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Influences of nutrition during pregnancy and lactation on birth weights and growth to weaning of calves sired by Piedmontese or Wagyu bulls

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Abstract. The aim of this study was to quantify the effects of nutrition during pregnancy and lactation on birth weight and growth to weaning of Piedmontese and Wagyu sired calves. This research was also conducted to provide animals for long-term studies on the consequences of growth early in life. During 2 breeding cycles, Hereford cows were managed within low or high pasture-based nutritional systems from about 80 days of pregnancy to parturition. During lactation, the calves and their dams remained on the low or high nutritional system or crossed over to the alternative system. From commencement of the nutritional treatment during pregnancy until parturition, and then during lactation, cows on low nutrition lost an average of 45 and 23 kg liveweight, respectively, and those on high nutrition gained 55 and 40 kg, respectively. Calves of Wagyu sires weighed less at birth (31.0 *v* 35.9 kg, s.e. = 0.31 kg) and weaning (182 *v.* 189 kg, s.e. = 2.26 kg) than those of Piedmontese sires. Calves of cows on low nutrition during pregnancy weighed less at birth than those of cows on high nutrition (32.5 *v.* 35.2 kg, s.e. = 0.32 kg). Low nutrition during pregnancy adversely influenced birth to weaning ADG (676 *v.* 759 g, s.e. = 9.2 g), weight gain (145 *v.* 160 kg, s.e. = 2.1 kg) and liveweight (177 *v.* 195 kg, s.e. = 2.3 kg) of calves at weaning. The nutritional system during lactation had greater effects on ADG (618 *v.* 816 g, s.e. = 9.2 g), weight gain (131 *v.* 174 kg, s.e. = 2.1 kg) and liveweight (164 *v.* 207 kg, s.e. = 2.3 kg) of calves at weaning than the nutritional system during pregnancy. Overall, the responses to the nutritional treatments were consistent for the progeny of both sire-genotypes.

Additional keywords: calf, cattle, meat, newborn.

Introduction

Australian cattle producers are increasingly targeting specific markets by selecting appropriate genotypes and by tailoring their nutritional management to allow expression of genetic advantages. These markets range from those favoured by high yielding, lean carcasses to those requiring high intramuscular fat or marbling content. As a result, animals of markedly different genetic characteristics are used as terminal sires. More advanced beef cattle husbandry practices aim to grow cattle efficiently at pasture during the early phases of their lives, followed by the use of high quality feedstuffs during later growth phases to meet market specifications. Pasture-reliant growth of cattle is typically a prolonged process during which cattle experience widely differing nutrition due to variable pasture quality and availability, climatic extremes, and management of cattle and pastures. Hence, it is important to understand influences of nutrition during pregnancy and lactation on cows mated to sire-breeds with high muscling or marbling potential, and on the performance of their offspring.

Fetal growth of cattle has been extensively studied in relation to calf survival. Growth of the fetal calf can be slowed during the latter half of pregnancy by severely restricted maternal nutrition (Holland and Odde 1992). Similarly, during late pregnancy, the size of the dam can restrict the growth of fetuses with high prenatal growth potential (Ferrell 1991; Joubert and Hammond 1958). However, consequences of fetal growth for subsequent performance, particularly in relation to carcass and eating quality characteristics at market weights are less well understood (reviewed by Greenwood *et al*. 2005) and appear

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not to have been assessed in cattle differing in sire-genotype. In this regard, severe growth retardation during fetal life has been shown to reduce muscle growth and increase fatness later in life in sheep (Greenwood *et al*. 1998, 2000; Villette and Theriez 1981), but had lesser effects on composition in Hereford cattle (Tudor *et al*. 1980).

Influences of pre-weaning nutrition on post-weaning growth and composition of cattle at market weights are better described (see reviews by Berge 1991; Hearnshaw 1997). Nutritional restriction early in life can have prolonged effects on subsequent growth of cattle (Reardon and Everitt 1973) and severe restriction before weaning does not appear to result in increased carcass fatness when animals are recovered for prolonged periods on pasture (Berge 1991; Hearnshaw 1997; Tudor *et al*. 1980). However, when fed high-energy diets in pens, animals severely growth-retarded from birth to weaning were fatter at market weights than their counterparts well-grown to weaning (Tudor 1972; Tudor and O'Rourke 1980; Tudor *et al*. 1980). As with fetal growth, influences of nutrition before weaning on subsequent performance, and interactions between prenatal and pre-weaning nutrition, in cattle of extreme sire-genotypes for muscling and marbling appear not to have been studied.

In this paper, we tested the hypotheses that cows mated to high muscle growth or high marbling potential bulls, and their offspring, will exhibit different liveweight and growth responses to divergent nutrition during pregnancy and lactation. To test these hypotheses, low and high pasture quality and availability nutritional systems were imposed during pregnancy and from birth to weaning, with the aim of maximising divergence, within animal welfare limitations, in fetal and pre-weaning growth of progeny sired by Piedmontese (high muscle growth and high birth weight) and Wagyu (high marbling and low birth weight) bulls.

The mechanisms underlying how particular growth-paths early in life affect cellular development of carcass tissues, future muscle and fat deposition, and eating quality in cattle have not been well defined. Hence, this study was also designed to provide subsets of animals with divergent prenatal growth (about 30% difference in birth weight) and growth to weaning (about 0.5 *v.* 1.0 kg/day ADG) in divergent genotypes for related studies on molecular and cellular development of carcass tissues, and on carcass and eating quality characteristics (Greenwood *et al*. 2006). Ultimately, this information will be used to enhance models for phenotypic prediction of beef cattle performance.

