Shearing Merino ewes at different stages of pregnancy: some consequences for the progeny

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Abstract

Merinos are bred primarily for wool production, valued specifically for the fine-wool they produce. Wool returns have been diminishing over recent years so using management to improve wool quantity and quality is beneficial to growers. Shearing ewes at different stages of pregnancy has been shown to potentially influence the follicle population which in turn could achieve a finer, heavier fleece in the offspring, although this has not been examined in Merinos. A consequence of the diminishing wool returns is a greater emphasis on meat production, resulting in a shift in focus to increase live weight and body condition in order to increase reproductive performance and produce heavy lambs for sale. The whole Merino wool market is also currently threatened by the perception of overseas purchasers towards the practice of mulesing. Mulesing is undertaken in approximately half of New Zealand's Merino lambs as a means of reducing blowfly strike.

There are few data available under New Zealand conditions for these pre-mentioned management factors that influence Merino production. Therefore, the aim of this thesis was to profile the live weight and body condition of single- and twin-bearing Merino ewes; investigate the effect of shearing time of Merino ewes on the live weight, fleece characteristics and the follicle population in their progeny; and to investigate the effect of mulesing Merino lambs on their live weight, dag score and fleece characteristics.

Two hundred and ninety nine Merino ewes were bred to 4 mature Merino rams on day 0 of the experiment (d0; May 20, 2006). Pregnant ewes were then allocated to one of three shearing times; mid-pregnancy (d106), late-pregnancy (d141) and post-lambing (d191). Ewes were weighed and condition scored on d0, d79, d106, d141, d191 and d283 of the experiment.

The ewes produced 128 ewe-lambs which were used for subsequent measurements. Ewe-lambs were identified using DNA parentage testing to their dam's maternal shearing treatment. Ewe-lambs were weighed on d191 (approximately 6 weeks of age) and weighed and dag scored on d191 (approximately 6 weeks of age), d283 (approximately 4 months of age), d359 (approximately 7 months of age) and d499 (approximately 1 year of age). Ewe-lambs were wrinkle scored on d191. On d191, 60 ewe-lambs were mulesed; the remaining 67 were left un-mulesed. A skin biopsy was taken from the mid-side of the lamb at d359 and analysed for primary and secondary follicle density. Two mid-side wool samples were taken from the lambs; one at d359

(approximately 7 months of age) and one at d499 (approximately 1 year of age). The first of these samples was analysed for washing yield, colour and fibre diameter. The second mid-side was analysed for fleece class, staple length and staple strength respectively. At d499 fleece weight was measured before the mid-side sample was taken.

Twin-bearing ewes were heavier ($P<0.05$) than single-bearing ewes from d0 (start of breeding) through to d79 (pregnancy diagnosis). They were also heavier ($P<0.05$) following this period. However, this is most likely due to the weight of their foetuses. Body condition score of twin-bearing ewes decreased following lambing until d191 (tailing) but recovered by d283 (weaning). Single-bearing ewes were more likely ($P<0.05$) to be rearing a lamb at d191. Single-born lambs were heavier ($P<0.05$) at d191 and d283, had heavier fleeces and had a higher primary follicle number index than their twin-born counterparts.

Shearing time of Merino ewes had no effect on lamb live weight at any stage of the experiment. It also had no effect on ewe live weight apart from in late-pregnancy where the mid-pregnancy shorn ewes were heavier ($P<0.05$) than late-pregnancy shorn and post-lambing shorn ewes. Shearing ewes in mid-pregnancy had no effect on the fleece characteristics of their lambs. The progeny of lambs born to ewes shorn post-lambing had a significantly greater follicle density, secondary follicle density, follicle number index and secondary follicle number index than their mid- and late-pregnancy shorn counterparts.

Mulesing Merino lambs had no effect on their growth, live weight or fleece characteristics. It resulted in a reduction in dags at d359 and d588 which is likely to reduce susceptibility to blowfly strike. The purpose of mulesing is to reduce wrinkles around the breech, and in this study, the more wrinkles a lamb had at d191 the greater the secondary to primary follicle ratio, total follicle density, secondary follicle density, secondary follicle number index, primary follicle number index, total follicle number index, and fleece weight. This suggests a productive advantage to sheep with more wrinkles; however, they also had more dags and therefore were at greater risk of blowfly strike than the less wrinkly lambs.

In conclusion, shearing ewes post lambing increased the secondary follicle density of the ewe progeny but had no affect on fleece characteristics. In contrast to experiments with other breeds, shearing Merino ewes in mid-pregnancy compared with post-lambing had no effect on fleece or follicle characteristics. There is an opportunity for

future work investigating the mechanisms behind the response of lambs to shearing their ewe post-lambing. The results suggest that maintaining high ewe live weight and body condition score throughout pregnancy will result in more lambs reared to at least tailing, and heavier lambs at weaning. Further work is required to examine the potential benefits of differential management of single and twin-bearing/rearing ewes. Mulesing lambs reduces dag score, and hence is likely to reduce flystrike rates but had no effect on live weight, or fleece characteristics. Alternatives to the practice of mulesing that give equal protection, compared to mulesing, against blowfly strike need to be found.

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The Reasons

It is not fame or fortune
That makes men muster sheep,
On broken, rugged hillsides
And ranges rough and steep.
It is not love of comfort
Or the working of short hours,
That makes them tread the mountains
'Mid the pure, fresh alpine flowers.

It's the frosty early mornings
As the dawn breaks clear and bright,
And the mists rise from the valleys
As the day takes o'er from night.
It's the climbing out with gang of mates
To reach your beats on high;
The kea soaring on the wing
In the slowly lightening sky.
It's the feel you get when top is reached
And the whole world's stretched below,
A maze of peaks and ridges
Bright red in the sunrise glow.

It's the stirring sight of stringing sheep
As they move for the days first noise,
But it never pays to take them cheap
For they're full of many ploys.
It's the pride you feel when your heading dog
Hooks a mob a mile away,
Though he's cast on running shingle
And his pads have bled all day.
It's the satisfaction at day's end
When the last sheep's through the gate,
With weary tread you head to camp
For the evening's getting late.

It's the smell of woodsmoke rising
From the hut tucked in the lee,
Of the towering bluff bound massif,
Clothed with bush and shingle scree.
It's the swinging billy boiling
As the packy makes a brew,
And the dixie on the fireside
Full of simmering mutton stew,
It's the old camp oven sitting
In the embers glowing red,
And the smells that issue from it
From the slowly rising bread.

It's the yarning in the sacking bunks
And the smell of candle wax,
The rolling of the day's last smoke
The whinnies from the hacks.
The hobble chains are clinking
As they head down to the creek,
And the morepork in the birch trees
Tells the world it's time to sleep

By Jim Morris

For Gordy

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List of Abbreviations

Abbreviations

kg	kilogram
µm	micrometres
N/kt	Newtons per kilotex
BCS	body condition score
PD	pregnancy diagnosis
S:P	secondary to primary follicle ratio
S°	secondary follicle
P°	primary follicle
TFNI	total follicle number index
SFNI	secondary follicle number index
PFNI	primary follicle number index
cvMFD	coefficient of variation of mean fibre diameter

Statistical terms

*	Significant at $P<0.05$
**	Significant at $P<0.01$
***	Significant at $P<0.001$
NS	Non-significant $P>0.05$

Chapter 1
General Introduction and Objectives

Introduction

Merino sheep were introduced to New Zealand in 1834 as a slow-maturing, specialist wool breed, providing the raw material for quality woollen and worsted fabrics (Wolfe 2006). Historically, the focus of Merino farmers has been largely on wool traits, which are still the most significant determinant of their profitability. In recent years there has been a greater emphasis on meat production through cross-breeding and the use of terminal sires due to lower prices paid for wool, and higher lamb prices. In addition, Merino wool markets are threatened by the continued practice of mulesing. This study examined how three management tools could be used to influence the productivity of a Merino system.

Wool fibre diameter is the dominant influence over fine wool prices (Wuliji *et al.* 1998). The challenge for Merino farmers is to decrease mean fibre diameter while increasing, or at least maintaining, fleece weight (influencing the value of the clip). Manipulation of the follicle population can alter the fibre diameter and fleece weight. Shearing crossbred ewes during pregnancy has been shown to alter the follicle population during its development *in utero* and therefore may be a useful management technique to improve the value of wool (Revell *et al.* 2002). To date, this has not been investigated in Merinos.

In recent years, income from meat has provided an increasing contribution to profitability of Merino farms (Scales *et al.* 2000). Merinos have a low average reproductive rate, associated with their lower liveweight gain compared to some British breeds and crossbreeds (Young *et al.* 1965; Dolling and Nicolson 1967; Hocking Edwards and Starbuck 2006). In addition, genotypes with high wool production can have lower reproductive performance (Safari *et al.* 2005). Combined, these factors restrict the number and quality of progeny that are available for sale (Kleemann *et al.* 2006). Ewe live weight and body condition score throughout pregnancy are important factors in determining reproductive performance and lamb live weight during the first 4-6 months of life (Hall *et al.* 1995; Kleemann and Walker 2005). Knowledge of live weight and condition score and its effect on reproductive performance could improve the profitability of the system.

A potential threat to future profitability of Merino farming systems is the increasingly negative reaction of markets towards the mulesing of Merino lambs. Mulesing is the practice of removing strips of skin from the breech area of lambs at tailing to remove wrinkles and minimise the risk of flystrike. There are significant welfare issues

associated with the practice (Rothwell *et al.* 2007), which is causing consumer-driven pressure from the markets to cease the practice. Mulesing potentially results in a decrease in production which may be greater than the cost of flystrike at any point in an animal's lifetime as shown by Rose *et al.* (1972). The costs associated with the prevention and treatment of flystrike may therefore be offset by the potential cost of lost production that may arise from mulesing. Information is required to investigate whether mulesing has any effects on production besides flystrike control.

Both genetic and management approaches will be useful in addressing the three issues described above. This review will outline current knowledge on reducing fibre diameter and increasing fleece weight. Using this information, it will discuss the effect of the shearing time of ewes on both the ewes and the performance of their progeny and follicle characteristics. The influence of ewe live weight and body condition score on the reproductive outcomes will be examined briefly. Lastly, knowledge about the effect of mulesing lambs on lamb growth and wool production will be covered.

The influence of the wool follicle population on fibre diameter and fleece weight

The follicle population is related to fleece characteristics responsible for determining the end-product from raw wool (e.g. fibre diameter, staple length, staple strength, fibre diameter variation, wool colour, crimp definition and crimp frequency) (Colditz *et al.* 2005). Therefore, in order to manipulate the raw wool, an understanding of the relationship between follicles and wool characteristics is important.

The density of fibre-producing follicles within the skin is related positively to clean fleece weight and related negatively to fibre diameter (Nancarrow *et al.* 1998; Scobie and Young 2000). These two characteristics drive the profitability of the wool industry (Coelli and Atkins 1995). Therefore, in order to maximise profitability, maximising the number of follicles which form in the skin is important in maintaining the fibre-producing capacity of the animal throughout its lifetime (Toland Thompson *et al.* 2007).

