.626	0.478	0.392	0.148	0.046	0.092	-0.201	-0.178	-0.305
lPC1	0.099	0.253	0.074	0.007	-0.138	0.043	-0.138	0.905	1	0.742	0.763	0.589	0.495	0.641	0.354	0.365	0.164	0.506	0.700	0.437	0.400	0.164	0.022	0.229	-0.142	-0.111	-0.222
lPC2	0.025	0.098	0.404	0.180	0.390	-0.106	0.029	0.662	0.742	1	0.957	0.871	0.522	0.544	0.764	0.716	0.635	0.490	0.590	0.835	0.750	0.668	-0.177	0.025	0.184	0.119	0.023
lW1	0.126	0.103	0.426	0.435	0.297	0.043	0.017	0.696	0.763	0.957	1	0.958	0.384	0.518	0.669	0.748	0.637	0.416	0.518	0.700	0.765	0.595	-0.044	0.162	0.226	0.317	0.221
lW2	-0.035	0.061	0.301	0.229	0.510	0.077	0.057	0.526	0.589	0.871	0.958	1	0.397	0.282	0.653	0.696	0.732	0.337	0.327	0.697	0.667	0.662	-0.288	0.027	0.116	0.217	0.336
lp8500	0.044	0.108	0.044	-0.016	-0.021	-0.226	-0.268	0.499	0.495	0.522	0.384	0.397	1	0.922	0.689	0.567	0.665	0.856	0.794	0.606	0.516	0.587	0.055	0.021	-0.110	-0.156	-0.128
lp8PC1	0.071	0.289	0.114	0.159	-0.083	-0.151	-0.217	0.558	0.641	0.544	0.518	0.282	0.922	1	0.775	0.701	0.591	0.765	0.920	0.646	0.640	0.479	0.010	0.141	-0.106	-0.111	-0.185
lp8PC2	-0.013	0.067	0.447	0.398	0.378	-0.191	0.027	0.348	0.354	0.764	0.669	0.653	0.689	0.775	1	0.914	0.930	0.558	0.603	0.929	0.862	0.816	-0.101	-0.001	0.342	0.211	0.178
lp8W1	0.028	-0.019	0.443	0.525	0.320	-0.207	-0.066	0.356	0.365	0.716	0.748	0.696	0.567	0.701	0.914	1	0.976	0.513	0.618	0.875	0.966	0.926	-0.150	-0.046	0.175	0.283	0.239
lp8W2	-0.012	0.013	0.376	0.364	0.665	-0.038	0.102	0.184	0.164	0.635	0.637	0.732	0.665	0.591	0.930	0.976	1	0.507	0.442	0.800	0.864	0.964	-0.045	-0.027	0.348	0.400	0.535
lrib500	0.184	0.230	0.109	0.072	0.001	-0.157	-0.270	0.521	0.506	0.490	0.416	0.337	0.856	0.765	0.558	0.513	0.507	1	0.855	0.715	0.603	0.656	0.202	0.142	-0.126	-0.101	-0.140
lribPC1	0.068	0.288	0.091	0.104	-0.111	-0.103	-0.153	0.626	0.700	0.590	0.518	0.327	0.794	0.920	0.603	0.618	0.442	0.855	1	0.726	0.698	0.539	0.000	0.149	-0.064	-0.102	-0.238
lribPC2	0.082	0.121	0.488	0.400	0.424	-0.131	-0.007	0.478	0.437	0.835	0.700	0.697	0.606	0.646	0.929	0.875	0.800	0.715	0.726	1	0.970	0.941	-0.005	0.073	0.340	0.304	0.149
lribW1	0.049	-0.033	0.435	0.510	0.326	-0.176	-0.032	0.392	0.400	0.750	0.765	0.667	0.516	0.640	0.862	0.966	0.864	0.603	0.698	0.970	1	0.999	-0.092	0.009	0.276	0.312	0.258
lribW2	-0.002	0.011	0.377	0.405	0.603	0.021	0.125	0.148	0.164	0.668	0.595	0.662	0.587	0.479	0.816	0.926	0.964	0.656	0.539	0.941	0.999	1	-0.046	0.010	0.346	0.406	0.483
w500	0.346	0.305	0.203	0.100	-0.046	0.730	0.616	0.046	0.022	-0.177	-0.044	-0.288	0.055	0.010	-0.101	-0.150	-0.045	0.202	0.000	-0.005	-0.092	-0.046	1	0.900	0.763	0.777	0.609
wPC1	0.339	0.460	0.445	0.224	0.172	0.788	0.754	0.092	0.229	0.025	0.162	0.027	0.021	0.141	-0.001	-0.046	-0.027	0.142	0.149	0.073	0.009	0.010	0.900	1	0.942	0.853	0.859
wPC2	0.300	0.322	0.656	0.469	0.471	0.720	0.778	-0.201	-0.142	0.184	0.226	0.116	-0.110	-0.106	0.342	0.175	0.348	-0.126	-0.064	0.340	0.276	0.346	0.763	0.942	1	0.945	0.950
wW1	0.113	0.054	0.542	0.571	0.452	0.685	0.729	-0.178	-0.111	0.119	0.317	0.217	-0.156	-0.111	0.211	0.283	0.400	-0.101	-0.102	0.304	0.312	0.406	0.777	0.853	0.945	1	0.954
wW2	0.168	0.174	0.536	0.411	0.725	0.661	0.725	-0.305	-0.222	0.023	0.221	0.336	-0.128	-0.185	0.178	0.239	0.535	-0.140	-0.238	0.149	0.258	0.483	0.609	0.859	0.950	0.954	1

Note: P8 and Rib fat have been log-transformed (lp8, lrib) because of a scale effect on the variance, i.e. there is more variation in fat depth when the average fat depth increases.

A cluster analysis was performed on the 27 trait/time combinations and presented as a dendrogram and heat map (Figures 7 and 8). Some clear conclusions can be drawn:

1. The weight traits grouped together, although the heifer traits (500 and PC) were slightly different to the cow weights (W1, PC2, W2). This leads to a simplistic statement that as a heifer goes through parturition and lactation, she becomes a cow, i.e. genetically after lactation all weight traits are approximately the same trait.
2. Height was extremely highly correlated across time and very highly correlated with weight.
3. The eye muscle area traits grouped together, but separate from weight and height. Interestingly, in contrast to weight, EMA at PC2 grouped more closely with PC1 than with W1 or W2.
4. The fat traits were all different to weight, height and muscle traits. They also had different relationships with each other than the other traits did.
5. The 6 heifer fat traits grouped closely together (P8, Rib and IMF at 500d and PC1), but separate from the fat traits post-calving.
6. P8 and Rib measurements on cows were closely related: 6 combinations of P8 and Rib at W1, PC2 and W2.
7. The 3 intramuscular fat measurements on cows (IMF at W1, PC2, W2) grouped separately from the subcutaneous fat measures.

A range of reduced rank (factor analytic) models have been fitted in an attempt to get the best estimates of genetic covariances between traits and times from multi-variate models. The reason for this is that the correlation matrix based on 351 bivariate analyses is not likely to be positive definite which is necessary for multi-trait estimation of EBVs. The analyses have proved more difficult than expected but some have been done as outlined in the appendices.

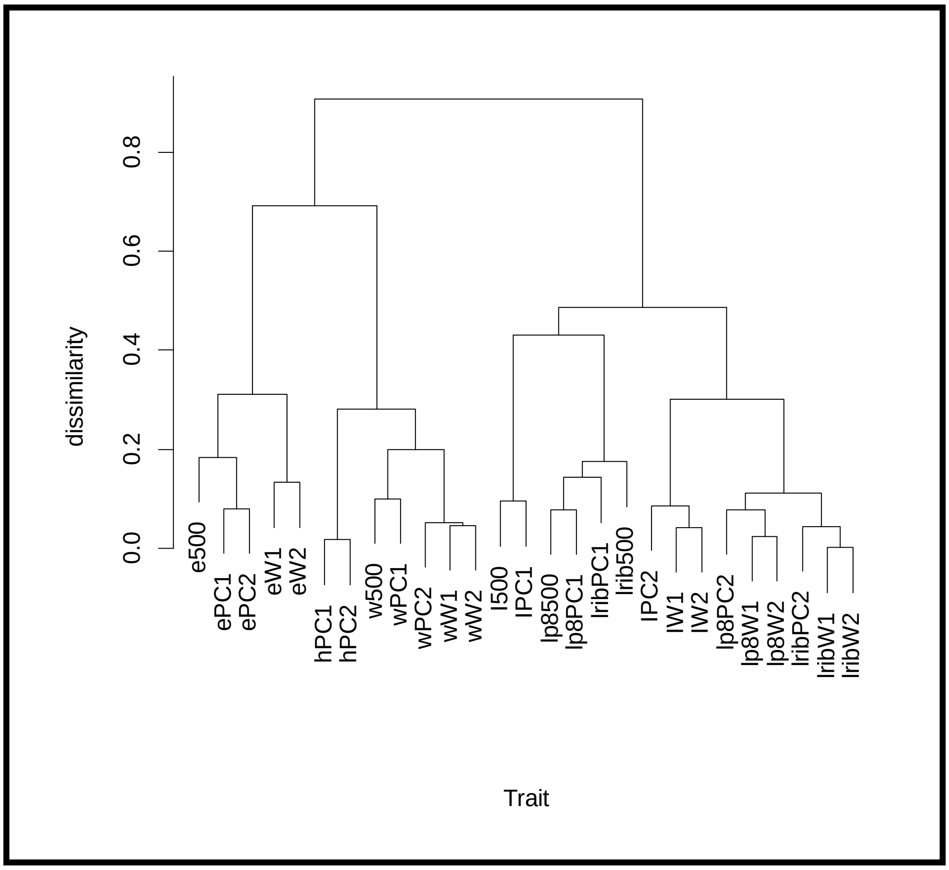

Figure 7. Dendrogram from hierarchical cluster analysis based on genetic correlation matrix estimated from bivariate analyses between 6 traits measured at 5 times

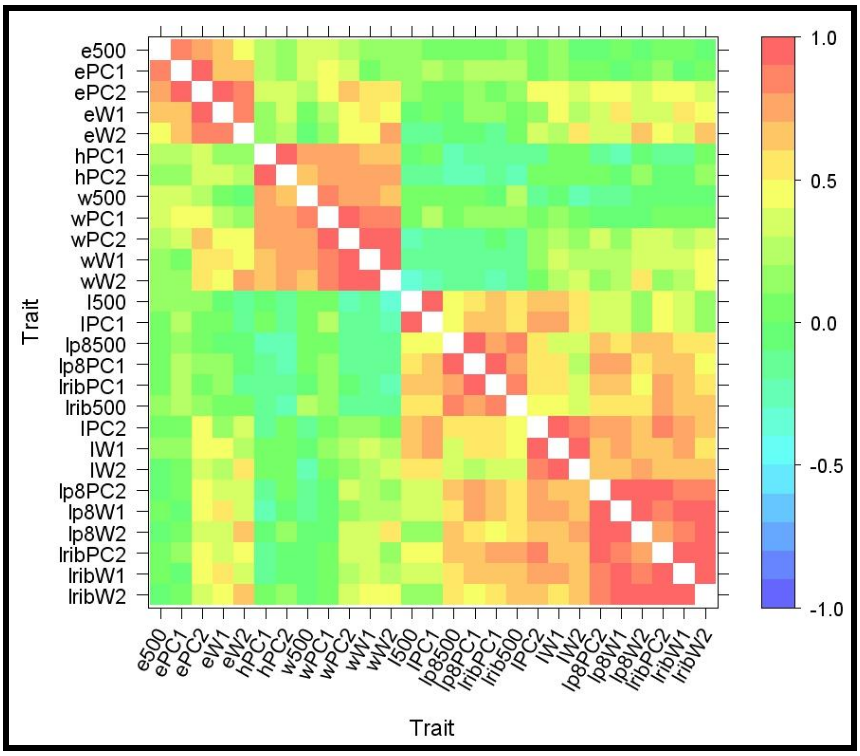

Figure 8. Heat map representation of correlations between traits at different times based on correlation matrix estimated from bivariate analyses

The primary remaining issue that can be addressed from the industry data is the outcome of selecting for changes in body composition. This was addressed by regressing cow body composition measures on appropriate EBVs. It is important to note that the EBVs used are mid-parent EBVs with the individual's data specifically excluded when estimating. If it had been included, then the relationships could have reflected non-additive genetic and permanent environmental effects in addition to the additive genetic relationships which are the primary interest of the project.

As expected, most traits were strongly related to their appropriate EBV. The relationships differed depending on the time (pre-calving or weaning for 1st or 2nd calf). A slope of 1 represents a direct relationship. For weight, the slope was greater than 1 so for every extra 1kg 600d EBV, cow weight increased by up to over 2kg. For eye muscle area the relationship was closer to 1, but tended to be higher pre-calving than at weaning time.

There was a large scale effect on the variance of fat depth so P8 and Rib routinely have been log-transformed. Thus, the slopes on EBVs are as a percentage per 1 mm EBV. For both P8 and Rib fat, the times after the first lactation were consistent but still different from the heifer pre-calving measure. If the average P8 fat depth is 10mm, then a 1mm increase in the EBV was associated with a 1.2mm (12%) increase in cow fat depth. For intramuscular fat the relationships were less than 1 at all time points, with the most extreme being at W2 where a 1% increase in IMF EBV was associated with only a 0.48% increase in cow IMF.

Table 7. Relationships (slopes) between cow body composition traits and EBVs for Angus cows. Hereford cow relationships were very similar

	PC1	W1	PC2	W2
Weight (kg/kg)	1.60±0.06	1.80±0.06	1.86±0.06	2.17±0.06
EMA (cm^2/cm^2)	1.21±0.07	0.97±0.07	1.27±0.08	0.74±0.08
P8 (%/mm)	15.6±0.6	12.0±0.5	12.0±0.5	12.0±0.5
Rib (%/mm)	16.5±0.6	13.6±0.5	13.6±0.5	13.6±0.5
IMF (%/%)	0.89±0.05	0.81±0.05	0.63±0.05	0.48±0.06

3. Research herds

The research herds comprised Angus cows established in four genetic groups or genotypes. The genotypes comprised cattle selected on the basis of their mid-parent EBV for high and low residual or net feed intake (RFI=NFI) cattle, and high and low subcutaneous rib fat (Fat) cattle. The cows were run on two nutritional treatments at two sites: DAFWA's Vasse Research Centre near Busselton WA (Vasse Latitude 33.45°S, Longitude 115.21°E, elevation 35m, median annual rainfall 740mm), and SARDI's Struan Research Centre near Naracoorte SA (Struan Latitude 37.10°S, Longitude 140.79°E, elevation 65m, median annual rainfall 544mm).

