Increasing the dietary energy of diets fed to first-litter sows on lactation performance and subsequent reproduction

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Executive Summary

This project investigated the response to increasing levels of dietary energy fed to first-litter sows in terms of lactation and reproductive performance. First-litter, or primiparous sows, are regarded as being most at risk of not having their nutrient requirements met during lactation because of low appetites and high maternal requirements. Progeny from primiparous sows are also compromised because they are born light and have a lower milk intake than older parity progeny. Energy requirements for primiparous sows have been investigated in the past, most comprehensively at QAF over 10 years ago (Tritton *et al*, 1996). Other studies overseas have investigated the benefits of adding fat to lactation diets to improve lactation performance, particularly over summer when high temperatures depress appetite. Given the rapid changes made in genetic leanness and possible adverse effects on sow appetite, a revision of the dietary energy requirements for primiparous sows based on lactation and subsequent reproductive performance was conducted.

Two hundred and eighty five pregnant gilts were allocated to one of five dietary energy levels: 13.0; 13.6; 14.2; 14.7 or 15.3 MJ DE/kg. Sows were offered their diets to appetite each day over a 27 day lactation and litter weight, weaning weight, sow intake, weight and fat loss over lactation and subsequent reproductive performance and sow retention were recorded. There was no response to increasing dietary energy on litter gain or weaning weight of the piglets. Sow appetite was also unaffected by dietary energy level fed during lactation. Sow weight loss was significantly reduced at the higher energy levels, and as P2 fat loss was unaffected, it is assumed that body protein loss was minimized. The resumption of oestrus and sow retention was improved with higher energy levels fed in the previous lactation, whereas subsequent size was unaffected. Over two parities, the cumulative litter size was increased by 9.6% when the lactation diet offered to parity 1 sows was at 14.2 MJ DE or higher

In conclusion, the project results showed that lactation performance and weaning weight is not responsive to dietary energy, supporting other published studies. The benefits of increasing dietary energy in first lactation are on reproductive performance and sow retention in the breeding herd. It is recommended that dietary energy at a minimum of 14.2 MJ DE/kg will optimize the reproductive performance of primiparous sows and reduce the risk of being culled or removed from the breeding herd before their second litter. Reducing energy supply from current levels of 14 MJ DE during times of high feed costs is to be avoided. It is currently estimated that an increase from 14.0 MJ DE to 14.7 MJ DE will cost $20/tonne or $2.80 per sow. An increase of 10% in litter size over the first two parities on the current cost of lactation diets is a return of 8:1. Alternatively, on a sow replacement basis, if an extra 5 sows per 100 are retained in the herd by increasing DE from 14.0 to 14.7 MJ DE, at $380/gilt replacement value, there would be a return of 6.8:1. There is economic justification to increase dietary energy levels fed to gilts, particularly over the summer.

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Introduction

It has been widely reported that high sow replacement rates are predominantly caused by poor reproductive performance or reproductive failure (Hughes and Varley 2003; Levis 2005; Lucia *et al.* 2000). In analysis of herd production records using PigChamp, Koketsu et al. (1997) reported that for every kg increase in lactation intake there was 0.80-0.9 times less likely to be removed from the herd due to reproductive failure. One of the main causes of low reproduction in the breeder herd results from body catabolism during lactation in first-litter sows. There have been numerous experiments to investigate the response of the first-litter sow to increased lactation intake, or specific amino acid intake such as lysine. King and Williams (1984) reported that it took first-litter sows longer to resume oestrus when weight loss during lactation was high, however found no effect of lactation intake on ovulation rate and subsequent litter size. King and Dunkin (1986) showed that first-litter sows were able to minimise lactation tissue loss by consuming 63 MJ DE/day and 815 g crude protein (35.5 g lysine/d). Ten years later, Tritton et al (1996) evaluated a range of dietary energy levels from 12.6 MJ DE-15.1 MJ DE/kg in cereal-based diets typically used in Australia on first-litter lactation and subsequent reproductive performance. By increasing digestible energy (DE) density of the diet, these authors reported that primiparous sows were able to increase daily energy intake in a linear relationship from 54-68 MJ DE. There was no effect on sow appetite. Although there was no effect on subsequent onset of oestrous or litter size, they did record a negative linear response in lactation weight loss and P2 loss with dietary energy level.