The first stage in follicle development is the proliferation of epidermal cells to form a placode beneath which an aggregation of dermal cells occurs and the two cell formations grow down together into the dermis. Progressively the dermal cells move into the epithelial bud to form the pre-papilla and finally the epithelial bulb cells envelop the pre-papilla as the follicle lengthens and descends into the dermis. The first follicles formed are the primary follicles followed by the secondary follicles and then the secondary-derived follicles that branch from the secondary follicles (Rogers 2006). In Merinos the bulk of the fleece is made up of secondary derived follicles (Rogers 2006).

The positioning and size of the primary follicles is determined as early as day 40 in the foetus (Hocking Edwards *et al.* 1996; Kelly *et al.* 1996) as a trio pattern characterized by a central primary and two lateral primaries (Rogers 2006). The positioning and size of the primary follicles determine the subsequent positioning and size of the secondary follicles (Kelly *et al.* 1996). The majority of primary follicles are producing fibres by day 111 of gestation (Hocking Edwards *et al.* 1996). Secondary follicles begin to appear at approximately 70 days of gestation (Hocking Edwards *et al.* 1996) in association with the primaries and together they form a distinguishable cluster in the skin. By day 105 secondary derived follicles begin to appear as branches from the secondary follicles (Hocking Edwards *et al.* 1996; Rogers 2006). Secondary follicles continue developing until approximately day 125 of gestation (Hocking Edwards *et al.* 1996). By birth, all secondary follicles are present although in the Merino only 16-33% of the secondary follicles are producing a fibre (Short 1955; Schinckel and Short 1961; Hocking Edwards *et al.* 1996; Kelly *et al.* 1996). Genetic controls operate to instigate branching of the

original secondaries which occurs right up until birth (Kelly *et al.* 1996). The extent to which follicle branching occurs is a significant determinant of follicle density, ratio of number of secondary to number of primary follicles (S:P), fibre diameter, fibre length, and clean fleece weight (Kelly *et al.* 1996).

In many Merino wool-producing enterprises the objective is to produce fine, strong fibres of relatively uniform diameter, whilst at the same time maintaining high clean fleece weights. Unfortunately, there are antagonisms between these objectives in that changes in fibre length are usually accompanied by changes in fibre diameter as shown by the genetic and phenotypic correlations in the report by Safari and Fogarty (2003) ranging from -0.05 to 0.34 and 0.11 to 0.29 for genetic and phenotypic correlations respectively. The combination of high fleece weight and fine fibre diameter is only attained in sheep of high follicle density such as Merinos (Meikle *et al.* 1988).

Wool quantity per unit area of skin is closely related to the total volume of follicle bulb tissue in that area of skin (Hocking Edwards and Hynd 1992; Hynd 1995). This in turn depends on follicle density (total number of follicles per unit area of skin) and the average volume of the follicle bulbs. In other words, large follicle bulbs produce more fibre because they produce more mitotic cells per unit time than small follicle bulbs (Hocking Edwards and Hynd 1992; Hynd 1995).

The S:P ratio is deemed to be a reliable index of variation in the S follicle population (Corbett 1979). In the past difficulties in accounting for variability in the amount of shrinkage in a skin biopsy, meant the S:P was used because a greater density is associated with a greater S:P (Scobie and Saville 2000). Total follicle density is related to fibre density (Scobie and Young 2000) and is a commonly used method of determining follicle population characteristics now that biopsy shrinkage can be accurately determined. Selection for skin follicle density alone decreases fibre diameter, but also fleece weight, staple strength, coefficient of variation of fibre diameter and body weight (Fozi *et al.* 2007). The follicle number index gives more favourable responses due to a strong genetic correlation between a composite of follicle density and skin surface area (Fozi *et al.* 2007). The present study used all three measurements to investigate follicle characteristics to get a clearer picture of the follicle population than just using one.

It is well-recognised that wool growth and quality are influenced by environmental conditions (Denney 1990). In addition to that, environmental influences early in life may restrict or enhance the ability of the sheep to grow wool over its lifetime (Denney 1990).

Toland Thompson *et al.* (2007) proposed that a reduction in the follicle population early in postnatal life is attributed to increased cortisol levels at this time. Increased cortisol levels also have a detrimental effect on wool growth (Ferguson *et al.* 1965). If the follicle population could be manipulated through management to increase the number of follicles this would achieve the desired objective of wool farmers – to increase fleece weight, and decrease fibre diameter. Environmental factors that are known to affect maternal nutrition and therefore wool growth and quality, include their season, shearing date, pregnancy (including pregnancy rank and lambing date), lactation, daily feed intake, weather, breed, birth weight and genetics (Underwood and Shier 1942; Allen and Lamming 1961; Peart 1967; Cumming 1977; Gibb and Treacher 1980; Geenty and Dyson 1986; Waters *et al.* 2000; Duguma *et al.* 2002; Steinheim *et al.* 2002).

The effect of shearing during pregnancy on productive outputs, wool characteristics and the follicle population of their progeny

Shearing mature ewes in mid- to late-pregnancy (days 70-100 of gestation) has been shown to increase the birthweight of the progeny of crossbred and coarse-wooled sheep (Morris and McCutcheon 1997; Morris *et al.* 1999; Morris *et al.* 2000; Smeaton *et al.* 2000; Kenyon *et al.* 2002a; Kenyon *et al.* 2002b; Revell *et al.* 2002; Kenyon *et al.* 2004; Kenyon *et al.* 2005; Kenyon *et al.* 2006; Corner *et al.* 2007). The increased birthweight has been associated with increases in lamb survival rates to weaning in some cases (Morris *et al.* 1999; Kenyon *et al.* 2002a; Kenyon *et al.* 2006). It has also been associated with heavier lamb weaning weights (Morris *et al.* 1999; Smeaton *et al.* 2000; Kenyon *et al.* 2004). Further research investigated the effects on fleece and follicle characteristics in the progeny of mid-pregnancy shorn ewes (Revell *et al.* 2002; Sherlock *et al.* 2002). In some cases there was an effect and as a result the present study was undertaken to investigate if this response occurred in Merinos.

The type of shearing comb used for shearing (Morris and McCutcheon 1997; Morris *et al.* 2000); the resulting increased intake from shearing (Kenyon *et al.* 2003); and an increase in thyroid hormones (Symonds *et al.* 1989; Morris *et al.* 2000; Sherlock *et al.* 2003) was shown not to be the mechanism or at least the sole mechanism responsible for the observed effect. A number of factors increased gestation length but this was not attributed to the response (Kenyon *et al.* 2003). They include shearing during pregnancy (Kenyon *et al.* 2002b; Revell *et al.* 2002) and cold exposure (Thompson and Goode 1981). Two criteria have been proposed to explain the birthweight response of dams to mid-pregnancy shearing (Kenyon *et al.* 2002b). Firstly, the dam must have the potential to respond (i.e. have been destined to give birth to an otherwise lightweight lamb); secondly, the ewe must have the means to respond (i.e. an adequate level of maternal reserves and/or level of nutrition to partition towards additional fetal growth). Shearing at the time of follicle development may alter the development mechanism and therefore the follicle population.

The development of secondary wool follicles in the skin may be susceptible to changes in the nutritional or hormonal environment of the fetus caused by shearing at day 70 of pregnancy due to their development between days 90 and 110 of gestation (Hocking-Edwards *et al.* 1996). Revell *et al.* (2002) examined the effect of shearing Border Leicester x Romney ewes at day 70 of pregnancy. However, the density of primary wool follicles did not differ between fetuses from shorn and unshorn ewes. The density of secondary follicles (immature and mature) increased by about 9% in response to

mid-pregnancy shearing in both single and twin fetuses. The S:P of follicles in the skin was significantly greater in both single and twin fetuses from shorn ewes (2.44) compared with fetuses from unshorn ewes (2.18). In contrast to the study by Revell *et al.* (2002), Kenyon *et al.* (2005) and Kenyon *et al.* (2006) found no effect of shearing treatment on primary or secondary follicle density of progeny born to mid-pregnancy shorn Romney hoggets and Coopworth ewes respectively. There was also no effect on the S:P in single lambs born to mid-pregnancy shorn ewes (Kenyon *et al.* 2006).

In the study by Revell *et al.* (2002) single-born lambs produced 21% more wool than twin-lambs overall. However, wool production in the progeny of mid-pregnancy shorn dams was only significantly affected in singletons with a reduction of 17% of greasy fleece weight. Despite this reduction, the yield of clean wool was unaffected by shearing treatment. Fibre diameter was not affected by shearing treatment. In a different study, there was no effect of mid-pregnancy shearing ewes on mean fibre diameter, curvature, % medullation, yield, staple length, Y colour measurement, coefficient of variation of mean fibre diameter (cvMFD), or loose wool bulk (Kenyon *et al.* 2005) in their progeny. Sherlock *et al.* (2002) reported that at 6 months of age, the wool from ewe lambs born to shorn dams was of greater mean fibre diameter. There was a significant interaction between rearing rank and shearing treatment for greasy fleece weight; such that while dam shearing treatment had little effect on the greasy fleece weight of single-born lambs, it caused an increase in the greasy fleece weight of twin-born lambs. Lambs born to shorn dams had whiter wool than those born to unshorn dams. There were no significant effects of shearing time on fibre curvature, staple length or yield (Sherlock *et al.* 2002).

Although studies to date have been inconsistent, the finding by Revell *et al.* (2002) of increased S:P in the progeny born to mid-pregnancy shorn ewes has the potential to increase the value of the Merino wool clip if the same affect was to be observed (Kelly *et al.* 1996). In fine-woolled breeds reducing diameter, even at a small level can increase profitability, whereas in coarse woolled breeds a significant decrease in fibre diameter is required to increase profitability of a fleece. However, to-date, the affect of mid-pregnancy shearing on the resulting progeny's follicle population and fleece characteristics has not been examined.

Live weight and condition score of ewes

Relationship to wool production

Increasing live weight by selection in Merino sheep has long been a contentious issue due to wool being the principal product from Merinos (Roberston 1987). It is unlikely that selection for increased live weight would improve wool production per unit area of skin or the efficiency of wool growth (Pattie and Williams 1967). A slight to moderate correlation is observed between live weight and clean fleece weight, as shown in a review by Safari and Fogarty (2003) ranging from -0.06 ± 0.21 to 0.58 ± 0.12 and 0.24 ± 0.03 to 0.48 for genetic and phenotypic correlations respectively. The correlation between live weight and fleece weight has been attributed to a greater surface area for wool growth (Pattie and Williams 1967). Selection for increased live weight also increases fibre diameter ranging from 0.02 ± 0.15 to 0.61 and 0.09 to 0.26 ± 0.03 for genetic and phenotypic correlations respectively (Safari and Fogarty 2003). The challenge therefore, is to increase ewe live weight and condition score to maximise reproductive performance and the performance of the progeny, while maintaining fleece quality.

The effect on ewe reproductive performance

Live weight and condition score both influence reproductive performance (Kleemann and Walker 2005). Condition score is a subjective measurement of the body condition of the ewe on a scale of 1 (emaciated) to 5 (obese) (Jefferies 1961). It is considered that condition score mainly reflects variations in live weight (Milligan and Broadbent 1974). At the same live weight, small ewes in improving body condition can have a significantly higher ovulation rate than large ewes in reducing body condition (Ducker and Boyd 1977). It is an advantage to have as many ewes as possible conceiving in the first cycle of the breeding period, which has been shown to be directly related to ewe live weight and condition score (Kenyon *et al.* 2004). Nutrition influences live weight and body condition.