The "Fat line" heifers were purchased from 14 and 5 Breedplan recorded Angus herds in eastern and Western Australia respectively. The criteria for choosing the heifers were mid-parent EBVs for Rib fat >+0.8mm (High Fat) or <-0.8mm (Low Fat) representing the top and bottom 10% of the breed respectively. An additional aim was to match them on growth EBV (mature cow weight within 30 kg of +70kg which was breed average at the time) and to source both High and Low Fat animals from the same property (to minimise property of origin effects). Both these criteria proved difficult although Struan came closer to achieving them because there were a greater number of animals available in eastern than Western Australia (Table 8). They were also matched for age and were purchased from Winter calving herds for Vasse and from Autumn calving herds for Struan. Vasse Fat line heifers were 2005 "A" or 2006 "B" drop and Struan 2006 "B" or 2007 "C" drop.

Table 8. Average EBV[1] for Research lines

	All 646 heifers joined				Just 504 heifers remaining			
	High Fat	Low Fat	High NFI	Low NFI	High Fat	Low Fat	High NFI	Low NFI
Post-weaning NFI (kg/d)			0.65	-0.47			0.65	-0.47
Feedlot NFI (kg/d)			0.77	-0.87			0.77	-0.87
Gestation length (days)	-2.4	-1.8	-1.1	-0.5	-2.4	-1.8	-1.3	-0.5
Birth weight (kg)	4.5	5.6	3.7	5.3	4.5	5.6	3.5	5.6
200d wt direct (kg)	36.3	40.5	24.3	30.2	36.1	41.1	24.0	30.9
400d wt (kg)	68.3	72.3	47.2	54.1	68.0	73.2	46.5	54.7
600d wt (kg)	86.0	92.1	57.9	69.6	85.5	93.1	57.0	70.1
Mature cow wt (kg)	77.9	90.7	53.2	69.3	77.2	90.8	51.7	70.6
MILK (200d maternal, kg)	11.6	11.5	9.0	9.5	11.4	11.4	8.9	9.2
Scrotal Size (cm)	1.3	1.0	0.9	0.6	1.3	1.0	0.9	0.7
Days to calving (days)	-3.2	-1.9	-1.7	0.6	-3.3	-1.9	-1.9	0.6
Carcass wt (kg)	47.4	53.6	27.5	35.9	47.1	54.5	26.4	35.5
Eye muscle area (cm^2)	2.5	2.2	1.0	0.9	2.5	2.3	0.9	0.8
Rump P8 fat depth (mm)	1.1	-1.4	2.5	-0.6	1.3	-1.5	2.9	-0.8
Rib fat depth (mm)	1.0	-1.3	2.8	-0.5	1.1	-1.4	3.2	-0.7
Meat yield (%)	-0.4	0.8	-0.9	0.4	-0.5	0.9	-1.0	0.5
Intramuscular fat (%)	1.1	0.3	0.5	0.0	1.1	0.3	0.6	-0.1

[1]Based on mid-parent information with data on individuals excluded

Residual feed intake is a measure of feed efficiency (Koch 1963). It is calculated as the difference between actual feed intake by an animal measured over a test period and the expected feed intake for the animal based on its liveweight and weight gain over the test. Cattle that eat less than expected are considered to be more efficient. The major beef cattle breeds in Australia have adopted NFI (called residual feed intake in scientific literature: RFI) for the purpose of genetic improvement in feed efficiency. The NFI cattle were sourced from the NFI selection lines from the Trangie Agricultural Centre NSW (Arthur *et al.* 2004).

The cattle used from the High and Low NFI lines differed in mean post-weaning NFI EBV (NFI_P) by 1.12 kg/d and feedlot NFI EBV (NFI_F) by 1.64 kg/d, following 2.5-3.5 generations of selection for divergence (Table 4). A number of studies have reported correlated response in fatness in these lines (e.g. Herd and Pitchford 2011) and this was demonstrated in the large difference (3.6mm for Rib fat) in fat EBVs between the NFI lines (Table 8). They also differed slightly in growth and mature size with the High NFI being smaller (13 kg at 600d).

The 2005 “A” drop NFI heifers at Vasse underwent a feed efficiency test in Autumn 2006 following standard protocol (Exton 2001). The heifers were joined starting in September 2006 (Figure 9). The 2006 Trangie “B” drop heifers were sorted by mid-parent EBV for NFI and the top and bottom-ranked 35 sent to Vasse for NFI testing, and the remainder went into a NFI test at the “Tullimba” research feedlot, near Armidale NSW, before being trucked to Struan. Since Struan joining starts in June, the heifers would have only been 10 months old so they were held over a year and not joined until 22 months of age in June 2008. Thus, these heifers were not included in analysis of heifer pre-joining body composition and pregnancy rate, but were included in all subsequent analyses.

Due to differences in climate and grazing system, mating, calving, weaning and grazing at Struan took place at different times of the year to Vasse. The primary driver was to avoid having mating while cows were grazing the TechnoGrazing^{TM} system (Kiwitech Int. Ltd. 2011). At Struan 2 cows died or needed to be removed from the experiment due to injury. These were replaced with suitable replacement cows from the spare animals. For most measurements, data from replacement animals have not been included in statistical analyses until cows have been in their experimental group for 12 months. This is not the case for measurements involving feed intake.

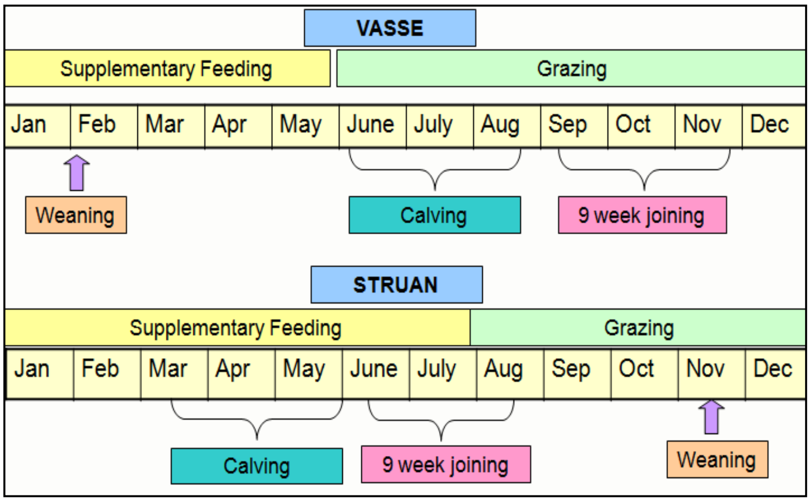

Figure 9. Management of cattle at Vasse and Struan

Upon arrival at Vasse, the 2005 “A” drop and the 2006 “B” drop Trangie NFI heifers (both born between July and August) underwent a standard feed test in Autumn 2006 and 2007 respectively (Exton 2001) from April to early August. They were then run as one grazing herd until early September, when they were allocated to joining herds. The heifers were joined from early September to November for 9 weeks (Figure 8).

Heifers all received a course of two injections of Ultravac 7 in 1 Vaccine (Commonwealth Serum Laboratories Limited, Australia) to induce immunity against *Leptospira borgpetersenii* serovar *hardjo*, *Leptospira interrogans* serovar *pomona*, *Clostridium perfringens*, *Cl. tetani*, *Cl. septicum*, *Cl. novyi* type B and *Cl. chauvoei*. Two 2.5ml doses were given subcutaneously in the ischiorectal fossa, 4 weeks apart, in April of the year the animals arrived at Vasse. In subsequent years the animals received a single 2.5ml dose which acted as a booster. Heifers were also given a course of two injections of Pestiguard Vaccine (Pfizer Animal Health) to induce immunity against Bega and Trangie isolates of Australian Bovine Viral Diarrhoea Virus. Two 2ml doses were given subcutaneously into the ischiorectal fossa, four weeks apart, a minimum of six weeks before joining start date each year. In subsequent years each animal was given a 2ml dose, six weeks before joining start date, as a booster.

In the year of their arrival at the research centres, bulls were given a course of two injections of *Ultravac 7 in 1 Vaccine* (Commonwealth Serum Laboratories Limited, Australia) to induce immunity against *Leptospira borgpetersenii* serovar *hardjo*, *Leptospira interrogans* serovar *pomona*, *Clostridium perfringens*, *Cl. tetani*, *Cl. septicum*, *Cl. novyi* type B and *Cl. chauvoei*. Two 2.5ml doses were given subcutaneously in the ischiorectal fossa (Colazo *et al.*, 2002), 4 weeks apart, in April of the year the animals arrived at Vasse. In subsequent years the animals received a single 2.5ml dose which acted as a booster. In the year of their arrival, each bull was given a course of two injections of Vibrovax Vaccine (Pfizer Animal Health) to induce immunity against *Campylobacter fetus* subspecies *venerealis,* biotypes *venerealis* and *intermedius*. Two doses of 5ml were given into the ischiorectal fossa, four weeks apart and at least four weeks before the joining start date. In subsequent years each bull was given one 5ml dose at least four weeks before joining start date as a booster. All cattle were treated once a year, in May, for external and internal parasites with 0.5 mg/kg Cydectin (Moxidectin, Triclobendazole) pour-on (Fort Dodge, New South Wales, Australia).

At their first pregnancy test, heifers were checked for freemartinism and generally culled accordingly. In the first year at both sites, heifers were synchronised to start the project with calving as compact as possible. However, this was abandoned in the second cohort of heifers as it masks variation in days to calving.

Bulls were chosen based on moderate birth weight and mature cow weight EBVs to minimise calving difficulty as a confounding factor in the project. Bull breeding soundness examinations were conducted annually. Mating was done with two bulls per mating group with bulls rotated between groups every three weeks at Vasse and fortnightly at Struan (ratio 1 bull to 25-30 cows). In subsequent years at Vasse, 2 bulls were joined to each replicate groups and rotated every 3 weeks.

Joining was for nine weeks to give maximum chance of breeding success. Pregnancy testing was conducted by ultrasound approximately 4 weeks after the end of the joining period at Struan and by manual palpation at weaning at Vasse. Foetuses were classed based on size as resulting from conception early, medium or late in the joining period. DNA parentage was undertaken on all calves weaned to determine sire which was included in the statistical model fitted to calf birth and weaning weight. A 9 week joining was chosen as close to a longer industry standard. Pregnancy rates following a 6 week joining have been inferred by excluding those with later calving dates.

Dry heifers at Vasse were culled with the aim of starting all treatment groups with pregnant females and to decrease variation between groups but this did not happen at subsequent matings. Also, some heifers at Vasse that were pregnant but had a large change in their EBV once their own scan results were added were also culled. This was not necessary since all analyses in the project are based on mid-parent EBVs to avoid bias from their own phenotype on later phenotypic performance (i.e. repeatable rather than heritable relationships). In contrast, at Struan, information on all females was collected and adjustments made at the time of analysis. This difference in practice probably led to some differences between the sites.

At Vasse, heifers were allocated to nutritional treatments (High or Low) prior to calving whereas at Struan, this was done after joining. Allocation was done to ensure sire groups, ages, sizes, fat and NFI. EBVs were balanced across the treatments. They were also allocated to replicate groups within genetic line x nutrition treatment and they remained in these groups for the remainder of the experiment (weaned 3rd or 4th calf). The nutritional treatments were designed to achieve a 20% difference in feed intake under grazing, and subsequent body weight, not to be fed at a specific level. Change in body condition through the year was an important part of the design. The aim was to push the low nutrition treatment as low as possible to simulate cows going through tough seasonal conditions. To ensure all cows did not suffer from under-nutrition, if any animal in the group fell to a condition score of 2 (Graham and Clarke 1984), then supplementary feed was increased to all cows in the line (Fat or NFI) x nutrition treatment combination. When supplementary feeding was increased, it was done for both high and low Fat or both high and low NFI lines within a nutrition level.

There were 251 NFI heifers and 162 have remained in the project (Table 9). The 119 pregnant “A” drop (born 2005) heifers at Vasse have remained in the project for 4 parities and the “B” drop (born 2006) for 3 parities. While lactating with their final project calf, cows were mated and pregnancy tested and so there is pregnancy rate data for 4-5 parities. There are 100 Fat line cows at Vasse and 238 at Struan after starting with a total of 392.

Table 9. Numbers of heifers mated and remaining as cows (in brackets) in the experiment for each genetic group and site

Joining	NFI Low	NFI High	Fat Low	Fat High	Total
Vasse					
2006	59 (30)	60 (30)	58 (30)	36 (30)	213 (120)
2007	36 (20)	34 (20)	30 (20)	28 (20)	128 (80)
Struan					
2007	0 (0)	0 (0)	75 (75)	75 (75)	150 (150)
2008	31 (31)	31 (31)	45 (44)	45 (44)	152 (150)
Total	126 (81)	125 (81)	208 (169)	184 (169)	643 (500)

Animal measurements

Cows were weighed almost every 2-4 weeks and body composition (BCS, P8 and Rib fat) was monitored at least bi-monthly (Table 10). Ultrasound scans (P8, Rib, EMA, IMF) were conducted at pre-joining and at calf weaning time. The pre-joining scan was chosen to better capture the “trough” in body condition than pre-calving as was done in the industry herds. This change came from the benefit of hindsight and advice from the advisory group of cattle breeders in WA since the industry herd protocols and measurements began before the research herds. That said, also with the benefit of hindsight, it would have been good to have pre-calving scans as well.

Table 10: Number of records per animal at Vasse

	2006	2007	2008	2009	2010
Cows					
CS			5	4	6
Weight[1]		23	27	23	24
IMF Scan		2	2	2	2
P8 fat Scan		7	6	6	6
Rib fat Scan		7	6	6	6
EMA_Scan		2	2	2	2
Height		1	2	2	1
Pregnancy Test	2	1	1	1	1
Calves					
Birth weight		1	1	1	1
Weaning weight		1	1	1	1
Other weight[1]		≤12	≤11	≤12	≤12

[1] Approximately fortnightly

Table 11. Number of records per animal at Struan

	2007	2008	2009	2010	2011
Cows					
CS	6	12	10	9	10
Weight[1]	19	12	10	9	10
IMF Scan	2	2	2	2	2
P8 fat Scan	3	6	10	10	10
Rib fat Scan	2	6	10	10	10
EMA_Scan	2	2	2	2	2
Height	2	2	2	2	2
Pregnancy Test	1	1	1	1	1
Calves					
Birth weight		1	1	1	1
Weaning weight		1	1	1	1
Other weight[1]		5	4	4	4

[1] Approximately monthly

Vasse feeding and measurement system

In 2007 at Vasse there were not sufficient numbers of pregnant cows in the first cohort ("A" born in 2005) to populate the original design and only three groups of five animals could be formed for each of the four genotypes (2 traits x 2 levels of each trait) and stocking rates (120 animals). Shortly after the commencement of grazing it became obvious that it was not possible to manage the planned divergence of at least 20% between the nutritional treatments (stocking rates) and in September 2007 the cows within each genotype and nutritional treatment were re-allocated to two groups (7 or 8 cows per group). In 2008, a second cohort of 80 animals (10 per genotype; "B" born in 2006) was allocated to the existing groups bringing replicate group sizes to 12 or 13 cows. No further changes or additions were made to the experimental design after this. The experimental design is summarised in Table 1. At Vasse in grazing seasons from 2008 onwards animals carrying their 1st and 2nd calves grazed together in the same replicate groups.

