The effect of nutrition during pregnancy on hogget reproduction

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Abstract

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The reproduction rate of hoggets in New Zealand is much lower than that observed in adult ewes. New Zealand farmers have indicated this is a major limitation to the uptake of hogget breeding and lambing. A series of studies conducted during pregnancy in the U.K. under housed conditions, utilising a concentrate diet, reported rapidly grown hoggets had reduced placental and fetal development and lamb birth weight. It is, therefore, possible nutrition during pregnancy plays a role in the poor reproductive performance seen in New Zealand hoggets. This thesis investigates the impact of 'low', 'medium' and 'high' levels of feeding on pasture during pregnancy on hogget pregnancy rate, fetal loss, lamb birth weight and growth rate of resulting lambs.

Two-hundred-and-forty hoggets that were mated (identified by crayon tupp mark) during a five day breeding period were randomly allocated one of three (n=80) nutritional regimes ('low', 'medium' and 'high'). The 'low' treatment group during the first 100 days of pregnancy were fed to maintain live weight. From day 100 until term, these hoggets were offered herbage to ensure a daily live weight change of 100 g/day. The 'medium' treated group were fed to ensure live weight change was 100 g/day throughout the entire pregnancy period, while the 'high' treated group were offered *ad libitum*, with the aim of achieving 200 g/day throughout the entire pregnancy period.

The target live weight changes were achieved in the 'low', 'medium' and the 'high' hogget feeding treatment groups. Pregnancy rates at day 50 of pregnancy were significantly ($P<0.05$) higher in the 'medium' (66%) than the 'high' (46%) treated hoggets. At P87, pregnancy rate was significantly higher in the 'low' and the 'medium' treated hoggets than the 'high' treated hoggets with pregnancy rates of 58, 66 and 33%, respectively. This led to a significantly ($P<0.05$) reduced proportion of

the hoggets lambing in 'low' and 'high' feeding treatment hoggets when compared to the 'medium' hogget feeding treatment. Lamb birth weight was reduced in lambs born to the 'low' (3.5±0.16 kg) treatment hoggets when compared to the 'medium' (4.0±0.19 kg) and the 'high' (4.0±0.19 kg) hogget treatment groups. A 'high' level of nutrition during pregnancy did not result in reduced lamb birth weight compared to the 'medium' level of nutrition. At L87, lambs born to 'low' (18.1±1.01 kg) treated hoggets were significantly ($P<0.05$) lighter than lambs born to 'medium' (20.6±0.76 kg) and 'high' (21.8±0.98 kg) treated hoggets. The numbers of lambs reared at L87 was 15, 27 and 17 for 'low', 'medium' and 'high' treated hoggets, respectively.

In conclusion, feeding hoggets at a 'low' and 'high' level of nutrition led to a substantially reduced number of lambs produced. In addition, lambs born to the 'low' fed hoggets were much lighter than lambs born to 'high' fed hoggets at L87. Therefore, this study indicates that farmers wishing to maximise reproductive performance of hoggets should feed hoggets to ensure live weight gain during pregnancy is above 60 g/day but below 200 g/day.

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Table of Contents

List of tables

Chapter one

Review of literature and scope of trial

1.1 Introduction

The reproductive performance of hoggets (7-9 months old) under New Zealand pastoral conditions is lower than that of adult ewes (Gavigan and Rattray 2002; Kenyon *et al.* 2004b). In New Zealand (2004), a total of 8.01 million ewe hoggets were wintered and, of these ewes, only 2.66 million or 33% were exposed to the ram (Anon 2005a). These hoggets produced 1.4 million lambs (43% lambs produced from hoggets put to the ram) at tailing. The latest adult ewe statistics indicate 26.7 million adult ewes were put to the ram resulting in 32.2 million lambs (120%) (Anon 2005a).

Table 1.1 Hogget and adult ewe numbers (millions) in New Zealand and their reproductive performance (Anon 2005a)

	1984	1994	2004
Total hoggets	13.15	9.63	8.01
Hoggets put to ram	1.22	1.31	2.66
% to ram	9.3	13.7	33.2
Total adult ewes	51.87	35.21	27.03
Adult ewes put to ram	51.81	34.44	26.71
% put to the ram	98.7	97.8	98.8

Table 1.1 shows that, although the proportion of hoggets put to the ram has increased over the past 20 years, this proportion is only a third of that in older ewes (Table 1.1). Therefore, increasing the proportion of hoggets put to the ram could lead to a greater number of lambs produced and potentially lead to an increase in farm income. The results of a survey of 763 farmers throughout New Zealand suggested the average hogget lambing percent (defined as numbers of lambs docked/ number of hoggets put

to ram) was 60% although some farmers achieved over 100% (Kenyon *et al.* 2004a). Therefore, there is scope to increase the average lambing percent achieved by New Zealand hoggets.

Anecdotal evidence in New Zealand from ultrasound pregnancy scanning technicians and veterinarians indicates a high level of fetal loss in hoggets compared to mature ewes. This has not been associated with the known causes of abortion (toxoplasmosis, campylobacteriosis, *Salmonella* Brandenberg, border disease, listeriosis, fusobacterium spp, Bacillus spp, mycotic infections, yersiniosis and *Brucella ovis*) (West 2002). Nutrition of the hogget during pregnancy may be impacting on the poor reproductive performance.

Studies throughout the world have indicated that human teenage pregnancy can lead to a higher incidence of preterm deliveries (from 32 weeks), therefore, shorter gestation lengths (Alexander *et al.* 1987; Adelson *et al.* 1992; Cooper *et al.* 1995; Olausson *et al.* 1999), low infant birth weight (Eisner *et al.* 1979; Makinson 1985; Alexander *et al.* 1987; Brown *et al.* 1991; Cooper *et al.* 1995; Olausson *et al.* 1999) and lower infant survival rates (Alexander *et al.* 1987; Adelson *et al.* 1992) when compared to adults. In addition, Lenders *et al.* (1997) reported that high dietary sugar intake of human adolescents during pregnancy (intake of around 206 g/day) led to increased preterm deliveries or reduced gestation lengths and low birth weights (<2500g) when compared to a moderate dietary sugar intake of 111g/day. Scholl *et al.* (1990; 1994) also reported that reduced infant birth weights were observed in young human adolescents that were growing rapidly. These findings led to adolescent ewes being used as a model for human teenage pregnancy in experiments conducted in the United Kingdom using concentrate diets, embryo transfer and prepuberal hoggets (Wallace *et al.* 1996; 1997a; 1997b; 1998; 1999b; 2000a; 2000b; 2002a; 2002b; 2003; 2004b; 2005a).

Under New Zealand pastoral systems relatively little work has been undertaken investigating the effect of high levels of nutrition during pregnancy on reproductive performance of hoggets. It is possible that a high level of nutrition is playing a role in the observed pregnancy losses in New Zealand. Therefore, research is required to

determine the effect of pregnancy nutrition from early pregnancy under pastoral conditions on hogget reproductive performance.

1.2 Studies from the United Kingdom on the reproductive performance of hoggets

1.2.1. Introduction

Nutrition during pregnancy could be one limiting factor to help explain the poorer reproductive performance of hoggets compared to adult ewes. Studies conducted in the United Kingdom (U.K.) with human adolescents and then hoggets have investigated the effects of nutrition on reproductive performance, and identified it as being a major factor reducing the reproductive performance of pregnant adolescents and hoggets.

Poor reproductive performance in hoggets has been measured by conception rates, incidence of spontaneous abortions, placental, fetal and birth weights, gestation length, colostrum yield and lamb survival, lamb growth rate and concentrations of certain metabolites and hormones to give an indication of the physiological aspects occurring in the pregnant hogget.

Human adolescent pregnancy leads to an increased incidence of preterm deliveries, shorter gestation lengths, low infant birth weights and lower infant survival rates (Eisner *et al.* 1979; Makinson 1985; Alexander *et al.* 1987; Brown *et al.* 1991; Adelson *et al.* 1992; Cooper *et al.* 1995; Olausson *et al.* 1999). In addition, Lenders *et al.* (1997) reported from the Camden study conducted in New Jersey that high dietary energy intakes throughout pregnancy (15.2 MJ/day) reduced the reproductive rate in human adolescents when compared to comparatively low dietary energy intakes throughout pregnancy (9.4 MJ/day). In addition, Scholl *et al.* (1990; 1994) concluded that teenagers who consumed a diet that maintained maternal tissue growth throughout the duration of pregnancy gave birth to lighter infants when compared to adolescents that did not increase conceptus free weight during pregnancy. There have been a series of 12 trials (Wallace *et al.* 1996; 1997a; 1997b; 1998; 1999b; 2000a;

2000b; 2002a; 2002b; 2003; 2004b; 2005a) investigating the effect of two nutritional levels on reproductive outcomes in hoggets. The normally grown hoggets were fed to ensure 50-75 g/day for the first 100 days of pregnancy, then the feed intake was adjusted to maintain condition score (2.1) and to meet the increasing nutrient requirements of the gravid uterus (Wallace *et al.* 1996). The amount of feed offered to the hoggets grown rapidly increased over the first two weeks of gestation until refusal was 15%. The amount offered was adjusted three times a week based on the weight change data (recorded weekly) and the amount of feed refused (Wallace *et al.* 1996).

The first research study examining the effects of nutritional treatment from the U.K. used concentrate diets and reported that a high level of nutrition during pregnancy from the time of embryo transfer resulted in increased incidence of spontaneous abortions and reduced placenta and fetal weight (Wallace *et al.* 1996). The study utilised a complete concentrate diet containing 10.2 MJ ME/kg DM and 13.7% crude protein offered indoors for an 8 hour period from 8am-4pm (hoggets remained indoors for the rest of they day). The diet contained 30% milled hay, 50% barley, 10% molasses, 9% fishmeal, 0.3% salt, 0.5% dicalcium phosphate and 0.2% of a vitamin-mineral supplement and had an average dry matter concentration of 86% (Wallace *et al.* 1996). This study and the series of studies that followed utilised two treatment groups, hoggets that had restricted nutrient intake or achieved normal live weight gain profiles and hoggets that were fed *ab libitum* nutrient intakes and grew rapidly from day 1 of pregnancy till term.