Waters *et al.* (2000) observed Merino ewes that fell pregnant had the greatest live weights immediately before lambing and live weight was least at weaning in that year and at the following mating. In contrast, the live weights of empty ewes increased over the year. Ewes that were empty or lost a lamb(s) had the highest live weights at the following mating. At weaning, empty ewes had a condition score of 0.8 more than ewes that lambed (Waters *et al.* 2000). Losing one or more lambs before weaning resulted in a 0.6 higher condition score compared with ewes that successfully reared one or more

lambs. Variation between years and flocks were large for this study. This suggests that condition tends to decline with pregnancy and lactation; performance could potentially be improved by maintaining this.

Effects on progeny performance

Ewe live weight and body condition influence the performance of their lambs throughout their lifetime. Hall and Wall (1995) concluded that lamb birth weight increased with dam liveweight in mid-pregnancy; and lamb weaning weight and liveweight gain increased with dam liveweight at joining. In a study by Steinheim *et al.* (2002) it was found that ewes that had an initially low birth weight (frequently suggested to be a function of poor condition ewes during pregnancy), produced smaller offspring throughout their lifetime. They also produced fewer lambs at the first and second parturition. The daily liveweight gain for lambs during the first 8 weeks of life are significantly higher for lambs suckled by ewes of high condition score (3.2) than lambs suckled by ewes of low condition score (2.4) (Gibb and Treacher 1980). Therefore, greater ewe live weight and condition throughout pregnancy and lactation will result in heavier lambs which will result in greater profitability.

Mulesing Merino lambs

Merinos are disadvantaged by having folds in the skin (wrinkles) around the breech that accumulate dags, urine and sweat, predisposing them to blowfly strike (Anson and Beasley 1975; Heath and Bishop 2006). Blowfly strike is a painful condition (Hall and Wall 1995) and is an extension of the carrion-feeding habits of a few species of Calliphoridae, wherein gravid female blowflies are attracted to sheep by a variety of cues, predominantly olfactory, and stimulated to deposit eggs or live larvae under the influence of another set of cues (Hall and Wall 1995). The rapidly growing maggots eat the living flesh of the sheep and poison them through their ammonia secretions (Guerrini 1988). Sheep show signs of irritation during the first 2 days after eggs have been laid. Once blowfly strike has been initiated, further flies are attracted to the site, and the sheep can die from ammonia poisoning 3-6 days from the onset of the first strike (Sandeman *et al.* 1987; Guerrini 1988).

Blowfly strike is one of the major animal health problems faced by sheep farmers in New Zealand (Thompson *et al.* 1990; Cottam *et al.* 1998). Approximately 3-5% of sheep in New Zealand suffer from blowfly strike each year (Blackwell *et al.* 1997; Heath and Bishop 2006). The cost of the disease is estimated to be $60 million per year (Heath and Bishop 2006). Forty million dollars of this is made up of lost production, productivity, deaths, and costs of chemicals. The additional $20 million is for the downgrading of pelts and from poor quality wool, particularly in Merinos (Heath and Bishop 2006). Further there is the stress on farmers when considering how to deal with these pests and animal welfare issues (including pressure from markets and animal activist groups) (Thompson *et al.* 1990; Brandsma and Blair 1997; Cottam *et al.* 1998). Blowfly strike is also a big problem in Australian sheep flocks with welfare, social and economic impacts on agricultural enterprises (Davidson *et al.* 2006), and a reduction in reproductive performance (Anson and Beasley 1975).

Since the introduction of the 'super-wrinkly' Vermont Merino to Australia in the late 19th century (Townend 1987) (Figure 1.1), Merinos have been successfully selected for their wrinkliness as a means to increase greasy fleece weight (Belschner *et al.* 1937; Gregory 1982b; 1982a). Mulesing largely removes the wrinkly area of the breech, causing it to heal smoother and free of wool, thus reducing the susceptibility to blowfly strike (Luff 1976; Beveridge 1984). It also makes crutching easier and improves hygiene for mulesed ewes at lambing (Luff 1976).

FIGURE 1.1 The 'super-wrinkly' Vermont Merino, introduced to Australia in the late 19th Century (source: http://en.wikipedia.org/wiki/Merino).

The greatest difficulty faced by the industry today with regards to mulesing is the animal welfare issue (Rothwell *et al.* 2007). There is increasing market pressure to stop mulesing, with many markets demanding non-mulesed wool. There is a reluctance to cease the practice due to the lack of alternative methods that provide equal protection against blowfly strike. There have been a number of alternatives to mulesing investigated as outlined in a review by Rothwell *et al.* (2007). Blowfly strike has been a serious production-limiting disease for New Zealand sheep farmers for more than a century. Its severity has increased in recent years for a variety of reasons, some related to changes in farming practice and stocking rates, but principally because another blowfly species has been added to the blowfly strike-initiating fauna. Despite the use of efficacious and persistent insecticides as well as mulesing, blowfly strike continues to be a major problem for New Zealand farmers (Gleeson and Heath 1997). Although mulesing is currently supported by the New Zealand Government Code for Animal Welfare (Morris 2000), the legislation will likely follow that of Australia and have phased out the practice by 2010.

There are two types of mulesing; the modified- and the radical-mules technique (Luff 1976). The modified mulesing operation involves the removal of skin in a crescent-shaped piece either side of the crutch, starting above the base of the tail and extending below the bare area, leaving wounds up to five centimetres wide opposite the vulva (Beveridge 1984). Next, a small strip is removed from the top of the tail (tail stripping), this varies depending on the severity of wrinkles and susceptibility to strike (Beveridge 1984). The radical mules procedure involves extending the two side wounds so that they join above the base of the tail, which combined with extensive tail stripping leaves no wool over the area (Beveridge 1984).

Any form of protection against blowfly strike has the greatest effectiveness while wool is short following shearing or crutching (Luff 1976). Alternatively, the practice of mulesing offers a permanent, and effective method of control against breech strike (Rose *et al.* 1972), the most commonly struck area (69%) of New Zealand sheep (Heath and Bishop 2006). Dun and Donnelly (1965) showed that mulesing provided adequate protection against blowfly strike in a year when strike rates were otherwise high. In addition to mulesing, organophosphates and insect growth-regulator pesticides are used; however, there is increasing industry pressure to reduce their use because of residues in the wool, environmental impacts of chemical usage and increasing resistance from the targeted species (Schinckel and Short 1961; Atkinson and Leathwick 1995; Leathwick and Atkinson 1998; Willams and Brightling 1999).

Mulesing causes abnormal behaviour indicative of pain for 24-48 hours following the procedure (Morris 2000). In addition, levels of endorphins and cortisol are still high 24 hours after the procedure (Morris 2000). Rose *et al.* (1972) reported that mulesed lambs were lighter 6 months after the procedure compared to non-mulesed lambs. There was also a corresponding reduction in liveweight gain, being most pronounced in the very wrinkly sheep. The wrinkly lambs took longer for their mulesing wounds to heal than the plain and moderately wrinkled lambs. This suggests that mulesing may result in reduced liveweight gain at least in the early life of the lamb, the cost of which, could be high over the lifetime of the animal (given that future reproductive performance is also related to live weight). The cost of flystrike may not outweigh the cost of the potential loss in production over the lifetime of the animal. Although genetics can potentially be used as a long-term solution, with the practice ceasing in 2010, an on-farm solution for 'now' is required. There are currently few data available on the effects of mulesing on live weight and fleece characteristics. Knowledge of these relationships would be advantageous in determining the cost of mulesing on the profitability of Merino farms where the practice remains.

Summary and experimental objectives

- This study examined how three management tools could be used to influence the productivity of a Merino system.
- Wool production is influenced by the follicle from which the wool fibres are produced. Secondary wool follicles begin to appear at around day 70 of gestation and influence the fibre diameter and fleece weight. Influencing secondary follicle development can result potentially in a reduction in fibre diameter and an increase in fleece weight therefore increasing profit margins.
- Shearing ewes on or around day 70 of gestation can increase birthweights of their progeny, and potentially altering their follicle population and fleece characteristics to reduce fibre diameter and increase fleece weight. If this was found in Merinos, there could be potential financial advantages.
- Ewe live weight and body condition score throughout the reproductive cycle have an effect on reproductive performance and the performance of their progeny. High live weights and body condition throughout pregnancy and lactation should ensure maximum profitability through lamb production of these ewes. Currently there is sparse information which identifies how live weight and body condition influences reproductive performance in Merino ewes.
- Mulesing Merino lambs reduces their susceptibility to flystrike over their lifetime. Mulesing is a significant welfare issue in New Zealand and Australia at present. Knowledge of how these parameters are linked will help maximise lamb production and performance.

Therefore, the aim of the current thesis was to provide new information on the following:

- **Chapter 2 - Aim:** To investigate the effect of shearing Merino ewes at mid-pregnancy (approximately day 70 of gestation), late-pregnancy (approximately day 110 of gestation) and post-lambing on live weight, fleece characteristics and skin follicle population characteristics of their ewe progeny from tailing through to shearing at approximately 1 year of age.
- **Chapter 3 - Aim:** To profile the live weight and body condition score of Merino ewes and determine the influence of live weight and body condition score on pregnancy diagnosis outcome, lamb weaning weight and the probability that ewes diagnosed as pregnant were lactating at tailing.

- **Chapter 4 - Aim:** To examine the effects of mulesing on lamb liveweight from tailing to their first shearing and dag score from tailing to their first shearing; and fleece characteristics.
- **Chapter 5 - Aim:** To discuss the implications of the results obtained and make recommendations for the practical application of the research.

The thesis consists of three research chapters. While these chapters examine different management parameters, they contain the same animals. In each chapter, the numbers of animals used is identified as they vary between chapters. In addition, a timeline of measurements is given in Chapter 2 for ewe measurements and Chapter 3 for lamb measurements.

Chapter 2

The effect of shearing time of Merino ewes on their progeny

Introduction

Research has shown, with a varying degree of response, that shearing of the dam during pregnancy (approximately day 70 of gestation) may increase lamb birth weight (Austin and Young 1977; Morris and McCutcheon 1997; Morris *et al.* 2000; Revell *et al.* 2000; Smeaton *et al.* 2000; Kenyon *et al.* 2002b; Kenyon *et al.* 2004; Kenyon *et al.* 2005; Kenyon *et al.* 2006; Corner *et al.* 2007), lamb survival (Morris *et al.* 1999; Kenyon *et al.* 2002a; Kenyon *et al.* 2006) and lamb weaning weights (Morris *et al.* 1999; Smeaton *et al.* 2000; Kenyon *et al.* 2004). A number of studies have investigated the effect on fleece characteristics and the follicle population in offspring born to mid-pregnancy shorn ewes, although results have been inconsistent. Sherlock *et al.* (2002) reported a decrease in the number of secondary follicles in the progeny of mid-pregnancy shorn ewes and a corresponding increase in fibre diameter. In contrast, Revell *et al.* (2002) showed an increase in the density of secondary follicles in response to mid-pregnancy shearing, with a higher S:P in the progeny of mid-pregnancy shorn ewes. Single-lambs born to mid-pregnancy shorn ewes had a reduction of 17% greasy fleece weight. Kenyon *et al.* (2006) found no effect of mid-pregnancy shearing on fleece characteristics or on the follicle population. None of these experiments investigated the effect of shearing during pregnancy on Merino ewes. A reduction in fibre diameter in Merinos could potentially be a financial advantage to the farmer.