Cows grazed pasture at Vasse from May to December in each year of the experiment (Table 6). Calves grazed with their mothers from birth to weaning. In order to impose a nutritional difference, feed on offer (FOO) and pasture quality measurements were taken weekly to establish differences between high and low nutrition based on the feed available to the cows. Paddocks were either 6.3ha (High nutrition) or 3.6ha (Low nutrition) and at times of high pasture productivity, some paddocks were further subdivided to limit intake. The low nutrition cows were to be fed to approximately maintenance at a feed on offer (FOO) of less than 1200 kg DM/ha, and the high nutrition cows were to be offered at least 20% above the maintenance requirement with FOO>1600 kg DM/ha. Groups of cows were moved from paddock to paddock as pasture availability fell below that required to maintain the nutritional level. Managing the nutritional treatment divergence under the grazing system proved to be a challenge. Pasture management difficulties in 2007 have already been described above (see Experimental design). In 2008 and 2009 there were 190 and 112 herd movements during the grazing seasons respectively. Despite these challenges a difference in the live weight and fat was evident between the high and low nutrition treatments.

Every week or fortnight (depending on pasture growth rates) during the grazing season, visual assessments of FOO were made on paddocks that were being grazed or had been grazed recently. On each occasion pasture assessment calibrations were carried out using samples across the range of FOO levels in all paddocks in order to estimate FOO (kgDM/ha). For each paddock, linear interpolation of FOO values across dates was used to estimate FOO as herd groups entered and left each paddock. Pasture disappearance for each paddock in each grazing period (kgDM/head/day) was calculated as:

$$\frac{A_j(DM_{i,j} - DM_{i+1,j})}{d_i n_{ij}}$$

where $DM_{i,j}$ is the estimated FOO (kgDM/ha) in paddock *j* in grazing period *i*, A_j is the area of paddock *j*, d_i is the number of days in grazing period *i*, and n_{ij} is the number of animals in the herd group in paddock *j* in grazing period *i* (12 or 13).

Since groups of animals remained in the same paddock for up to three weeks, pasture growth during this period contributed to pasture intake and needed to be estimated. For this reason FOO was also assessed in ungrazed paddocks on pasture assessment dates and it was planned to estimate pasture growth from measurements of FOO on these paddocks. However because of high variability in estimates of FOO, this gave unreliable estimates of growth during grazing periods in both 2008 and 2009.

As an alternative, pasture growth was calculated using pasture growth estimates (kgDM/ha) from the Pastures from Space Program (http://www.pasturesfromspace.csiro.au/) for the Vasse site every two weeks during the grazing season. Pasture growth for each grazing period, G_i, was calculated using linear interpolation. Pasture intake (kgDM/head/day) for paddock *j* in grazing period *i* was calculated as the sum of pasture disappearance and pasture growth for the whole paddock divided by the number of animals grazing the paddock and the number of days in the period, i.e.

$$\frac{A_j(DM_{i,j} - DM_{i+1,j}) + A_j G_i d_i}{d_i n_{ij}}$$

Pasture intake values were accumulated for each herd group over the grazing season.

Metabolisable energy of the pasture (ME; MJ/kg) was measured on pasture samples that were collected when FOO was assessed. ME of pasture on each paddock during each grazing period was estimated by fitting splines to ME data over dates. Because there was a relatively small amount of data for each paddock, data were combined across paddocks. In 2008 a separate spline was fitted for each group of paddocks with similar pasture composition, but in 2009 there was no difference in the ME profiles for different paddocks and so a single spline was used to estimate ME for each paddock during grazing periods. ME values were then incorporated into the calculations of intake.

Supplementation with hay was started when FOO on the paddocks dropped below adequate levels to meet treatment (High/Low nutrition) requirements. Replicates were then placed on paddocks with similar FOO (negligible) and Hay was fed *ad lib*. Supplementation with hay continued until after the break of season, when feed on offer in the paddocks reached appropriate DM levels to sustain nutritional treatment.

Due to animal ethics regulations for experimental animals, the following guidelines were followed to decide if and when to initiate additional supplementation with pellets. Condition score (CS) of the dams were monitored regularly, and for High nutritional treatment if average CS for a replicate dropped below 3 or individual CS dropped below 2.5 all replicates for High treatment of that particular trait (NFI or Fat) start being supplemented with pellets. For Low nutrition replicates, the triggering points for pellet supplementation is replicate CS average below 2.5 and individual CS below 2. Grazfeed™ (http://www.csiro.au/en/Outcomes/Environment/Biodiversity/grazfeed.aspx) was used to calculate the amount of pellets necessary to meet maintenance requirements. The calculation was done using the average live weight for each replicate. Depending on how animals responded to pellet supplementation, various rates (25, 50 or 100%) of the amount of pellets recommended by Grazfeed ™ was fed. Associated replicates (same nutritional level, correspondent trait) were fed the same rates. As in previous experimental trials Grazfeed™ tended to overestimate maintenance requirements and therefore 100% rate was seldom used to avoid condition score fluctuations and stop/start pellet supplementation. As dams were entering either their second or third trimester of pregnancy during the supplementation period, once pellet supplementation was started it continued until the break of season to maintain CS.

Struan feeding and measurement system

Heifers were grazed from the end of mating (mid-August) until weaning (late November) on the TechnoGrazing at Struan Research Centre using small plots for each replicate of animals. The dryland "Techno" at Struan consists of 192ha pasture which is typically phalaris based with strawberry clover, annual ryegrass and barley grass making up the bulk of other pasture species. The area is divided into 6x32ha systems, each of which consists of 8x4ha permanent lanes that can be subdivided into a further 90x0.067ha cells using temporary electric fencing.

Figure 10. Cows on the TechnoGrazing System at Struan showing feed eaten in 2 days

Replicate groups were randomly allocated to a lane on the Techno area with Fat line and NFI females blocked separately to allow better management of the two genotypes. Overall feed availability was adjusted by allocating an appropriate number of 0.067 ha cells to match feed requirements as estimated by GrazFeed^{TM}. This was determined by the quantity of feed on offer, feed growth rate and animal performance and the initial allowance was based on meeting maintenance requirements for the low nutrition group. A 20% difference in intake between the high and low nutrition group was achieved through the difference in numbers of animals (5 vs 8) between the treatments. On-going adjustments to the grazing area were then made to maintain the appropriate condition score (3 to 3.5 for high nutrition and 2 to 2.5 for low nutrition) of the animals. Animals were generally moved to a fresh allocation of pasture every two days during the spring growing period.

Approximately every two weeks during the grazing period, visual estimates (Lodge GM 1998) of FOO in kg DM/ha were made on each lane after cows had been shifted to a fresh pasture allocation. Estimates were made of the FOO both in front of the cows (pre-grazing) and grazing residual behind the cows post-grazing as a measure of pasture disappearance. Due to the short period of time between each shift, this could be equated to an estimation of pasture intake for the group of animals in the respective lane. However, this technique does not account for losses from trampling, pugging etc.

Preliminary analysis of the intake data found that weekly intake measurements were not normally distributed, but were skewed to the right indicating a greater likelihood of measurement error overestimating rather than underestimating intake. Thus, it was decided to log-transform the intake values (kg DM/d or MJ ME/d) before summing them over the period of interest (e.g. between scan dates). On the log-scale there were very few obvious outliers. The effect of the transformation was to lower the impact of a high weekly estimate on mean and total intake values.

At the end of the spring growing period, calves from every treatment group were weaned. Cows remained on the Techno until pasture availability had fallen to a level below that required to maintain the nutritional treatment. This period varied depending on the genotype, year and season (Table 8). The NFI lines remained on the Techno for longer each year than the Fat lines due to the number of animals and area required.

After removal from the Techno, cows which were in small replicates were grouped by genotype treatment, nutritional treatment and year of birth for supplementary feeding. Groups were placed in paddocks with negligible feed on offer and fed a daily silage/straw based ration prepared on site using a Keenan mixer wagon. Mated heifers were fed a ration that was formulated by Keenan with allowance for growth (approx 100g/day for low nutrition and 300g/day for high nutrition). From 3 years of age onwards it was formulated to maintain body condition (3 to 3.5 for high nutrition and 2 to 2.5 for low nutrition) using the average weight and condition score of the group. Rations were adjusted based on animal performance and physiological status (pregnant/lactating). For low nutrition, the quantity fed was increased if any individual animal fell below CS 2. For high nutrition, the quantity fed was increased if any individual animal fell below CS 2.5.

The weight of supplement fed to each group was recorded daily. An assessment of wastage using the Keenan system was undertaken in 2011 (Dairy Australia, 2009).

During the 9 week mating period, cows remained grouped by genotype treatment (i.e. Fat or NFI), nutritional treatment (high or low) and year of birth. During this period cows were fed a hay based ration in addition to grazing pasture. Pasture availability throughout the mating period at Struan was limited due to low pasture growth rates during winter. Fortnightly assessments of pasture disappearance were undertaken similar to the method described at Vasse.

Heifer pregnancy results

As stated above, the NFI heifers at Struan were approximately 22 months at joining and so were not included in analysis of heifer results where the others ranged from 12-18 months at joining. Thus, the maximum number of heifers was 579 (Table 12). At Vasse in the first year, there was not an EMA and IMF scan and height measurement recorded when protocols were still being developed so there are less heifers in that data set (370). It was decided to analyse days to calving for those that actually calved, rather than giving a 21 day penalty for dry heifers as done by Breedplan. There seemed little advantage in using the penalty because pregnancy rate was also analysed. However, it does mean that fewer heifers had data for DTC (471 versus 574).

Table 12. Summary of data

Trait	Number of Animals	Mean	Minimum	Maximum	CV (%)
Age (days)	579	440	317	564	11.5
Weight (kg)	573	350	243	542	13.7
EMA (cm2)	370	57.5	35	78	13.6
Height (mm)	370	1213	1060	1330	3.8
P8 (mm)	575	6.99	1	21	54.5
Rib Fat (mm)	575	4.92	1	16	46.1
IMF (mm)	370	3.27	1	7.4	37.4
PR9 (%)	574	86.6	0	100	39.4
PR6 (%)	574	72.65	0	100	44.6
DTC9 (days)	471	302	267	358	5.7
DTC6 (days)	417	298	267	325	4.2

PR9 = pregnancy rate under a 9 week joining (observed) and PR6 under a 6 week joining (additional dry heifers inferred from DTC6). DTC9 = days to calving under a 9 week joining (observed) and DTC6 was inferred based on a 6 week joining.

Compared to the Low Fat line, the High Fat line were 10 days older, 10mm shorter and had 27% greater rib fat depth but with no significant difference in weight or muscle. They also had a 8.5% (P=0.052) and 12.3% (P=0.033) higher pregnancy rates after a 9 or 6 week joining respectively. The High NFI line had a 19% greater fat depth than the Low NFI line. Differences in pregnancy rate were not significant, but in the same direction as for the Fat lines (3.9% and 7.5%).

Not surprisingly, age, weight and fat depth of heifers were correlated and related to heifer pregnancy rate. The raw phenotypic correlations between these three traits were 0.68 (age and weight), -0.01 (age and rib fat) and 0.19 (weight and rib fat). After major fixed effects were fitted to pregnancy rate, weight, fat and age accounted for 13% of the variation in pregnancy rate (under a 9 week joining) within a cohort (i.e. after adjustment for site and year). The three traits were fitted in various orders to determine the most important affecting heifer pregnancy rate (Table 14). Weight accounted for the most variation, followed by fat and then age. In fact, once weight and fat were in the model (Orders 5 and 6), age was not significant. Under a 6 week joining, the results were similar although once weight was in the model, age was just significant but fat was not significant.

Table 13. Best linear unbiased estimates of line effects

	High Fat	Low Fat	F Prob	High NFI	Low NFI	F Prob
Number	186	204		94	95	
Age (days)	473±3	463±3	0.003	398±4	393±4	0.435
Weight (kg)	360±5	364±5	0.114	323±17	330±17	0.363
EMA$^{\#}$ (cm^2)	58.9±1.1	57.6±1.1	0.435	62.5±2.4	59.6±2.4	0.119
Height$^{\#}$ (mm)	1223±4	1233±4	0.004	1170±11	1176±10	0.638
P8 (mm)	6.1±0.3	4.8±0.3	<0.001	11.0±0.8	9.2±0.8	<0.001
Rib Fat (mm)	4.4±0.2	3.5±0.2	<0.001	7.6±0.5	6.4±0.5	<0.001
IMF$^{\#}$ (mm)	3.3±0.1	2.8±0.1	<0.001	3.8±0.3	3.3±0.3	0.098
PR9 (%)	91.5±3.1	83.0±3.4	0.052	92.4±3.3	88.5±4.0	0.360
PR6 (%)	77.3±4.7	65.0±3.9	0.033	81.2±5.5	73.7±6.2	0.323
DTC9$^{\wedge}$ (days)	300±2	303±2	0.276	303±3	306±3	0.133
DTC6$^{\wedge\wedge}$ (days)	296±1	297±1	0.489	298±2	302±2	0.174

$^{\#}$ the number of animals measured for these traits were 150, 150, 34 and 36 respectively;

$^{\wedge}$ the number of animals measure that had DTC9 measured was 158, 151, 82 and 82 respectively, i.e. DTC is only reported for those that calved,

$^{\wedge\wedge}$ the number of animals that had DTC6 measured was 143, 132, 75 and 67 respectively.