1.2.2 Reproductive outcomes

1.2.2.1. Conception Rate

Wallace *et al.* (1996) reported that conception rate (determined by ultra sound scanning at day 60 of pregnancy) after embryo transfer was lower in rapidly growing (57%) than in normally growing (85%) hoggets. In contrast, in a subsequent trial conducted in the same manner, Wallace *et al.* (1997b) reported that the conception rate was higher in rapidly growing (90%) than normally growing (59%) hoggets. Wallace *et al.* (1999b) reported that conception rate did not differ between nutritional groups (79 and 78% for rapidly growing and normally grown hoggets, respectively).

Although the live weight and condition score of the hoggets at embryo transfer were similar in the three studies (Wallace *et al.* 1996; 1997a; 1999a), the hoggets in the study of Wallace *et al.* (1996) were 148 days old compared with 224 days olds in the study of Wallace *et al.* (1997b). This age difference may explain the differing conception rates in the three studies (Wallace *et al.* 1996; 1997b; 1999).

Table 1.2 outlines the main reproductive results of the U.K. studies and the one New Zealand study found in this area. As conception rate was only presented in three U.K. studies, it was not included in Table 1.2.

The maternal growth rates during pregnancy could not explain the differences in conception rates in the studies by Wallace *et al.* (1996; 1997b; 1999). The daily growth rate was 60g higher in the hoggets grown rapidly in Wallace *et al.* (1997b) than in Wallace *et al.* (1996) while the hoggets grown rapidly of Wallace *et al.* (1997b) were growing intermediary to these two studies. The growth rates were similar for normally grown hoggets in all three studies. The faster growth rate from the hoggets grown rapidly by Wallace *et al.* (1997b) when compared to Wallace *et al.* (1996; 1997b) and the subsequent high conception rate suggests that other mechanisms are affecting conception rate and not the nutritional level. Therefore, the association between growth rate and conception rate is not seen when the studies of Wallace *et al.* (1996; 1997b) are compared, as the absolute growth rates do not account for the differences in conception rate between these two studies.

Table 1.2 Reproductive performance of hoggets in the core* trials conducted in the UK and New Zealand

Study	Age (d)[1]	Weight[2] (kg)	Treatment group	ADG[3] (g/day)	Fetal wt[4] (kg)	Birth wt (kg)	Gestation length (d)
U.K. studies							
Wallace *et al.* (1996, 1997a)	148	44.4	NMG[5]	75^{a}	0.645 (95)	4.34^{b}	143.1^{b}
			RMG[6]	234^{b}	0.817(95)	2.74^{a}	140.2^{a}
Wallace *et al.* (1997b)	224	47.4	NMG	84^{a}		4.82^{b}	145.4^{b}
			RMG	294^{b}		3.49^{a}	142.7^{a}
Wallace et al (1998, 2003)	210	46	NMG	66^{a}		5.16^{b}	148^{b}
			RMG	323^{b}		2.89^{a}	144^{a}
Palmer *et al.* (1998)	200	43.7	NMG	84^{a}	1.57 (104)		
			RMG	294^{b}	1.37 (104)		
Wallace *et al.* (2000)	210	43.6	NMG	90^{a}	4.19^{b} (128)		
			RMG	301^{b}	2.65^{a} (128)		
Wallace *et al.* (2002a)	210	45.6	NMG	57^{a}	4.67^{b} (130)		
			RMG	282^{b}	3.07^{a} (130)		
Wallace *et al.* (2002b)	210	45	NMG	52^{a}	4.6^{b} (134)		
			RMG	275^{b}	3.3^{a} (134)		
Da Silva *et al.* (2002)	210	46	NMG	68^{a}	4.3^{b} (131)		
			RMG	308^{b}	2.96^{a} 131)		
New Zealand study							
Morris *et al.* (2005)	270	35.9	Low	80^{a}		3.91	147.9
	270	36.8	Medium	145^{b}		3.78	147.9
	270	36.1	High	210^{c}		3.94	146.1

*core studies are those trials conducted that did not involve dietary switches or progesterone supplements, the U.K. studies implemented their nutritional regimes immediately after embryo transfer while the New Zealand study began their nutritional treatments at day 21 of pregnancy

[1] age at embryo transfer/ mating

[2] weight at embryo transfer/ mating

[3] average daily gain during pregnancy for each treatment group

[4] day hogget euthanased shown in brackets

[5] normal maternal daily gain [6] rapid maternal daily gain. Means within study and column with different subscripts differ significantly.

1.2.2.2 Spontaneous abortions

Wallace *et al.* (1996; 1997a; 1997b) consistently reported that the incidence of spontaneous abortions was higher in hoggets grown rapidly than normally grown hoggets. Wallace *et al.* (1996; 1997a) reported that spontaneous abortion at day 125 of pregnancy (P125) occurred in hoggets growing rapidly, while Wallace *et al.* (1997b) found abortions occurred later in pregnancy (P135-142). The greater proportion of spontaneous abortion in the hoggets grown rapidly than hoggets grown normally was also linked to a shorter gestation length in the hoggets grown rapidly, suggesting that slow placental growth may play a critical role in maintaining pregnancy in late gestation where an inadequate placenta in hoggets grown rapidly may lead to insufficient maternal nutrient transfer to the fetus to maintain pregnancy to term (Wallace *et al.* 1996).

1.2.2.3. Placental, Fetal and Birth weight

The placenta is the primary factor mediating the growth trajectory of the fetus (Wallace *et al.* 1999b; 2000b). Rapid hogget growth during pregnancy has been shown to reduce placental growth and development (Wallace *et al.* 1996; 1997b; Da Silva *et al.* 1998; Palmer *et al.* 1998; Wallace *et al.* 1998; 2000a; 2000b; Da Silva *et al.* 2001; Thomas *et al.* 2001; Da Silva *et al.* 2002) in comparison to hoggets grown normally during pregnancy.

The difference in fetal and placental components is not apparent until the final trimester when the fetal nutrient requirement is increasing exponentially. Lea *et al.* (2005) slaughtered hoggets at P81 and found no difference in the total placentome weight (703g and 658g for normal and rapidly grown hoggets, respectively) or fetal weight (426g and 412g for normal and rapidly grown hoggets, respectively). Wallace *et al.* (1996; 1999b) reported that fetal weight and placental weight were significantly lower in hoggets grown rapidly than in normally grown hoggets at P95 and P104, respectively. In contrast, Palmer *et al.* (1998) found that at P105 there was no difference in fetal weight (1.35kg and 1.57kg for normal and rapidly grown hoggets, respectively). This indicates that the nutrient flow across the placenta is meeting

nutrient requirements of the conceptus for growth for normal and rapidly grown hoggets during pregnancy.

Fetal weight post P105 and lamb birth weight from normally grown treatments were significantly heavier when compared to those of the rapidly growing treatment hoggets (Wallace *et al.* 1996; 1997a; 1997b; 1998; Wallace 2000; Da Silva *et al.* 2002; Wallace *et al.* 2002a; 2002b; 2003). When hoggets were switched from rapid to a normal growth at P50 (resulting in the growth rate of rapidly grown hoggets decreasing to that of normally grown hoggets), resulting placental and fetal weights were intermediary between those hoggets grown rapidly or normally for the entire pregnancy (Wallace *et al.* 1999b).

Increased nutrient intake in hoggets grown rapidly has resulted in a reduction in the number of attachment sites, and nutrient flow across the placenta has been reported to decrease (Wallace *et al.* 1996). This resulted in lower nutrient supply to the fetus consequently restricting fetal growth and led to a lower fetal weight and led to lower than required surface area at the materno-placental interface (Wallace *et al.* 1996). Therefore, reducing the fetal nutrient supply resulted in reduced fetal growth. The difference in fetal weight between rapidly and normally grown hoggets was not observed until the final trimester when most of the fetal growth occurred.

1.2.2.4. Gestation length

The duration of gestation was, on average, three days shorter in hoggets grown rapidly during pregnancy compared to normally grown hoggets (142 vs. 145 days) (Wallace *et al.* 1996; 1997a; 1997b; 1998 and Da Silva *et al.* 1998). Wallace *et al.* (1999b) also reported that suddenly reducing the nutrient intake at P50 increased gestation length when compared to those hoggets growing rapidly throughout pregnancy. While increasing hogget growth from normal to rapid resulted in gestation lengths which were similar to that of those normally grown throughout pregnancy (Wallace *et al.* 1999b).

Birth weight and gestation length were positively associated (Wallace *et al.* 1996), therefore, the shorter gestation length in the hoggets grown rapidly may explain the

lighter birth weights of their resulting lambs. The fetal growth rates calculated from day 95 of pregnancy till term from Wallace *et al.* (1996; 1997a) (77 and 43g per day for normal and rapidly grown hoggets, respectively) suggests that the three-day difference in gestation length between normally grown hoggets and hoggets grown rapidly does not fully account for the lamb birth weight differences observed between these two feeding regimes. Therefore, other mechanisms may also be involved in the lamb birth weight difference.

1.2.2.5. Colostrum yield

Colostrum yield has been consistently lower in hoggets grown rapidly than in the normally growing hoggets (Wallace *et al.* 1996; 1997b; 2001; Da Silva 2001). The growth restricted placenta of the hoggets grown rapidly may not have been able to secrete sufficient concentrations of placental hormones that stimulate mammary gland development (Wallace *et al.* 1996) or the low growth hormone concentration observed in serum, reduced mammary gland growth leading to lower colostrum yields (Wallace *et al.* 1997b).