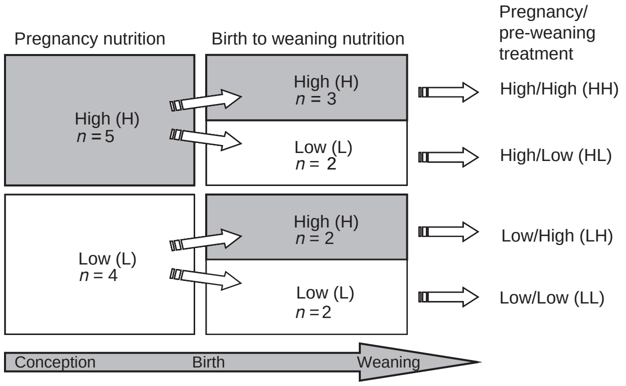

Fig. 1. Experimental design illustrating the plane of nutrition imposed on progeny from both cycles through the dam's pregnancy and from birth to weaning at Grafton Agricultural Research and Advisory Station. *n*, number of replicants in each cycle.

Materials and methods

All procedures were conducted with the approval of the NSW Department of Primary Industries North Coast Animal Care and Ethics Committee (Approval No. G2000/05).

Experimental design

Two planes of nutrition (low and high) were imposed on pregnant cows and, following parturition, on the lactating cows and their calves. From birth, cow-calf replicates either continued on the same treatment they received during pregnancy (low-low and high-high), or entered the opposite nutritional system (low-high and high-low nutrition) until weaning (Fig. 1).

The experiment was conducted in 2 consecutive years (cycle 1 and cycle 2) to produce replicated cohorts of male and female calves. The first breeding cycle is described in detail, and variations from the first cycle are described for cycle 2.

Animals and matings

Cycle 1

A total of 220 Hereford heifers of about 18 months of age were purchased from 4 sites in Northern NSW and South-West Queensland. They were acclimatised at the NSW Department of Primary Industries Grafton Agricultural Research and Advisory Station (GARAS), Grafton NSW (29°37′S, 152°55′E, altitude 20 m) from August for a 12-week breeding period that commenced in November 2000. An additional 140 cows from the existing Hereford herd at Grafton were included with the heifers to form mating groups. Ovulation of females was synchronised using a 7-day progesterone regimen (Easi-breed CIDR devices, InterAg, Hamilton, NZ), which included an injection of sodium cloprostenol (Estrumate, Scheering-Plough, Pty Ltd, North Ryde, NSW). Breeding was by artificial insemination using semen of 4 Piedmontese and 4 Wagyu sires selected (using breed society information and gene-test results) for high capacity for muscle growth or marbling, respectively, followed by back-up paddock matings. After 2 cycles of inseminations, 2 Piedmontese and 2 Wagyu bulls (also selected for high muscling and marbling potential respectively within their breed) were introduced to the sire-breed groups to maximise pregnancy rates. Pregnancy was detected between 30 and 90 days of gestation using a real-time ultrasound scanner (5 MHz probe, model 210 DxII, Aloka Inc., Tokyo, Japan).

A total of 288 pregnant cows and heifers were allocated to 9 replicates each of 32 animals. The allocation of animals to cells was on a stratified basis so that the herds were comparable in terms of the distribution of sire breeds and sire within breed; cow liveweight, age, origin and previous lactation status; and age of fetus. Four replicates were randomly allocated to the low, and 5 replicates to the high nutritional system from February 2001 until calving, a period of 6–8 months depending upon conception and calving dates.

Calving commenced in July 2001. Two of the low and 2 of the high pregnant cow replicates were randomly allocated to swap nutritional treatments at parturition, creating 2 low-high and 2 high-low nutritional replicates. Two replicates underwent low-low nutrition and 3 replicates high-high nutrition. All replicates remained on their pre-weaning treatment from birth until weaning in April 2002.

Calves were dehorned and male calves were castrated at about 3 months of age. All calves were vaccinated against bacterial diseases (7 in 1 vaccine; Cyanamid Websters Pty Ltd, Castle Hill, NSW) at 3 months of age and again 6 weeks later.

Cycle 2

A total of 350 cows from cycle 1 and an additional 120 two-year-old maiden Hereford heifers, sourced predominantly from Southern Queensland, were mated in cycle 2. They were prepared for breeding as in cycle 1, and mated to Piedmontese or Wagyu sires as in cycle 1 by artificial insemination in November and December 2001, or by natural mating during January 2002. The AI sires from cycle 1 were used again, plus an additional AI sire of each breed. For the back-up paddock matings a new bull of each breed was used in addition to the bulls used in cycle 1.

Cycle 2 mating occurred when 60% of the herd was in the pre-weaning nutritional phase of cycle 1. Hence the lactating cows were committed to their existing low or high nutritional treatment for the pregnancy phase of cycle 2. The 120 newly-purchased maiden heifers and 80 dry cows from cycle 1 were allocated to nutritional treatments when pregnancy tested in January 2002, and entered their nutritional treatments in February 2002.

Calving commenced in mid-July 2002. At calving, as for cycle 1, 2 low and 2 high cow-calf replicates were swapped to the alternate plane of nutrition, while the remaining 5 replicates continued on their low or high nutritional treatments (Fig. 1). All replicates remained on their pre-weaning treatment from birth until weaning in April 2003.