Table 14. Tests of significance of relationships between growth and pregnancy rate (under 9 and 6 week joining)

1	F Stat.	2	F Stat.	3	F Stat.	4	F Stat.	5	F Stat.	6	F Stat.
9 wk	joining										
A	7.92**	W	17.09***	A	7.92**	R	14.65***	W	17.09***	R	14.65***
W	12.93***	A	3.75†	R	11.42***	A	4.70*	R	5.70*	W	8.14**
R	4.86*	R	4.86*	W	6.36*	W	6.36*	A	2.91†	A	2.91†
6 wk	joining										
A	11.84***	W	20.43***	A	11.84***	R	10.69***	W	20.43***	R	10.69***
W	13.18***	A	4.59*	R	6.63	A	7.78**	R	2.90	W	12.63***
R	2.13	R	2.13	W	8.68	W	8.68**	A	3.83	A	3.83

A=Age, W=Weight, R=Rib fat depth fitted in various orders

† P<0.10; * P<0.05; ** P<0.01; *** P<0.001

Based on this information, it is possible to provide growth targets for breeders managing heifers (Tables 15a). Since most breeders prefer calves born early in the season, a reasonable target for growth and condition is based on the 6 week joining (Table 15b). By having both the NFI and industry Fat lines in the project, the targets span a wide range of “maturity types” within the Angus breed. Fat depth was actually less significant for the 6 week than 9 week joining. An example target is 400kg with 8mm Rib Fat which is much higher than what many breeders would currently be achieving but roughly matches with the recommended aim of 65% of mature weight.

The targets presented are based on phenotypic measures. When pregnancy rate was regressed on EBVs, there was no relationship with the 400d or EMA EBVs. There was a weak relationship with scrotal circumference and Fat depth. The strongest relationship was with the EBV designed for selection for improved reproduction (DTC, Figure 11). Given that the current breed average DTC EBV is -

3.3 days, the relationship for current stud cattle is likely fairly weak compared with heifers with positive DTC EBVs.

Table 15a. Phenotypic effects: Predicted pregnancy rate (%) for a range of pre-joining (400d) weights and Rib fat depths of heifers after a 9 week joining

Weight					Rib	Fat	(mm)				
(kg)	1	2	3	4	5	6	7	8	9	10	11
250	58	64	69	74	78	82	85	88	*	*	*
300	66	71	76	80	83	86	89	91	93	94	95
350	73	78	81	85	88	90	92	94	95	96	97
400	79	83	86	89	91	93	94	95	96	97	98
450	84	87	90	92	93	95	96	97	97	98	98
500	*	*	92	94	95	96	97	98	98	98	99

Colours coded as <85 red=poor; 85-94 yellow=average; >94 green=good

* No heifers in this range

Table 15b. Phenotypic effects: Predicted pregnancy rate (%) for a range of pre-joining (400d) weights and Rib fat depths of heifers after a 6 week joining

Weight					Rib	Fat	(mm)				
(kg)	1	2	3	4	5	6	7	8	9	10	11
250	46	49	52	54	57	59	62	64	*	*	*
300	56	59	61	64	66	68	71	73	75	77	79
350	65	68	70	72	74	76	78	80	82	83	85
400	74	76	78	79	81	83	84	86	87	88	89
450	80	82	84	85	86	88	89	90	91	92	92
500	*	*	88	89	90	91	92	93	94	94	95

Colours coded as <85 red=poor; 85-94 yellow=average; >94 green=good

* No heifers in this range

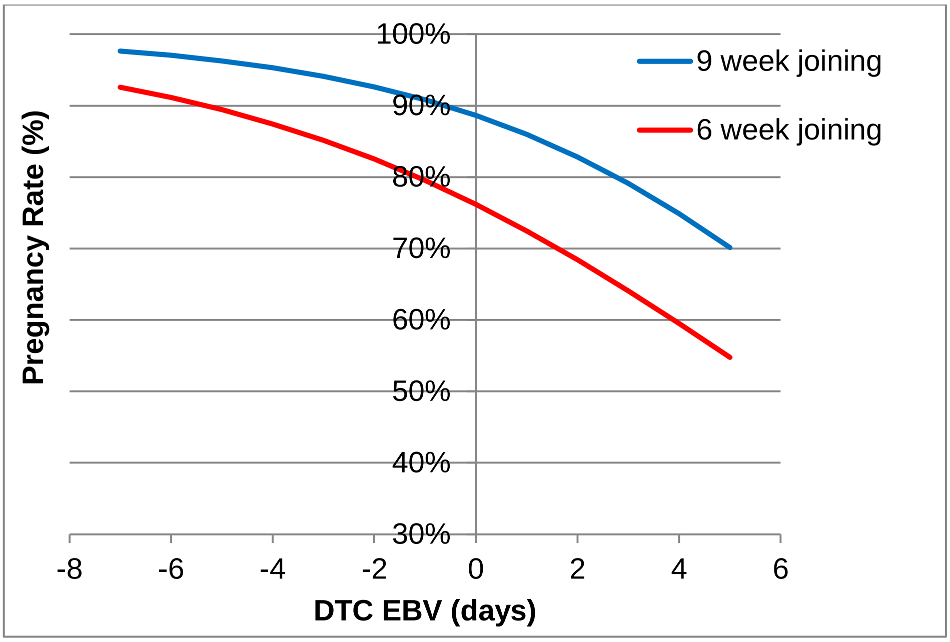

Figure 11. Relationship between heifer pregnancy rate and days to calving EBV

First parity results (first calvers)

For first lactation cows, treatment differences in weight were modest, but differences in body composition were substantial. The High Nutrition treatment were 8% heavier with 11% greater EMA and 23% more rib fat depth than Low Nutrition. The industry cows were just slightly heavier (1%), but with surprisingly a 12% lower EMA and 18% lower fat depth than the NFI lines. This reflects the greater condition on the NFI lines. The High Fat line was 5% lighter but with 14% greater fat depth than the Low Fat line. The High NFI line had 4% bigger EMA and 24% more fat depth than the Low NFI line. Despite these substantial treatment differences in body composition, there were not significant differences in pregnancy rate or days to calving. That said, the High Fat line did have 4% higher pregnancy rate and calved 3 days earlier than the Low Fat line. While not significant and smaller effects, these were in the same direction as for heifers. There were also no substantial treatment interaction effects.

Table 16. Best linear unbiased estimates for genotype and nutrition treatments for first parity lactating cows at start of mating

Nutrition	High		Low		High		Low	
Genotype	High Fat	Low Fat	High Fat	Low Fat	High NFI	Low NFI	High NFI	Low NFI
Weight (kg)	502±7	523±7	441±7	458±7	485±14	479±15	477±14	469±14
EMA (cm^2)	69.0±1.6	69.0±1.6	56.3±1.6	57.8±1.6	74.9±3.2	70.3±3.4	71.7±3.3	70.2±3.3
P8 fat (mm)	13.5±0.5	11.8±0.5	10.5±0.4	9.3±0.4	17.0±1.2	13.0±1.0	13.6±1.0	11.6±0.8
Rib fat (mm)	6.0±0.4	4.1±0.3	5.0±0.3	3.4±0.2	8.3±0.9	6.5±0.7	6.2±0.7	5.1±0.6
PR (%)	96.5±2.1	91.1±3.9	92.0±3.2	89.0±3.9	88.5±12.3	90.4±10.8	94.6±7.5	87.7±12.8
DTC (days)	309±4	310±4	306±4	311±4	309±6	309±7	314±6	312±7

For Weight, EMA, DTC and PR means are followed by standard errors, for P8 and Rib means are followed by 67% confidence limits because are back-transformed from being analysed on the log-scale.

In addition to the substantial treatment differences at start of mating, there were differences between treatment groups and especially lactating versus dry cows in weight gain during spring (approximately start of mating to weaning). This is shown for the 8 treatment groups and 3 traits (Figures 12a and 12b). One of the very clear messages from these is the large weight gain of dry cows. In southern beef systems, this is why the cost of not calving is less than northern systems. In spring, a dry cow can gain as much weight as a calf would and the difference in price per kg is often not that substantial, although currently could be up to 70 centsor 1/3rd.

Following the mating recommendations for heifers (Tables 15a and 15b), a similar analysis was undertaken for first calvers. A best subsets regression was used to examine the relationship between conception at 2nd mating and age at 2nd mating, days in lactation to 2nd mating and weight, P8 and Rib fat depth at start of 2nd mating for cows which were lactating at 2nd mating. Location, year of mating and year of birth were included in the model before all other independent variables. In order of importance, days in lactation to 2nd mating ($P<0.001$), age at 2nd mating ($P<0.001$) and weight at 2nd mating ($P=0.059$) were significant accounting for 22.1% of the variance in conception. Pregnancy rate predictions from the regression for animals that have been lactating for different numbers of days according to their age and weight are presented (Table 17).

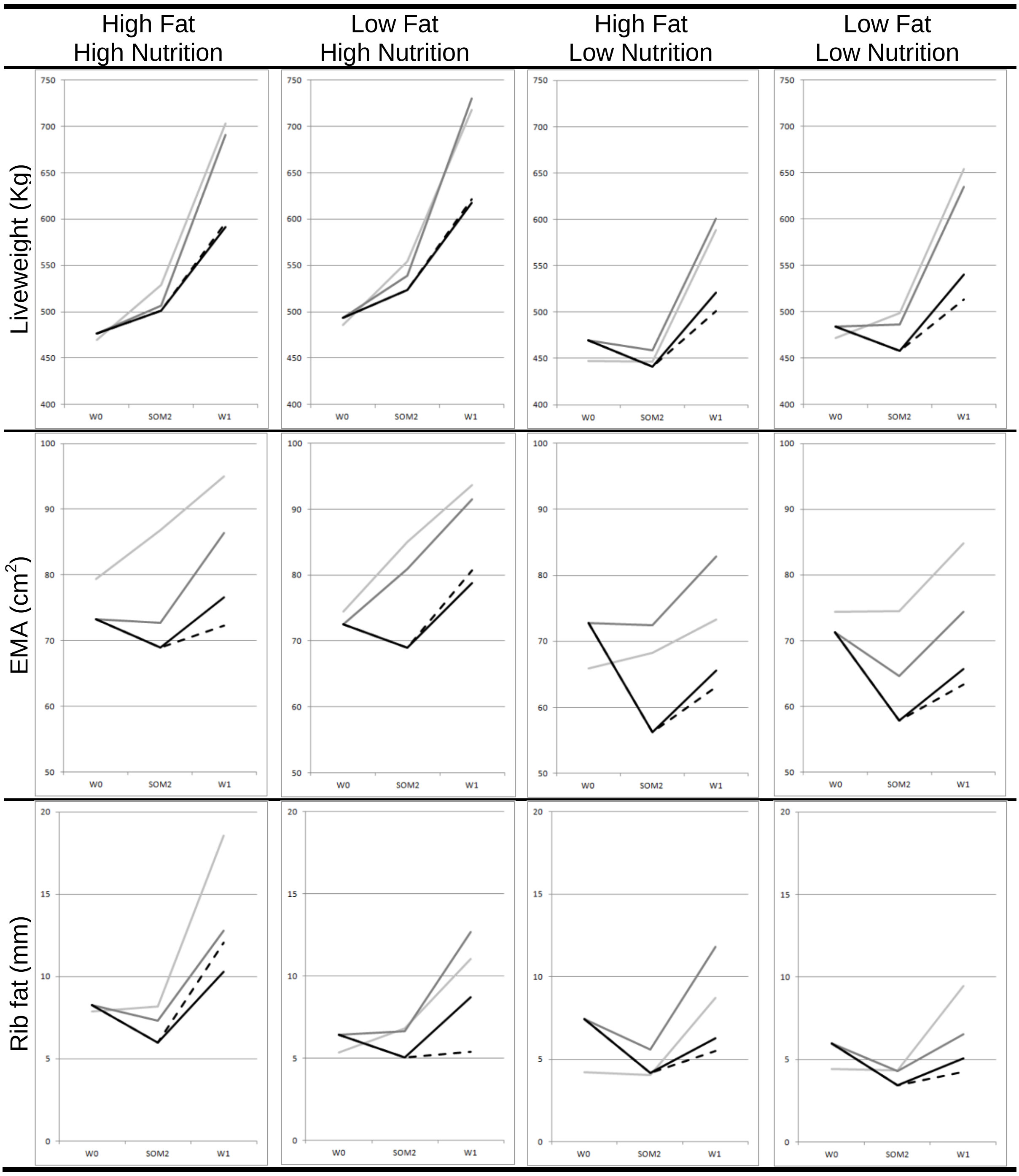

Figure 12a. Weight, EMA, P8 and Rib fat means 12 months before 1st weaning (W0), the start of 2nd mating (SOM2) and at 1st weaning (W1) for Fat cows in each treatment group that were pregnant(P1)/Lactating/Pregnant(P2) (black solid line), Pregnant(P1)/Lactating/not Pregnant(P2) (Black broken line), Pregnant(P1)/not Lactating/Pregnant(P2) (dark grey solid line) and not Pregnant(P1)/ Pregnant(P2) (light grey solid line)