Since the study by Tritton et al (1996), there has been little work published on the response of primiparous sows to dietary energy, despite considerable changes in the genotype commercially used in Australia. The use of adding fat to the diet has been widely studied in the US (Tilton *et al.* 1999); and in Europe (Babinszky *et al.* 1992; Theil *et al.* 2004). Providing dietary fat to corn-soybean diets has mixed effects on milk production and litter gains, though an increase in fat composition in milk is generally recorded. Genetic selection indexes can negatively affect voluntary food intake (Revell and Williams 1993) and this may result in a lower daily energy intake than previously observed, if dietary energy levels have remained constant. Genetic selection for leanness is also likely to have contributed to a larger sized sow at first farrowing due to an increase in mature body size. Consequently, sows' maintenance requirement will increase, as well as a larger demand for energy if litter size and therefore lactation demand has increased. Under commercial farrowing house environments, feed intakes are often lower than recorded experimentally due to animal and genetic variation, environmental stressors such as high temperature, labour resources for frequent feeding and disease challenge.

Close and Cole (2000) provided examples of typical lactation diets from the different countries, which indicates that typical Australian diets are formulated to lower energy levels (14.0 MJ DE/kg) than the diets in the US (14.7 MJ DE/kg), probably due to the use of higher energy corn-soy diets in the latter. Dietary nutrient recommendation ranges from 14-14.2 MJ DE/kg (NRC 1988), but are largely dependent on three critical contributions: sow daily intake; lactation demand; and bodyweight loss of the sow. Close and Cole (2000) calculated that the energy requirements for a 200 kg primiparous sow nursing 10 piglets growing at a litter gain of 2 kg/day for 21 or 28 days would be 87 MJ DE/day without maternal loss. Low daily intakes of energy (<68 MJ DE) may restrict a commercial response to high levels of lysine or protein during lactation and is likely to result in greater tissue mobilisation (Tritton *et al.* 1996). Kim et al (1999) reported that daily energy intakes of 74 MJ DE were required to support mammary growth and milk production whilst supplying sufficient energy for maternal tissue mobilization.

The aim of this experiment was to evaluate the response to increasing dietary energy in lactating primiparous sows of a lean commercial genotype on lactation performance and sow fertility under commercial conditions. The study was conducted over summer when sow appetite is commercially accepted as being at their lowest. The hypothesis tested was that litter gain would increase in a linear response to increasing dietary energy supply, and secondly that subsequent fertility would improve.

Methodology

Dietary treatments

All sows were allocated to dietary treatment on entry to the farrowing houses at QAF Corowa, Research and Innovation facility, NSW. Two diets, a low or high energy diet (13.0 v 15.3 MJ DE/kg) were formulated from commercial ingredients. The low and high diets differed in the cereal ingredient composition and added tallow. These diets were then blended at 100:0, 75:25, 50:50, 25:75 and 0:100 ratios respectively to create a total of five dietary treatments varying in dietary energy at 13.0, 13.6, 14.2, 14.7 and 15.3 MJ DE/kg (Table 1). Dietary crude protein varied from 218 to 259 g/kg. Total lysine ranged between 11.7 to 13.7 g/kg. All dietary amino acids were held in constant ratio to lysine and were formulated at levels higher than recommended by industry standards (Close and Cole 2000; NRC 1998) for a estimated daily intake of 4.75 kg. Diets were manufactured in 3 tonne batches and supplied to the piggery in 25 kg bags. Due to the high amounts of fat, all diets were prepared as a mash to avoid variability in diet quality.

Sow management, housing and feeding procedures

Two hundred and eighty five pregnant commercial gilts (Large White x Landrace F1 cross; PrimeGro Genetics™) were allocated to one of five dietary treatments over a 14 week period. Approximately 25 animals were allocated weekly, commencing in the first week of December during the summer. The last group commenced the study in mid-March. The minimum and maximum daily temperatures are presented in Figure 1. Between December to April there were 30 days with a temperature that exceeded 35 ^{o}C, with the average maximum temperature of 30 ^{o}C during the lactation phase of the study (December to April). Sheds were composed of insulated walls and ceilings and blinds were automatically adjusted from a thermostat sensor set at 22^{o}C in the youngest shed, declining to 19 ^{o}C after 3 weeks. Sows were cooled from a drip-cooling system set on a thermostat at 26 ^{o}C and run for three minutes every 20 minutes. There was no fan-forced automatic ventilation apart from natural airflow through the side blinds. Sows were housed during their lactation in farrowing crates (0.8 x 2.0 m) on top of steel tribar flooring. Creep zones were heated with a 175W heat lamp set at 28 ^{o}C for the first 14 days and 26 ^{o}C for the third week. A plastic composite creep mat was located under the heat lamp for the first three weeks of age. Farrowing crates were fitted with a sow bite nipple drinker located outside the feeder, delivering a flow rate of 2 l/minute. Feeders were an open bowl with 6 kg capacity.