Animal measurements

All calves were weighed within 12 hours of birth. At the same time dams were weighed and an estimate of their muscle and tissue cover (body condition: score 1–9, where 1 is emaciated and 9 is very fat, Oklahoma system, NRC 1996) made by an experienced assessor. Cows and calves were subsequently weighed every 3 weeks to allow re-assessment of supplementary feeding rates and maintenance of the selected growth path. Cows and calves were scanned by real time ultrasound (3.5 MHz/180 mm linear array animal science probe, Esaote Pie Medical, Maastricht, the Netherlands) for body composition in November of each cycle (calf age about 3 months) and again at weaning. Calves were weaned at a mean age of 210 days. Weaned calves were then relocated to the NSW Department of Primary Industries Glen Innes Agricultural Research and Advisory Station (29°42′S, 151°42′E, altitude 1065 m) where they were grown-out as part of studies on consequences of nutrition early in life (see Greenwood *et al*. 2006).

Seasonal climatic conditions

Rainfall was recorded on-site. Recordings during the 2 years of the study (Fig. 2) relative to the recorded long-term average (1919–95) indicated below average rainfall during those months (April–October) when active growth of ryegrass is expected, and in the summer of 2002–03 when active growth for subtropical plants should have occurred in the medium and low pastures. The experimental area had previously suffered from a series of droughts (1991–94) and dry years (1999–2003), and water for irrigation was unavailable from October until December in 2001 and August 2002 to February 2003.

Nutritional treatments

The 2 planes of nutrition (low and high) were provided through the use of 2 different nutritional systems. Both systems were pasture-based, with the addition of supplements when necessary to maintain a divergence in nutritional status of the cows and their progeny between the 2 treatments. From previous work conducted at Grafton Research Station, the maximum potential divergence in calf growth expected to be created by the available nutritional systems was a 30% difference in calf birth weights and a 2-fold difference (approximately 0.5 *v.* 1.0 kg/day ADG) in pre-weaning growth rates.

Pastures

The low plane pastures grew on unfertilised, duplex soils with low organic matter and mineral status (soil phosphorus <6 mg/kg soil organic matter; Bray and Kurtz 1945), and were rotationally grazed by the low nutrition replicates of cattle year-round. Generally, the yield and quality of these pastures remained low [i.e. organic matter digestibility (OMD) <63% and crude protein <6%] owing to the preponderance of carpet grass (*Axonopus follicipeda,* 37% of the total dry matter), blady grass (*Imperata cylyndrica,* 29%), native grasses (e.g. *Bothrichloa* spp. 15%) and Bahia grass (*Paspalum notatum*, 12%). The growth phase of these species is between October and January when flowering commences, after which pasture quality gradually declines.

High nutrition replicates grazed on medium-high plane pastures from February to May each year, and again from October to the following May. These pastures were primarily comprised of kikuyu grass (*Pennisetum clandestinum*), Rhodes grass (*Chloris gayana* cv. Pioneer), carpet grass and Bahia grass, with a small contribution from white clover (*Trifolium repens* cv. Clarence). These pastures were generally of moderate yields (≥2000 kg DM/ha) and quality (OMD 60–70%, crude protein 6–9%).

High quality winter grazing was available to the high nutrition replicates from May to October each year. This was supplied by short-rotation ryegrasses (*Lolium multiforum* cvv. Concord and Marbella) sown into permanent pastures at the end of the summer growth period. The quality and growth of these pastures were maintained by fertilising with urea (1.6 kg N/ha daily equivalent) and by supplementing rainfall with irrigation when indicated by soil moisture deficit, measured at 150 mm depth. With adequate moisture, pasture yields were high (>3500 kg DM/ha), as was quality (OMD > 70% and crude protein >15%).

Pasture data were collected whenever animal management requirements permitted. The dry matter yield of low and medium-high plane pastures was measured twice in cycle 1 and regularly in cycle 2 (most commonly before paddock grazing) by a dry-weight-yield method (DWY) based on the ranking method by Haydock and Shaw (1975). The yield of high plane pastures was measured before and after grazing of the ryegrass paddocks by an electronic rising plate meter (FarmTracker; BMButler Computing, Farm Works, Feilding, NZ) using the technique by Earle and McGowan (1979).

The pattern of dry matter yield on offer upon entry of the replicates to a paddock for grazing in cycle 2 is shown in Figure 3.

During cycle 2, ryegrass production was reduced by inadequate rainfall throughout its growth period and the unavailability of irrigation water from August until the end of the ryegrass growth period in October. Yields of high and medium–high pastures were particularly poor during the summer when the cows and calves from cycle 2 were undergoing their

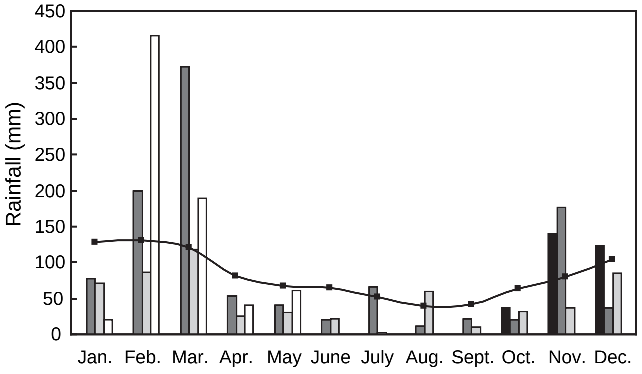

Fig. 2. Rainfall recorded at Grafton Agricultural Research and Advisory Station from 1 October 2000 to 1 June 2003 (black bars, 2000; dark grey bars, 2001; light grey bars, 2002; white bars, 2003) compared with the 1919–95 long-term average rainfall (solid line).

pre-weaning nutritional treatments. Significant falls of rain did not occur until February 2003, which allowed the medium–high quality pastures to grow, but was too late to elicit growth in the native low plane pastures.