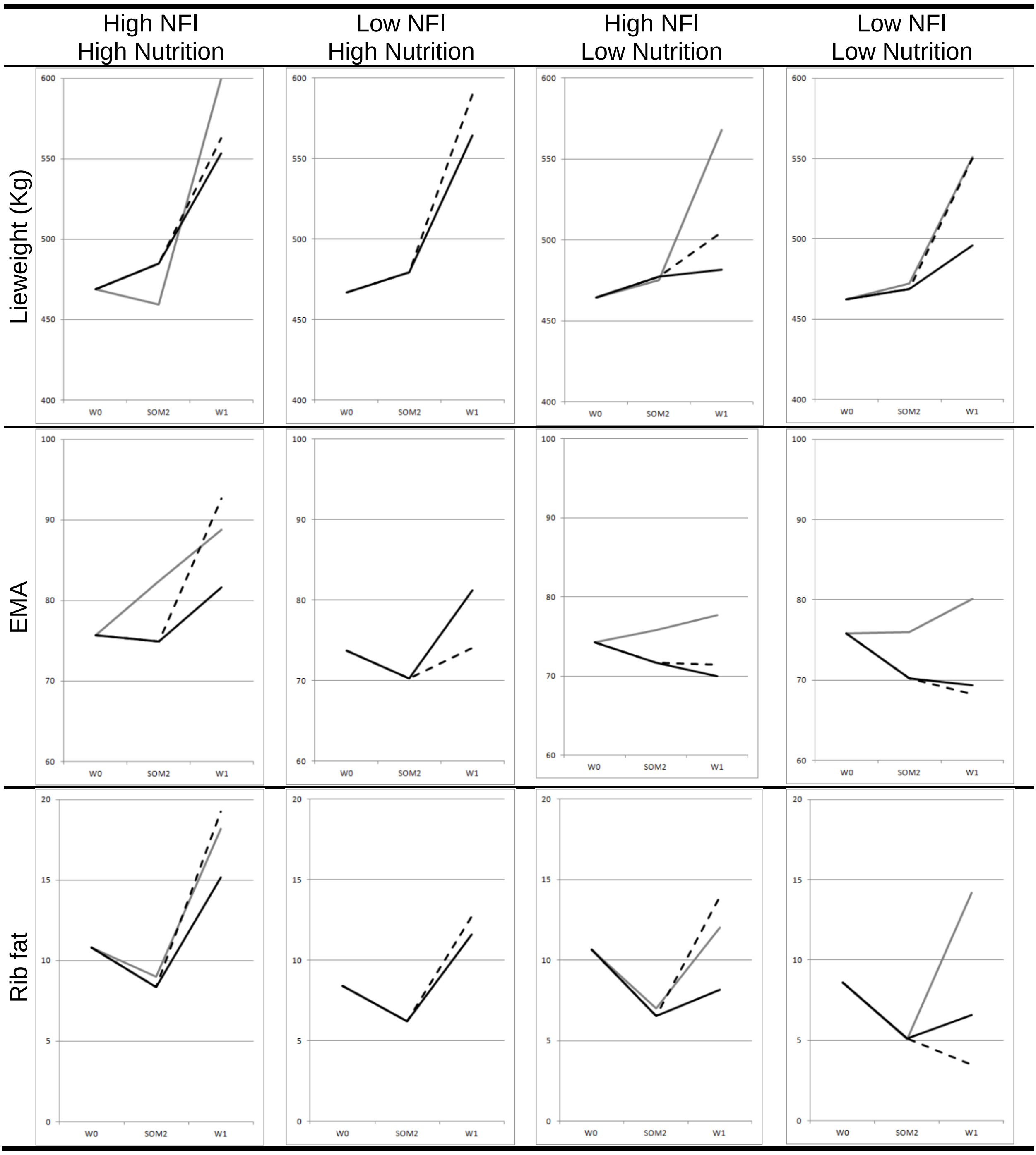

Figure 12b. Weight, EMA, P8 and rib fat means 12 months before 1st weaning (W0), the start of 2[nd] mating (SOM2) and at 1[st] weaning (W1) for NFI cows in each treatment group that were Pregnant(P1)/Lactating/Pregnant(P2) (black solid line), Pregnant(P1)/Lactating/not Pregnant(P2) (Black broken line), Pregnant(P1)/not Lactating/Pregnant(P2) (dark grey solid line) and not Pregnant(P1)/ Pregnant(P2) (light grey solid line)

Table 17. Expected pregnancy rates (%) at range of age, weights and time from calving to 2nd start of mating (joining) period

Weight at SOM2	Age at SOM2	Days in Lactation to SOM2								
Kg	Months	10	20	30	40	50	60	70	80	90
350	24	52	55	58	62	65	69	73	77	80
350	26	59	63	66	70	74	77	81	83	86
350	28	68	71	75	78	81	84	86	89	91
350	30	76	79	82	85	87	89	91	93	94
350	36	92	94	95	96	97	98	99	99	99
400	24	54	57	61	64	68	72	76	79	82
400	26	62	65	69	73	76	80	83	85	87
400	28	70	74	77	80	83	86	88	90	92
400	30	78	81	84	86	89	91	92	94	95
400	36	94	95	96	97	98	98	99	99	99
450	24	56	60	63	67	71	74	78	81	84
450	26	64	68	72	75	79	82	84	87	89
450	28	73	76	80	82	85	87	89	91	93
450	30	80	83	86	88	90	92	93	95	96
450	36	95	96	97	98	98	99	99	99	100
500	24	59	62	66	70	73	77	80	83	85
500	26	67	71	74	78	81	84	86	88	90
500	28	75	79	82	84	87	89	91	93	94
500	30	82	85	87	89	91	93	95	96	97
500	36	96	97	97	98	99	99	99	100	100
550	24	61	65	69	72	76	79	82	85	87
550	26	70	73	77	80	83	85	88	90	92
550	28	78	81	84	86	88	90	92	94	95
550	30	84	87	89	91	93	94	95	97	97
550	36	96	97	98	99	99	99	99	100	100
600	24	64	67	71	75	78	81	84	86	89
600	26	72	76	79	82	85	87	89	91	93
600	28	80	83	85	88	90	92	93	95	96
600	30	86	88	90	92	94	95	96	97	98
600	36	97	98	98	99	99	99	100	100	100
650	24	66	70	74	77	80	83	86	88	90
650	26	75	78	81	84	86	89	91	92	94
650	28	82	85	87	89	91	93	94	96	97
650	30	88	90	92	93	95	96	97	98	98
650	36	98	98	99	99	99	100	100	100	100
700	24	69	73	76	80	82	85	87	89	91
700	26	77	80	83	86	88	90	92	93	95
700	28	84	86	88	90	92	94	95	96	97
700	30	89	91	93	94	96	97	97	98	99
700	36	98	99	99	99	99	100	100	100	100

One measure of reproductive performance that has excellent traction with industry is the proportion of first parity cows that are "wet and pregnant" (WAP). To achieve this, the animal must have conceived as a heifer, calved and raised a calf successfully and then conceived a second time while lactating. It is likely that cows that achieve this will go on to be productive cows. In this project there was some culling of heifers at Vasse which prevents a formal analysis of this as a trait. However, the expected average performance of lines can be calculated from the means presented in Tables 13 and 16. The additional information needed is calf losses from heifer pregnancy test to weaning. This figure was approximately 10% for all treatment groups, and so a constant value (0.9) has been assumed for the calculations (Table 18).

Not surprisingly, the treatment differences are most stark with the restricted heifer joining. The difference between the Fat lines was 12.3% and NFI lines was 7.8%. In both cases it was the fatter (High) lines being better and these also had the superior DTC EBV (Table 8). In addition to the line differences being large, a greater concern may be that the proportion of cows being successful as both heifers and 1st calvers may be so low (e.g. 53.3%) as to affect herd structure by not breeding sufficient replacements.

Table 18. Estimates of reproductive rate differences (WAP=wet and pregnant) between treatments (%) based on 9 or 6 week heifer and 9 week cow joining period

	High Fat	Low Fat	Difference	High NFI	Low NFI	Difference
Heifer PR9	91.5	83.0	8.5	92.4	88.5	3.9
Heifer PR6	77.3	65.0	12.3	81.2	73.7	7.5
1st Parity PR	94.3	91.1	3.2	91.6	89.1	2.5
WAP9	77.7	68.1	9.6	76.2	71.0	5.2
WAP6	65.6	53.3	12.3	66.9	59.1	7.8

Mature cow results (2nd and 3rd parity data)

The genetic and nutrition effects on mature cow traits were tested within lactation status which was defined as having 3 categories: LS1 lactated every opportunity, LS2 currently lactating but has missed one or more previous lactation opportunities, and LS3 currently dry (Table 19). The means (BLUEs) presented for genetic lines and nutrition treatments are for LS1 only (Table 20).

Compared to cows that were lactating every time (LS1), the dry cows were 13% heavier with 63% greater fat depth. However, while the pregnancy rate was high for both groups, it was 5.6% higher for the lactating than dry cows. Both had the same days to calving. Cows that were currently lactating, but would have been culled in many herds because of missing a lactation had a pregnancy rate of 91.4% which was intermediate between the LS1 and LS3 cows.

Table 19. Best linear unbiased estimates of differences in body composition at the start of mating and reproductive performance between lactation status

	Lactating every time LS1	Lactating but >0 dry LS2	Currently dry LS3
No. parity 2	338	70	96
No. parity 3	310	116	78
Weight	566±8	613±9	640±9
Height	1314±4	1333±5	1325±5
EMA	66.2±0.9	71.9±1.2	80.9±1.2
P8	8.0±1.1	10.7±1.1	14.0±1.1
Rib	6.4±1.0	8.1±1.1	10.4±1.1
IMF	4.9±0.1	5.3±0.2	5.6±0.2
PR	94.0±1.0	91.4±2.3	88.4±2.8
DTC	299±1	296±2	300±2

At weaning the LS1 cows were 12% heavier with 7% bigger EMA and 37% greater rib fat depth than at start of mating. At start of mating, the High Nutrition treatment cows were 15% heavier with 15% bigger EMA and 61% greater rib fat depth than the cows on Low Nutrition. The differences at weaning were similar and the calves from the High Nutrition treatment were 10% heavier than the Low Nutrition.

At weaning time, the industry sourced Fat line cows were 3% taller and 4% heavier but with 6% smaller EMA and 28% lower rib fat depth than the Trangie NFI cows. None of the genetic line differences in pregnancy rate or days to calving were significant despite differences in body composition. At start of mating, the High Fat line were 7% lighter with 6% smaller EMA and 16% greater rib fat than the Low Fat line. The difference in both weight and fat depth meant that when adjusted for weight, the fatness difference was even greater (30%). The High NFI line was 4% lighter with the same EMA but 40% greater rib fat depth (48% fatness) than the Low NFI line.

The average pregnancy rate of lactating cows from both Fat lines was 95% and there was no line difference on Low Nutrition. There was only a 0.5 day difference between the lines in DTC which is absolutely negligible. It didn't matter how the data were analysed, the result was always the same. The industry concerns about differences in reproduction just didn't exist in mature cows, especially after culling those that were dry as heifers or first calvers. Words have been chosen carefully here, the differences in reproduction did not exist within the constraints of this experiment which did not include drought conditions and excluded cows with extremely high mature weight EBVs.

The average age at weaning was 207 days. Calves on High nutrition were 10% heavier than those from Low nutrition. The differences between the genetic lines matched those expected based on the line differences in EBVs. The industry Fat lines weaned 6% heavier calves than the Trangie NFI lines. Within the Fat or NFI lines, the Low lines had greater growth EBVs and weaned heavier calves.

One area where there was a difference between the lines which could be of concern to breeders is the cow's ability to maintain condition. The genetically Low Fat cows on Low Nutrition definitely had the lowest fat levels at the two reported times (start of mating and at weaning). While the data is still being processed, both reports from stockmen and graphs such as that shown (Figure 12) demonstrate that every time it was a Low Fat (or Low NFI) line cow that dropped to a condition score (1.5) that triggered increases in supplementary feeding. For example, if 4mm P8 fat as a group average was a trigger, the Low Fat line dropped to that point approximately 1 month earlier than the High Fat line.

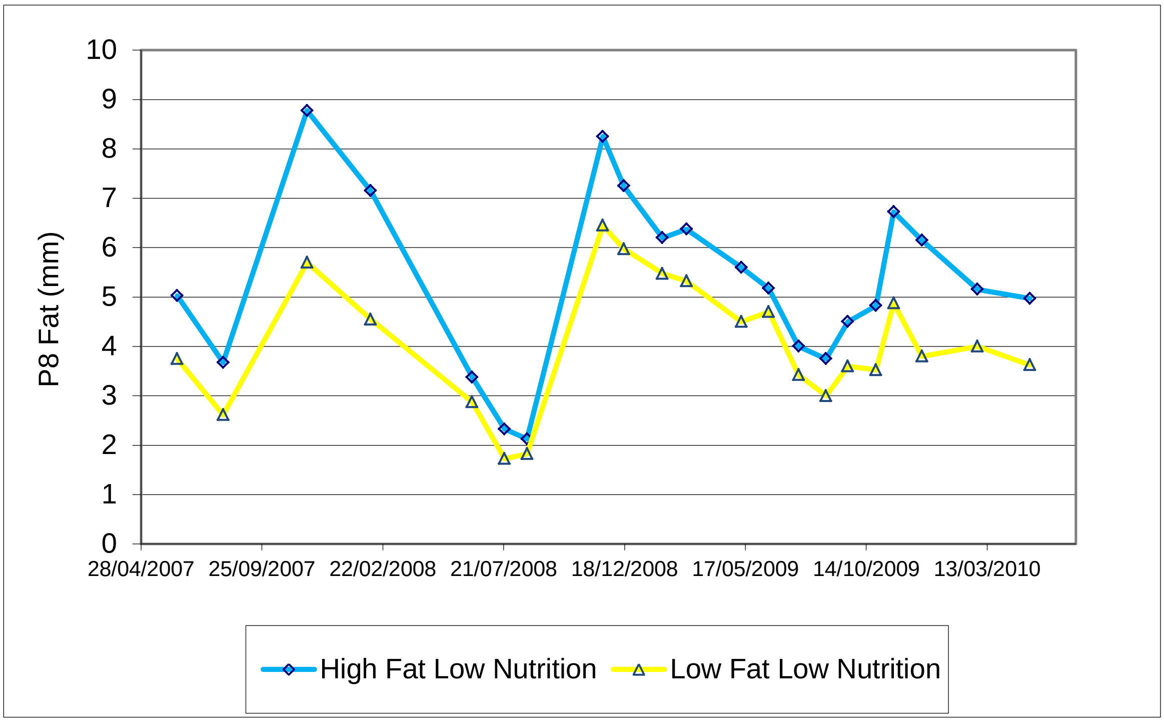

Figure 12. Variation in fat depth for one cohort of cows (High and Low Rib Fat on Low Nutrition at Struan)

Table 20. Best linear unbiased estimates for genotype and nutrition treatments for mature cows