Colostrum samples taken from the hoggets grown rapidly had a higher concentration of immunoglobulin, lower concentrations of fat and lactose, but similar amounts of crude protein to the samples from normally grown hoggets (Wallace *et al.* 2001). The higher concentration of immunoglobulin in the colostrum of hoggets grown rapidly may not have positively affected the lamb survival (Wallace *et al.* 2001), as there was a reduction in the total colostrum yield in hoggets grown rapidly.

1.2.2.6. Lamb Survival

There have been variable reports on the effect of hogget nutrition during pregnancy on lamb survival. Wallace *et al.* (1996) reported a survival rate at 72 h post-parturition of 38% and 91% for lambs born to rapid and normally grown hoggets, respectively.

It has been suggested that placental restriction in hoggets grown rapidly leads to lambs suffering hypoxia and hypoglycaemia, which may lead to reduced brain, lung

and small intestine development (Wallace *et al.* 1996). However, autopsies have not been performed on enough lambs to make any clear conclusions.

The lighter lambs born to hoggets grown rapidly would have had a relatively larger surface area per unit weight, making these lambs more susceptible to death from hypothermia (McCutcheon *et al.* 1981). In addition, the reduction in absolute fat content of the fetal carcass from the lambs born to the hoggets grown rapidly combined with lower total liver glycogen stores (Wallace *et al.* 2000b) could have a major impact on the viability of the lamb under adverse weather conditions. However, the hoggets were lambed indoors, eliminating the effect of weather conditions on lamb survival.

1.2.2.7. Lamb Growth Rate

Da Silva *et al.* (2001) reported lambs born to hoggets grown rapidly grew slower than their counterparts born to normally grown hoggets for the first 12 weeks of life (304 vs. 376 g/d, respectively). This led to lighter lambs at 12 weeks of age and these lambs remained lighter at 25 weeks of age (Da Silva *et al.* 2001).

The slower growth rate of the lambs born to hoggets grown rapidly may be attributable to a lower birth weight, as lamb birth weight and growth rate are positively related (Wardrop 1968). Milk production in hoggets grown rapidly or normally has not been determined. Therefore, the impact of milk production on lamb milk intake and the effect on lamb growth rate cannot be determined.

1.2.3. Mechanisms behind the fetal growth restriction

Several mechanisms have been hypothesised for the placental growth restriction observed in the hoggets grown rapidly (Wallace *et al.* 1996; 1999b; Wallace 2000). The first mechanism may be, blood flow to the fetus is reduced to support maternal tissue at the expense of uteroplacental blood flow, leading to a reduction in the placental and functional development (Wallace *et al.* 1996). The second, is a reduction in the attachment sites (the point at which the cotyledon and caruncle form the placentome) caused primarily by the high level of nutrition (Wallace *et al.* 1996).

Thirdly, it could be a compensatory mechanism on placental growth is occurring by switching the diet from rapid growth to a normal growth diet at P50 (Wallace *et al.* 1999b), therefore, indicating that the critical period for placental development is the nutrient supply prior to P50. Conversely, there was a suggestion that it was the final 100 days of gestation that were the most important (Wallace *et al.* 1999b) as placental and fetal development is still occurring until about P80 and the difference between fetal weight is not seen until the final trimester of pregnancy (Wallace *et al.* 1996).

Interestingly, when Wallace *et al.* (2003) supplemented progesterone to hoggets grown rapidly led to an intermediary effect on fetal weight (i.e. fetal weight was lighter in the normally grown hoggets but heavier in the rapidly grown hoggets). Wallace *et al.* (1998) reported that progesterone is linked to an increase in inner embryonic cell mass and not associated with an increase in placental weight as cotyledon number and mean weight were the same for both groups. This indicates that when the pregnant hoggets grown rapidly are supplemented with progesterone it will increase the inner cell mass resulting in compensatory placental growth and fetal weight.

1.2.4 Blood Flow Across Placenta

Trans-placental blood flow is dependent upon uterine and umbilical blood flow, and blood flow rates are in turn dependent on vascularisation (Redmer *et al.* 2004). Therefore, factors that influence placental vascular development will have a dramatic impact on fetal growth and development (Redmer *et al.* 2004).

Blood flow across the placenta was lower in rapidly grown hoggets compared to the normally grown hoggets (Wallace *et al.* 2002b). However, when blood flow was corrected for conceptus weight, there was no difference in blood flow from the maternal supply to the placenta between the normal and rapidly grown hoggets (Wallace *et al.* 2002b). This was due to a smaller placenta with reduced surface area for blood flow from the maternal supply in the hoggets grown rapidly (Wallace *et al.* 2002b).

In addition, nutrients were partitioned towards maternal tissue rather than the placenta in hoggets grown rapidly (Wallace *et al.* 1996). This suggests there is a two-fold mechanism involving a reduction in absolute materno-placental blood flow and a reduction in maternal and placental nutrient flow leading to lower than expected nutrient transfer to the fetus (Wallace *et al.* 2002b). Wallace *et al.* (2002b) stated that the weight-specific placental transport capacity was the same between normal and hoggets grown rapidly.

Maternal arterial and venous blood oxygen concentration was similar in rapidly and normally grown hoggets (Wallace *et al.* 2002b). In contrast, fetal arterial and umbilical vein oxygen concentration was lower in fetuses from hoggets grown rapidly and absolute uterine and umbilical oxygen uptake was higher in normally grown hoggets (Wallace *et al.* 2002b). The smaller placenta in the rapidly grown hoggets allowed for a reduced blood flow. This reduced the amount of oxygen diffusing across from the maternal supply to the placental supply. This suggests it is the smaller placenta of the hoggets grown rapidly and not a poorly developed placenta that is reducing the oxygen concentration in the corresponding fetuses.

1.2.5 Metabolites and hormones

The previously discussed reduction in placental and fetal growth and development has been reported to be in conjunction with a switch from conceptus growth to maternal growth (Wallace *et al.* (1996; 1997a; 1997b; 2002a; 2002b; Wallace 2000; Da Silva *et al.* 2002). This is primarily due to hormonal and metabolic interactions which partition the nutrients towards maternal growth. These will each be discussed below.

1.2.5.1. Glucose

Maternal plasma glucose concentrations increase with increasing nutrient intake (Tortora and Grabowski 2003) while glucose is the primary energy substrate in the growing fetus (Mellor and Cockburn 1986; Diesch *et al.* 2004). Therefore, glucose provides a good indication of the nutritional state of both the dam and fetus during pregnancy.

Wallace *et al.* (1997b; 1999b; 2000) found maternal glucose concentration was higher in hoggets grown rapidly when compared to normally grown hoggets. Wallace *et al.* (1997b) reported no increase in maternal glucose concentration between trimesters in hoggets grown rapidly while, in contrast, glucose concentration increased from the first (3.5mmol/l) to the third (3.8mmol/l) trimester in normally grown hoggets (Wallace *et al.* 1997b).

Uterine glucose extraction (uterine venous blood glucose-uterine arterial blood glucose/uterine venous blood glucose) was not affected by nutritional treatment, but fetal glucose extraction (fetal venous blood glucose–fetal arterial blood glucose) was higher in hoggets grown rapidly when compared to normally grown hoggets (Wallace *et al.* 2002b). This may indicate that the glucose that does pass through to the placenta is utilised more efficiently by the restricted fetuses when compared to the normal growth fetuses. In addition, both absolute uterine and umbilical glucose uptake was lower in hoggets grown rapidly when compared to normally grown hoggets (Wallace *et al.* 2002b). Placental-uterine interface glucose concentration was lower in hoggets grown rapidly, but was largely proportional to the difference in placental mass (Wallace *et al.* 2002b) and fetal glucose concentration was lower in hoggets grown rapidly when compared to normally grown hoggets (Da Silva *et al.* 1998; Thomas *et al.* 2001; Wallace *et al.* 2002b).

The reduced flow of glucose across the placenta observed in hoggets grown rapidly was primarily due to the poorer development of the placenta (i.e. fewer attachment sites). When glucose concentration was expressed as a proportion of the weight of the fetus and compared between the rapidly and normally growing hoggets there was no difference between feeding levels, Wallace *et al.* (2002b) suggested the reduced absolute glucose flow across the placenta was the primary cause of the restricted fetal growth in the hoggets grown rapidly.

1.2.5.2. Non-Esterified Fatty Acids (NEFAs)

Triglyceride is the most abundant lipid found in the body and the diet (Tortora and Grabowski 2003) and consists of three fatty acids attached by dehydration synthesis reactions, one to each carbon of the glycerol backbone (Tortora and Grabowski 2003).

After the addition of water, the ester bond is broken, leaving NEFAs and glycerol. NEFAs are an indication of the turnover in lipids and is often seen in the third trimester of pregnancy in sheep (Wallace *et al.* 2005a). This is usually a period when the hogget is in a negative energy balance and is mobilising fat that can then be used as an energy source (Wallace *et al.* 2000b; 2001; Thomas *et al.* 2001). Therefore, circulating NEFA concentration is also an indication of nutritional state.

NEFA concentration was consistently elevated in normally grown hoggets when compared to hoggets grown rapidly, especially in the last trimester (Wallace *et al.* 1997b; Wallace 2000; Thomas *et al.* 2001). Wallace *et al.* (2000b) and Thomas *et al.* (2001) investigated NEFA concentrations in the last trimester when the pregnant hogget is mobilising fat in its catabolic state. They subsequently found higher NEFA concentrations in normally grown hoggets when compared to hoggets grown rapidly. This indicates that the nutrient supply to the normally grown hogget was not meeting both the fetus and maternal energy requirements resulting in fat mobilisation to meet energy requirements.