The mechanism responsible for the response to shearing during pregnancy has not been confirmed. It is clear that shearing a pregnant ewe is somehow influencing follicle development in her lamb. The first follicles to develop in the sheep fetus are the primary follicles which are visible from 40 days of gestation. These follicles are producing fibres by 90 days of gestation (Hocking Edwards 1999). Secondary follicles are not apparent until approximately 70 days of gestation, with branching beginning at around 100 days of gestation and continuing until birth (Hocking Edwards 1999). Follicle density is determined by the number of secondary follicles (Hocking-Edwards *et al.* 1996). There is a relationship between follicle density and fibre diameter (Nancarrow *et al.* 1998; Scobie and Young 2000) such that an increase in follicle density generally results in a decrease in fibre diameter. A depression in secondary follicle initiation due to changes in the maternal environment has been shown to decrease wool production and increase fibre diameter because it is the later-initiated follicles that produce fibres with a smaller diameter (Hocking Edwards 1999). Manipulating the follicle density, may result in a reduction in fibre diameter increasing the value of the fleece. It is therefore

possible that shearing ewes during the period of secondary follicle development may alter the follicle population and fleece characteristics of the progeny.

Wool from Merinos has a much higher value than that of strong-wool breeds because a higher price is paid for fine wool. The follicle development in Merinos differs from strong-wool breeds (Rogers 2006); therefore there is more chance of achieving an economically important response from manipulating this development. Thus, the aim of this study was to determine whether shearing Merino ewes at different times of pregnancy affected their progeny's live weight, wool follicle population and fleece characteristics.

Materials and Methods

Animals and treatments

Dams

Four-tooth (n=150) and six-tooth (n=149) ewes were randomly selected from a mob of 1300 mixed-age Merino ewes and bred with four full-mouthed Merino rams during the period of May 2, 2006 (d0) to June 5, 2006 (d34). Pregnancy diagnosis on d79 was used to identify ewes that were not pregnant (n=27; pregnancy rank=0), single-bearing (n=183; pregnancy rank=1) or twin-bearing (n=85; pregnancy rank=2). Non-pregnant ewes were excluded from subsequent measurements. A total of 26 ewes were lost during the experiment, for various reasons including misadventure and hypocalcaemia.

Pregnant ewes were allocated to one of three different shearing treatments, shorn with a cover comb at mid-pregnancy (d106; approximately day 79 of pregnancy; n=90); late-pregnancy (d141; n=85) or post-lambing (d191; n=83). Treatment groups were balanced for pregnancy rank, age and live weight and condition score at d0 and d79. Due to the nature of high-country farming (steep, vast terrain), and the variability of mothering ability of Merino ewes, it was not possible to match lambs to their dams at birth. As a result, a blood sample was collected from ewes and rams at d79 for DNA analysis to determine parentage of their progeny and therefore match the progeny to dam shearing treatment.

Lambs

A total of 250 lambs were present at d191 (tailing/docking) including 128 females which were matched subsequently to their dam and sire using DNA (Genetic Technologies

Ltd, Melbourne, Australia) from a blood sample collected at d191. Only the female lambs that were matched to dams were used in the present experiment.

Timeline of measurements

As lamb birth-date was not measured, the day of experiment was used (e.g. d191 = day 191 of experiment). A timeline of when measurements occurred is shown in Table 2.1. A timeline for the measurements of ewes is given in Chapter 3 – Table 3.1.

TABLE 2.1 Timeline of measurements on Merino ewe lambs throughout the experiment including day of experiment, date of measurement, approximate age of the lamb (determined by calculating the expected start of lambing from the mid-point of breeding) at the time point and a description of what was measured at this time.

Day of experiment (d*x*)	Date of measurement	Approximate age of lamb	Description
191	9 November, 2006	6 weeks	Lambs weighed
192	10 November, 2006	6 weeks	Tailing/docking
283	9 February, 2007	4 months	Weaning
359	26 April, 2007	7 months	Lambs weighed and dag scored
360	27 April, 2007	7 months	Skin biopsy and midside sampling
499	22 September, 2007	12 months	Shearing and midside sampling

Measurements

Dams

Ewes were weighed and condition scored after approximately 4 hours off pasture on d0, d79, d106, d141, d191, and d283 of the experiment. To account for different shearing dates, fleece weights were recorded and added to subsequent live weights.

Lambs

Lambs were weighed after approximately 4 hours off pasture on d191 (approximately 6 weeks of age), d283 (approximately 4 months of age), d359 (approximately 6 months of age) and d499 (approximately 1 year of age). At d191 lambs were given a subjective wrinkle score using a visual assessment of their entire body (Scobie *et al.* 2005). Scores ranged from 1; completely plain skin, through to 5; a large number of prominent wrinkles. Figure 2.1 shows a selection of lambs from the experiment and their allocated wrinkle scores.

FIGURE 2.1 Merino lambs at tailing (d192) with subjective wrinkle scores from 2 (slightly wrinkly skin) to 5 (large number of prominent wrinkles).

A subjective dag score was taken at d283, d359, d499 and d588 using a visual assessment with scores ranging from 0 (no dag) to 5 (heavy dag) (Larsen *et al.* 1994) (Figure 2.2).

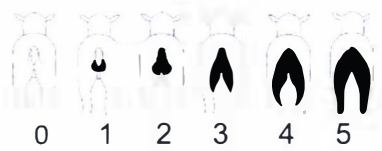

FIGURE 2.2 The scale used to estimate dag score by visual assessment with a score of 0 having no dags and a score of 5 showing extensive dag accumulation (Larsen *et al.* 1994).

All ewe lambs were tailed on d192 using a gas-heated docking iron and 'Novartis-Clik', an insect growth regulator containing dicyclanil, was applied to their backs and the site of the tail removal. Mulesed lambs also had alcohol-based iodine applied to the wounds. All lambs were drenched with selenium. Lambs were weaned on d283 at approximately 4.5 months of age.

At approximately 7 months of age (d360), a mid-side wool sample was collected from the right side of the lamb. The wool was cut as close to the skin as possible using electric Oster small animal clippers. This sample was used to measure fleece parameters of the lambs at 7 months of age (see later for details). A skin biopsy was taken from these lambs within the clipped mid-side area (McCloghry 1997). The clipped skin patch was sterilised with iodine and a local anaesthetic (2ml, Nopaine 2%; containing lignocaine hydrochloride, Ethical Agents, New Zealand Ltd.) was injected

subcutaneously in an L-block pattern around the area to be sampled. This was left for 3 minutes, before a skin biopsy was taken adjacent to the injection site, using a 10-mm biopsy trephine. The biopsy was then elevated using blunt forceps and scissors were used to trim off trailing strands of dermis. The skin sample was immediately fixed in formaldehyde. The biopsied area was then retreated with iodine.

The lambs were shorn at approximately 1 year of age (d499). Fleeces were weighed and a further mid-side wool sample was collected for analysis of length and strength. A professional classer sorted fleeces into 7 commercial lines for sale. The line each fleece was classed into was recorded (Table 2.2).

Animals were managed on Lincoln University's Mt Grand Station, Hawea Flat, New Zealand under commercial farming practices. The study was approved by the Massey University Animal Ethics Committee.

TABLE 2.2 Subjective description of each fleece line based on a visual appraisal by a professional wool classer of fibre diameter, staple length and other characteristics.

Line	Fibre diameter description	Staple length description	Other
1	Superfine/Extrafine	Long	-
2	Fine	Long	-
3	Medium	Long	-
4	Extrafine	Medium	-
5	Fine	Medium	-
6	-	-	Tender
7	-	-	Short (less than 55mm), coloured, plus backs etc

Laboratory methods

The wool samples collected at d360 were conditioned at 20°C and 65% relative humidity for 168 hours prior to removing a 50g sub-sample which was scoured in a 4-bowl sample scour. These scoured samples were then conditioned for a further 72 hours and re-weighed. The washing yield was calculated using the following equation:

$$\%\ yield = \frac{weight\ of\ greasy\ sample}{weight\ of\ scoured\ sample} \times \frac{100}{1}$$

A sample of 10g was taken from the clean sample which was put through a two-drum hand-operated card 3 times and any excess vegetable matter was removed.

Carded samples were then measured for colour using a HunterLab ColourQuest in Y-Z units to the New Zealand Standard for the measurement of colour (NZS8707:1984) (SANZ 1984). The sample was then cored by hand using a 2mm trocar and the core samples used to measure mean fibre diameter in microns using an Optical Fibre Diameter Analyser (OFDA100) (IWTO 1998).

Mid-side samples collected at d499 (shearing) were sent to the New Zealand Wool Testing Authority, Napier, New Zealand to be analysed for length and strength using ATLAS (Automatic Tester for Length and Strength) (IWTO-7 and 17 respectively). The test uses a sample (n=5) of staples drawn from the mid-side sample, and measures the length of the sampled staples, the force required to break them and the position of the break along the staple.

The skin samples collected on d360 were embedded in paraffin wax and sectioned to 8-µm thickness transverse to the plane of the follicle and stained using haematoxylin, eosin and picric acid (McCloghry 1997). Sections containing primary (P) and secondary (S) follicles were selected at the level of the sebaceous gland in the skin, and were examined using a light microscope at 200 times magnification. Wool follicles were counted in a minimum of 6 fields-of-view for each skin sample. P and S follicles were counted and their respective densities were calculated after adjusting for shrinkage. Image-Pro Plus - Image analysis software (Version 4.1 for Windows, 1993) and Media Cybernetics, L.P, were used to measure the area of the embedded biopsy samples. The area of the initial biopsies, pre-fixation was calculated using the area of the trephine and the shrinkage factor was calculated as:

$$Shrinkage\ factor = \frac{Area\ of\ embedded\ biopsy}{Area\ of\ the\ trephine}$$

The shrinkage factor was used to adjust the measured follicle densities back to the original density in the dermis of the animal.

Statistical analyses

All statistical analyses were carried out using SAS (Statistical Analysis System, version 8.2; SAS Institute Inc., Cary, NC, USA, 2001). Live weights of ewes shorn at different times were analysed as repeated measures using the MIXED procedure with linear models. The fixed effects of shearing treatment, day of measurement, the interaction of day-by-shearing treatment and the random effect of ewe were considered. The effect of shearing treatment on live weight of the lambs at d191, d283, d359 and d499 were

analysed using the MIXED procedure with a linear model that included the fixed effects of dam shearing treatment, mulesing treatment, ewe age, wrinkle score, pregnancy rank, dag score at d283, d359 and d499; and the random effect of sire. Live weight of ewes at d0, d79, d106, d141, d191, and d283; and live weight of lambs at d191, d283 and d359 were fitted as covariates where indicated.

The effect of shearing treatment on fleece fibre diameter, colour, washing yield at d360, and fleece weight, fleece line, staple length and staple strength at d499 was analysed using the MIXED procedure with a linear model that included the fixed effects of dam shearing treatment, mulesing treatment, wrinkle score, ewe age and pregnancy rank, and the random effect of sire.