	Nutrition Genotype	High High Fat	High Low Fat	Low High Fat	Low Low Fat	High High NFI	High Low NFI	Low High NFI	Low Low NFI
SOM	Weight	580 ± 11	627 ± 11	520 ± 11	557 ± 12	597 ± 16	631 ± 16	516 ± 16	524 ± 17
	Height	1327 ± 6	1346 ± 6	1307 ± 6	1334 ± 6	1266 ± 9	1315 ± 9	1264 ± 9	1279 ± 10
	EMA	68.0 ± 1.6	72.0 ± 1.6	58.4 ± 1.6	62.4 ± 1.6	75.6 ± 2.3	74.5 ± 2.3	65.0 ± 2.2	65.5 ± 2.4
	P8	10.3 ± 1.1	8.3 ± 1.1	6.3 ± 1.1	5.2 ± 1.1	17.4 ± 1.1	11.9 ± 1.1	7.8 ± 1.1	6.8 ± 1.1
	Rib	8.0 ± 1.0	6.5 ± 1.1	4.9 ± 1.1	4.6 ± 1.1	12.9 ± 1.1	9.0 ± 1.1	7.5 ± 1.1	5.5 ± 1.1
	IMF	5.8 ± 0.2	5.2 ± 0.2	4.1 ± 0.2	3.9 ± 0.2	6.0 ± 0.2	5.4 ± 0.2	4.5 ± 0.2	4.0 ± 0.2
	Muscularity	68.1 ± 1.2	67.5 ± 1.3	64.1 ± 1.3	64.8 ± 1.3	74.5 ± 1.8	70.4 ± 1.8	70.9 ± 1.8	70.9 ± 1.9
	P8 fatness	10.3 ± 1.0	7 ± 1.1	7.8 ± 1.0	5.7 ± 1.0	16.5 ± 1.1	10.2 ± 1.1	11.4 ± 1.1	8.3 ± 1.1
	Rib fatness	7.9 ± 1.0	5.7 ± 1	5.9 ± 1.0	4.9 ± 1.0	12.4 ± 1.1	7.9 ± 1.1	9.0 ± 1.1	6.5 ± 1.1
	IMF fatness	5.9 ± 0.2	5.0 ± 0.2	4.4 ± 0.2	4.1 ± 0.2	6.0 ± 0.2	5.2 ± 0.2	4.8 ± 0.2	4.3 ± 0.2
	PR	96.6 ± 2.1	96.1 ± 2.5	94.1 ± 2.5	94.7 ± 2.7	93.0 ± 4.3	89.0 ± 5.2	97.2 ± 2.9	90.7 ± 4.9
	DTC	300 ± 2	303 ± 2	303 ± 2	299 ± 2	294 ± 3	297 ± 3	296 ± 3	297 ± 3
Wean	Weight	670 ± 10	722 ± 10	584 ± 10	615 ± 10	647 ± 14	693 ± 14	567 ± 14	584 ± 14
	Height	1340 ± 6	1364 ± 6	1326 ± 6	1342 ± 7	1276 ± 9	1314 ± 9	1276 ± 9	1303 ± 10
	EMA	76.0 ± 1.3	76.7 ± 1.3	64.0 ± 1.3	64.9 ± 1.4	79.1 ± 1.8	79.8 ± 1.9	70.4 ± 1.8	69.5 ± 1.9
	P8	15.9 ± 1.1	13.1 ± 1.1	9.0 ± 1.1	6.5 ± 1.1	23.1 ± 1.1	16.7 ± 1.1	13.2 ± 1.1	9.4 ± 1.1
	Rib	11.9 ± 1.1	9.6 ± 1.1	6.8 ± 1.1	5.6 ± 1.1	17 ± 1.1	12.4 ± 1.1	10.2 ± 1.1	7.4 ± 1.1
	IMF	6.6 ± 0.2	6.0 ± 0.2	4.9 ± 0.2	4.2 ± 0.2	6.5 ± 0.2	6.4 ± 0.2	5.6 ± 0.2	5.0 ± 0.2
	Muscularity	75.4 ± 1.2	73.7 ± 1.2	67.4 ± 1.2	66.9 ± 1.2	79.6 ± 1.6	78.1 ± 1.6	74.5 ± 1.6	72.9 ± 1.7
	P8 fatness	15.4 ± 1.1	11.3 ± 1.1	10.6 ± 1.1	7.2 ± 1.1	23.6 ± 1.1	15.4 ± 1.1	16.2 ± 1.1	11.1 ± 1.2
	Rib fatness	11.6 ± 1.0	8.5 ± 1.0	8.0 ± 1.0	6.0 ± 1.0	17.3 ± 1.1	11.6 ± 1.1	12.1 ± 1.1	8.5 ± 1.1
	IMF fatness	6.5 ± 0.1	5.7 ± 0.1	5.3 ± 0.1	4.5 ± 0.1	6.6 ± 0.2	6.2 ± 0.2	6.1 ± 0.2	5.4 ± 0.2
	Weaning Weight	284 ± 5	288 ± 5	261 ± 5	265 ± 5	265 ± 7	278 ± 7	238 ± 7	251 ± 7

Feed intake and efficiency results

All the feed intake data has been collected, but it takes significant processing as there are close to weekly feed intake measures for 64 groups for 3½ years. The last cohort at Struan and Vasse is currently being processed. This is an additional (final) years data for 24 groups at Struan from 2011 (3rd parity, 2nd cohort) and 16 groups at Vasse from 2010 (3rd and 4th parity, 2nd cohort). The results of intake presented are based on 152 of the potential 192 groups (64 groups x 3 calvings).

Feed intake has been measured on groups and not individuals. These groups of cows include those lactating, dry and a small number that may have calved but lost the calf. Also, the cows should ideally be back in calf, and so they will also be pregnant. The period of measure is over an annual cycle beginning and ending at the time of weaning (November at Struan and January at Vasse). For heifers calving at 2 years or 24 months of age, the first intake period would go from 19 months to 31 months of age. Thus, there is significant growth of the heifer during this time. Also, for the 7 months of lactation, calf pasture intake is included in the intake estimates.

The model for analysing intake data included the proportion lactating and lactation length. Preliminary analysis of these traits identified significant differences between genetic lines but no nutrition effects. The High Fat line had 4.5% greater wet cows and calved 4 days earlier than the Low Fat line (Table 18). The High NFI Line had 2.3% greater wet cows and calved 8 days earlier than the Low NFI Line. The values presented are the values that intake and efficiency measures have been predicted at so that later line differences include reproduction as well as growth and feed intake effects.

Table 18. Reproductive performance of the four genetic lines

Genotype	High Fat	Low Fat	High NFI	Low NFI
Proportion Lactating (%)	85.4±0.02	80.9±0.02	87.2±0.03	84.9±0.03
Lactation Length (days)	213±2	209±2	205±3	197±3

The annual intake were large numbers so daily intakes have also been presented (Table 19). The two output traits are weaning weight of calves and weight gain of cows. Since a significant proportion of income in southern beef production systems can be from cull cows, efficiency measures including cow weight gain have been presented as well as just calf gain. The primary definition of maternal productivity adopted throughout the project has been cow plus calf output per unit of energy input. However, this trait was not normally distributed whereas the inverse was better. The inverse is akin to feed conversion ratio (FCR) that is used by feedlots but in this case was energy required per unit of calf or cow weight. Maternal productivity has still been presented without standard errors.

Recent experience in presenting results to producers has prompted calculation of additional measures. The first is a cost of production which only includes pasture feed costs (not animal health, supplementary feed etc.) and is simply FCR multiplied by a constant cost of feed (0.5c/MJ). The second is a per hectare measure of productivity and so is simply maternal productivity multiplied by 6900, the estimated pasture feed energy able to be consumed per ha per 100mm annual rainfall.

As planned as part of the project design, the High Nutrition treatment ate 24% more than the Low Nutrition (Table 19). Cows on High Nutrition produced 12% more calf and themselves gained 48% more weight than Low Nutrition. Thus, cost of producing a calf was 11% higher and the maternal productivity was 10% lower on

High than Low Nutrition. However, there was no difference in the cost of gain or productivity when cow weight gain was included.

Comparing industry sourced Fat line cows to Trangie NFI cows wasn't really an aim of the project, many observers described them as being of quite different "type". The industry Fat lines were 4% heavier and 3% taller than the "earlier maturing" Trangie NFI lines (Table 17). The industry lines ate 3% more, produced 7% more calf and gained 8% more as cows (Table 19). Thus, their cost of gain was 3% lower and maternal productivity 4% higher than the average of the NFI lines, although a lot of these differences are due to the poor performance of the High NFI line.

The High NFI line ate 12% more, only produced 1% more calf and 16% less cow gain than the Low NFI line. Thus, the cost of production was 14% greater and maternal productivity 12% lower than the Low NFI line. This demonstrates that selection for post-weaning feed efficiency does lead to changes in the efficiency of the breeder herd. However, there are two caveats to this result. First, most of the extra feed eaten by the High NFI line was actually during spring when feed is relatively cheap and pasture utilisation is often low. Second, rather than the Low NFI line standing out as being more efficient, it performed similarly to the industry Fat Lines and it was the High NFI that stood out as the poor performer. It would have been interesting to know how a control NFI line would have performed.

The High Fat line only ate 1% more than the Low Fat line (Table 19) despite producing 4.5% more calves (Table 18). This is likely due to the Low Fat cow being 6% bigger (Table 17). Being smaller and having less dry cows meant that the High Fat line cows gained 21% less weight than the Low Fat line (Table 19). Surprisingly, the differences in efficiency were not that large. The High Fat line had 4% lower cost of calf production and 5% higher maternal productivity although these values were effectively reversed when cow weight gain was included.

The major concern that stimulated the initiation of this project was that the focus on selection for feedlot performance of steers (increased gain and efficiency, decreased fat and feed conversion) is changing the body composition of cows which will lead to declines in maternal productivity, especially when under lower pasture availability due to increased stocking rate or dry seasons. This project has tested cows with variation in body composition and efficiency EBVs under diverse nutritional regimes. There were large effects on heifer pregnancy rates with small effects persisting to first calvers. However, if producers are culling for heifer fertility, then the differences found in breeder herd efficiency are small. Thus, it would appear best for producers to focus on other factors affecting productivity.

Table 19. Feed intake and efficiency of the genotype and nutrition treatments

Nutrition Genotype	High High Fat	High Low Fat	Low High Fat	Low Low Fat	High High NFI	High Low NFI	Low High NFI	Low Low NFI
Intake (MJ/year)	56720±963	54768±965	44571±1089	45559±1090	57778±1680	50983±1691	45913±1873	41923±1883
Intake (MJ/day)	157±3	152±3	123±3	126±3	159±5	141±5	127±5	116±5
Calf wt weaned (kg)	237±3	224±3	208±4	193±4	211±6	209±6	195±7	191±7
Cow wt change (kg)	72±5	91±5	48±6	62±6	69±9	82±9	47±10	54±10
FCR calf (MJ/kg)	253±6	250±6	219±7	243±7	283±11	244±11	247±12	222±12
FCR cow+calf (MJ/kg)	193±6	175±6	180±7	186±7	209±10	174±10	203±11	183±11
CoP calf ($/kg)	1.27±0.03	1.25±0.03	1.10±0.03	1.22±0.03	1.41±0.05	1.22±0.05	1.24±0.06	1.11±0.06
CoP cow+calf ($/kg)	0.96±0.03	0.88±0.03	0.90±0.03	0.93±0.03	1.05±0.05	1.01±0.05	0.87±0.06	0.91±0.06
MP calf (g/MJ)	3.95	4.00	4.56	4.11	3.54	4.09	4.05	4.51
MP cow+calf (g/MJ)	5.19	5.70	5.57	5.36	4.78	5.75	4.94	5.48
Prod calf (kg/ha/100mm)	27	28	31	28	24	28	28	31
Prod cow+calf (kg/ha/100mm)	36	39	38	37	33	40	34	38

Intake is on a per cow joined basis but includes calf intake for a full year starting and finishing at the time of weaning.

FCR is feed conversion ratio measured as MJ feed per kg weight gain.

Additional measures have been added to aid traction when communicating the message to producers.

CoP is cost of production assuming feed costs 0.5c/MJ (equivalent to $50/tonne if 10 MJ/kg DM) and is a constant multiplied by FCR.

MP is maternal productivity in g/MJ. It is literally the inverse of FCR but would have had small numbers if remained as kg/MJ.

FCR was more closely to normally distributed which is why FCR has been formally analysed and has standard errors presented.

Prod is a measure of productivity on a per ha basis assuming that Vasse had 20 DSE/ha and 740mm rainfall and Struan had equivalent which is 14.6 DSE/ha for 540mm rainfall. The second assumption is daily energy requirements of a DSE is 7 MJ. Thus, 20 DSE/ha x 7 MJ/d x 365 days/year / 740mm rain x 100 mm rain = 6900 MJ/ha/100mm. Thus, the MP values in kg/MJ have literally been multiplied by 6900 to convert them to kg/ha/100mm.

4. Further work required

This project has clearly identified fertility issues in young Angus cattle. From a commercial viewpoint, a lot of this can be managed by growing out heifers well prior to joining. However, the issue of genetic improvement or at least monitoring fertility remains for Angus studs because of the large use of AI and ET programs which mask genetic variation in fertility. Time will tell whether the changes made to Breedplan recording will capture data of sufficient quality to improve DTC EBVs. The work of Donoghue *et al.* (2004) demonstrated the genetic correlation between natural service and AI calves was 0.81 which is encouraging that AI records may be useful in future. However, since this is a sex-limited trait and is difficult to record, it really is an ideal candidate for genomic selection. There is a project in the USA that has begun in this area and we will attempt to collaborate with them.

An area of work that has not been mentioned earlier in the report (included in Appendix) is analysis of genotype by environment interactions (GxE) for body composition traits. Analysis of Hereford scan data on young cattle did identify GxE for some traits, but there was not a strong case for including it in Breedplan analyses since sire by herd is already included and probably accounts for similar effects. For many traits the genetic correlation between males and females was less than 1 which indicates there is genetic variation in sexual dimorphism. This should be examined further to test whether selection indices should account for this in future.

Given that the project title is "Simultaneous genetic improvement of maternal productivity, feed efficiency and end-product traits in variable environments", an obvious limitation of the project was that it finished at weaning of calves. Thus, two cohorts of weaner steers from the project in SA and WA were purchased, grown out and had carcass data collected. Neither of these were funded by the project and the one in SA was actually privately funded by a committed scientist in the group (Mick Deland). The SA steers were grown out on grass and the WA steers in a feedlot immediately post-weaning. The results from both groups have greatly aided communication of messages to producers. The steers performed exactly as expected based on half of the differences between dam genetic line EBVs for carcass traits. In SA there was a significant penalty for carcasses with less than 6mm P8 fat and there were more of these from Low Fat than High Fat dams. When the Low Fat steers were grown out for longer, they were penalised for increased dentition. Even in the young rapidly grown WA steers, many were below a 6mm threshold although they were not penalised because the grid had a lower threshold. Further work in this area should be through producer demonstration type activities rather than research *per se*.

The heritability of change in most cow body composition traits was low but fat depth was an exception. This warrants further data analysis to probe the cause of this. For example, it could just be a function of a scale effect. This means that the variation in fat depth is greater in fat than skinny cows. There are a number of ways of accounting for this effect, but the simplest is to log-transform the data when analysing. This has been done for research herd data and but not for genetic parameters in industry data. There are other things that should also be examined to probe this moderate heritability further.

The maternal efficiency results suggest that there are negligible differences between lines which leads to a recommendation for industry to focus on selection for production traits. However, every time supplementary feed was triggered, it was a lean genotype (Low Fat or Low NFI). It is likely that supplementary feed costs will be the driver of economic differences between breeder herd cost of production. An economic analysis of the treatments at Struan and Vasse is currently being conducted and will also be applied to model farms in representative regions across southern Australia.