1.2.5.3. Urea

Urea is a waste product of nitrogen metabolism and is also a metabolite from unutilised ammonia in the rumen and is produced in the liver (McDonald *et al.* 1995). Urea can be either recycled via saliva or can be excreted via urine (McDonald *et al.* 1995). Urea is often an indicator of nitrogen being poorly utilised and a lack of utilisable energy, leading to more ammonia being produced, thus increasing the amount of urea produced during the digestion process in the rumen (McDonald *et al.* 1995).

Urea was elevated in both the dam and the fetus in hoggets grown rapidly (Wallace *et al.* 2000; 2000b; Wallace 2000). The higher urea concentration in the fetus may indicate that a lack of nutrients being transferred across the placenta, therefore, the fetus may need to mobilise protein reserves to use as an energy source via gluconeogenesis.

1.2.5.4. Insulin

The primary role of insulin, along with glucagon is control of blood glucose concentrations (Tortora and Grabowski 2003). Insulin and glucagon have reciprocal roles. Insulin promotes the uptake of glucose, therefore increasing gluconeogenesis and glycogenesis, the uptake of amino acids and protein synthesis, lipogenesis and a reduction in glycogenolysis (Tortora and Grabowski 2003).

Plasma insulin concentrations were higher in hoggets grown rapidly when compared to normally grown hoggets (Wallace *et al.* 1997b; 1999; 2000b). In hoggets grown rapidly, plasma insulin concentration increased from the first to the second trimesters and reached a peak in the final third of gestation (Wallace *et al.* 1997b; 2000b). This indicates that the insulin concentration is increasing with increasing glucose concentration which in turn is increasing due to the increased nutrient intake.

After a dietary switch at day 50 of pregnancy (Wallace *et al.* 1999b) the plasma insulin concentration in hoggets grown rapidly, that had their growth rate reduced to the level of normally grown hoggets decreased by 40%, whereas when the nutrient intake of normally grown hoggets was rate increased equivalent to rapidly growing hoggets, it increased by 55% (Wallace *et al.* 1999b).

Insulin concentrations were lower in fetuses from rapidly grown hoggets (Da Silva *et al.* 1998; Wallace *et al.* 2000b). This indicates that insufficient glucose is passing through to the fetus via the placenta and no increase is observed in fetal plasma insulin concentrations (as the glucose concentrations would be expected to increase with increasing nutrient intake), therefore, indirectly restricting placental growth.

1.2.5.5. Insulin Like-Growth-Factor 1 (IGF-1)

In response to growth hormone, cells in the liver, skeletal muscle, cartilage and bone secrete insulin like growth factors, which may enter the bloodstream from the liver or act locally as autocrine or paracrine substances (Tortora and Grabowski 2003). The role of IGFs is to promote cellular growth (Tortora and Grabowski 2003), via increasing uptake of amino acid into cells and increasing protein synthesis (Tortora

and Grabowski 2003). Other functions include increasing lipolysis and decreasing glucose uptake (Tortora and Grabowski 2003).

In the studies of Wallace *et al.* (1997b; 1999) IGF-1 concentrations remained higher in hoggets grown rapidly. IGF-1 concentration increased between the first and the second trimester, then again from the second to the third trimester in hoggets grown rapidly (Wallace *et al.* 1997b). However, IGF-1 concentration in normally grown hoggets was not affected by stage of gestation (Wallace *et al.* 1997b) with a dietary switch at P50, IGF-1 concentration was not altered when the growth rate of rapidly growing hoggets was reduced to a growth rate equivalent to hoggets growing normally but it increased when the growth rate was increased from normally grown hoggets (Wallace *et al.* 1997b). The increasing plasma IGF-1 concentrations during the second and third trimesters in hoggets grown rapidly or when the growth rate was increased from normally grown hoggets to ensure the hoggets were growing rapidly (Wallace *et al.* 1999b), suggests high sensitivity of insulin-like-growth factor concentration to nutrition level.

In contrast to what was observed in the dam, the IGF-1 concentration was lower in fetuses from hoggets grown rapidly (Da Silva *et al.* 1998; Wallace *et al.* 1998; 1999). Since IGF-1 concentration is glucose dependent, the low IGF-1 concentration in the fetus suggests that there is insufficient nutrient supply diffusing across the placenta (Wallace *et al.* 1999; 2000b). This resulted in restricted fetal growth in hoggets grown rapidly when compared to fetal growth of normally grown hoggets (Wallace *et al.* 1999; 2000b).

1.2.5.6. The role of Insulin, IGF-1 and Glucose in the Control of Placental Growth

A high maternal insulin, IGF-1 and glucose concentrations in hoggets growing rapidly but low concentrations in the fetus compared to normally grown hoggets indicates that nutritionally sensitive hormones are controlling nutrient partitioning away from the fetus (Wallace *et al.* 1997b). In the studies of Wallace *et al.* (1997b; 1999; 2000b) and Da Silva et al (1998) maternal insulin, IGF-1 and glucose concentrations were all negatively correlated with both placental and fetal weight. This suggests the primary

mechanism behind the placental growth restriction is the lack of nutrients passing from maternal blood to fetal blood via the placenta (Wallace *et al.* 1997b; 1999; 2000b; Da Silva *et al.* 1998). High maternal insulin and IGF-1 concentrations alter nutrient partitioning leading to an anabolic state in the dam at the expense of the placenta (Wallace *et al.* 1997b; 1999; 2000b; Da Silva *et al.* 1998).

Although reduced fetal weight from hoggets grown rapidly was not observed until the final trimester, the restricted growth trajectory has been already set before the final trimester (Wallace *et al.* 1999b). The reduced number of implantation sites led to a reduced number of nutrient receptors on the placenta (Wallace *et al.* 1999b). The ovine placenta contains IGF type 1 receptors throughout gestation and these are involved in the placental proliferative growth and metabolic activity of the developing placenta (Reynolds *et al.* 1997; Wallace *et al.* 1997b). Uteroplacental IGF-1 receptor expression was down regulated around P50 and expression was low in the hoggets grown rapidly; this may have regulated placental growth (Reynolds *et al.* 1997).

In a normal pregnancy, the number of glucose transporters (GLUT 1 and GLUT 3) increases as gestation continues due to the increasing growth of the placenta (Wallace *et al.* 1997b). However, in hoggets grown rapidly (with a growth restricted placenta) the number of glucose transporters was reduced this may account for the reduction in glucose uteroplacental transport (Wallace *et al.* 1997b).

1.2.5.7. Leptin

Hoggard *et al.* (1998) reported that leptin plays an important role during pregnancy in lean mice as leptin restored fertility in sterile *ob/ob* homozygous mice. In addition, leptin at low concentrations have been shown by Yu *et al.* (1997) to play an important role in controlling gonadotrophin secretion by stimulating hypothalamic or pituitary secretion, therefore, may affect the onset of puberty. Hoggard *et al.* (1998) suggested three possible explanations for the rise in leptin concentration during pregnancy. Firstly; increased production via maternal fat; second, expression by the placenta; and third, increased concentrations of leptin binding proteins in the maternal circulation.

Thomas *et al.* (2001) reported that rapidly growing hoggets for the first 104 days of pregnancy had significantly elevated leptin concentrations compared to hoggets that grew normally during the same period. These authors suggested that the increase in maternal fat mass is primarily responsible for the increase in plasma leptin concentration with no direct affect of feed intake.

The leptin in the adipose tissue acts negatively on the hypothalamus in the brain, then sends signals back to reduce the accumulation of adipose tissue and potentially reduce feed intake (Thomas *et al.* 2001). However, Thomas *et al.* (2001) reported the negative feedback loop between the brain and adipose tissue was inactivated leading to a 'snow-balling' effect on fat synthesis in hoggets grown rapidly. This suggests that these hoggets were resistant to the increasing leptin concentration throughout pregnancy as the adipose tissue content continued to rise throughout the entire pregnancy (Thomas *et al.* 2001).

Thomas *et al.* (2001) reported higher leptin concentrations in the subcutaneous and perirenal adipose tissue in hoggets grown rapidly when compared to normally grown hoggets. This also supports one of the explanations put forward by Hoggard *et al.* (1998) who suggested that the increased leptin concentration during pregnancy was due to increased secretion from an increased maternal adipose deposition.

Maternal leptin concentration was negatively associated with lamb birth weight, fetal cotyledon weight and cotyledon number (Thomas *et al.* 2001). Leptin is expressed in very small quantities in the ovine placenta, while leptin protein was found in the trophectoderm at both the maternal and fetal interface (Thomas *et al.* 2001). The high leptin concentration at the maternal and fetal interface may well be due to attachment to a leptin receptor and not necessarily an increase in placental secretion (Thomas *et al.* 2001). This supports the second explanation offered by Hoggard *et al.* (1998) who suggested that increased leptin led to increased levels of binding protein in maternal circulation and increased leptin secretion by the placenta. Although there was a high correlation between leptin and reduced fetal growth observed in the hoggets growing rapidly it was only associated with the increasing fat deposition in these hoggets and did not directly affect fetal growth restriction (Thomas *et al.* 2001).

1.2.5.8. Thyroid Hormones

Thyroid hormones (tri-iodothyronine (T3) and thyroxine (T4)) are involved in energy metabolism, protein synthesis, heat production and oxygen use (West *et al.* 2002) and brown adipose tissue metabolism (Freer and Dove 2002). During pregnancy, West *et al.* (2002) stated that thyroid hormones were required for the fetal brain, lungs, heart and wool follicle development. Thyroid hormone deficiency during pregnancy can lead to reduced fetal development (McIntosh *et al.* 1979; Potter *et al.* 1980), pregnancy rates (Mulvaney 1997; Sargison *et al.* 1998) and a reduced lambing performance (Ross and Lewis 1959; Mulvaney 1997; Sargison *et al.* 1997).