The effects of shearing treatment on secondary to primary follicle ratio (S:P), total follicle density, primary follicle density, secondary follicle density, total follicle number index, primary follicle number index and secondary follicle number index were analysed using the MIXED procedure with a linear model that included the fixed effects of dam shearing treatment, wrinkle score, ewe age and pregnancy rank, and the random effect of sire.

Follicle index was calculated as the product of follicle density and approximate surface area of the lamb (Fozi *et al.* 2007). Approximate surface area was calculated with the following equation (Freer *et al.* 1997).

$$Approximate\ surface\ area = 0.09 \times Live\ weight^{\frac{2}{3}}$$

The effect of shearing treatment on fleece line and wrinkle score was analysed using the GENMOD procedure for non-continuous data that included the fixed effect of dam shearing treatment.

Non-significant (P>0.05) variables were removed from each model to determine final solutions; significant effects are detailed in the results. Not all animals had measurements for all parameters; therefore, numbers are shown in the text or the tables. Rearing rank was not determined, so pregnancy rank was used in the models.

Results

The only difference in live weight observed was at d141 (late-pregnancy shearing) when the mid- and late-pregnancy shorn ewes were heavier (P<0.05) than the post-lambing shorn ewes after live weight had been adjusted for fleece weight. This difference had disappeared by d191 (Figure 2.3).

Figure 2.4 profiles the ewe-lamb live weight from d191 to d283. No difference in live weight was observed between treatments except at d359 where lambs born to mid-pregnancy shorn ewes tended to be heavier (P=0.091) than lambs born to late- and post-lambing shorn ewes. Single-born lambs were heavier than their twin-born counterparts at tailing (d191; P<0.05) and at weaning (d283; P<0.05) but did not differ after this point (Figure 2.5).

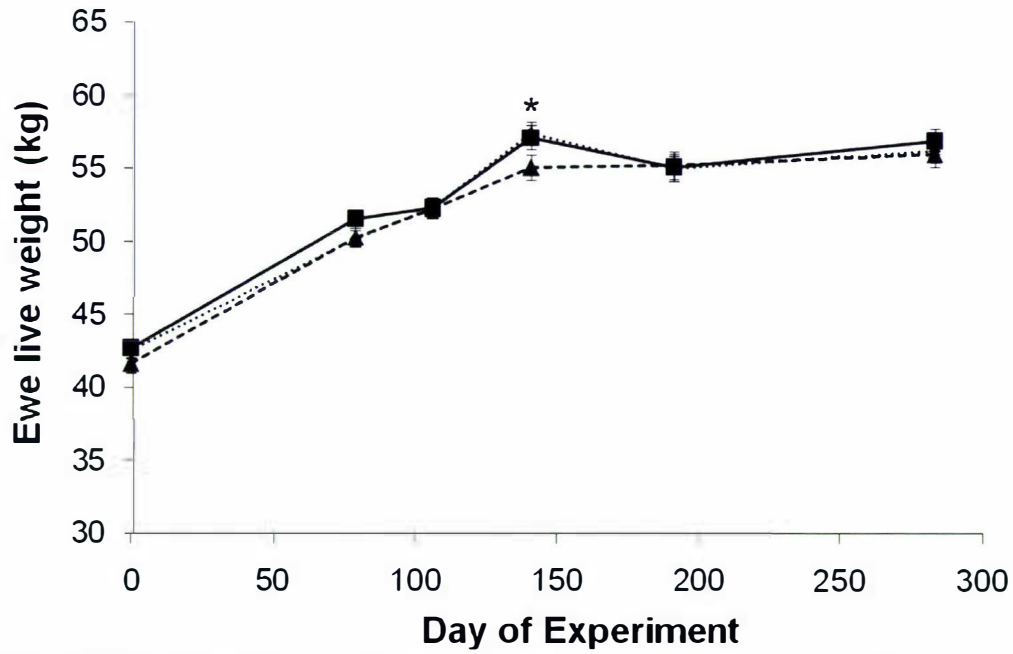

FIGURE 2.3 The live weight profile using least squares means and standard errors of the means of mid-pregnancy shorn (d106; ···♦···), late-pregnancy shorn (d141; –■–) and post-lambing shorn (d191; --▲--) Merino ewes. * indicates mid-pregnancy shorn and post-lambing shorn ewes differ at the P<0.05 level.

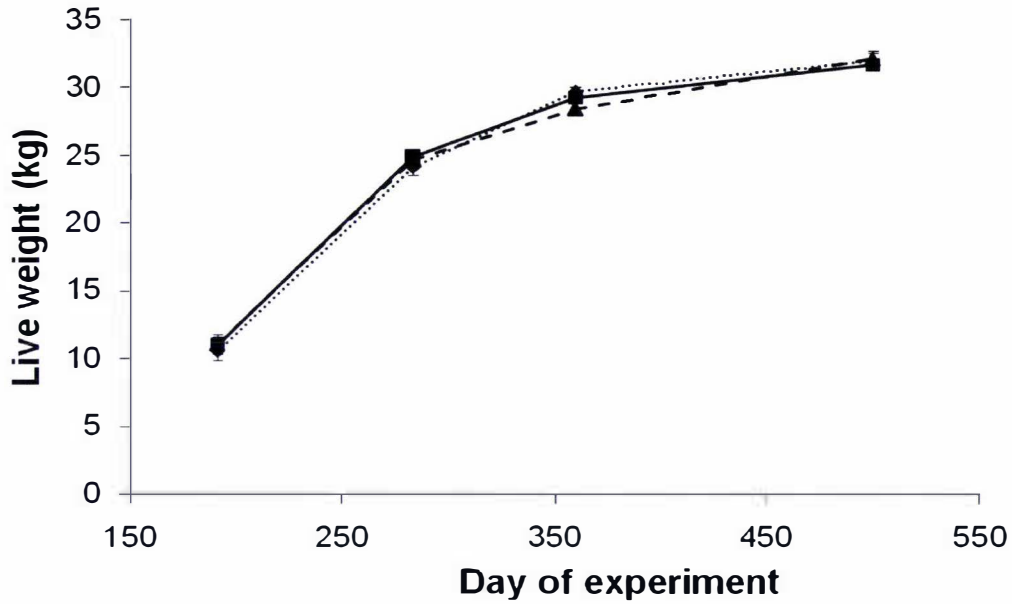

FIGURE 2.4 The live weight profile using least squares means and standard errors of the means at tailing (d191), weaning (d283), biopsy (d359) and shearing (d499) of Merino lambs whose dams were mid-pregnancy shorn (d 106; n=31; ···♦···), late-pregnancy shorn (d141; n=37; –■–) and post-lambing shorn (d192; n=28; --▲--).

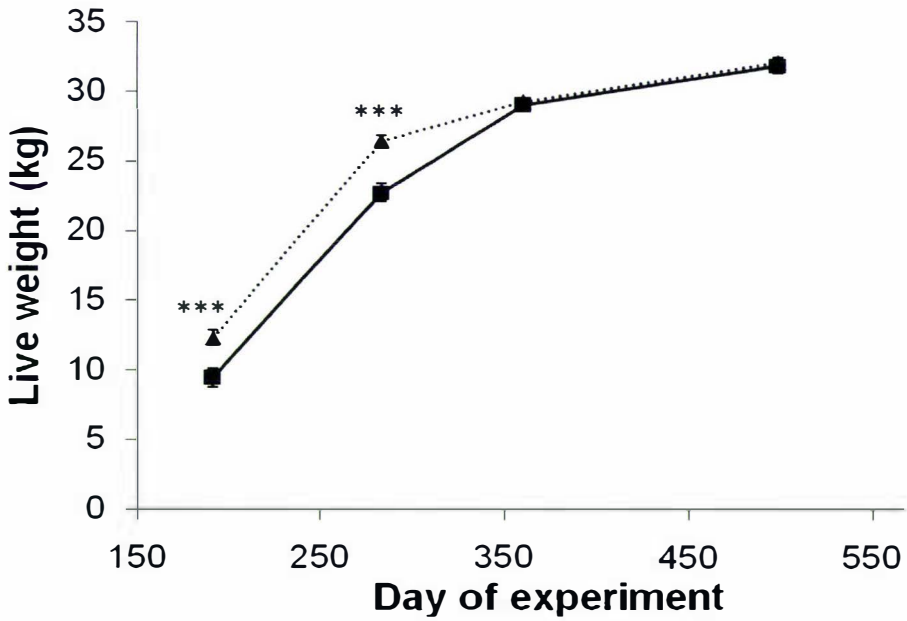

FIGURE 2.5 The live weight profile using least squares means and standard errors of the means at tailing (d191), weaning (d283), biopsy (d359) and shearing (d488) of single- (n=64, 61, 62 and 62 respectively; ···▲···) and twin-born (n=37, 33, 35 and 34 respectively; —■—) Merino lambs. *** indicates significant difference at P<0.001 level.

TABLE 2.3 The effect of shearing treatment, wrinkle score and pregnancy rank on the secondary to primary follicle ratio (S:P), total follicle density, primary follicle density (P°density), secondary fol licle density (S°density), total follicle number index (T FNI), primary follicle number index (P°FNI) and secondary follicle number index (S°F NI). Values are least squares means and standard errors of the means at d360 (approximately 7-month-old) Merino ewe lambs. Data points in a column without letters in common differ significantly (P<0.05).

	n	S:P	Total follicle density	P°density	S°density	TFNI	P°FNI	S°FNI
Shearing treatment								
Mid-pregnancy shorn	31	16.00 ± 0.67	81.13 ± 3.37[a]	5.02 ± 0.23	76.22 ± 3.28[a]	69.31 ± 3.00[a]	4.22 ± 0.19	65.16 ± 2.90[a]
Late-pregnancy shorn	37	16.26 ± 0.62	86.29 ± 3.51[a]	5.16 ± 0.22	81.35 ± 3.41[a]	72.71 ± 3.13[a]	4.33 ± 0.17	68.49 ± 3.01[a]
Post-lambing shorn	28	17.16 ± 0.71	94.59 ± 3.47[b]	5.47 ± 0.24	89.31 ± 3.38[b]	79.54 ± 3.09[b]	4.50 ± 0.19	75.03 ± 2.99[b]
Wrinkle score								
2	2	16.63±2.48	85.62±10.12	4.91±0.75	80.78±9.86	70.88±8.68	4.23±0.61	68.90±8.62
3	25	14.64±0.74[a]	79.42±2.92[a]	5.30±0.25	74.15±2.85[a]	65.03±2.52[a]	4.38±0.21	61.55±2.49[a]
4	33	17.32±0.69[b]	94.54±2.67[b]	5.29±0.23	89.28±2.60[b]	82.50±2.18[b]	4.57±0.19[a]	76.70±2.28[b]
5	26	17.65±0.75[b]	89.86±3.03[b]	4.86±0.25	84.99±2.95[b]	77.03±2.45[b]	4.08±0.21[b]	71.51±2.58[b]
Pregnancy rank								
Single lambs	55	16.45±0.48	87.75±3.38	5.34±0.17	82.45±3.29	76.17±2.94	4.63±0.15[a]	71.59±2.87
Twin lambs	32	16.51±0.66	86.97±3.25	4.98±0.21	82.15±3.17	71.72±2.84	4.07±0.18[b]	67.74±2.77

Dam shearing treatment had no effect on the S:P, primary follicle density and primary skin follicle number index of their progeny at d360 (Table 2.3). The progeny of post-lambing shorn dams had a higher ($P<0.05$) total follicle density, secondary follicle density, total skin follicle number index and secondary follicle number index than the progeny of mid- and late-pregnancy shorn dams (Table 2.3). Lambs born as singles had a greater ($P<0.05$) primary follicle number index than their twin-born counterparts (Table 2.3).