Linked to the project herein was a PhD project on the physiology of NFI. High and Low NFI heifers which were raised in individual pens on maintenance or close to *ad lib* diet. When on the maintenance diet there were no differences between the lines in weight gain, feed intake or NFI. When there was more feed available, there was a difference between the lines. The High NFI line heifers ate more, but the entire extra energy intake was associated with increased fatness. Thus, it was concluded that under restricted feed, there were no differences in efficiency and when feed was available, there was only a difference in fatness not metabolic rate. This was a small study and so an energy “audit” was conducted on a feedlot trial with NFI cattle and the maternal productivity cows herein. In both cases, about half of the difference between lines in NFI was associated with fat. The difference between the pen trials (all due to fat) and others (half due to fat) was assumed due to differences in activity (High NFI being more active). However, there are a number of other potential causes for the difference and further field studies on efficiency are warranted.

Lastly, tremendous relationships have been developed between breeders and scientists during this project. It is the intention of the team to continue to work closely with these people in future projects.

5. People involved in the project

Industry herds:

Bald Blair Angus

Barwidgee Angus

Booroomooka Angus

Chis Angus

Eastern Plains Angus

Kenny's Creek Angus

Rennylea Angus

South Boorook Herefords

Te Mania Angus

Tuwharetoa Angus

Wirruna Herefords

Twynam Angus

Yalgoo Herefords

Willalooka Angus

Yavenvale Herefords

Ultrasound technicians:

Jim Green

Liam Cardile

Matt Wolcott

Herefords Australia

Angus Australia

ABRI

AGBU

Victoria:

John Graham DPI

Students:

Michael Laurence PhD (Murdoch)

Stephen Lee Honours & PhD (Adelaide)

David Lines Honours & PhD (Adelaide)

Brendon O'Rourke PhD (NSW DPI)

Mary Chirgwin Honours (Adelaide)

Claire Coffey Honours (UWA)

Rachel Savage Honours (Adelaide)

Jennifer Mann Honours (Adelaide)

Alex Roberts Honours (UWA)

South Australia:

Katrina Copping SARDI

Mick Deland SARDI

Nick Edwards SARDI

Ian Carmichael SARDI

John Cooper SARDI

Liz Abraham SARDI

Sid Patterson SARDI

Shane Walker SARDI

Cameron Williams SARDI

Colin Windebank SARDI

Bruce Hancock Rural Solutions

Michelle Hebart Uni Adelaide

Wayne Pitchford Uni of Adelaide

Western Australia:

Jeisane Accioly DAFWA

Lucy Anderton DAFWA

Peter Jelinek DAFWA

Fiona Jones DAFWA

Jane Speijers DAFWA

Geoff Tudor DAFWA

Ryan Drage DAFWA

Kevin Gardiner DAFWA

John (Tex) Hann DAFWA

Nola Mercer DAFWA

John Milligan DAFWA

Leonarda Paszkudzka-Baizert DAFWA

Garry Russell DAFWA

Brad Sieb DAFWA

Neroli Smith DAFWA

Anne Barnes Murdoch Uni

Dominique Blache Uni WA

NSW – Armidale, Trangie and Glen Innes

Photo showing heifers leaving Trangie NSW for Vasse WA

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6. Extension activities

As part of its commitment to extension and implementation of scientific outcomes to industry the Beef CRC has developed a “Champions Network” of 25 extension professionals representing most geographic regions of Australia. Each Champion has worked with a senior scientist to develop a factsheet and presentation to form part of a presenters kit. The kit contains some 20 fact sheets and PowerPoint presentation, 8 producer case studies and other resources. Champions are expected to be active in facilitating the distillation of CRC messages to their colleagues, alternate deliverers and producers across the country. Within the Maternal Productivity Project there are 4 Champions from 3 states that have formed 5 fact sheets and presentations, two case studies and delivered presentations at many producer and industry service provider events. The Champions network will likely be funded for a further period using residual CRC funds and will seek to engage new and existing Champions to form a further set of factsheets and presentation for delivery to industry. For the Maternal Productivity Project further fact sheets will focus on efficiency and economic messages. Past extension activities are listed below.

JOURNAL ARTICLES

Donoghue, K. A., Arthur, P. F., Wilkins, J. F. &Herd, R. M. (2011). Onset of puberty and early-life reproduction in Angus females divergently selected for post-weaning residual feed intake. *Animal Production Science* 51: 183-190

Herd, R. M., Accioly, J. M., Arthur, P. F. & Dibley, K. C. P. (2008). Angus bulls and heifers more efficient following selection on feed efficiency EBV. *Animal Production in Australia* 27: 51.

Herd, R. M., Arthur, P. F. & Archer, J. A. (2006). Repeatability of residual feed intake and interaction with level of nutrition in Angus cows. *Animal Production in Australia* 26: Short Communication Number 80.

Jones, F. M., Phillips, F. A., Naylor, T. & Mercer, N. B. (2011). Methane emissions from grazing Angus beef cows selected for divergent residual feed intake. *Animal Feed Science and Technology* 166-167: 302-307.

Conference proceedings

Donoghue, K., Wilkins, J., Arthur, P., Dibley, K. & Mula, D. (2010).The impact of divergent selection for post-weaning residual feed intake on puberty. In *Animal Production in Australia. Proceedings of the 28th Conference Australian Society of Animal Production*, Vol. 28, 93 (Ed R. Dobos). UNE, Armidale, NSW, Australia: Australian Society of Animal Production.

Donoghue, K. A., Accioly, J. A., Jones, F. M., Copping, K., Deland, M. P. B., Hebert, M. L., Herd, R. M., Graham, J. & Pitchford, W. S. (2010).Maternal efficiency in variable nutritional environments. In *Animal Production in Australia. Proceedings of the 28th Conference Australian Society of Animal Production*, Vol. 28, 108 (Ed R. Dobos). UNE, Armidale, NSW, Australia: Australian Society of Animal Production.

Donoghue, K. A. & Parnell, P. F. (2009).Maternal productivity in industry herds: Preliminary results. In *Proceedings of the 18th Conference of the Association for the Advancement of Animal Breeding and Genetics*, Vol. 18, 117-120.

Herd, R. (2005). Maternal productivity of Angus cows divergently selected for postweaning residual feed intake. *Paper presented to the 16th Conference of the Association for the Advancement of Animal Breeding and Genetics, Noosa Qld, 28 September 2005*.

Herd, R. M., Arthur, P. F. & Archer, J. A. (2011).Associations between residual feed intake on ad-libitum, pasture and restricted feeding in Angus cows. In *Proceedings of the Association for Advancement of Animal Breeding and Genetics*, Vol. 19, 47-50 Perth WA.

Herd, R. M., Arthur, P. F. & Archer, J. A. (2011).Associations between residual feed intake on ad-libitum, pasture and restricted feeding in Angus cows. In *Proceedings of the Association for Advancement of Animal Breeding and Genetics*, Vol. Oral preseantation to Conference 11 July 2011Perth WA.

Herd, R. M. & Pitchford, W. S. (2011).Residual feed intake selection makes cattle leaner and more efficient. In *Recent Advances in Animal Nutrition - Australia*, Vol. 18, 45-58 (Ed P. Cronje). Armidale NSW: Animal Science, University of New England.

Laurence, M., Accioly, J. M., Barnes, A. L., Blache, D., Jones, F. M., Speijers, E. J. & Pitchford, W. S. (2011).Single nucleotide polymorphisms in the bovine leptin gene and their association with carcass and efficiency traits, and endocrine profiles, in female Angus cows. In *Proceedings of the Association for Advancement of Animal Breeding and Genetics*, Vol. 19, 383-386 Perth WA.

Lee, S. J., Nuberg, I. K. &Pitchford, W. S. (2009).Breeder perspectives on fat and female management. In *Proceedings of the 18th Conference of the Association for the Advancement of Animal Breeding and Genetics*, Vol. 18, 600-603.

Lee, S. J., Nuberg. I.K, Pitchford W.S. (2009) Associations between production potential and body energy reserves. Paper presented at *Beef CRC Postgraduate Conference, Gold Coast, Qld.*

Lee, S. J., Nuberg. I.K, Pitchford W.S. (2010) Effect of selection for production on energy reserves in beef cows. Paper presented at *9th World Congress on Genetics Applied to Livestock Production*, Leipzig, Germany.

Lee S.J. Donoghue, K. Hebart, M. Pitchford W.S (2011) Association between Breedplan EBVs, calf weaning weight & cow change during lactation. In *Proceedings of 19th Conference of the Association for the Advancement of Animal Breeding and Genetics, Vol. 18, 127-130.*

Lines, D. S., Wolcott, M. L., Pitchford, W. S., Bottema, C. D. K., Herd, R. M. &Oddy, V. H. (2009).Energy expenditure of Angus heifers divergently selected for residual feed intake. In *Proceedings of the International Symposium on Ruminant Physiology*, Vol. XI, 2-pages Clermont-Ferrand, France: INRA.

Lines, D. S., Wolcott, M. L., Pitchford, W. S., Bottema, C. D. K., Herd, R. M. &Oddy, V. H. (2009).Some consequences of selection for residual feed intake in beef cattle. In *Proceedings of the 18th Conference of the Association for the Advancement of Animal Breeding and Genetics*, Vol. 18, 604-607.

Torok, V. A., Jones, F. M., Percy, N. J., Durmic, Z., Phillips, F. A., Naylor, T., Vercoe, P. E. &Ophel-Keller, K. (2011).Changes in rumen microbial ecology are linked with feed efficiency, diet and methane production in beef cattle. In *Recent Advances in Animal Nutrition - Australia*, Vol. 18, 135 (Ed P. Cronje). Armidale NSW: Animal Science, University of New England.

Popular press and other

Accioly, J (2006) Maternal productivity updates. WA Angus Newsletter.

Accioly, J (2007) Maternal productivity updates. WA Angus Newsletter.

Accioly, J (2008) Maternal productivity updates. WA Angus Newsletter.

Accioly, J (2009) Maternal productivity updates. WA Angus Newsletter.

Accioly, J (2010) Maternal productivity updates. WA Angus Newsletter.

Accioly, J (2011) Maternal productivity updates. WA Angus Newsletter.

Accioly, J (2012) Maternal productivity updates. WA Angus Newsletter.

Accioly, J. (2008). Maternal productivity project - Part 1: An overview. In *The Maternal Journal*, 7-9 Armidale, NSW: Beef CRC.

Donoghue, K., Wilkins, J., Arthur, P., Dibley, K. & Mula, D. (2009).Relationship between age at puberty and residual feed intake. In *Industry & Investment NSW Beef & Sheep Conference*, 4-7 Orange Agricultural Institute, Orange, NSW.

Herd, R. (2006). Cows go west. *Independent Country Magazine in the Armidale Independent Newspaper* 21 April 2006: 6.

Herd, R. (2006). Trangie cows go west to undergo a series of trials. *Today's Feed Lotting* 18: 4.

Herd, R. (2007).West coast girls efficient. In *Science and Research Updates*, Vol. February 2007.

Herd, R. & Accioly, J. (2007).West coast girls efficient. In *Agriculture Today Newspaper*, Vol. 22 February 2007, 12.

Herd, R., Accioly, J., Arthur, P., Copping, K., Deland, M., Donoghue, K., Edwards, N., Graham, J., Hebart, M., Jones, F., Laurence, M., Lee, S., Parnell, P., Pitchford, W. &Speijers, J. (2010). Cow maternal productivity: "Giving the girls some credit". *AFBM Journal* 7(2): 1-3.

Herd, R. M. &Pitchford, W. S. (2011).Residual feed intake selection makes cattle leaner and more efficient. In *Engormix.com*, 31/08/2011 Engormix.com.

Jones, F. (2008).Maternal productivity project - Part 2: Genotype by environment - the impacts of nutrition. In *The Maternal Journal*, 10-12 Armidale, NSW: Beef CRC.

Laurence, M. (2008).Maternal productivity project - Part 3: Bulls, cows and calves. In *The Maternal Journal*, 13-14 Armidale, NSW: Beef CRC.

Lee S.J. (2012) Increasing Genetic Gain with Beef CRC Genomic Prediction Equations. South Australian Stock Journal '*Beef Informed'* column.

Lee S.J. & Pitchford W.S. (2012) Association of Breedplan EBVs with Cow Body Composition. Southern Beef Technology Services Winter Newsletter.

Lee S.J. (2011) Careful consideration of weaning strategies could pay dividends later. South Australian Stock Journal '*Beef Informed'* column.

Lee S.J. (2011) Increase income by increasing muscle. South Australian Stock Journal '*Beef Informed'* column.

Pitchford W.S. & Lee S.J. (2011) Higher pre-joining rib fat depth leads to increased heifer conception rate. Beef CRC Beef Bulletin.

Pitchford W.S. & Lee S.J. (2011) Rib fat depth: the key to high conception rates in heifers. Angus Spring Journal.

Pitchford W.S. & Lee S.J. (2011) Higher pre-joining rib fat depth leads to increased heifer conception rate. Southern Beef Technology Services Summer Newsletter.

Pitchford, WS (2007) Maternal Productivity Project. MLA Feedback

Pitchford, WS (2009) Maternal Productivity Project. MLA Feedback

Pitchford, WS (2011) Maternal Productivity Project. MLA Feedback

Presentations

Pitchford, WS (2005) Maternal Productivity Project. CRC Launch, Brisbane Qld

Pitchford, WS (2005) Maternal Productivity Project. CRC/MLA Planning meeting, Sydney NSW

Pitchford, WS (2006) Maternal Productivity Project. SABRC, Sydney NSW

Accioly, J (2007) Maternal Productivity Project. Vasse Field Day WA

Jones, F (2007) Maternal Productivity Project. Vasse Field Day WA

Laurence, M (2007) Maternal Productivity Project. Vasse Field Day WA

Accioly, J (2008) Maternal Productivity Project. Vasse Field Day WA

Jones, F (2008) Maternal Productivity Project. Vasse Field Day WA

Laurence, M (2008) Maternal Productivity Project. Vasse Field Day WA

Parnell, P (2008) Maternal Productivity Project. Vasse Field Day WA

Pitchford, WS (2008) Maternal Productivity Project. SABRC, Hamilton Vic

Accioly, J. (2006).Genetic impacts on maternal productivity in variable temperate environments. In *SABRC meeting* Vasse, WA.