Tri-iodothyronine concentration was higher in hoggets grown rapidly compared to the normally grown hoggets from P91 and remained higher throughout gestation, while T4 concentrations were higher in the hoggets grown rapidly compared to hoggets growing at a normal rate from P119 (Wallace *et al.* 1997b). Wallace *et al.* (1997b) found that elevated thyroid hormone levels in the hoggets growing rapidly was negatively associated with fetal growth. In contrast, Spencer and Robinson (1993) found that T4 administration to pregnant rats enhanced fetal and placental growth. Dauncey *et al.* (1983) and Dauncey (1990) stated that thyroid concentrations were highly correlated with feed intake and energy concentration of the diet in young growing pigs. The higher thyroid hormone concentrations observed in the hoggets growing rapidly may be due to the direct effects of the greater energy and feed intake (Dauncey *et al.* 1983; Dauncey 1990) and have no direct effect on the impaired fetal growth observed.

1.2.5.9. Growth Hormone (GH)

The biological function of GH includes the stimulation of cell division, protein synthesis, fatty acid release and oxidation, anabolic carbohydrate metabolism and mineral metabolism, while inhibiting fat synthesis, fat-cell size and steroid metabolism (Hart 1980). Browne and Thorburn (1989) reported that GH does not cross the placenta in physiologically important quantities. Despite this, Wallace *et al.* (1997b) suggested that GH may indirectly regulate nutrient partitioning between the maternal, placental and fetal compartments.

The pulse frequency and GH concentration on days 68 and 122 of pregnancy were lower in hoggets grown rapidly when compared to normally grown hoggets, although the difference did not reach significance until day 122 (Wallace *et al.* 1997b). Irrespective of treatment, mean GH concentrations were negatively associated with feed intake during the week preceding day 68 (Wallace *et al.* 1997b) but positively correlated with placental weight, fetal weight and colostrum yield (Wallace *et al.* 1997b).

1.3 New Zealand studies

Studies from the U.K. have shown that hoggets experiencing high maternal growth rate during pregnancy reduced conception rate, increased the incidence of spontaneous abortion, reduced birth weight, lamb survival, lamb growth rate and resulted in poorly formed reproductive organs in the lambs.

As a result of the findings in the U.K. studies, a similar study was conducted by Morris *et al.* (2005) under New Zealand pastoral conditions. In that study the three nutritional manipulations used began at day 21 of pregnancy and included a 'low' (80 g growth total maternal gain/day of pregnancy), 'medium' (140 g/day) and 'high' (200 g/day) treatment groups. They reported no effects on pregnancy rate, spontaneous abortions, birth weight, gestation length or lamb survival between 'low', 'medium' and 'high' treatment hogget groups. They also found that the growth rate of lambs born to hoggets fed a 'medium' and 'high' level of nutrition during pregnancy were significantly higher than those fed a 'low' level of nutrition, leading to heavier weaning weights. There were no differences in maternal glucose, β-hydroxybuterate, non-esterified fatty acids and magnesium concentrations between the treatment groups. In the only other study found under New Zealand conditions examining the effects of hogget nutrition on reproductive performance, McMillan and McDonald (1983) reported a negative relationship between conception rate and hogget growth during early pregnancy.

1.4 Possible reasons for the observed differences between New Zealand and U.K. studies

The later timing of the nutritional treatments of Morris *et al.* (2005) and the lack of an observed effect may indicate that when the nutritional regime is implemented very early in pregnancy (prior to day 21), it causes the observed effect. In the U.K studies of Wallace *et al.* , nutritional diet treatments were implemented immediately after breeding using embryo transfer, while in the study of Morris *et al.* (2005) nutritional treatment began at P21.

Additionally, the U.K. studies utilised younger (190-225 days) hoggets than that of Morris *et al.* (2005) (270 days old). It is, therefore, possible but it is not known if the observed effects are due to differences in age. In addition, the hoggets involved in the U.K. studies were prepuberal. In contrast, Morris *et al.* (2005) suggested that a significant proportion of their hoggets had reached puberty before CIDR insertion. Under New Zealand farming conditions most hoggets are 7-9 months of age at breeding.

The Scottish Greyface breed base used in the U.K. research is a relatively prolific breed with a mature ewe live weight of 70 kg (Robinson *et al.* 1991; Robinson *et al.* 1992). In the New Zealand study, Romney and Coopworth hoggets were used. Although not known, any breed differences observed may have contributed to the differences observed.

The use of a single sire in the U.K. studies (one Dorset Horn ram's semen) may have also caused some bias to the results. The rams' semen may have affected reproductive performance as it may have specific genetic properties that lead to altered fetal growth. In addition, the recipient hoggets were different (Dorset Horn and Suffolk) and may additionally affect fetal growth trajectories. The effect of using the two different genetic compositions of the recipient hoggets on fetal growth and development is not mentioned by Wallace *et al.* (1996).

Fetal phenotypes differed (½ Dorset Horn, ¼ Border Leicester and ¼ Scottish Blackface and ½ Suffolk, ¼ Border Leicester and ¼ Scottish Blackface) but the effect this had on the observed results is unknown.

In the U.K. studies, indoor feeding with concentrate diets were used compared to grazing herbage only in the study of Morris *et al.* (2005). It is possible that the composition of the two diets could have affected the results observed. Robinson *et al.* (1971b) and Quirke *et al.* (1978) reported that protein and energy concentrations in a diet influenced lamb birth weight. Robinson *et al.* (1971b) fed-eight-month old ewes three diets for the last 100 days of pregnancy containing 12.3, 14.1 and 16.5 % crude protein while the energy content remained constant (8.8 MJ ME/kg DM), this led to birth weights of 5.1 kg, 3.1 kg and 4.1 kg respectively. The low dietary energy content may account for the reduced birth weights from the higher dietary protein diets (Robinson *et al.* 1971a) possibly because the energy and protein balance was not optimal for ideal rumen digestion, leading to sub-optimal performance of both the foetus and maternal growth. In support of this, Quirke *et al.* (1978) fed six separate diets to hoggets containing variable amounts of energy (8.1-13.3 MJ ME/kg DM) and protein (10.9-23.4 %) concentration. They concluded that birth weights decreased as energy content increased.

The growth rates of the hoggets grown rapidly in the U.K. studies (Table 2.1) were 25-110 g/day higher than that observed by Morris *et al.* (2005) which were 210 g/day. Therefore, the higher hogget growth rate may lead to differences in nutrient partitioning, possibly affecting the reproductive outcome of both studies.

Under New Zealand farming conditions hoggets, are managed on a mob basis, generally offered herbage only and are naturally mated. The U.K. research offered an individual concentrate diet with intakes controlled. Before any advice is given to New Zealand farmers regarding the effects of nutrition during pregnancy, studies under New Zealand conditions are required. Therefore, the aim of the present study was to examine the effects of a high hogget nutritional treatment beginning early pregnancy in naturally mated 7-9 month old Romney hoggets.

Chapter Two

The effect of nutrition during pregnancy on hogget reproduction.

2.1 Introduction

Recent reports have shown that 8.6 million ewe hoggets (7-9 months old) were wintered in New Zealand in 2004 (Anon 2005b), from these, 3.2 million were exposed to the ram leading to 1.4 million lambs at tailing (43%) (Anon 2005b). In comparison, the adult ewe lambing percentage in New Zealand is in the range of 120-130% (Anon 2005b). This difference in the lambing percentage outlines the potential that exists to increase the reproductive performance of hoggets in New Zealand.

Under housed conditions, utilising concentrate feeding, Wallace *et al.* (2004a; 2004b) reported that excessive nutritional levels beginning immediately post embryo transfer had detrimental effects on hogget reproductive performance, including reduced conception rate, increased rates of abortions, reduced lamb birth weight and survival. In contrast, Morris *et al.* (2005), under New Zealand's pastoral conditions, found no detrimental effects. However, in that study, the nutritional treatment did not begin until 21 after the end of breeding. The later starting point may have contributed to different results between the pastoral study and those of Wallace *et al.* (2004a; 2004b).

The objective of the present study was to investigate the effects of hogget nutritional treatment beginning immediately after the end of a synchronised breeding period, on hogget reproductive performance under pastoral conditions. It was hypothesised that a 'high' level of feeding under pastoral conditions beginning in early pregnancy would reduce pregnancy rates, increase the incidence of abortions, and reduce lamb birth weights and lower lamb survival rates.

2.2 Materials and Method

2.2.1 Experimental Design and Animals

Three-hundred-and-sixty-eight progesterone synchronised (CIDR, type G, Livestock Improvement Corporation, Hamilton, New Zealand) Romney hoggets (7-9 months of age) were used in the trial. Twelve days after insertion, CIDRs were removed (P0) and 26 Perendale crayon harnessed rams (ram to hogget ratio of approximately 1:15) were introduced for a five day breeding period and crayon marks were recorded daily. Those hoggets (n = 240) that displayed crayon marks were randomly allocated to one of three feeding regimes ('low', 'medium' or 'high') beginning at the end of the 5-day breeding period (P5) to P148.

The aim of the 'low' treatment group was to achieve no change in total live weight during the first 100 days of pregnancy; thereafter feeding was increased to ensure a daily live weight change of 100 g/day. The aim of the 'medium' treatment was to achieve a 100g/day increase in total liveweight over the entire pregnancy period and the 'high' treatment was offered *ad libitum*, with the aim of achieving a 200 g/day total liveweight increase during the entire pregnancy period. At P5 the average liveweight of the hoggets was 36 ± 0.5 kg, therefore the target liveweights at parturition were 45, 50 and 70 kg for the 'low', 'medium' and 'high' hogget treatment groups, respectively.