Pregnant gilts were 109.6 ± 0.11 days (mean ± SE) of gestation at treatment allocation. Animals begun their respective dietary treatment the following day and all sows were fed 3 kg once a day at 0700 h. Within 24 hours of farrowing, each sow was walked out of the crate and weighed on electronic weigh scales, and back fat thickness measured by real-time ultrasound using a 3.5 mHz linear array probe (Piemedical™) at the P2 site (65 mm from the midline over the last rib). Litters at farrowing were recorded for litter size born, live litter birth weight, and average piglet weight at birth was calculated. Within 24 hours, piglets were fostered between sow treatments and litters standardized to an average of 10.6±0.05 pigs with a range from 8 to 13 pigs. Thereafter, if piglets became ill-thrifty and were in poor condition, they were removed on welfare grounds to an off-trial foster sow. If a sow had fewer than four piglets remaining, she was removed from the experiment and excluded from the data analysis.

Sows were offered their treatment diet *ad libitum* from the day of farrowing from pre-weighed plastic buckets containing 3 kg. Each day, sows were offered feed four times a day up to a daily maximum of 9 kg. Feeders were filled in the afternoon to provide adequate feed during the night and early hours of the morning when sows predominantly fed. Each week, feed residues were recorded and this was subtracted from the feed offered amounts. Feed that was spilled by the sow and wasted was unrecorded.

Litters were weighed at 14 days of age and again the day prior to being weaned. Sows were weighed and backfat P2 measured on the day of weaning on exit from the farrowing crates and lactation weight and fat loss was calculated. Following weaning, sows were moved to individual stalls (0.6 x 1.8m) and fed 3 kg of a common sow diet (13.8 MJ DE/kg;

191 g crude protein; 9 g lysine/kg) once a day. Sows were mated on first oestrus post-weaning by artificial insemination using an am/pm/am service with 3 x 10^9 total cell count. Following mating, sows were moved into pens with other sows and gilts mated in the same week in group sizes of 80-90 sows. Accommodation was on rice hull and straw bedding in ecosheds (200 x 9 m; Croft™) and sows remained in their group until 15 weeks of gestation or removal from the weekly mated cohort. All sows were fed once a day 2.5 kg of a gestation diet (13 MJ/DE; 140 g crude protein; 6 g lysine/kg). Sows were moved into the farrowing accommodation the week prior to farrowing and subsequent litter data at farrowing and fate of the sows after mating was measured.

Statistical analysis

Data was analyzed using SPSS v 15.0 in a General Linear Model Univariate analysis of variance (ANOVA) for litter size records, litter and sow weights and backfat changes and sow intake. Random factors and co-variate factors were included in the model if there was a significant effect ($P<0.05$) on each dependant variable analysed. Where co-factors were included, this was stated in the footnote of each table. The proportion of sows mated with 7 days, and subsequent farrowing rate and sow retention was analyzed by chi-square. Linear and quadratic regression analysis was performed for litter average daily gain, sow weight and P2 loss, and subsequent litter size born for dietary energy treatment.

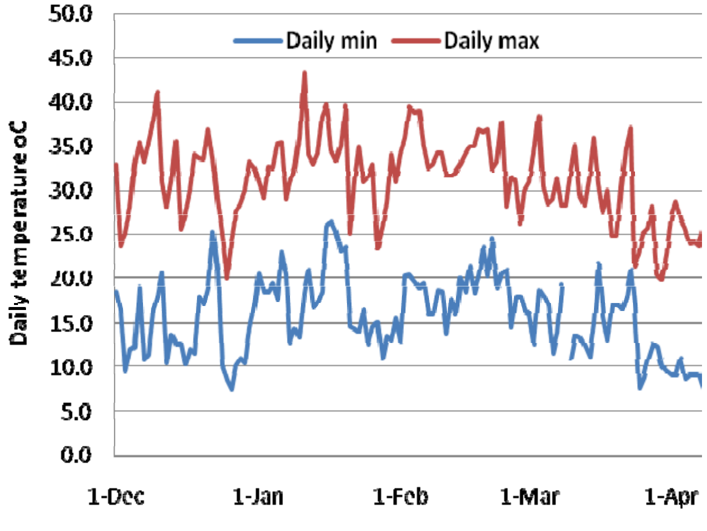

Figure 1. Daily minimum and maximum temperatures (°C) recorded at Corowa airport over the period of the lactation treatment feeding.