Herd, R. (2005). Maternal productivity of cows selected for residual feed intake. *Seminar to UNE, NSW DPI Beef Industry Centre, Armidale, 13 October 2005*.

Herd, R. (2010).The Maternal Efficiency Project. In *Talk to 2010 Armidale Feeder Steer School, 1-4 February 2010* University of New England, Armidale, NSW: I&I NSW.

Accioly, J (2010) Maternal Productivity Project. Vasse Field Day WA

Jones, F (2010) Maternal Productivity Project. Vasse Field Day WA

Laurence, M (2010) Maternal Productivity Project. Vasse Field Day WA

Herd, R. (2011).Selection for net feed intake and its effect on the breeding herd and progeny carcass value. In *Beef and Dairy Breeding and Genetics Day*, Field day talk 22 July 2011(Ed C. Mack). Vasse WA: Department of Agriculture and Food WA.

Lee, S. J., Nuberg. I.K, Pitchford W.S. (2010) Maternal Efficiency: a research approach combining social science and animal genetics. Seminar presented at Meat Animal Research Centre, Clay Center, Nebraksa.

Lee, S. J., Nuberg. I.K, Pitchford W.S. (2010) Reporting outcomes from social science and industry herd data analysis. Seminar presented at collaborating herds producer workshop, Albury, NSW.

Lee S.J. Donoghue, K. Hebart, M. Pitchford W.S. (2010) Animal performance in industry herds. Seminar presented at collaborating herds producer workshop, Albury, NSW.

Lee, S. J., Nuberg. I.K, Pitchford W.S. (2010) Reporting outcomes from social science and industry herd data analysis. Presentation at producer workshop, Vasse, WA.

Lee, S. J., Nuberg. I.K, Pitchford W.S. (2010) Maternal Productivity: Fat, Feed and Fertility. Presentation at Herefords Australia Conference, Griffith, NSW.

Lee S.J. (2011) Balancing Maternal Productivity and Progeny Performance. Presentation at Moyle Pathfinder Client workshops, Struan, SA and Hamilton, Vic.

Lee S.J. (2011) Applying results of the maternal productivity project. Series of workshop with Fleurieu Beef Group, SA.

Lee S.J., Pitchford W.S. (2011) Maternal Productivity Project. Seminar and workshop for SA beef industry consultants and service providers, Murray Bridge, SA.

Lee S.J. (2011) Breedplan EBVs and cow body composition. Seminar presented at Beef CRC Champions Workshop, Melbourne, Vic.

Lee S.J. (2011) Maternal productivity project. Seminar presented at the Victorian More Beef from Pastures presenter workshop, Ballarat, Vic.

Lee S.J. (2011) Improving on-farm productivity. Producer workshop presented to Adelaide Hills Farm Management Group, Kuipto, Adelaide Hills.

Lee S.J. (2011) Beef R&D in Australia. Seminar for group of Kazakhstan beef producers, Roseworthy, SA.

Lee S.J (2012) Implications of maternal productivity project outcomes for seedstock breeders. Seminar presented at South Australian Murray Grey Conference, Roseworthy, SA.

Lee S.J. (2012) Beef CRC Maternal Productivity Project – links with the sheep industry. Workshop presentation at Sheep CRC Maternal Project Team Meeting, Glenelg, SA.

Lee S.J. (2012) Optimising Weaner Throughput. Presentation at Wootoona More Beef from Pastures workshop, Angaston, SA.

Lee S.J. (2012) Beef R&D in Australian. Seminar for Tatarstan government delegation, Roseworthy, SA.

Lee S.J. (2012) Role of genetic and nutrition in maternal productivity. Seminar at Beef CRC Champions workshop, Brisbane, Qld.

Lee S.J. (2012) BREEDPLAN EBVs and cow body composition. Seminar at Beef CRC Champions workshop, Brisbane, Qld.

Lee S.J. & Andrew T. (2012) Understanding Net Feed Intake. Seminar at Beef CRC Champions workshop, Brisbane, Qld.

Lee S.J. (2012) Reproductive performance in southern industry herds. Seminar at Beef CRC Final Forum, Brisbane, Qld.

Lee S.J. (2012) Improving productivity and profitability of beef production in the cereal zone. Producer presentation at Jamestown, SA.

Lee S.J. (2012) On-farm implications of results from Beef CRC Maternal Productivity Project. Producer presentation at Rennylea Angus and Wirruna Herefords joint workshop, Holbrook, NSW.

Lee S.J. (2012) Outcomes from the Beef CRC Maternal Productivity Project. Seminar and workshop for SA beef industry consultants and service providers, Murray Bridge, SA.

Lee S.J. (2012) Messages from Beef CRC Maternal Productivity Project for More Beef from Pastures Producer Advocates. Seminar at the MLA More Beef from Pastures forum, Mansfield, Vic.

Lee S.J. (2012) Presentation at Moyle Pathfinder Client workshops, Struan, SA and Hamilton, Vic.

Pitchford W.S. (2012) Outcomes from the Beef CRC Maternal Productivity Project. More Beef from Pastures Producer workshop presentation, Spotshill Herefords, Millicent, SA.

Pitchford, W.S. (2010) Maternal Productivity (southern Aust). Seminar presented at *Beef CRC Industry Review*, Coffs Harbour, NSW.

Pitchford, WS (2008) Beef genetics research: a tale from both ends. Shorthorn Field Day, Hahndorf SA.

Pitchford, WS (2008) Talkin' Bull. Fleurieu Beef Group, Flaxley SA

Pitchford, WS (2008) CRC overview. Vasse Field Day WA

Pitchford, WS (2008) CRC overview. Struan Field Day SA

Pitchford, WS (2009) Maternal Productivity Project. MLA insights forum, Melbourne Vic.

Pitchford, WS (2009) Importance of muscling in beef cattle. Fleurieu Beef Group, Flaxley SA

Pitchford, WS (2010) Advanced beef genetics workshop, MBfP modules 5&8. Mt Pleasant Beef Group SA

Pitchford, WS (2010) Maternal Productivity Project – various talks. Maternal Productivity Project collaborating breeders workshop. Albury NSW

Pitchford, WS (2010) Maternal Productivity Project, Katherine Research Centre NT

Pitchford, WS (2010) Breeding herd EBVs. Vasse Field Day WA

Pitchford, WS (2010) Report on Maternal Productivity Project. SABRC

Pitchford, WS (2010) Maternal Productivity Project. Fleurieu Beef Group, Flaxley SA

Pitchford, WS (2010) CRC Genomics work, Struan Field Day SA

Pitchford, WS (2011) Maternal Productivity Project. MLA insights forum, Melbourne Vic

Pitchford, WS (2011) Maternal Productivity Project. Angus Field Day, Tasmania

Pitchford, WS (2011) Maternal Productivity Project. University of Tasmania

Pitchford, WS (2011) Maternal Productivity Project. Pasture Agronomy Services conference, Mulawala NSW

Pitchford, WS (2011) Maternal Productivity Project. Breeder Cow Workshop, Glen Innes NSW

Pitchford, WS (2011) Maternal Productivity Project. SA Cattle consultants

Pitchford, WS (2011) Growth path research in the CRC. SA Cattle consultants

Pitchford, WS (2011) Maternal Productivity Project. More Beef from Pastures workshop, Hahndorf and Naracoorte SA

Pitchford, WS (2011) Impact of CRC Genomics research. Fleurieu Beef Group, Flaxley SA

Pitchford, WS (2011) Maternal Productivity Project. MLA Genetics workshop, Brisbane Qld

Pitchford, WS (2012) Maternal Productivity Project. Rennylea Beef Week Field Day, Holbrook NSW

Pitchford, WS (2012) Maternal Productivity Project. Angus Field Day, Warrnambool Vic

Copping, K (2012) Maternal Productivity Project. Angus Cattle Assessment School SA

Pitchford, WS (2012) Maternal Productivity Project. MLA Updates forum, Vic

Pitchford, WS (2012) Maternal Productivity Project. Graham Lean Beef Group, Hamilton Vic

Pitchford, WS (2012) Maternal Productivity Project. Beef 2012 Rockhampton Qld

Pitchford, WS (2012) Maternal Productivity Project. CRC Final conference, Brisbane Qld

Pitchford, WS (2012) CRC Genomics research. SA Cattle consultants, Murray Bridge SA

Pitchford, WS (2012) CRC Genomics research. SA Junior Heifer Expo, Wayville SA

Pitchford, WS (2012) Efficiency messages from the Maternal Productivity Project, Coota Park, Cowra NSW

Pitchford, WS (2012) Effect of body composition on maternal productivity. SBTS Webinar

Pitchford, WS (2012) Effect of body composition on maternal efficiency. SBTS Webinar

Pitchford, WS (2012) Maternal Productivity Project – various talks. Maternal Productivity Project collaborating breeders workshop. Albury NSW

Pitchford, WS (2012) Maternal Productivity Project. Vasse Field Day WA

Accioly, J (2012) Maternal Productivity Project. Vasse Field Day WA

Jones, F (2012) Maternal Productivity Project. Vasse Field Day WA

Pitchford, WS (2012) Maternal Productivity Project. Team Te Mania annual workshop, Hamilton Vic.

Pitchford, WS (2012) Maternal Productivity Project. Stud breeder workshop, Vasse WA

Accioly, J (2012) Maternal Productivity Project. Stud breeder workshop, Vasse WA

Jones, F (2012) Maternal Productivity Project. Stud breeder workshop, Vasse WA

Accioly, J (2012) Maternal Productivity Project. Breeder workshop, Mt Barker WA

Accioly, J (2012) Maternal Productivity Project. Breeder workshop, Dongara WA

7. References

Arthur, PF, Archer, JA and Herd, RM (2004) Feed intake and efficiency in beef cattle: overview of recent Australian research and challenges for the future. Aust. J. Exp. Agric. 44:361-369.

Arthur, PF, Renand, G and Krauss, D (2001) Genetic and phenotypic relationships among different measures of growth and feed efficiency in young Charolais bulls. Livestock Production Science 68:131-139

Barwick, SA and Henzell, AL (2005) Development successes and issues for the future in deriving and applying selection indexes for beef breeding. Aust. J. Exp. Agric. 45:923-933.

Colazo, MG, Martinez, MF, Kastelic, JP and Mapletoft (2002) Effects of dose and route of administration of cloprostenol on luteolysis, estrus and ovulation in beef heifers. Animal Reproduction Science 15:47-62.

Cundiff, LV, Gregory,KE. Koch, RM (1998) Germplasm evaluation in beef cattle-cycle IV: Birth and weaning traits. Journal of Animal Science, 76:2528–2535

Donoghue, KA, Rekaya, R, and Bertrand, JK (2004) Threshold-linear analysis of measures of fertility in artificial insemination data and days to calving in beef cattle. Journal of Animal Science. 82:357–361.

Exton, S (2001) Testing beef cattle for net feed efficiency – standards manual. http://www.dpi.nsw.gov.au/agriculture/livestock/beef/feed/publications/feed-efficiency Accessed September 2012.

Herd, R. M. & Pitchford, W. S. (2011).Residual feed intake selection makes cattle leaner and more efficient. In Recent Advances in Animal Nutrition - Australia, Vol. 18, 45-58 (Ed P. Cronje). Armidale NSW: Animal Science, University of New England.

Graser, H-U, Tier, B, Johnston, DJ, and Barwick, SA (2005) Genetic evaluation for the Beef industry in Australia. Aust. J. Exp. Agric. 45:913-921.

Jenkins, TG and Ferrell, CL (1994) Productivity through weaning of nine breeds of cattle under varying feed availabilities: I. Initial evaluation. J Anim Sci 1994. 72:2787-2797

Johnston, DJ and Bunter, KL (1996) Days to calving in Angus cattle: Genetic and environmental effects, and covariances with other traits. Livestock Production Science 45:13-22.

Koch RM, Swiger LA, Chambers D, Gregory KE (1963) Efficiency of feed use in beef cattle. Journal of Animal Science 22, 486-494.

McKiernan, WA, Wilkins, JF, Barwick, SA, Tudor, GD, McIntyre, BL, Graham, JF, Deland, MPB, and Davies, L (2005) CRC 'Regional Combinations' project — effects of genetics and growth paths on beef production and meat quality: experimental design, methods and measurements**.** Aust. J. Exp. Agric. 45:959-969.

Pitchford, W.S., Deland, M.P.B., Siebert, B.D., Malau-Aduli, A.E.O. and Bottema, C.D.K (2002) Genetic variation in fatness and fatty acid composition of crossbred cattle. J. Anim. Sci. 80:2825-32.

Pitchford WS (2004) Genetic improvement of feed efficiency of beef cattle: what lessons can be learnt from other species? Australian Journal of Experimental Agriculture 44, 371–382.

Pitchford, W.S., Mirzaei, H.M., Deland, M.P.B., Afolayan, R.A., Rutley, D.L., Verbyla, A.P. (2006) Variance components for birth and carcass traits of crossbred cattle. Aust. J. Experimental Agriculture. 46:225-231

Upton, W, Burrow, HM, Dundon, A, Robinson, DL, and Farrell, EB (2001) CRC breeding program design, measurements and database: methods that underpin CRC research results. Aust. J. Exp. Agric. 41, 943–952

8. Appendices – a list of papers to be published in a special edition of Animal Production Science (separate document to be published in 2014)

8.1. Maternal Productivity review

8.2. Seedstock breeder attitudes to maternal productivity

8.3. Direction of selection by seedstock breeders

8.4. Project design

8.5. Genetic parameters for body composition of Angus and Hereford cows - pre- and post-lactation

8.6. Genetic parameters for body composition of Angus and Hereford cows - changes during and after lactation

8.7. Relationships between body composition and carcass EBVs for Angus and Hereford cows

8.8. Multivariate modelling of body composition of Angus cows

8.9. Selection for residual feed intake affects appetite rather than efficiency

8.10. Effect of selection for residual feed intake on steer performance in a commercial feedlot

8.11. Effect of selection for muscle on cow performance

8.12. Effect of fat and residual feed intake EBVs on heifer pregnancy rate

8.13. Effect of fat and residual feed intake EBVs and nutrition level on maternal productivity of first parity cows

8.14. Effect of fat and residual feed intake EBVs and nutrition level on maternal productivity of mature cows

8.15. Effect of fat and residual feed intake EBVs and pre-weaning nutrition of dams on carcass performance of steers

8.16. Effect of fat and residual feed intake EBVs and nutrition level on maternal efficiency of cows

8.17. Effect of fat and residual feed intake EBVs and nutrition level on body condition and supplementary feed requirements of cows

8.18. Economic analysis of maternal productivity project

8.19. Modelling maternal productivity