Hogget pregnancy status was determined on two occasions via ultrasound, at P50 and P87. All non-pregnant hoggets identified at this stage were removed. Fetal loss after P87 was assumed to have occurred if a hogget that had been identified as pregnant at P87 failed to give birth to a lamb(s). Within 48 hours of lambing, hoggets and their lambs were removed from their feeding regime and were offered *ab libitum* feeding level on herbage with a mass not falling below 1200 kg DM/ha during lactation at a stocking rate of 47 hoggets/ha.

The trial was conducted from the 1st May to 13th December in 2004 at Massey University's Keebles Farm (latitude 41°10'S), 5km south of Palmerston North, New Zealand. The trial was conducted with the approval of the Massey University Animal Ethics Committee.

2.2.2 Hogget live weights

Hoggets were weighed unfasted (within 1hour off pasture) at CIDR insertion twelve days prior to the breeding period (P-12), P7, P21, P38, P52, P66, P87, P117 and P129 and 53 days after lambing (L53) and L87.

2.2.3 Pasture measurement

Hoggets were grazed on a total area of 19 hectares of perennial ryegrass (*Lolium. perenne*) and white clover (*Trifolium. repens*) mixed pasture. The size of the grazing area and grazing interval were determined by the previous live weight, and the feeding allowance adjusted to ensure live weight targets were met. Herbage mass was monitored via a rising plate metre (Ashgrove Pastoral Products, Palmerston North) to allocate the interval spent on each grazing area.

Herbage pluck samples (to simulate herbage eaten by animals) were taken at P24, P49 and P122 pre-grazing from the 'low', 'medium' and 'high' treatment grazed areas and dried in a convection oven over night at 105°C. The protein content of the herbage was determined by total combustion (LECO model, AOAC 968.06). Metabolisable energy content of the herbage were determined using bomb calorimetry and neutral detergent fibre (NDF) and acid detergent fibre (ADF) was determined using a Tecator Fibretec System (Robertson and van Soest 1981).

2.2.4 Blood Samples

A 10 ml blood sample taken by jugular venepuncture (SST gel and heparin clot activation, Becton Dickinson Vacutainer Systems, USA) from thirty hoggets randomly selected from each nutritional treatment group on P17 and P24. Samples were immediately placed on ice and once chilled, centrifuged at 2000 rpm for 20 minutes. The plasma was then frozen (-20°C) until analysis for progesterone, non-esterified fatty acids (NEFAs), glucose and β-hydroxybuterate (OHB). NEFAs and OHB were analysed using enzymatic assays (Wako Pure Chemical Industries Ltd, Osaka, Japan and Sigma, Illinois, USA, respectively). Serum glucose concentrations were analysed using a hexokinase assay (Roche Diagnosis Ltd, Switzerland). Serum progesterone concentrations were analysed using coated tube radioimmunoassay (Diasorin, Stillwater, Minnesota).

2.2.5 Lamb measurements

Lambs were identified to their dam and date of birth recorded, tagged, sexed and recorded for litter size and weight within 12 h of birth (L0). In addition, crown rump length (CRL), girth, rear limb length (distance from the hip to the tip of the hoof) and fore limb length (distance from the shoulder to the tip of the hoof) were measured. Lamb coat colour at tagging (meconium score) was ranked on a four point system (0 = white coat, 1 = pale yellow colouration, 2 = dark yellow colouration and 3 = yellow to orange staining) (Oliver *et al.* 2001) and was recorded as an indication of fetal stress peri-parturition. Lambs were weighed again at L53 and L87.

Time for the lamb to bleat, stand, time to come into contact with its dam, suckle and follow the dam post tagging was determined (Everett-Hincks *et al.* 2005) in the 5 minute period post tagging. The number and type (high and low pitch) of lamb bleats during that 5 minute period was also recorded (Everett-Hincks *et al.* 2005). Hogget maternal behaviour was observed during the lamb dimension measuring procedure and was determined by a 5 point scoring (scale 1-5) system similar to O'Connor *et al.* (1985).

2.2.6 Statistical Analysis

Birth weight (L0), gestation length (calculated from day of tup mark recorded to parturition), CRL, girth, fore and rear leg length, lamb weight at L53 and L87 and blood metabolites and hormones were all analysed separately using the Generalised Linear Model Technique procedure (SAS 2005). Fixed effects of pregnancy rank and hogget nutritional treatment and their interactions were tested for each parameter, Non-significant ($P>0.05$) interactions were removed and the model re-run.

Pregnancy rate at P50 and P87, fetal loss, number of hoggets lambed, meconium score and lamb survival to L87 were all analysed using a randomised GENMOD model. They were then back transformed to calculate a percentage value.

2.3 Results

2.3.1 Herbage Data

On days P24, P49 and P122, crude protein concentration of the herbage sampled ranged from 15.2-29.2 %, metabolisable energy concentration ranged from 7.0-9.4 MJ ME/ kg DM, NDF ranged from 42.1-54.7% total DM and the ADF ranged from 19.0-27.6 % of the total DM, there were no differences in these herbage quality parameters between the different treatment groups (Table 2.1).

Table 2.1. Crude protein (%), metabolisable energy (MJ ME/ kg DM), neutral detergent fibre (% DM, NDF) and acid detergent fibre (% DM, ADF) content of herbage sampled from 'Low', 'Medium' and 'High' treatment group paddocks at P24, P49 and P122.

Group	Crude protein	Metabolisable energy	NDF	ADF
'Low'				
P24	28.7	9.1	44.5	19.8
P49	24.4	7.0	53.2	26.4
P122	19.9	7.2	54.7	25.0
'Medium'				
P24	29.6	8.9	43.3	19.0
P49	23.3	7.1	51.4	27.6
P122	15.2	7.7	50.9	24.9
'High'				
P24	26.0	8.8	42.1	21.8
P49	19.0	7.7	50.7	26.8
P122	20.9	9.4	43.4	20.1

2.3.2 Hogget Liveweights

The nutritional treatments imposed on the hoggets throughout pregnancy were successful in achieving hogget target live weights. The 'high' group was significantly ($P<0.05$) heavier than both the 'medium' and the 'low' hogget treatment groups throughout pregnancy, except at P21 where hoggets on the 'medium' treatment were similar to the 'high' hoggets (Table 2.2). The 'medium' treatment group were significantly ($P<0.05$) heavier than the 'low' treatment group throughout pregnancy. At L52 and L83, the 'high' group hoggets were significantly ($P<0.05$) heavier than their 'low' and 'medium' hogget group counterparts, which did not differ.

2.3.3 Blood Metabolites

Nutritional treatment had no effect on hogget progesterone concentration at P17 or P24 (Table 2.3). Glucose concentration was not affected by nutritional treatment at P17, however, at P24 glucose concentration of the 'medium' treatment group was significantly ($P<0.05$) lower than that of both, the 'low' and 'high' treatment hoggets (Table 2.3).

At P17, the 'medium' treated hoggets had significantly ($P<0.05$) higher maternal OHB concentrations when compared to the 'low' group. At P24, maternal OHB concentrations were significantly ($P<0.05$) higher in the 'high' treatment group compared to the 'low' treated hoggets (Table 2.3).

The 'medium' treated hoggets had significantly ($P<0.05$) lower NEFA concentrations when compared to the 'low' and 'high' treated hoggets at P17. No difference was observed in the NEFA concentration between groups at P24 (Table 2.3).

Table 2.2. The effect of hogget nutritional treatment ('Low', 'Medium' and 'High') on hogget liveweight (kg) during pregnancy and lactation (mean ± SE). Means within rows with different superscripts are significantly different (P<0.05)

Day weighed	'Low'		'Medium'		'High'	
	n		n		n	
P-12	80	36.5±0.47	80	36.1±0.47	80	36.1±0.47
P7	80	35.5±0.49^{a}	80	37.6±0.48^{b}	80	40.8±0.48^{c}
P21	80	34.6±0.54^{a}	80	38.8±0.54^{b}	80	38.1±0.54^{b}
P38	80	37.8±0.52^{a}	80	41.1±0.51^{b}	80	45.3±0.53^{c}
P52	48	37.1±0.66^{a}	53	41.0±0.62^{b}	36	46.6±0.75^{c}
P66	48	36.5±0.74^{a}	53	42.5±0.70^{b}	36	49.6±0.84^{c}
P87	46	36.3±0.71^{a}	53	43.5±0.66^{b}	29	50.2±0.80^{c}
P129	46	44.1±0.98^{a}	53	51.8±0.89^{b}	29	64.5±1.15^{c}
L52	46	44.3±1.06^{a}	53	46.9±0.88^{a}	29	56.0±1.14^{b}
L83	46	45.2±1.07^{a}	53	47.9±0.90^{a}	29	55.8±1.07^{b}

Table 2.3. The effect of hogget nutritional treatment ('Low', 'Medium' and 'High') on serum concentrations of progesterone (ng/ml), glucose (mmol/L), β-hydroxybuterate (OHB, mmol/L) and non-esterified fatty acids (NEFA, mmol/L) at days 17 and 24 of pregnancy (means ±SE). Means within columns with different superscripts differ significantly (P<0.05).