Supplementary feeding

The design incorporated a plan to supplement the high nutrition cow-calf units during periods of lower quality and/or yield of pastures (≤60% digestibility or 1500 kg pasture DM), or to supplement low nutrition cow-calf units when pasture yield was less than 1200 kg DM/ha in accordance with animal welfare requirements. Because of persistent drought circumstances throughout much of the experiment, pasture growth was poor for large periods and supplementation was required to ensure high performance of the high plane groups, and the welfare of the low groups.

Supplementation was in the form of cottonseed meal (38% CP, 9.4 MJ ME/kg DM) in cycle 1 and the pregnancy phase of cycle 2. For the pre-weaning phase of cycle 2, two types of pelleted supplement were purchased from a commercial distributor (Oleo Industries, Moree, NSW). These formulations best met the project aims for achieving high nutrition or low nutrition during the dry seasons for pregnant and lactating cows and their calves. Performance pellets were used to supplement high nutrition groups and EC pellets used for low nutrition groups. The specifications of both types of pellets are detailed in Table 1. Supplementation was based on predictions from GrazFeed (Version 4.0. Horizon Technology; Roseville, NSW) using the mean group liveweight of cows, their stage of lactation, and the yield and quality (FeedTest analysis; Department of Primary industries, Hamilton, Vic.) of the pasture on which they grazed.

High nutrition supplementation. During cycle 1, cottonseed meal was fed twice per week (at a daily rate equivalent to 1.2 kg/cow) to replicates of pregnant cows in the high nutrition group during the final weeks of gestation, ceasing at calving. During cycle 2, supplementation with Performance pellets (Table 1) was provided to high nutrition lactating cows and their calves from November 2002 until March 2003. Following an adjustment period, pellets were fed at a maximum allowance of 4.5 kg/cow.day, 3 times per week, such that 2-days feed was supplied on Monday and Wednesday of each week, and 3-days feed was supplied on Friday. The maximum allowance was reduced where possible when replicates entered paddocks of higher pasture availability. Supplements to the high nutrition replicates were fed on the pasture, which provided good ground cover, in windrows over a distance that ensured all cows had an opportunity to feed. Calves were not excluded from access to the supplement and many attempted to compete with cows when the feed was offered.

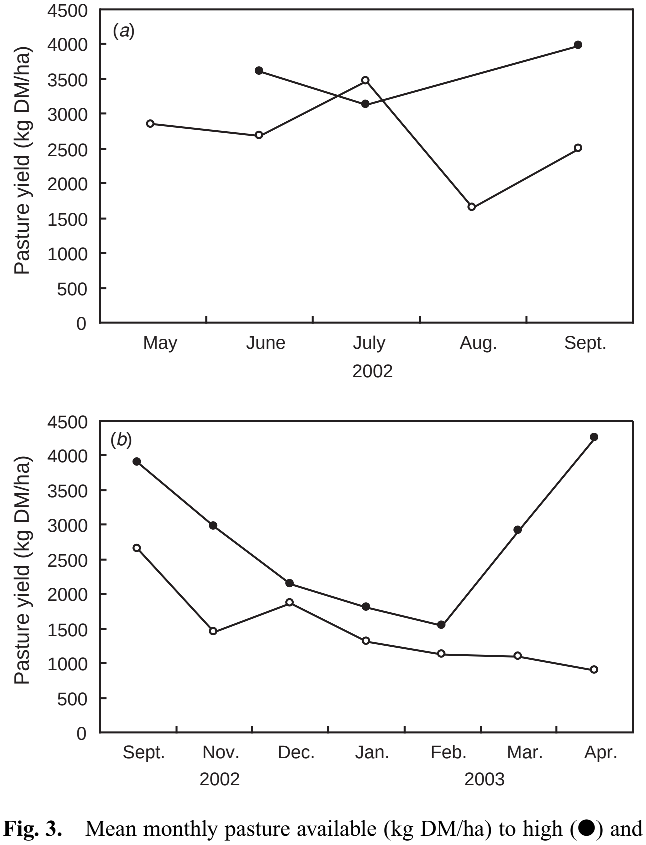

Fig. 3. Mean monthly pasture available (kg DM/ha) to high (●) and low (○) replicates at entry to a fresh grazing area during (*a*) pregnancy and (*b*) pre-weaning phases of cycle 2.

Low nutrition supplementation. Supplementation was provided to pregnant cows on low nutrition in cycle 2 from July 2002 until calving, and to the lactating cows and their calves on the low nutrition replicates from calf birth until weaning in April 2003.

The pregnant cows were supplemented with cottonseed meal as some pasture dry matter remained available for grazing during this phase. Lactating cows and their calves were supplemented with EC pellets (Table 1) from birth to weaning since pasture dry matter was minimal for this entire period (see Fig. 3). Following an adjustment period, the pellets were fed at a maximum rate of 2.5 kg/cow.day 3 times per week, using the same schedule as detailed for the high nutrition replicates. This maximum level was reduced for a replicate upon entry into a paddock with higher available DM or when calves grew at more than 500 g/day between each 3-weekly weighing.

Cows in low nutrition replicates were fed in troughs to minimise their ingestion of soil. The pellets were spread across 3 troughs per replicate providing >300 mm/cow trough space, and allowing all cows to eat without restriction. The ration was consumed within 20 min of being offered to each group of cows. The objective of the supplementary feeding regimen was to maintain cows' lactation, although calves were not excluded from the supplement. Most calves on the low pre-weaning replicates attempted to compete with cows for the supplement from an early age.