Wrinkle score had an influence on total follicle density, secondary follicle density, total skin follicle number index and secondary follicle number index. Animals that had higher wrinkle scores were associated with a higher S:P, total follicle density, secondary follicle density, total follicle number index, primary follicle number index and secondary follicle number index (Table 2.3).

Fleece characteristics at d360 and 499 did not differ between treatment groups (Table 2.5). Single-born lambs had heavier fleeces (2.53kg ± 0.08; $P<0.01$) than their twin-born counterparts (2.27kg ± 0.08) but there was no difference between any other characteristics (Table 2.5). Wrinkle score had a significant effect on fleece weight ($P<0.001$); the higher the wrinkle score the heavier the fleece weight at d499 (Table 2.4). There was no difference between wrinkle scores at d191 for the lambs of mid-, late-pregnancy and post-lambing shorn ewes (data not shown).

TABLE 2.4 Least squares means and standard error of the mean of fleece weight at d499 (approximately 1 year of age) for each wrinkle score class (measured at d191).

Wrinkle score	n	Fleece weight (kg)
2	2	2.34 ± 0.24^{abc}
3	29	2.22 ± 0.07^{a}
4	35	2.41 ± 0.07^{ab}
5	30	2.63 ± 0.07^{abc}

TABLE 2.5 The effect of shearing treatment and pregnancy rank of Merino ewe lambs on: fibre diameter, colour and yield on d360 (approximately 7-months-old); and fleece weight, staple length, staple strength and fleece line on d499 (approximately 1-year-old). Values are least squares means and standard errors of the means. Data points in a column without letters in common differ significantly ($P<0.05$).

	n	Fibre diameter (µm)	Colour (Y-Z)	Washing yield (%)	n	Fleece weight (kg)	Staple length (mm)	Staple strength (N/kt)	Fleece line
Shearing treatment									
Mid-pregnancy shorn	31	17.12 ± 0.14	-0.015 ± 0.18	72.52 ± 0.84	-	2.37 ± 0.07	69.58 ± 1.46	37.32 ± 2.07	4.32 ± 0.35
Late-pregnancy shorn	37	17.13 ± 0.14	0.16 ± 0.17	70.89 ± 0.79	-	2.46 ± 0.06	69.78 ± 1.35	40.80 ± 1.95	3.46 ± 0.32
Post-lambing shorn	28	16.86 ± 0.15	-0.11 ± 0.19	70.61 ± 0.88	-	2.41 ± 0.07	67.54 ± 1.53	39.29 ± 2.14	4.46 ± 0.37
Pregnancy rank									
Single-born lambs	61	17.14 ± 0.11	-0.018 ± 0.15	71.25 ± 0.63	62	2.53 ± 0.08[b]	69.11 ± 1.05	38.77 ± 1.63	4.02 ± 0.26
Twin-born lambs	35	16.85 ± 0.14	0.063 ± 0.18	71.51 ± 0.81	34	2.27 ± 0.08[a]	68.70 ± 1.43	39.80 ± 2.05	4.06 ± 0.35

Discussion

Previous studies have found a response to shearing time of crossbred ewes in the fleece characteristics and follicle population of their progeny (Revell *et al.* 2002; Sherlock *et al.* 2002), although, effects have been inconsistent. The aim of this experiment was to determine if the shearing time of Merino ewes had an effect on fleece and follicle characteristics in their progeny. The effect of shearing time on live weight from tailing (at approximately 6 weeks of age) to shearing (approximately 1 year of age) was also investigated.

It has been suggested that the number of primary follicles is not influenced to any great extent by maternal environment but the secondary follicles are. Therefore in order to manipulate the follicle population, the secondary follicles should be targeted (Kelly and Macleod 1991). Shearing at day 70 of pregnancy (mid-pregnancy) coincides with the start of the wave of secondary follicles that begin to appear in fetal skin, but it is after the wave of primary follicles (Kelly and Macleod 1991; Hocking-Edwards *et al.* 1996). This experiment targeted this wave of follicles by shearing at approximately day 79 of pregnancy. Total follicle density, secondary follicle density, total skin follicle number index and secondary skin follicle number index were greatest in lambs whose dams were not shorn during pregnancy. This did not reduce fibre diameter as is often the case with an increased secondary follicle population. A potential reason for this is that there may have been different nutrient allocations in response to shearing between follicle and fibre development which was suggested by Kelly *et al.* (1996). The nutrient allocation may have caused a change in the follicle development but not influenced the outcome of fibre development.

In contrast to the present experiment, Revell *et al.* (2002) increased the density of secondary follicles in the progeny of Border Leicester x Romney ewes in response to mid-pregnancy shearing and also increased the S:P. A persistent reduction in the number of mature secondary follicles is related to reduced numbers of follicles per unit area of skin and to reduced body size (Turner 1961; Dun and Grewal 1963; Lax and Brown 1967). The maturation of secondary follicles can be retarded if the nutrient supply is restricted in late pregnancy of the ewe (Corbett 1979). The response from shearing time may depend on the nutritional status of the ewe (Kenyon *et al.* 2002b). This is a potential explanation for the contrasting result of the present experiment with Revell *et al.* (2002). Sherlock *et al.* (2002) found that the number of secondary follicles decreased in response to mid-pregnancy shearing, as with the present study. This was attributed to different breeds responding differently to shearing. Sherlock *et al.* (2002)

used Romney lambs and concluded differences may be based on different breeds, which may also explain the response that was found in the present study with Merinos.

Previous studies have found both live weight and fleece changes in the progeny of mid-pregnancy shorn ewes. Contrary to previous studies on mid-pregnancy shearing of ewes (Kenyon *et al.* 2002b; Kenyon *et al.* 2004), the present experiment found no live weight difference or difference in fleece characteristics between the progeny of mid-, late-pregnancy and ewes not shorn during pregnancy at any stage of the experiment. In agreement with Kenyon *et al.* (2006) the present experiment found no effect of mid-pregnancy shearing on fleece characteristics. Kenyon *et al.* (2002b) suggested that the best conditions to get a birthweight response were the ewe having the potential to respond to shearing, and having the maternal reserves to partition to the foetus. In the present experiment the ewes were of poor condition during breeding which may have reduced their ability to partition extra nutrients to the fetus and therefore affect follicle development, fleece characteristics and live weight of their progeny.

Another potential explanation for the lack of a response in live weight, follicle and fleece characteristics (apart from secondary follicle numbers) is that in other studies (Revell *et al.* 2002; Sherlock *et al.* 2002) ewes were shorn at day 70 of pregnancy and in the present study ewes were shorn at day 79. This is still before secondary follicle development at between day 90 and 110 (Hocking Edwards *et al.* 1996) so is unlikely to be a significant contributor to the lack of response.

In some studies, ewe live weight during pregnancy was not affected by shearing treatment (Morris and McCutcheon 1997; Morris *et al.* 2000; Kenyon *et al.* 2002b; Revell *et al.* 2002). Smeaton *et al.* (2000) found that shearing resulted in ewe live weight loss which persisted through to August. However, after lambing, shorn ewes were heavier than their unshorn counterparts. Contrary to these studies, the present study found that mid-pregnancy shearing resulted in a higher live weight in late-pregnancy compared with ewes that were not shorn during pregnancy. A potential explanation for this is an increased intake as a result of shearing (Kenyon *et al.* 2003), which could have initially increased the live weight gain of the mid-pregnancy shorn sheep.

Live weight was greater in single-born lambs compared with twin-born lambs, at tailing and weaning. After this point there was no difference, presumably due to compensatory growth in twin-born lambs. Egan *et al.* (1977) showed that twin-born ewes are able to achieve compensatory growth under favourable growing conditions.

The primary follicle number index was greater in singles; however, this difference was not enough to alter the overall density or indices. Corbett (1979) reported that at first shearing the greasy fleece weight of twins compared with singles was less by up to 0.25 kg. This does not affect the clean scoured fleece weight (Brown *et al.* 1966), suggesting that the additional fleece weight is actually grease and suint content. Lighter fleeces were also observed in the present study in twin-born lambs, supported by Revell *et al.* (2002) and Dun and Grewal (1963). Dun and Grewal (1963) suggested that despite their lower fleece weights; twin ewe lambs had an equivalent wool production per unit area of skin and were therefore just as productive as single-born lambs.

Merinos have been selected for wrinkliness in an effort to increase fleece weight (Belschner *et al.* 1937) by increasing the skin area. In the present experiment the wrinklier the lambs were, the heavier their fleeces were, a finding confirmed by Scobie *et al.* (2005). However, wrinklier animals also had higher S:P, total density, secondary density and follicle indices, suggesting that their heavier fleeces may also have been due in part to the increased fibre density, caused by an increased number of secondary follicles. This suggests that animals with greater wrinkliness may have increased fleece production and potentially decreased fibre diameter by increasing the skin follicle number index compared to less wrinkly animals. One of the implications of selecting for increased wrinkles is the increased susceptibility to blowfly strike and potential reduction in wool quality (Scobie *et al.* 2005). Wrinkle scores in the present experiment were skewed towards the higher end of the scale, with no animals having a wrinkle score of 0 or 1, and 2 animals having a wrinkle score of 2. This suggests conclusions drawn with regards to wrinkle score should be interpreted with caution.

In conclusion, the shearing time of Merino ewes did not affect the live weight of their progeny. Progeny born to ewes that were not shorn during pregnancy had higher secondary follicle densities than progeny born to ewes shorn in mid- or late-pregnancy. The consequence of this was an increased follicle density, follicle number index and secondary follicle number index. No effect on fleece characteristics was observed. Based on these findings not shearing ewes during pregnancy has the potential for economic advantage from the increase in follicle density, which may result in a decrease in fibre diameter, although this was not observed in the present study. These results suggest that in Merinos, shearing in either mid- or late-pregnancy, under the conditions of the present study, is not a management tool farmers could use to alter the fleece characteristics of the resulting progeny.

Chapter 3

Live weight and body condition score of Merino ewes

Introduction

Merino ewes in New Zealand are bred primarily for wool production but also potentially go through several reproductive cycles producing one to two lambs per year. Although Merinos are bred primarily for wool production, prices paid per kilogram of wool have been diminishing placing greater emphasis on meat production (Scales *et al.* 2000). Live weight and body condition throughout the reproductive cycle relate to reproductive performance measures (Kleemann and Walker 2005). This means that reproductive performance is also important.

High reproductive performance results in heavier lambs and an increased lambing percentage and in some studies minimises lamb losses (Gibb and Treacher 1980; Hall *et al.* 1995; Steinheim *et al.* 2002). Potentially more lambs for slaughter can result in increased value (assuming feed efficiency is maintained or improved). Reproductive losses are traditionally high in Merino ewes (Hocking Edwards and Starbuck 2006) and the correct management of live weight and body condition could potentially reduce this. Despite this, there is minimal data currently available currently under New Zealand grazing conditions for Merino ewes on the effect of live weight and body condition score and its influence on reproductive performance. The aim of this experiment was to profile the live weight and body condition score (BCS) of Merino ewes throughout one reproductive cycle from breeding through to the weaning of their lambs. The profiles were then used to investigate the influence of live weight and condition score of ewes on the result at pregnancy diagnosis, lamb weaning weight and the probability that ewes diagnosed as pregnant were lactating at tailing.