Table 1. Composition and nutritive values of experimental diets (g/kg air-dry basis)

Dietary energy level (MJ/kg)	13.0	13.6	14.2	14.7	15.3
Wheat	408.3	442.4	476.5	510.7	544.9
Barley	150	112.5	75.0	37.5	0.0
Millrun (wheat middlings)	150	112.5	75.0	37.5	0.0
Canola meal	60.0	62.5	65.0	67.5	70.0
Soybean meal	83.7	95.3	107.0	118.7	130.3
Meat meal	75.0	83.5	92.0	100.0	109.0
Blood meal	20.0	25.0	30.0	35.0	40.0
Water	10.0	10.0	10.0	10.0	10.0
Molasses	10.0	10.0	10.0	10.0	10.0
Tallow	5.0	21.25	37.5	53.75	70.0
Salt	3.5	3.5	3.5	3.5	3.5
Limestone	10.0	8.3	6.7	5.0	3.3
Di-calcium phosphorus	4.0	3.0	2.0	1.0	0.0
Lysine (L-lysine HCl)	1.47	1.10	0.73	0.37	0.0
Methionine (DL-methionine)	0.57	0.59	0.62	0.64	0.67
Threonine	0.60	0.49	0.38	0.28	0.17
Isoleucine	1.27	1.32	1.37	1.42	1.47
Potassium chloride	4.17	4.17	4.17	4.17	4.17
Mineral vitamin premix[a]	1.3	1.3	1.3	1.3	1.3
Mineral vitamin premix suppl.[b]	1.0	1.0	1.0	1.0	1.0
Preservative	0.2	0.2	0.2	0.2	0.2
Nutrient analyses (g/kg)[2]					
Digestible energy (MJ/kg)	13.0	13.6	14.2	14.7	15.3
Crude protein	217.9	228.1	238.2	248.4	258.6
Crude fat	32.9	48.6	64.3	80.0	95.7
Crude fibre	43.5	40.0	36.5	33.0	29.5
Calcium	10.0	9.7	9.4	9.0	8.7
Total phosphorus	7.5	7.3	7.0	6.8	6.6
Available phosphorus	4.5	4.5	4.5	4.5	4.5
Lysine	11.7	12.2	12.7	13.2	13.8
Ileal digestible lysine (g/MJ DE)	0.75	0.75	0.75	0.76	0.76
Methionine	3.8	3.9	4.1	4.2	3.2
Methionine + cysteine	7.6	7.9	8.2	8.5	6.4
Threonine	8.2	8.6	8.9	9.3	7.0
Valine	10.6	11.2	11.9	12.5	13.1
Isoleucine	8.3	8.6	8.9	9.3	9.6
Leucine	15.3	16.3	17.3	18.3	19.3
Histidine	5.7	6.1	6.5	6.9	7.3
Tryptophan	2.5	2.6	2.7	2.8	2.9

[1]Includes antioxidant added as a mixture of plant oil extracts at 3 g/kg. [2]Nutrient value was based upon QAF Meats Pty Ltd proprietary composition data.
[a]Premix provided the following nutrients (per kg air-dry diet): copper, 20 mg; iron, 80 mg; manganese, 40 mg; zinc, 100 mg; iodine, 1 mg; selenium inorganic, 0.15 mg; selenium organic, 75 mg; chromium picolinate, 3.2 mg, 0.45 mg; manganese, 40 mg; betaine, 100 mg; antioxidant (Endox®), 100 mg; vitamin A (retinol), 15 m.i.u.; vitamin D (cholecalciferol), 1.5 m.i.u.; vitamin E (α-tocopherol), 60 mg; vitamin B_2 (riboflavin), 3.5 mg; vitamin B_6 (pyridoxine), 2 mg; vitamin B_{12} (cyanocobalamin), 0.02 mg; biotin, 0.2 mg; folic acid, 0.5 mg; niacin, 15 mg; pantothenic acid, 5 mg. [b]Supplementary premix provided following nutrients (per kg air-dry diet): Organic selenium (Selplex®), 75 mg; organic iron (Bioplex Iron®), 500 mg; vitamin E (α-tocopherol), 60 mg; niacin, 5 mg.

Outcomes

Results

First litter size and lactation performance

The first-litter parity performance at birth was unaffected by dietary treatment (P>0.40). Litter size live born averaged 10.5±0.15, with a total litter size born of 11.5±0.15. Birth weight averaged 1.44±0.13 (P>0.25). Within 24 h, fostering was completed and the litter and average piglet weight gains over lactation (26.8±0.13 d) are summarized in Table 2. Average piglet weight after fostering was similar between dietary treatment levels (1.49±0.013 kg; P>0.20), whereas litter weight after fostering was not equalized (P<0.05) and was subsequently included in the statistical model as a co-variate as appropriate.

Table 2. Litter response to increasing dietary energy supply pre-farrowing (6.2±0.13 d) and offered *ad libitum* during lactation (26.8±0.13 d).