Statistical analyses

Associations between the set of measured variables and the animal classification factors generated by the experimental design were examined by fitting linear models. Predictors in each model included terms to classify the animals according to pregnancy nutrition level, pre-weaning nutrition level, sire genotype, sex of calf and breeding cycle. Terms to allow for second and higher order interactions between the main factors were also included in each model. Additional animal-based covariates were included in the models when appropriate. The statistical importance of each term was assessed by construction of analysis of variance tables.

Table 1. Composition and nutritional assessment of pellets used for supplementing high and low pre-weaning groups in cycle 2

Pellets were supplied by Oleo Industries, Moree, NSW

Component	Performance pellets	EC pellets
Barley (%)	68.4	42.8
Cotton hulls (%)	22.0	53.1
Cottonseed meal (%)	7.4	10.1
Urea (%)	0.6	0.6
Energy (MJ/kg DM)	11.5	10.7
Crude protein (g/kg DM)	130	120
Minerals (g/kg DM)	17.8	17.8

The replicate occupied by each animal was also included as an additional random source of experimental error but this had no substantive impact due principally to the strategy of creating roughly equivalent herds leading to high within-herd to between-herd variance ratios.

The models enabled prediction of the response for any factor or combination of factors averaged over the remaining factors and these predictions were used to summarise and discuss the data. Modelling was conducted through use of the GENSTAT software (Payne and Arnold 1997).

Results

Results for cows and calves are presented firstly as the main effects for the 2 nutritional treatments across the 2 breeding cycles, for the different breeds and sexes of calves, and for the 2 cycles (Tables 2, 4 and 6). A more detailed analysis of the effect on cows and calves of the interaction between the nutritional treatments during pregnancy and pre-weaning are subsequently presented (Tables 3 and 5).

Cow liveweight

Cow liveweights did not differ between pregnant cow nutritional treatment groups at mating nor at pregnancy test when low or high nutritional treatments commenced (Table 2). At parturition, cow liveweights were affected by the nutritional treatment imposed. The cows on low nutrition during pregnancy lost 45 kg during the treatment period, while those on high nutrition gained 55 kg, so that at commencement of lactation there was a 107 kg difference in cow liveweight due to nutritional treatment during pregnancy. Overall, there was no effect of sire-breed or calf sex on cow liveweight at parturition. There was an overall effect of cycle on cow weight at parturition, with cows in cycle 1 being 21 kg lighter than cows in cycle 2 at that point. An interaction between sex and genotype was also evident for cow liveweight at parturition. Cows with Wagyu-sired calves were the same weight at calving regardless of calf sex (450 *v.* 450 kg, s.e. = 6.4 kg), whereas cows with Piedmontese-sired male calves were lighter at calving than cows with Piedmontese-sired female calves (436 *v.* 454 kg, s.e. = 6.4 kg).

At the start of the pre-weaning period, cows allocated to low and high pre-weaning nutritional treatments did not differ in liveweight. During the period to weaning, the low nutrition cows lost 23 kg while the high nutrition cows gained 40 kg, resulting in the low and high pre-weaning cows

Table 2. Change in liveweight (kg) of cows from mating to weaning, as affected by pregnancy and pre-weaning nutritional treatment, sire-breed, cycle and calf sex

Values are predicted from models described in the 'Statistical analyses' section of Materials and methods. Results are for all cows that raised a calf to weaning in the first or second breeding cycles. Weight at mating refers to liveweight at commencement of the artificial insemination period, weight at pregnancy test is the weight at commencement of the pregnancy nutritional treatment, and the weight at parturition is cow weight immediately after the birth of the calf

	Number of cows	Liveweight at mating (kg)	Liveweight at pregnancy test (kg)	Liveweight at parturition (kg)	Liveweight at weaning (kg)
Pregnancy nutrition (B)					
Low	229	403	438	393	438
High	284	399	445	500	472
s.e.d.		7.6	6.3	5.9	5.1
Pre-weaning nutrition (P)					
Low	250	394	438	445	422
High	263	410	445	448	488
s.e.d.		7.7	6.3	5.9	5.1
Sire genotype (G)					
Wagyu	287	400	440	449	456
Piedmontese	226	401	444	445	454
s.e.d.		7.6	6.3	5.9	5.0
Cycle (C)					
1	215	381	441	436	442
2	298	421	443	457	467
s.e.d.		7.6	6.3	5.9	5.0
Sex (S)					
Female	225	404	447	451	456
Male or castrate	288	398	437	442	454
s.e.d.		7.6	6.3	5.9	5.1
Significance					
Main effects ($P<0.05$)	—	C	B	B, C	B, P, C
Interactions ($P<0.05$)	—	—	C × B, S × B	S × G, C × P	C × G, C × P

Table 3. Change in liveweight (kg) of cows showing pregnancy and pre-weaning nutritional treatment interactions

Values are predicted means from models described in the 'Statistical analyses' section of Materials and methods. LL, low pregnancy and low pre-weaning nutrition; LH, low pregnancy and high pre-weaning nutrition; HL, high pregnancy and low pre-weaning nutrition; HH, high pregnancy and high pre-weaning nutrition. Treatment started at pregnancy detection (see Table 2). Means within rows followed by the same letters are significantly different (*P* = 0.05)

Pregnancy and pre-weaning nutrition	LL	HL	LH	HH	s.e.d.
Number of cows	125	125	104	159	—
Liveweight at start of treatment (kg)	434a	443a	443a	448a	9.5
Liveweight at parturition (kg)	391a	499b	390a	502b	8.9
Liveweight change during pregnancy treatment (kg)	–42b	+56c	–53a	+54c	5.1
Liveweight at weaning (kg)	408a	434b	467c	510d	7.6
Liveweight change pre-weaning (kg)	+17b	–65a	+78c	+8b	6.1
Liveweight change over entire treatment period (kg)	–25a	–9b	+24c	+62d	6.7

differing in liveweight at weaning. Nutritional treatment during pregnancy also affected cow weights at weaning, with the cows on low nutrition during pregnancy weighing less at weaning than those that were on high nutrition during pregnancy (Table 2). There was also an effect of cycle on weight of cows at weaning, the cows in cycle 1 (2001-born calves) weighing less than those in cycle 2 (2002-born calves).