		Progesterone		Glucose		OHB		NEFA	
		P17	P24	P17	P24	P17	P24	P17	P24
	n								
'Low'	30	2.67±0.403	3.52±0.402	3.72±0.070	4.21±0.075^{b}	0.31±0.012^{a}	0.32±0.013^{a}	0.54±0.055^{b}	0.45±0.047
'Medium'	30	2.91±0.397	3.01±0.402	3.78±0.069	3.94±0.073^{a}	0.35±0.012^{b}	0.34±0.013^{ab}	0.27±0.055^{a}	0.41±0.047
'High'	29	2.55±0.397	2.86±0.396	3.80±0.069	4.14±0.075^{b}	0.34±0.012^{ab}	0.36±0.013^{b}	0.37±0.057^{b}	0.40±0.047

2.3.4 Hogget Reproductive Performance

Pregnancy rates at P50 were significantly ($P<0.05$) lower in the 'high' hogget treatment group compared to the 'medium' treatment group, no difference in pregnancy rate was observed between the 'low' and both the 'medium' and 'high' treated hoggets (Table 2.4). Pregnancy rate at P87 was significantly lower ($P<0.05$) in the 'high' treated hoggets when compared to both the 'low' and the 'medium' treated hoggets (Table 2.4.). The pregnancy rate at P87 corresponded to 46, 53 and 26 hoggets pregnant from the original 80 hoggets in the 'low' 'medium' and 'high' treatment groups, respectively. A significantly ($P<0.05$) greater proportion of hoggets from the 'high' group encountered fetal loss between P50 and P87 when compared to 'low' and 'medium' treated hoggets (data not shown).

Lamb survival was significantly ($P<0.05$) higher in the 'high' hogget treatment group compared to both the 'low' and 'medium' treatment groups, no differences were observed between the 'low' and 'medium hogget treatments groups.

Significantly ($P<0.05$) more of the 'medium' treatment hoggets lambed compared to the 'low' and 'high' hogget treatment groups (Table 2.4).

There was no effect of nutritional treatment on the proportion of hoggets scanned with multiples at P50 and 87 (data not shown).

2.3.5 Lambs

Lamb birth weight was significantly lower ($P<0.05$) in lambs born to the 'low' treatment hoggets when compared to lambs born to 'medium' and 'high' treatment hoggets which did not differ (Table 2.5). Lambs born to the 'high' and 'medium' treatment hoggets were significantly ($P<0.05$) heavier at L53 and L87 than those born to the 'low' treatment hoggets (Table 2.5).

Table 2.4. The effect of hogget nutritional treatment ('Low', 'Medium' and 'High') on hogget pregnancy rate (%) at P50 and P87 and the and the proportion of hoggets that lambed. Data are presented as logit-transformed means ± S. E. (and back-transformed percentages). Means within columns with different superscripts differ significantly (P<0.05)

		Proportion pregnant at P50	Proportion pregnant at P87	Hoggets that lambed
	n			
'Low'	80	0.44±0.230[1] (62%[2])[ab]	0.11±0.232(58%)[b]	-0.30±0.244 (42%)[a]
'Medium'	80	0.73±0.240 (66%)[b]	0.73±0.240 (66%)[b]	-0.62±0.234 (64%)[b]
'High'	80	-0.18±0.226 (46%)[a]	-0.69±0.245(33%)[a]	-0.85±0.226 (30%)[a]

[1] Logit-transformed

[2] Back-transformed percentage

Table 2.5. The effect of hogget nutritional treatment ('Low', 'Medium' and 'High'), lamb live weight (kg) at L0, at L53 and L87 and lamb survival from L0 to L87 (means ± SE). Means within columns with different superscripts differ significantly (P<0.05)

	L0		L53		L87		Lamb Survival	
	n		n		n		n	
'Low'	42	3.5±0.16[a]	20	13.3±0.81[a]	15	18.1±1.01[a]	42	-0.59±0.322[1] (36%[2])[a]
'Medium'	51	4.0±0.19[b]	27	16.1±0.63[b]	27	20.6±0.76[b]	51	0.12±0.281 (53%)[b]
'High"	20	4.0±0.19[b]	17	16.0±0.81[b]	17	21.8±0.98[b]	20	1.73±0.626 (85%)[b]

2.3.6. Ewe Behaviour

Nutritional treatment had no effect on hogget maternal behaviour score or the number of dam low pitch bleats immediately post tagging (Table 2.6). The number of dam high pitch bleats were significantly ($P<0.05$) higher in the 'high' treatment group when compared to 'low' fed hoggets at tagging (Table 2.6).

Table 2.6. The effect of hogget nutritional treatment ('Low', 'Medium' and 'High') on maternal behaviour score (MBS), high pitch bleats (HPB) and low pitch bleats (LPB) immediately post-tagging (means ±SE). Means within columns with different superscripts differ significantly ($P<0.05$)

		MBS	HPB	LPB
	n			
'Low'	35	2.9 ±0.15	10.2±1.94[a]	6.2±1.95
'Medium'	35	3.2±0.23	8.9±1.94[ab]	9.0±1.95
'High'	19	3.1±0.05	16.3±2..61[b]	11.4±2.63

2.3.7. Lamb Dimensions and Behaviour

Dam nutritional treatment had no effect on the lamb CRL or girth measurements (Table 2.7). Foreleg length was significantly ($P<0.05$) longer in the lambs born to the 'medium' treatment hogget group when compared to those born to the 'low' and 'high' treatment hoggets (Table 2.7). There was no difference in foreleg length between the lambs born to 'medium' and 'high' treatment hoggets. Hind leg length was significantly ($P<0.05$) longer in both the lambs born to the 'medium' and 'high' treatment hoggets when compared to the lambs born to the 'low' treatment hoggets. No difference in hind leg length was observed between either the lambs born to 'medium' and 'high' treatment hoggets (Table 2.7).

Number of lamb bleats, time to bleat, time to make contact with dam and time to stand was not affected by hogget nutritional treatment (Table 2.8).

Meconium score was significantly ($P<0.05$) higher in the lambs born to the 'medium' treatment hogget when compared to the lambs born to the 'low' and 'high' treated hoggets, however, no difference was observed between the lambs born to the 'low' and 'high' treatment hoggets (Table 2.8).

Table 2.7. The effect of hogget nutritional treatment ('Low', 'Medium' and 'High') on crown rump length (CRL, cm), girth (cm), foreleg length (FL, cm) and hind leg length (HL, cm) at L0 (means± SE). Means within columns with different superscripts differ significantly (P<0.05)

	n	CRL	Girth	FL	HL
'Low'	35	47.2±0.75	34.9±0.64	28.6±0.50[a]	32.9±0.46[a]
'Medium'	35	48.8±0.60	36.1±0.56	30.4±0.36[b]	34.7±0.40[b]
'High'	19	48.7±0.80	36.7±0.72	29.4±0.47[a]	33.6±0.52[b]

Table 2.8. The effect of hogget nutritional treatment ('Low', 'Medium' and 'High') on the number of bleats (NB), time for lamb to bleat (TLB, sec), time to make contact (TMC, sec), time to stand (TS, sec) and the meconium score (mean± SE). Means within columns with different superscripts differ significantly (P<0.05)

		NB	TLB	TMC	TS	Meconium
	n					
'Low'	35	12.1±2.99	19.0±8.0	55.2±11.14	40.1±10.31	1.46±0.15[a]
'Medium'	35	13.1±2.84	9.8±7.6	33.5±10.58	26.8±9.80	2.04±0.13[b]
'High'	19	8.6±3.63	22.1±9.7	36.7±13.51	40.1±12.52	1.60±0.17[a]

2.4. Discussion

The aim of the present study was to investigate the effects of three differing nutritional regimes starting immediately post-breeding under pastoral grazing conditions on hogget reproductive performance. It has previously been shown under housed conditions Wallace *et al.* (2004a; 2005b), that high levels of nutrition during pregnancy has detrimental effects on the reproductive performance of hoggets.

The changes in hogget live weight for the 'low', 'medium' and 'high' feeding regimes were 7.6, 15.3 and 25.4, which equated to live weight gains of 60, 121 and 202 g/day during pregnancy. These changes indicate that the hogget feeding regimes were successful at manipulating live weight change. In the studies of Wallace *et al.* (1996; 1997a; 1997b; 1998; 1999b; 2000a; 2000b; 2002a; 2002b; 2003b) the 'low' growth rate hoggets grew at 60-80 g/day throughout the gestational period while the faster growth rate hoggets grew at 250-300 g/day. Although the 'low' treated hoggets grew at an average of 60 g/day during pregnancy this liveweight change only occurred during the last trimester of pregnancy (the 'low' hogget treatment group grew at 2 g/day for the first 100 days of pregnancy), therefore, comparisons between these two growth rates are limited as the hoggets in the U.K. study grew at a constant rate throughout pregnancy.

Pregnancy rates at P50 lower in the 'high' when compared to the 'medium' treated hoggets, however, by P87 pregnancy rates were lower in the 'high' and 'low' treated hoggets compared to the 'medium' hogget treatment group. The reduction in the pregnancy rate at P87 in the 'low' treated hoggets could be due to direct impact of the undernutrition which leads to embryonic loss (Edey 1976).

Inconsistent results of the effect of 'high' levels of nutrition during early pregnancy on pregnancy rate have been reported in the literature. Wallace *et al.* (1996) found pregnancy rate was lower in the hoggets grown at a high growth rate when compared to the hoggets grown at lower rate (234 and 75 g/day, respectively). In contrast, Wallace *et al.* (1997b) found the pregnancy rate was higher in high growth rate hoggets than slower grown hoggets (294 and 84 g/day, respectively). Wallace *et al.*

(1999a; 2005b) found no effect of growth rate during pregnancy on pregnancy rate of ewe hoggets (260 and 130g/day, respectively). In the current study, of those marked by the ram, and not diagnosed pregnant at day 50, it is impossible to determine if they actually conceived or lost the pregnancy by day 50. However, the fetal loss later in gestation (i.e. those that lost their pregnancy and were scanned pregnant at day 50) indicates that these hoggets were pregnant at P50. McMillan and McDonald (1983) reported that conception rate was negatively associated with growth during the joining period. Using the equation produced by McMillan and McDonald (1983), the predicted conception rates were 85, 83 and 80% for 'low', 'medium' and 'high', respectively. These predicted conception rates are much higher than the pregnancy rate measured in the animal studies at P50.