Energy level (MJ DE/kg) (no. sows)	13.0 (59)	13.6 (58)	14.2 (53)	14.7 (59)	15.3 (56)	SED	Linear Response to DE
0-14 days							
Litter daily gain (kg/d)[1]	1.58	1.56	1.69	1.54	1.60	0.05	0.990
Piglet daily gain (kg/d)	0.177	0.175	0.189	0.178	0.186	0.003	0.334
14 days-weaning							
Litter daily gain (kg/d)	2.01	1.78	2.14	1.95	2.02	0.04	0.461
Piglet daily gain (kg/d)	0.209	0.188	0.231	0.220	0.209	0.005	0.371
0 days-weaning							
Litter daily gain (kg/d)[12]	1.78	1.65	1.88	1.74	1.81	0.03	0.580
Piglet daily gain (kg/d)	0.201	0.191	0.210	0.203	0.210	0.002	0.057
Litter weaned weight (kg)[12]	63.6	60.1	66.4	62.7	64.5	0.87	0.743
Piglet weaned weight (kg)[12]	6.9	6.6	7.1	7.0	7.2	0.07	0.155

[1]Litter weight at fostering included as a co-variate in the GLM model (FOSTWT= 15.75kg). [2]Weaning age included as a co-variate in GLM model (WEANAGE=26.8 days)

There were no significant linear effects of increasing dietary energy on lactation performance as indicated by litter gains or average piglet growth rates pre-weaning. Piglet growth rate tended to improve with higher levels of dietary energy (r^2 0.013), however the regression β coefficient in this relationship was low (0.005±0.003 kg/d).

Sow lactation tissue loss

Sows commenced the study in good condition and of similar live weight and backfat (Table 3). There was a significant difference in starting weight and backfat P2 between weekly allocations and this was adjusted for in the least square mean values reported. Sows were weighed within 24 hours after farrowing. There was no dietary response on sow post-farrowed weight after the short period of feeding prior to farrowing (6.2±0.13 d), however there tended to be an increase in backfat P2 at the higher dietary energy treatments (r^2 0.63; β 0.27±0.159). Sow weaning weight and sow backfat P2 increased significantly in a linear response to dietary energy (Table 3). Sow weaning weight responded to dietary energy with an r^2 of 0.510 and slope of 4.0±0.09. Sow P2 at weaning responded with an r^2 of 0.34 with a β of 0.66±0.23. Sow weight loss over lactation responded in an inverse relationship with dietary energy, though the data fit was highly variable (r^2 0.10; β +3.9±1.04). The loss of backfat over lactation was unaffected by dietary energy. Sow feed intake was similar between all dietary treatments.

Subsequent reproductive performance

Following weaning, all sows were fed a common diet and mated on their post-weaning oestrus. The subsequent reproductive performance is summarized in Table 4. The onset of oestrus, as measured by the proportion of sows mated within 7 days and the average weaning to oestrus interval period was positively related to dietary energy intake during lactation. There also tended to be an improvement (P<0.10) in subsequent farrowing rate and the proportion of sows retained in the herd to second parity between 13.6 MJ DE and 14.2 MJ DE and 15.3 MJ DE. Subsequent litter size did not respond to dietary energy intake during the previous lactation. The subsequent litter size in sows allocated to 13.6 MJ DE was significantly lower compared to 13.0 MJ DE (P<0.05). It was possible that there were proportionately more sows re-mated on an extended oestrus in the 13.0 MJ DE treatment group. The dataset was re-analyzed with weaning to oestrus period included as a co-variate. The adjusted mean total litter size for sows allocated to 13.6 MJ DE was 10.3±0.6, whilst the other treatment mean values as reported in Table 4 were unaffected when weaning to oestrus length was included in the model. The effect of weaning to oestrus period interacting with dietary energy response in subsequent litter size were non significant.

Table 3. Sow tissue change during lactation and subsequent reproductive performance response to feeding increasing dietary energy levels during first-litter lactation.

Energy level (MJ DE/kg) (no. sows)	13.0 (59)	13.6 (58)	14.2 (53)	14.7 (59)	15.3 (56)	SED	Linear Response to DE
Sow weight at start (kg)[1]	215.5	219.8	216.0	217.2	215.3	1.00	0.654
Sow P2 at start (mm)[1]	21.5	21.3	21.9	22.2	21.5	0.23	0.727
1st lactation							
Sow weight post-farrow (kg)[12]	201.8	200.8	201.7	202.0	200.8	1.07	0.770
Sow P2 post-farrow (mm)[123]	19.6	19.7	20.3	20.0	20.0	0.21	0.092
Sow weight weaning (kg)[124]	181.3	188.2	185.8	191.2	190.9	1.03	0.001
Sow P2 weaning (mm)[123]	16.1	16.4	16.8	17.4	17.2	0.22	0.004
0 days-weaning							
Sow daily intake (kg/d)[13]	4.68	4.69	4.69	4.66	4.68	0.04	0.938
Sow daily DE intake (MJ/d)	60.8	63.8	66.5	68.6	71.6	0.58	0.001
Sow weight change (kg)[12]	-20.3	-12.8	-16.6	-10.3	-9.8	0.88	0.001
Sow P2 change (mm)[123]	-3.4	-3.3	-3.6	-2.5	-2.8	0.21	0.102