Differences in effects of nutritional treatments on cow liveweight change are evident when the pregnant cow and pre-weaning treatments are combined (Table 3). Cows in the nutritional-crossover groups (LH and HL) exhibited large losses and gains in liveweight over the duration of a cycle as a result of changing nutritional system. Cows within the same nutritional system throughout pregnancy and lactation exhibited large weight changes during pregnancy, but little

Table 4. Growth of calves to weaning, as affected by pregnancy and pre-weaning nutritional treatments, sire genotype, cycle and calf sex

Values are predicted from models described in the 'Statistical analyses' section of Materials and methods. ADG, average daily gain

	Number of calves	Birth weight (kg)	Birth to weaning ADG (g)	Age at weaning (days)	Weaning weight (kg)	Pre-weaning gain (kg)
Pregnancy nutrition (B)						
Low	236	31.6	676	215	177	145
High	298	35.2	759	211	195	160
s.e.d.	—	0.44	13.0	1.9	3.2	3.0
Pre-weaning nutrition (P)						
Low	254	33.4	618	213	164	131
High	280	33.4	816	213	207	174
s.e.d.	—	0.44	13.0	1.9	3.2	3.0
Sire-genotype (G)						
Wagyu	294	31.0	710	214	182	151
Piedmontese	240	35.9	724	212	189	154
s.e.d.	—	0.44	13.0	1.9	3.2	3.0
Cycle (C)						
1	234	32.2	693	218	183	151
2	300	34.6	742	208	189	154
s.e.d.	—	0.44	13.0	1.9	3.2	3.0
Sex (S)						
Female	231	32.3	684	213	178	146
Male or castrate	303	34.6	751	213	194	159
s.e.d.	—	0.44	13.0	1.9	3.2	3.0
Significance						
Main effects ($P<0.05$)	—	B, G, C, S	B, P, C, S	B, C	B, P, G, S	B, P, S
Interactions ($P<0.05$)	—	—	—	C × P	—	—

change from birth to weaning. The change in cow liveweight over the combined treatment period followed the pattern of HH > LH > HL > LL, with cows on high pre-weaning nutrition gaining weight and those on low pre-weaning nutrition losing weight, overall.

Births

Calving was generally successful, with 90% of Piedmontese-sired and 98% of Wagyu-sired calves surviving birth. Thirty-nine percent of cows carrying Piedmontese-sired fetuses were assisted with birth, compared to 19% of cows carrying Wagyu-sired fetuses. Fewer calving problems were encountered in cycle 2 as a smaller percentage of maiden heifers were involved. The highest level of dystocia was associated with the Piedmontese-sired male calves born in cycle 1. More of this group were stillborn, or had births requiring a higher level of assistance than the other groups, and 7 were removed by caesarean section. The level of pregnant cow nutrition did not significantly affect the number of calves born alive nor the level of dystocia.

Table 5. Growth of calves to weaning showing pregnancy and pre-weaning nutritional treatment interactions

Values are predicted means from models described in the 'Statistical analyses' section of Materials and methods. LL, low pregnancy and low pre-weaning nutrition; LH, low pregnancy and high pre-weaning nutrition; HL, high pregnancy and low pre-weaning nutrition; HH, high pregnancy and high pre-weaning nutrition. Means within rows followed by different letters are significantly different ($P = 0.05$)

	Pregnancy and pre-weaning nutrition				
	LL	HL	LH	HH	s.e.d.
Number of calves	127	128	110	170	
Birth liveweight (kg)	31.8a	35.0b	31.5a	35.3b	0.67
Weaning liveweight (kg)	154a	175b	200c	215d	4.9
Birth to weaning ADG (g)	570a	665b	784c	852d	19.9
Birth to weaning gain (kg)	122a	140b	169c	180d	4.6
Age at weaning (days)	214a	211a	216a	211a	2.9

Calf birth weight

Calf birth weights presented are for those calves surviving to weaning, as their dataset is complete for study. Analyses were also performed for all calves born, which included those stillborn (n = 36), calves that died during the pre-weaning period (n = 5), and female calves euthanased at birth for base-line studies (n = 31). Inclusion of these extra calves in the analyses had no effect on the significance of results, and caused only minor changes in predicted means.

Calves born to cows on the low plane of nutrition during pregnancy weighed less than those born to cows on the high plane (Table 4). Wagyu-sired calves weighed less than Piedmontese-sired calves. There was also a significant effect of cycle and sex on birth weight, due to male and

Table 6. Calf body composition at weaning determined using real-time ultrasound measurements

Values are predicted from models described in the 'Statistical analysis' section of Materials and methods. Adjusted means use liveweight at scanning (W, if significant) as a covariate. EMA, eye muscle area