Materials and Methods

Animals and treatments

Four-tooth (n=150) and six-tooth (n=149) ewes were selected randomly from a mob of 1300 mixed-age ewes and bred with four full-mouthed Merino rams during the period of May 2, 2006 (day 0 of experiment; d0) to June 5, 2006 (d34). Pregnancy diagnosis (PD) was conducted using an ultrasound scanner on d79, to identify whether ewes were non-pregnant (n=27; pregnancy rank=0), carrying a single-foetus (n=183; pregnancy rank=1) or carrying twin foetuses (n=85; pregnancy rank=2). Ewes that were not pregnant were excluded from subsequent measurements. A total of 26 ewes were lost during the experiment, for various reasons including misadventure and hypocalcaemia.

As part of a separate experiment (Chapter 2), ewes were randomly allocated into one of three shearing treatments; mid-pregnancy shorn (d106), late-pregnancy shorn (d141) or post-lambing shorn (d192). To adjust for having been shorn at different times of the year, fleece weight was measured at shearing and added onto subsequent live weights for each ewe. The time of shearing was included in the statistical models to eliminate any effect it may have had on the results.

At breeding (d0), pregnancy diagnosis (d79), mid-pregnancy (d106), late-pregnancy (d141), tailing (d191) and weaning (d283) ewes were weighed and their BCS was assessed on a scale of 1 (emaciated) – 5 (obese) (Jefferies 1961). Udders of the dams were palpated at tailing to identify ewes that were not lactating (n=49). This was used to indicate whether the ewe had reared a lamb. Only ewe lambs were measured due to retention on the property as replacements.

Timeline of measurements

As lamb birth-date was not measured (due to difficult terrain and poor mothering ability of Merinos), the day of experiment is used. A timeline of when measurements occurred is shown in Table 3.1.

TABLE 3.1 Timeline of measurements on Merino ewes throughout the experiment including day of experiment, date of measurement and a description of measurement

Day of experiment (d*x*)	Date of measurement	Description
0	2 May, 2006	Breeding
79	20 July, 2006	Pregnancy diagnosis
106	16 August, 2006	Mid-pregnancy shearing
141	20 September, 2006	Late-pregnancy shearing
191	9 November, 2006	Ewe weighing
192	10 November, 2006	Post-lambing shearing and tailing/docking
283	9 February, 2007	Weaning

Statistical analyses

Statistical analyses were carried out using SAS (SAS 2001). Ewe live weight and BCS were analysed as repeated measures using the MIXED procedure with linear models. The fixed effects of shearing treatment, day of measurement, pregnancy rank and the interaction of day by pregnancy rank and the random effect of ewe were considered.

The logistic procedure with a regression model was used to analyse the effect of live weight and condition score on pregnancy rank; fitting live weight at breeding and PD as covariates and the fixed effects of ewe age and BCS at breeding and PD. This procedure was also used to analyse the probability that a ewe diagnosed as pregnant at PD was lactating at tailing, considering the fixed effects of BCS at all time points, ewe birth-year and Pregnancy rank. Ewe live weights at all time points were fitted as covariables.

Using the generalised linear model (GLM) procedure, the effect of ewe live weight and BCS throughout the reproductive cycle on ewe-lamb weaning weight was analysed. This model considered the fixed effects of ewe birth-year, pregnancy rank and BCS at d0, d79, d106, d141, d191 and d283 of experiment. Ewe live weights at d0, d79, d106, d141, d191 and d283 of experiment and the interactions between age and these live weights were fitted as covariables.

Non-significant ($P>0.05$) variables were removed from each model to determine final solutions; significant effects are detailed in the results. Not all animals had measurements for all parameters, so analyses were conducted on as many records as were available (numbers in each analysis are shown in the tables). The number of ewes available for measurement at any time point varied due to the vagaries of mustering in this extensive environment.

Results

Single-bearing ewes were lighter at d0, d79, d106 and d141 than their twin-bearing counterparts (Figure 3.1). From tailing onwards there was no difference between single- and twin-bearing ewes. The body condition score profiles of single- and twin-bearing ewes are shown in Figure 3.1. Ewe BCS was least at d0 and increased to d79. Twin-bearing ewes began to lose body condition late in pregnancy and had a lower condition than single-bearing ewes at d192. Twin-bearing ewes then recovered body condition so that there was no difference between single- and twin-bearing ewes at d283.

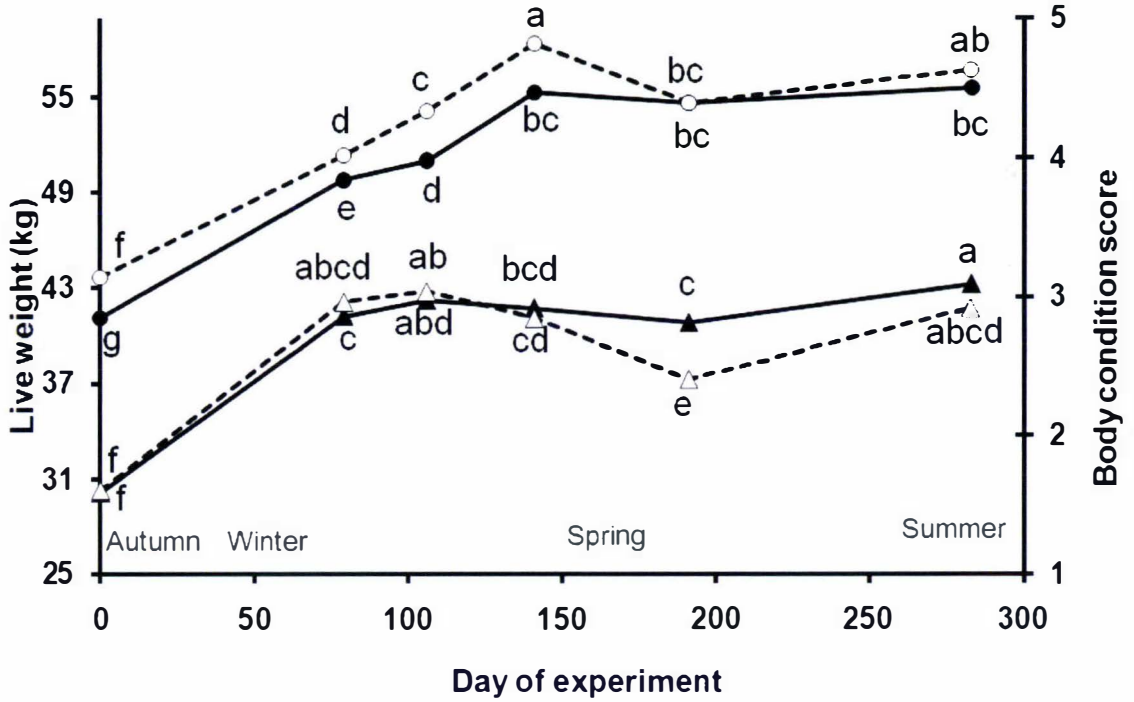

FIGURE 3.1 Live weight (singles: —●—; twins: ---○---) and body condition score (BCS) (singles: —▲—; twins: ---Δ---) profiles of Merino ewes throughout one reproductive cycle with measurements at d0 (breeding), d79 (pregnancy diagnosis), d106 (mid-pregnancy), d141 (late-pregnancy), d192 (tailing) and d283 (weaning) for single- (n=183, 181, 181, 183, 175 and 144 respectively) and twin-bearing ewes (n=85, 85, 85, 84, 74 and 53 respectively) using least squares means and standard errors of the means. Data points within live weight or within body condition score without letters in common differ significantly (P<0.05).

There was no difference in live weight or BCS at d0 (breeding) or d79 (PD) between ewes that were identified as either pregnant or non-pregnant at PD (Table 3.2).

TABLE 3.2 Means and standard errors for live weight and body condition score of ewes at d0 (breeding) and d79 (pregnancy diagnosis) for ewes diagnosed as pregnant and those that were not pregnant at d79.

	n	Pregnant at PD	n	Not pregnant at PD
Live weight at breeding	269	41.91 ± 0.30	26	40.61 ± 0.70
Live weight at PD	269	49.99 ± 0.28	26	50.15 ± 1.03
Condition score at breeding	269	1.36 ± 0.03	26	1.32 ± 0.07
Condition score at PD	266	2.83 ± 0.03	26	2.69 ± 0.09

Ewes that were diagnosed as pregnant but were identified as not lactating at tailing accounted for 19.5% of the total number of ewes present at tailing. Live weight at mid-pregnancy and tailing, and pregnancy rank were related to the probability of a ewe diagnosed as pregnant, lactating at tailing (rearing a lamb; Table 3.3). For every 1kg increase in live weight at mid-pregnancy, pregnant ewes were 1.23 times more likely to be lactating at tailing. For every 1kg increase in ewe live weight at tailing ewes were 0.20 times less likely to be lactating at tailing. Single-bearing ewes were 3.09 times more likely to be rearing a lamb at tailing than their twin-bearing counterparts.

TABLE 3.3 The probability that a ewe, diagnosed as pregnant at d79, was lactating at tailing (d191): Regression coefficients, standard errors, odds ratios, 95% confidence intervals for the odds ratios, and probability levels from logistic regression of live weight at mid-pregnancy (d106), live weight at lamb tailing and pregnancy rank of Merino ewes (n=235).

	Regression coefficient	Standard error	Odds ratio	95% confidence interval	Significance
Live weight mid-pregnancy (kg)	0.21	0.064	1.23	1.09–1.40	**
Live weight tailing (kg)	-0.23	0.059	0.80	0.71–0.89	***
Pregnancy rank					
1	0.56	0.200	3.09	1.42–6.71	**
2	0.0		1.0		

* P<0.05; ** P<0.01; *** P<0.001

Live weight of lambs at weaning was not affected by BCS of ewes at any stage of the reproductive cycle. In contrast, a 1 kg increase in live weight of ewes at PD resulted in a reduction of 0.17 kg in live weight of the lamb at weaning whilst a 1 kg increase in ewe live weight at mid-pregnancy resulted in a 0.21 kg increase in live weight of the lamb at weaning (Table 3.4). No other live weights of the ewes were associated with live weight of the lambs at weaning. Ewes identified as single-bearing at PD reared ewe lambs that were heavier (P<0.001) at weaning than those born to ewes that were identified as multiple-bearing (27.54 ± 0.44 kg vs 21.29 ± 0.63 kg).

TABLE 3.4 Regression coefficients of ewe live weight at pregnancy diagnosis (PD; d79) and mid-pregnancy (d106) and level of significance.

	Regression coefficient	Significance
Live weight PD (kg)	0.17	**
Live weight mid-pregnancy (kg)	0.21	**

* P<0.05; ** P<0.01; *** P<0.001

Discussion

This study examined the relationship between live weight and body condition score profiles of Merino ewes in the South Island High Country and their reproductive performance. Reproductive performance was measured using the indices of pregnancy diagnosis data, the probability of rearing at least one lamb through to tailing, and lamb weaning weight.