[1]Main effect of time period at start of treatment significant (P<0.05) and included as a random factor in the GLM model. [2]Sow weight at start included as a co-variate factor in GLM model (STARTWT=216.9 kg). [3]Sow P2 at start included as a co-variate factor in GLM model (START P2=21.7mm). [4]Age at weaning included in the GLM model (WEANAGE=26.8 days).

The cause of sow removal from the breeding herd between treatment allocation and second parity were predominantly due to reproductive causes. Of the sows allocated to 13.0 and 13.6 MJ DE respectively, there were 16/59 and 20/58 sows removed due to post-weaning anoestrus, return to oestrus, pregnancy failure by six weeks by ultrasound check and late-term pregnancy failure (not in pig on re-entry to the farrowing house). By comparison, in the three highest dietary energy treatments, there were 11/53, 14/59 and 12/56 that were removed for fertility failure ($\chi^2$2.77; P<0.10). Litter size born over the first two parities was included as a variable and expressed relative to the number of sows that farrowed their first litter. Thus a sow that failed to be re-mated or that failed to produce a second litter was given a value of 0 for her second litter. Offering diets during the first lactation of 14.2 MJ or higher improved cumulative litter size by parity 2 by 9.6% (P<0.05).

Table 4. Sow subsequent reproductive performance response to feeding increasing dietary energy levels during first-litter lactation

Energy level (MJ DE/kg)	13.0	13.6	14.2	14.7	15.3	SED	Linear Response to DE
Proportion sows in oestrus	0.85	0.80	0.86	0.92	0.90	χ^2 4.28	0.509[#]
Weaning to oestrus (days)[1]	8.1	6.7	6.1	5.6	5.7	0.43	0.055
Proportion mated ≤ 7 days	0.74[a]	0.79[ab]	0.92[ab]	0.88[b]	0.86[b]	χ^2 7.26	0.145[#]
Proportion retained 2nd parity	0.49[ab]	0.43[a]	0.68[c]	0.61[abc]	0.62[bc]	χ^2 8.23	0.086[#]
Number of litters 2nd parity	29	25	36	36	35		
Subsequent farrowed rate	0.58	0.54	0.73	0.69	0.73	χ^2 5.55	0.247[#]
Subsequent litter size live	11.5	9.7	10.2	10.8	10.9	0.25	0.959
Subsequent litter size total	12.1	10.1	10.9	11.5	11.6	0.24	0.907
Cumulative total born/sow	17.6[xy]	16.2[x]	18.7[y]	18.3[y]	18.6[y]	0.40	0.152

[1]Sow weight at start included as a co-variate factor in GLM model (STARTWT=216.9 kg). [abc]Chi square analysis comparison between each DE level significantly different (P<0.05).[#]Probability value of the non-linear treatment response. [xy]Litter size mean values within row differ significantly at P<0.10.

Discussion

Lactation performance as measured by litter gain and piglet weaning weight did not significantly respond to increases in dietary energy levels fed pre-farrowing and during lactation nor as a consequence of lower rates of sow tissue losses. This is a similar finding to the lactation dietary energy responses reported by Tritton *et al.* (1996) conducted in the same facilities and using similar ranges in dietary energy. The supply of energy for milk production, either from the diet or from maternal tissue reserves does not appear to affect milk production. Pluske *et al.* (1998) reported that milk production did not increase even when primiparous sows had exceptionally high energy intakes (111 MJ DE/d) and were made anabolic during lactation. Their conclusions were that the primiparous sow partitions extra energy into her maternal reserves rather than milk production. Our results support this hypothesis. The effect of adding fat to lactation diets on milk production and weaning weight has variable results in primiparous sows (Noblet and Etienne 1986; Tilton *et al.* 1999). These authors reported no difference in milk production or litter growth in primiparous sows, although milk composition was affected with an increase in total solids and fat content.

The response in milk production and mammary growth during lactation to energy intake is determined by the supply of adequate amino acids (Kim *et al.* 1999; Tokach *et al.* 1992). All diets were formulated to a minimum of 11.7 g lysine with ratios of other essential amino acids relative to lysine held constant. Daily lysine levels were calculated to be above the recommended requirement of 55 g. We conclude that the limitation to milk production in primiparous sows must therefore be due to factors other than energy intake, even when feed intake is depressed under hot environments.