	Number of calves	EMA (cm^2)	Adjusted EMA (cm^2)	Rump fat (mm)	Adjusted rump fat (mm)	Rib fat (mm)	Adjusted rib fat (mm)
			Pregnant cow nutrition (B)				
Low	236	33.9	35.9	1.6	1.8	1.1	1.2
High	298	36.0	34.9	2.0	1.9	1.3	1.3
s.e.d.	—	0.65	0.33	0.10	0.08	0.07	0.06
			Pre-weaning nutrition (P)				
Low	254	30.7	34.9	1.3	1.7	0.9	1.2
High	280	39.1	35.9	2.3	1.9	1.5	1.3
s.e.d.	—	0.65	0.37	0.10	0.09	0.07	0.07
			Sire genotype (G)				
Wagyu	294	33.5	34.4	2.1	2.2	1.4	1.5
Piedmontese	240	36.4	36.3	1.4	1.4	1.0	1.0
s.e.d.	—	0.65	0.32	0.10	0.08	0.07	0.06
			Cycle (C)				
1	234	34.0	34.9	1.8	1.9	1.1	1.1
2	300	35.8	35.8	1.8	1.8	1.3	1.3
s.e.d.	—	0.65	0.32	0.10	0.08	0.07	0.06
			Sex (S)				
Female	231	33.4	35.0	2.1	2.2	1.4	1.5
Castrate male	303	36.4	35.7	1.5	1.5	1.1	1.0
s.e.d.	—	0.65	0.32	0.10	0.08	0.07	0.06
			Significance				
Main effects ($P < 0.05$)	—	B, P, G, C, S	W, B, P, G, C, S	B, P, G, S	W, B, P, G, S	B, P, G, C, S	W, B, P, G, C, S
Interactions ($P < 0.05$)	—	G × P	S × P, G × P	S × P, G × P	G × B, S × P, G × P	S × P, G × P	G × B, S × P, G × P

female calves being born slightly heavier in cycle 2 (2002-born) than their respective counterparts in cycle 1 (2001-born).

Calf growth rate

Calves of cows subject to low nutrition during pregnancy grew more slowly to weaning than those of cows on high nutrition during pregnancy (Table 4). Calves within the low pre-weaning nutritional treatment grew more slowly to weaning than those within the high nutritional treatment. Extremes of growth were evident for the groups that did not change nutrition at birth, with calves on the crossover nutritional treatments being intermediate, such that HH > LH > HL > LL (Table 5). There was a significant effect of sex, with females growing more slowly than males, and a significant effect of cycle, with cycle 2 calves growing more quickly than cycle 1 calves.

Calf weaning weight

Calf weaning weight was significantly related to pregnant cow and pre-weaning nutrition. Calves that had a lower birth weight, as a consequence of low pregnant cow nutrition, were lighter at weaning than higher birth weight calves. Calves on high nutrition from birth to weaning were heavier at weaning than those on low nutrition, regardless of their dam's previous pregnancy nutritional treatment. Those which remained on high or low nutrition through both phases showed the greatest divergence in weaning weight with the crossover groups being intermediate, such that HH > LH > HL > LL (Table 5).

Males were heavier than females at weaning, and Piedmontese-sired calves were heavier than Wagyu-sired calves.

Calf body composition

Differences were evident for eye muscle area (EMA) at weaning, with calves whose dams were on low nutrition during pregnancy or lactation having smaller eye muscle areas than those on high nutrition for the corresponding phases (Table 6). This was largely explained by the larger size of the better-nourished calves. On an equivalent liveweight basis (189 kg), calves from low pregnancy nutrition had a higher EMA than those from high pregnancy nutrition. Cycle, sex and genotype also remained significant when the liveweight covariate was included in the model. Piedmontese-sired calves had a larger eye muscle area than Wagyu-sired calves. Females and cycle 1 calves had smaller eye muscle areas than castrate males and calves from cycle 2, respectively, and although remaining significant, the magnitude of these effects were reduced when adjusted to the same liveweight (Table 6).

Differences in rump and rib fat depth at weaning due to nutrition early in life were evident, with calves on high nutritional treatments either during pregnancy or before weaning being fatter than those on low nutrition. This was predominantly because the calves from high nutrition were heavier at weaning, and when liveweight was included as a covariate in the model, the differences in rump and rib fat due to nutritional treatment, although significant, were reduced (Table 6). Heifers had more rib and rump fat than steers, and Wagyu-sired calves had more rib and rump fat than Piedmontese-sired calves.

Discussion

This study has highlighted the importance of nutrition during the fetal and pre-weaning life of calves of 2 sire-breed types grown to weaning at 7 months of age. As part of an investigation to quantify the growth and development of cattle destined for meat marketing, this study also exposed the difficulty of establishing 'high' and 'low' planes of nutrition by relying solely on pasture quality and availability, as the nutritional objectives were achieved only with considerable inputs of supplementary feedstuffs. In particular, drought in cycle 2 resulted in all cows being fed supplements: those on low nutrition to ensure the welfare of cows and calves, and those on high to maintain calf growth targets.

Cows on high nutrition for the second and third trimesters of pregnancy gained weight, whilst those on low nutrition for the same period lost weight. This difference in nutritional status of the cows resulted in differences in calf birth weights, with calves from cows on low nutrition during pregnancy being born 10.2% lighter than those from cows on high nutrition during pregnancy. Cows that gave birth to Piedmontese-sired male calves were lighter than those that gave birth to Piedmontese-sired female calves or Wagyu-sired calves of either sex. Clearly, the male Piedmontese-sired fetuses had the highest fetal growth potential resulting in the heaviest birth weights in this study, and appear to have the greatest capacity to influence the nutritional status of the dam. This effect has been reported previously, with dams of male or Piedmontese-sired fetuses, which have higher fetal growth potential than female or Wagyu-sired fetuses, mobilising more muscle during pregnancy (Greenwood *et al.* 2002).

Wagyu-sired calves were smaller at birth than Piedmontese-sired calves, with no apparent difference in the manner in which the different levels of nutrition affected birth weight of calves of the 2 genotypes. Piedmontese-sired calves were born heavier in cycle 2 than in cycle 1, while there was no difference in the birth weight of Wagyu-sired calves between cycles. This was likely to be due to of the more restrictive effect of the smaller heifer dams in cycle 1 on the growth of the high potential birth weight Piedmontese-sired fetuses (Ferrell 1991).