In mature ewes increased metabolic clearance rate of progesterone due to elevated blood flow from the gut to the liver arising from increased feeding levels has been shown to reduce pregnancy rate (Parr *et al.* 1982; 1993). However, in the current 'high' treatment hoggets did not display lower progesterone concentration at the time points measured.

The incidence of fetal loss (losses between P50 and P87 and between P87 and lambing) was greater in the 'high' fed hogget group when compared to both the 'low' and 'medium' fed hogget groups. Wallace *et al.* (1996) reported higher spontaneous nutritionally associated abortions around day 125 of pregnancy in hoggets grown rapidly, while Morris *et al.* (2005) reported no effect.

In the adult ewe, nutrient partitioning during pregnancy generally favours the conceptus at the expense of the dam However, in the growing adolescent sheep the hierarchy of nutrient partitioning during pregnancy can be dramatically altered such that a high level of feeding during pregnancy can lead to a sustained stimulus for maternal tissue deposition and a shift of nutrient supply away from placental growth (Wallace 2000). This change in the hierarchy of nutrient partitioning is believed to be responsible for the fetal loss observed in rapidly growing hoggets (Wallace *et al.* 1996; Wallace 2000).

Lamb birth weight of the lambs born to the 'high' treated hoggets was heavier than the lambs born to the 'low' treated hoggets, but did not differ from those born to the 'medium' hoggets. These results are contrary to the decrease in lamb birth weight in the hoggets grown rapidly reported by Wallace *et al.* (1996, 1997a, 1998 and 2003). However, Morris *et al.* (2005) also reported that high feeding did not negatively affect birth weight.

Gestation length did not differ between the treatment groups in the current study, a finding which is in agreement with Morris et al. (2005). However, Wallace *et al.* (1996; 1997a, 1997b; 1998) and Da Silva *et al.* (1998) found shorter gestation lengths in hoggets fed a high plane of nutrition during pregnancy. These shorter gestation lengths were also associated with lighter lamb birth weights. Given the lack of a birth weight response in the present study, a change in gestation length may not have been expected.

One possible explanation for the absence of a negative affect on hogget lamb birth weight between studies maybe the relative protein and energy content of the herbage. Concentrate diets used by Wallace *et al.* (1996) contained 10.2 MJ ME/kg DM and 13.7 % crude protein, while in New Zealand pastoral systems the energy content is often round 11-12 MJ ME/kg DM, and the crude protein concentration ranges between 15-25 % (Holmes *et al.* 2002). In the current study, metabolisable energy content was 7-9.4MJ ME/kg DM and the protein concentration was between 19 and 29%. The impact of the different nutrient composition on the reproductive performance of the hoggets may warrant further investigation. The ME content was lower than expected in the current study. On a nearby farm, metabolisable energy content was 11.9 MJ ME/kg DM during winter (Machado *et al.* 2005). An explanation for this is unknown. Pasture samples were collected by plucking at grazing height which is a recognised technique (Wallis De Vries 1995). The changes in live weight observed in the 'high' hogget treatment group would suggest the ME concentration of the diet selected by the hoggets was not as low as indicated by the mean live weight changes of these hoggets.

Another possible explanation for the apparent differences in the lamb birth weights between the present study and the study outlined in Wallace *et al.* (1996) is the use of

embryo transfer compared to natural breeding in the current study. Embryo transfer has been shown to alter fetal growth trajectories (Walker *et al.* 1992).

Hogget nutritional treatment had no effect on lamb survival which is in agreement with Morris *et al.* (2005). Although it contrasts to Wallace *et al.* (1996). The study of Wallace *et al.* (1996) indicated that lamb survival to 72 hrs of age was lower in the high growth treatment group. McMillan (1983) reported that the optimum birth weight range for lamb survival was 3.3-4.1 kg, a range that corresponds to the mean live weight of lambs from all treatments in the present study. In the study of Wallace *et al.* (1996) the birth weight of lambs born to hoggets grown rapidly were only 2.74 kg compared to 4.34 kg in the normally grown hoggets.

Lamb weaning weight was affected by the hogget nutritional treatment, such that growth rate was lower in lambs born to the 'low' hogget treatment group. Peak milk production and milk yield is reduced due to undernutrition during pregnancy in adult ewes (Treacher 1970; Davis *et al.* 1980; Dove *et al.* 1988). Body reserves of the ewe can be utilised during lactation, with the additional energy produced potentially used for milk production (Treacher and Gaja 2002). However, the 'low' hogget fed treatment group in the current study may have had less body reserves to mobilise for milk production. Therefore, milk production may have been limited which may explain the lower lamb growth rate in lambs born to hoggets fed at 'low' levels during pregnancy. Condition scores could be measured before, during and after hogget pregnancy to provide an indication of any change in the ewe body reserves

A potential way to measure the efficiency of hogget mating is by calculating the total weight of lambs weaned divided by the number of hoggets mated for each treatment group. The 'low' fed hogget group produced the lowest value (3.37 kg/hogget bred), followed by the 'high' fed group (4.58 kg/hogget bred) with the 'medium' fed group producing the highest (7.55 kg/hogget bred). These values were primarily influenced by the lower pregnancy rate in both the 'low' and 'high' fed hogget treatment group rather than the lamb weaning weight itself. This suggests that the optimal feeding regime during pregnancy for hogget reproduction was the 'medium' fed hogget treatment group.

2.5. Conclusion

Lower pregnancy rates in the hoggets fed a 'high' level of nutrition during pregnancy led to fewer lambs being born and weaned when compared to hoggets fed 'low' and 'medium' nutritional levels during pregnancy. Lamb birth weight was lower in hoggets fed 'low' levels of nutrition during pregnancy when compared to hoggets fed 'medium' and 'high' levels of nutrition during pregnancy and this difference remained until L87. This, combined with the pregnancy rate, led to more lamb weaned at L87 in hoggets fed a 'medium' level of nutrition during pregnancy. Therefore, if New Zealand farmers want to maximise hogget reproductive performance, they should aim to feed their hoggets to grow faster than 60 g/day but less than 200 g/day during the entire pregnancy period.

Chapter Three

Implications, limitations and possible further studies

The overriding objective of this study has been to increase the pregnancy rate of hoggets in New Zealand where hoggets graze pasture and farmers use natural mating. The majority of the research from the United Kingdom on the effect of nutrition primarily on conception rate, spontaneous abortions, placental weight, fetal weight and lamb birth weight has been conducted indoors where hoggets have been fed a concentrate diet and bred using embryo transfer.

Research conducted under grazing conditions on a mob basis results in less control of individual animal intakes and hence liveweight gain than in studies where animals are individually penned and diets controlled and measured. Individual intake can be assessed using indirect markers such as n-alkane (Lewis *et al.* 2003) or chromium (Parker *et al.* 1990) methods. Another method would be to individually pen hoggets and cut and carry herbage to the hoggets to allow for determination of individual intakes.

The present study has identified the importance of the time of implementing the feeding regimes during early pregnancy. The affects of different feeding levels were also observed in the latter stages of pregnancy. To further investigate the impact of feeding level on the reproductive performance of hoggets, a nutritional switch can be applied while the placenta is still developing. If the diet offered was switched from 'high' to 'medium' level, compensatory placenta development may be observed such that this treatment will lead to an intermediary effect on reproduction when compared to hoggets that have been fed 'high' and 'low' amounts of herbage for the entire duration of pregnancy. This method may warrant further investigation. Research from the U.K. indicates the timing of the switch would be best done at around day 50 of pregnancy.

In the current study, there were limitations when identifying fetal losses that occurred during pregnancy. To determine embryonic loss, teaser rams can be joined with the hoggets after breeding has been completed to determine re-cycling hoggets; this will indicate that the hogget has not conceived or failure of pregnancy may have occurred where crayon tupp marks are present. Also, pregnancy specific proteins (i.e. pregnancy specific protein B and pregnancy specific glycoprotein's) can be investigated. Peripheral blood samples can be taken daily and used to produce a pregnancy specific profile during pregnancy. These proteins are released by the placenta beginning early pregnancy and the concentrations increase during pregnancy (Humblot 2001). From these profiles the time when losses occur can be determined (Humblot 2001). If the hogget loses pregnancy, the pregnancy specific protein secretion will cease. In addition to this, weekly ultrasound pregnancy scannings can be used to determine when actual fetal loss occurs.

Likewise, peripheral serum progesterone concentrations of the hoggets can be used to assist in determining when the embryonic losses are occurring. Progesterone concentration is inversely related to feeding level and embryonic loss. During a trial of 'high' and 'low' feeding, serum samples can be taken weekly to investigate the progesterone concentrations of the hoggets that were tupped from each treatment group. Embryonic loss can then be determined by a trigger level of serum progesterone concentration. However, there are variable reports on the exact progesterone concentration that indicates pregnancy failure.

It has been consistently shown by U.K. studies that during the pregnancy of rapidly grown hoggets there are elevated glucose and NEFA metabolites, together with IGF-1, leptin, thyroid and GH hormones. These were generally lower in normally grown hoggets and were associated with reduced birth weight of lambs born to hoggets grown rapidly. The present study analysed glucose, NEFAs and OHB during the early stages of pregnancy (serum samples taken on day 17 and 24 of pregnancy). In the present study, there was no effect on lamb birth weight of the nutritional regimes offered. This could be due to metabolic changes not occurring in these metabolites which were only analysed at an early stage of pregnancy. These metabolites are generally an indication of nutritional status and need to be measured to determine metabolic changes occurring as a result of the different feeding regimes. Therefore,

measuring these hormones in rapidly and normally grown hoggets under New Zealand conditions may offer further explanation of the possible mechanisms behind the absence of a reduced birth weight as a result of rapid growth rate.

There is no question that further research needs to be undertaken to unravel the effects of feeding during pregnancy on reproductive performance of hoggets. This research should ultimately assist New Zealand farmers to further utilise hogget breeding to improve their sheep production.

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