Our results show that daily energy intakes can be increased through dietary content without concomitant reductions in appetite. Some authors have reported that the feed intake in primiparous sow responds negatively to higher dietary energy contents (Kirkwood *et al.* 1988), whereas others have shown no influence of dietary energy content on voluntary food intake (O'Grady and Lynch 1978; Tilton *et al.* 1999; Tritton *et al.* 1996). The sow feed intake recorded in our present experiment was typical of commercial gilt feed intakes and were likely to be limited by the high ambient temperatures during the lactation period (Jones and Hermesch 2007). It is possible that under a thermal neutral environment, an effect of dietary energy content on sow intake may be evident, as it is in the grower-finisher pig (Revell and Williams 1993). However, when intakes are limited due to heat stress, our data shows that daily energy intakes can be increased by feeding the sow a higher dietary energy concentration.

At the dietary energy intakes used in this experiment, some maternal tissue mobilization would be expected given the model proposed by Close and Cole (2000). From their equations, a 215 kg primiparous sow with a litter gain of 1.8 kg/day would require 83.9 MJ DE /day: 0.492 MJ DE/$215^{0.75}$ for maintenance energy +1.85x 30.4 MJ DE for milk production

Minimizing the losses of body reserves during lactation in the primiparous sow is highly important for the resumption of oestrus and reproductive performance in her second parity (Aherne and Kirkwood 1985; Aherne and Williams 1992; King 1987; Sterning *et al.* 1990). Increasing the dietary energy content of the lactation diet reduced the amount of body weight loss and tended ($P<0.10$) to improve subsequent sow retention to second parity. The average weaning to oestrus interval and the proportion of weaned parity 1 sows that had a short post-weaning oestrus (within 7 days) was improved with increasing dietary energy level in lactation. Sow backfat loss was not significantly reduced with increasing dietary energy level fed in lactation, though the level of loss was small and may not have been realized with the number of replicates per treatment. In older genotypes, King (1987) concluded that there is a critical level of daily energy intake during lactation of 45 MJ DE below which the resumption of oestrus post-weaning is adversely affected. At the lowest level of dietary energy, the daily energy intake in the current experiment exceeded this level. Tritton *et al.* (1996) also failed to observe an lactation energy response in post-weaning onset of oestrus. It is possible that the amount of body protein reserves at weaning can offset the negative effect of large lactation losses on the resumption of oestrus and subsequent farrowing rate (Smits *et al.* 1997). Sows on the lower dietary energy diets in this experiment that lost the greatest amount during lactation were weaned with considerably more body protein reserves compared to sow weaning weight and backfat P2 reported by Smits *et al*. and Tritton *et al*. (170 kg, 17 mm and 164.7 kg and 16.3 mm, respectively). This did not prevent a delayed onset of oestrus. From our results, it appears that post-weaning oestrus responds to energy intake above that previously reported from studies 10-20 years ago, regardless of the amount of sow protein mass at weaning.

Subsequent litter size was not observed to respond to increasing dietary energy levels fed during the previous lactation. This finding is consistent with that reported by Tritton *et al.* (1996). In their review, Aherne and Kirkwood (1985) concluded that there was little evidence of an energy intake response on ovulation rate, whilst effects on embryo survival were equivocal. Kirkwood *et al.* (1987) showed that ovulation rate is unaffected by low feed intake in lactation and consequently sow weight loss, whilst embryo survival was reduced. Pregnancy rates were also improved by feeding at higher intakes in the previous lactation. Zak *et al.* (1998) however failed to observe an increase in embryo survival in primiparous sows kept in a positive energy balance during lactation compared to restricted and consequently catabolic sows. The high subsequent litter size observed in the lowest lactation dietary energy treatment in our study appears to be aberrant the variation of litter size born was no greater in this treatment than others. A longer weaning to oestrus period recorded in these sows may have compensated some of the body weight loss by weaning and hence returned the weaned sow to a similar metabolic state as those weaned sows on the higher energy diets. Mating weights or backfat P2 were not recorded in the experiment. The distribution of litter size was more skewed towards very low litter sizes in the 13.6 MJ DE treatment, but the other treatments were similar in distribution.