The changes in cow liveweight due to nutritional treatment during the pre-weaning period were similar but of a smaller magnitude than those due to nutrition during pregnancy. However, the pre-weaning nutritional treatment had a large effect on calf growth to weaning, with calves from low nutrition pre-weaning weighing 20.8% less at weaning than calves from high pre-weaning nutrition. Hence, the level of nutrition supplied to cows and calves pre-weaning had a substantial effect on growth from birth to weaning, with low pre-weaning growth rates likely to have been mediated through lower milk yields of the Hereford cows (Johnston *et al*. 1995). In this regard, we have previously found that milk yield of non-supplemented Hereford cows declines to <3 kg/day on low quality pastures (Hennessy *et al*. 2001), resulting in slow calf growth. Calves of the different sire-breeds responded to the pre-weaning nutritional treatments similarly, and there was no significant difference in the growth rates of calves of the different sire breeds to weaning. However, because of their higher birth weights and marginally faster ADG, the Piedmontese-sired animals were slightly heavier at weaning.

The effect of nutrition during pregnancy on cow and calf liveweights persisted throughout the pre-weaning period. Cows from low nutrition during pregnancy remained 34 kg (7.2%) lighter at weaning than cows from high pregnancy nutrition. The calf growth rate from birth to weaning was also affected by nutrition of the cow during pregnancy, with calves from cows on low pregnancy nutrition 9.2% lighter at weaning than those from cows on high pregnancy nutrition. The magnitude of the effect of nutrition during pregnancy on pre-weaning growth was about 40% of the magnitude of the effect due to nutrition during lactation. The effect of restricted maternal nutrition on subsequent calf growth from birth to weaning is also demonstrated by comparing the growth of calves within the same pre-weaning nutritional treatment but from different pregnancy nutritional treatments. Growth rates of calves on high nutrition from birth to weaning were 8.7% higher in those whose dams received high nutrition during pregnancy compared to those that were on low nutrition during the same period. This effect was more evident among the calves on low pre-weaning nutrition, whereby those from high nutrition during pregnancy grew 16.7% faster than those on low nutrition during pregnancy. Given these findings, a potential benefit of high nutrition during pregnancy, at least within the pastoral conditions in this study, is the persistently higher weight of the cows and growth of calves during lactation, especially within a low plane of nutrition from calving to weaning. Our findings are in contrast with those of Freetly *et al*. (2000) and probably reflect differences between the studies in the magnitude of the nutritional contrasts during pregnancy and/or the maternal genotypes..

Our results also suggest there may be an adverse effect of reduced fetal growth on the capacity of calves to compensate in liveweight, at least to weaning, a finding consistent with those of Wardrop (1966) and Ryan (1990), who concluded that undernutrition in calves up to 2 months of age severely restricted their ability for later compensatory growth. However, the lower weaning weights due to nutrition during pregnancy were most likely a function of reduced birth weight, lower cow liveweight and lactational performance, reduced mothering ability, in addition to any potential loss of calf growth potential due to restricted fetal growth. Clearly, it is not possible without removing calves from their dams at birth and rearing them in a controlled environment (Greenwood *et al*. 1998), to separate the effects of prenatal nutrition and calf birth weight from the prevailing postnatal environment (including plane of nutrition and milk consumption) on growth from birth to weaning. In this regard, milk consumption is the principal factor determining growth to 2 months of age (Bartle *et al*. 1984), and there is a high correlation between average milk yield and weaning weight of calves (r = 0.73, Arthur *et al*. 1997). In relation to body composition of calves at weaning, nutrition, calf sex and breed had significant effects, although the magnitude of the differences in eye muscle area and fat depth were relatively small. Nonetheless, the extent to which these differences indicate larger potential differences in life-time growth of these and other body tissues warrants investigation.

Most interactions with breeding cycle were due to the differences in cow liveweight from cycle 1 to cycle 2. Cow and calf weights were generally higher in cycle 2 than in cycle 1, as the majority of the herd in cycle 1 were first-calf heifers, with the cows in cycle 2 likely to have a higher potential for milk yield and to wean heavier calves (Barlow *et al*. 1994). Unexpectedly, however, cows that gave birth to Wagyu females in cycle 2 were no heavier than those giving birth to Wagyu females in cycle 1. Although it is unclear why this difference occurred only in cycle 2, it suggests a possible differential fetal effect depending on fetal sire genotype and sex on maternal efficiency during pregnancy.

In conclusion, calves born to cows managed within the low nutritional system were smaller at birth than those born to cows within the high nutritional system and, overall, the influences of nutrition were consistent for progeny of both sire-genotypes. Calves born to dams well nourished during pregnancy and/or lactation grew faster during the pre-weaning period, and were heavier and fatter at weaning than those of cows on restricted nutrition during the corresponding phases. The magnitude of the effect of nutrition during pregnancy on pre-weaning growth was about 40% of the magnitude of the effect due to pre-weaning nutrition. There was no evidence that calves from dams on restricted nutrition during pregnancy exhibited compensatory gain during the pre-weaning period. These animals remained smaller than their well-nourished counterparts to weaning, although this may simply be a consequence of cow lactational performance. Finally, this study will provide an important resource for developing understanding of effects of early nutritional restriction on subsequent performance of cattle (see Greenwood *et al.*

2006), for more detailed investigations on effects of growth paths on cellular and molecular development of carcass tissues, and in development of models to predict cattle phenotypes.

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