The sow retention tended to be improved ($P<0.10$) when dietary energy during lactation was supplied at 14.2 MJ DE or higher. Sow longevity in the breeding herd has deteriorated in recent years and most sow loss occurs in young parities, either because of reproductive failure or low performance (Hughes and Varley 2003). Through the combination of sow survival and litter size born through to second parity, sows that were fed 14.2 MJ DE or higher during lactation produced 10% more piglets than sows on lower energy diets over their first two parities. The improvement in the retention of sows through increased energy intake and the conservation of body reserves in primiparous sows has important economical and welfare advantages to the pig industry. Culled sows were shown by Hughes and Smits (2002) to be associated with low weight and fat reserves at the time of removal. Maximizing energy intake and feed intake during primiparous lactation is therefore a critical nutritional and management strategy to improve sow lifetime reproductive performance.

In conclusion, feeding high energy diets during the first lactation when intakes were limited by high summer temperatures improved reproductive performance and sow longevity but did not improve lactation performance. Post-weaning oestrus responses to energy intake in lactation were evident in sows with high levels of body reserves at weaning, suggesting that modern commercial genotypes with high protein masses may not alleviate subsequent reproductive performance.

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Application of Research

Feeding lactation sows with high energy diets was shown to significantly improve sow retention and subsequent fertility. However milk production and weaning weight were not responsive to increasing energy levels, which supports previous findings published in the literature. Some producers and nutritionists may be concerned that increasing dietary energy levels may have an adverse effect on sow appetite in lactation, especially over summer. The results confirm others published in the literature that this is not the case, and that daily energy intakes can be increased in a linear response to dietary level.

In the experimental design, it was decided that the diets would be manufactured as a mash rather than pellet form. Increasing fat content to diets in the range above 6% crude fat could result in poorer pellet quality. The decision to use a mash form that allows higher energy levels to be fed may depend on the feedmill processing requirements, silo management and silo design, and feeder design. Practically, turnover of feed in summer containing high levels of fat needs to be more frequent to avoid oxidation and feed spoilage. These are not insurmountable challenges and most producers can change their feed ordering accordingly.

Based on the number of piglets produced (born) per 100 sows that commenced the feeding strategy, there was an increase of 10% above the litter size born to sows fed diets less than 14.2 MJ DE during the first lactation. At 2008 feed prices, the cost per MJ of digestible energy (DE) is $28 MJ. Based on feed intakes recorded, this amounts to $4/sow/MJ DE. Assuming a return value of $30/piglet born, and an increase of 0.75 piglet, by increasing lactation energy values from typical values of 14 MJ DE/kg offers a return $22.50:$2.80 feed cost ($8.03:1).

An alternative payback calculation is by savings to the sow herd. We estimate that out of 100 sows in the herd, the improvement in sow retention will be 5% by increasing dietary energy from 14.0 to 14.7 MJ. Assuming a gilt replacement enters the breeding herd at $380 at breeding age, the net return through savings to sow numbers is therefore $19.00:$2.80 ($6.8:1). Additional benefits would also include higher litter size from retaining the older sow. So both methods of calculation are similar.

The adoption of the project findings are simple to implement and easy to convey. Producers have the ability to choose feed from a range of commercial feed companies or ask their nutritionist to provide simple payback scenarios based on their ingredient costs at any time. The project outcome of a 5% reduction in sow replacement rates contributes to 15c/kg cost of production according to Auspig.

Conclusion

In conclusion, feeding high energy diets during the first lactation when intakes were limited by high summer temperatures improved reproductive performance and sow longevity but did not improve lactation performance. There was no evidence of a decrease in lactation voluntary food intake when dietary energy was increased even as high as 15.3 MJ DE. Most producers in Australia feed sows with a lactation diet formulated to 14 MJ digestible energy/kg. Increasing this to 14.7 MJ DE/kg resulted in a return on investment calculated to be in the order of $7-8:1. In an economic climate of high feed costs, reducing energy levels to lactating sows should be avoided. Sow litter growth rates did not respond to dietary energy, and given that lysine was provided above requirement, other factors must be limiting lactation performance during summer in primiparous sows in summer. Further research is warranted to identify and alleviate these limitations.

Limitations/Risks

Feeding diets containing high levels of energy through increased fat levels can reduce pellet quality and higher rates of oxidation and feed spoilage. Implementation needs to take into account individual farm silo management and feeder design and feed delivery. These limitations are not major challenges to most producers. Antioxidant levels can be increased in formulations as a precaution against feed rancidity. However, in the study results, there was no evidence of a reduction in appetite or feed refusal in diets with up to 9.8% of crude fat.

Recommendations

As a result of the outcomes in this study the following recommendations have been made:

1. Dietary energy lactation levels fed to primiparous sows during summer should be increased above 14 MJ DE to maximize sow longevity and productivity.
2. Maximizing feed intake during summer through correct feeding management and dietary formulation should be prioritized in summer to reduce the impact of summer heat stress on sow wastage.

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Appendix 1 - Notes

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