The greatest live weight occurred in twin-bearing ewes in late-pregnancy, consistent with reports for Merinos in Australia (Waters *et al.* 2000). The live weight of twin-bearing ewes subsequent to PD was likely to be greater than single-bearing ewes due to the weight of the conceptus, rather than ewe live weight (evidenced by the decline in condition score in late-pregnancy of twin-bearing ewes). Single-bearing ewes weighed less at breeding, pre-lambing and lambing, but weighed more at weaning than twin-bearing ewes, in agreement with Waters *et al.* (2000). The size and timing of live weight changes showed similar patterns to that reported in Australian experiments (Waters *et al.* 2000; Kleemann *et al.* 2006). Ewes were of relatively low live weight and body condition at mating however made significant gains over the breeding period. The previous season had resulted in limited feed leading up to mating, at which point ewes were put on a fresh block of land with a much greater level of feed. This is the likely explanation for the increase in live weight and condition score over this period. In addition, the first condition score measurement was taken by a different person. Being a subjective measure this may have influenced this result.

The lesser live weight of single- compared with twin-bearing ewes at breeding in the present study was also observed by Gonzalez *et al.* (1997). Gonzalez *et al.* (1997) reported an increase in condition score between breeding and PD, which was proportionately more than the corresponding changes in live weight. Body condition declined in late pregnancy, particularly in twin-bearing ewes, consistent with results of Copping and Hocking Edwards (2006). Twin-bearing ewes can suffer from below

adequate total liveweight gain, including the conceptus. Therefore it may be beneficial to feed ewes (particularly twin-bearing) well in the later stages of pregnancy. This can minimise the loss in body condition that may result from higher energy demands at this time and improve twin ewe and progeny performance (Kenyon and Webby 2007; Toland Thompson *et al.* 2007).

There was no difference in live weight or BCS at breeding or PD between ewes that were identified as either pregnant or non-pregnant at PD. In contrast, Gonzalez *et al.* (1997) and Waters *et al.* (2000) found ewe live weight affects pregnancy rates, while McInnes & Smith (1966) showed no difference in live weight or condition score at breeding between ewes that conceived and those that did not. Differences in live weight and body condition can generally be attributed to nutrition (although not measured in this experiment).

Ewes that were diagnosed as pregnant but were not rearing a lamb at tailing made up 19.5% of the total number of ewes alive at tailing, this indicates that substantial lamb losses occurred. The individual causes of lamb losses were not assessed. However there were some pre-disposing factors. Live weight at mid-pregnancy appeared to be important; ewes that were heavier mid-pregnancy were more likely to be lactating at tailing, a result consistent with that of Behrendt *et al.* (2006a). These results may indicate that feeding the ewe well during early and mid-pregnancy to ensure a high live weight at mid-pregnancy may increase the likelihood of the ewe lactating at (indicative of rearing a lamb to) tailing. The growth of a foetus in a sheep is controlled by an interaction between the maternal environment and the foetus (Gootwine 2005). This effects foetal development and birth weight, and therefore lamb survival to weaning (Abbott *et al.* 2003). Ewes scanned as single-bearing were three times more likely to be rearing a lamb at tailing than twin-bearing ewes, which is further evidence for the need to ensure ewes are well fed, particularly twin-bearing ewes. There was a negative relationship between live weight at tailing and the probability of a ewe that was diagnosed pregnant, lactating at tailing. This was probably a consequence of, rather than a contributor to, it not rearing a lamb. Analysis fitted pregnancy status into the model to adjust for the difference in conceptus weight between singles and twins.

Live weight at weaning is important if animals are being produced for slaughter at that age (4-6 months of age) (Young *et al.* 1965). Ewe-lamb weaning weight was significantly affected by ewe live weight at pregnancy diagnosis, such that a heavier ewe had lighter lambs at weaning (d283). The outcome at pregnancy diagnosis was fitted into the model so that the model adjusted for the live weight difference between

singles and twins. Lower lamb weaning weights may have been as a result of the ewe partitioning nutrients to its own benefit rather than to its foetus as suggested by Wallace (1996). Ewe live weight at mid-pregnancy also affected lamb weaning weight, such that a heavier ewe had heavier lambs at weaning (d283). Munoz *et al.* (2008) observed greater liveweight gain to weaning from offspring born to ewes offered a high plane of nutrition during early pregnancy, which was associated with a significant decline in ewe live weight during lactation indicating high milk production and therefore producing heavier lambs at weaning. This may have been the case in the present experiment, if the same response was observed slightly later in gestation. The study used Border Leicester x Scottish Blackface ewes which are faster maturing than Merinos (Young *et al.* 1965; Dolling and Nicolson 1967; Hocking Edwards and Starbuck 2006). Lamb weaning weight was influenced by pregnancy rank, with the heavier lambs being those born to single-bearing ewes, and the lighter lambs born to twin-bearing ewes, also shown by Behrendt *et al.* (2006b) and Copping and Hocking Edwards (2006). This result is to be expected due to the higher energy demands of twins and the ewe's inability to produce twice as much milk to meet these demands (Kenyon and Webby 2007).

In conclusion, these results indicate that ewes that are heavier at mating are more likely to be diagnosed pregnant with twins. The consequence of bearing twins is decreased ewe body condition score in late pregnancy, lower weaning weights of their lambs and less chance of their lamb/s surviving to tailing. Ensuring good nutrition throughout pregnancy would be of particular benefit to twin-bearing Merino ewes to counteract these effects which may be detrimental in the following mating. Single-bearing ewes will also benefit, producing heavier lambs at weaning that have a good chance of survival. There is a possibility of future work investigating the influence of Merino ewe nutrition on these factors under New Zealand grazing conditions.

Chapter 4

The effect of mulesing Merino lambs on productive outputs

Introduction

Mulesing is a widely used method for the control of blowfly strike in the New Zealand Merino industry. However, the costs of mulesing to production are relatively unknown. Mulesing is the correction of a fault in the Australian Merino flock that resulted from the introduction of the 'super-wrinkly' Vermont Merinos in the late 19th century (Townend 1987). Mulesing is a surgical technique that was developed by J.H.W Mules of South Australia as a means of de-wrinkling the blowfly strike susceptible breech area of the sheep (Beveridge 1984).

Mulesing has recently come under scrutiny from animal welfare groups, threatening Merino wool markets (Scobie *et al.* 2005; Davidson *et al.* 2006). These groups have specifically targeted the use of mulesing for blowfly strike prevention, causing Australian Merino wool producers to phase out the practice by 2010. Wool grower levy bodies, such as Australian Wool Innovation are conducting research into alternatives to mulesing (Palmer 2004). Markets supplied by the New Zealand Merino wool industry are demanding non-mulesed wool, and therefore information about the effects of mulesing on production would be beneficial to help growers make informed decisions about future use of the practice.

Mulesing has a number of detrimental effects associated with it. Mulesing produces an increased cortisol response, which represents a pain response, that persists for 24-48 hours (Lee and Fisher 2007). In addition there are behavioural changes that indicate pain and discomfort as a result of mulesing. Research has shown that these resolve within 24 and 48 hours, respectively. Also indicative of pain are reductions in weight gain, which may persist for 14 days following mulesing (Lee and Fisher 2007), although mulesing has been shown to increase long-term live weight and fleece weight (Anson and Beasley 1975). Live weight reductions are a stress response and result in reduced nutrient supply. This tends to result in reduced fibre diameter and a weaker region in the staple because of the lower levels of keratin material present in the fibre (Reis 1992; Butler 1994). Another effect is that freshly-mulesed lambs become susceptible to blowfly strike prior to the skin healing (Pearse and Peucker 1991).

Although the costs of flystrike are well known in the Merino industry, there is very little data available on the effects on livestock production of mulesing in New Zealand. This research was carried out to examine the effects of mulesing on lamb liveweight gain, live weight and dag score from tailing to hogget shearing; and fleece characteristics.

Materials and Methods

Animals and treatments

Lambs

Of the 128 ewe lambs born (refer to materials and methods in Chapters 2 and 3), 60 were randomly selected at d191 at approximately six weeks of age and assigned to the 'mulesed' treatment group. They were mulesed following the modified mulesing procedure, which involves the removal of a strip of skin from the centre of the tail, with the cut starting level with the bottom of the vulva (Luff 1976). The remaining 68 ewe lambs were assigned to the 'non-mulesed' treatment group.

Measurements

Ewes

Ewes were weighed and body condition score assessed after approximately 4 hours off pasture on d0, d79, d106, d141, d191, and d283. To adjust for different shearing times, fleece weight was recorded and added to subsequent live weights.

Lambs

Lambs were weighed after approximately 4 hours off pasture on d191, d283, d359 and d499. At d191 lambs were given a subjective wrinkle score using a visual assessment of their entire body (Scobie *et al.* 2005). Scores ranged from 1; completely plain skin, through to 5; a large number of prominent ribs. Figure 3.1 (Chapter 3) shows a selection of lambs from the experiment and their allocated wrinkle scores.

Dag score was visually assessed on d283, d359, d499 and d588 with scores ranging from 0 (no dag) to 5 (heavy dag) (Larsen *et al.* 1994) (Figure 3.2; Chapter 3).

All ewe lambs were tailed using a gas-heated tailing iron and a dicyclanil-based insect growth regulator (Clik, Novartis) was applied to their backs and docked tail. Lambs that were mulesed had alcohol-based iodine applied to the wounds. All lambs were drenched with selenium. Lambs were weaned at approximately 130 days old (d283).

At approximately 7 months of age (d360), a 50g mid-side wool sample was collected from the right side of the lamb for fibre diameter, colour and washing yield measurements. The wool was clipped as close to the skin as possible using Oster

clippers with number 10 blades and the skin was stretched out by a second person to minimise cuts due to skin wrinkles.

Lambs were shorn at approximately 1 year of age (d499). Fleeces were weighed and classed into sale lines (Table 3.2; Chapter 3) by a registered classer. A mid-side wool sample was collected for length and strength analysis.

Animals were managed on Lincoln University's Mt Grand Station, Hawea Flat, New Zealand under standard farming practices. The experiment was conducted according to protocols approved by the Massey University Animal Ethics Committee.

Laboratory methods

Wool samples were conditioned at 20°C and 65% relative humidity for 168 hours prior to a 50g sub-sample being collected from each sample. The sub-sample was weighed then scoured in a 4-bowl sample scour. These scoured samples were then conditioned for a further 72 hours and and re-weighed. Washed yield was calculated using the following equation:

$$\%\ yield = \frac{weight\ of\ greasy\ sample}{weight\ of\ scoured\ sample} \times \frac{100}{1}$$

Following scouring, a 10g sample was taken and put through a two-drum hand-operated card three times. Any excess vegetable matter was removed.

Carded samples were then measured for colour (Y-Z) using a HunterLab ColourQuest to the New Zealand Standard for the measurement of colour (SANZ 1984) (NZS8707:1984) and fibre diameter in microns using the OFDA100 (IWTO 1998).

Mid-side wool samples collected at d499 were sent to the New Zealand Wool Testing Authority, Napier, New Zealand to be analysed for length and strength using ATLAS (Automatic Tester for Length and Strength) (IWTO-7 and 17 respectively). The test uses staples (n=5) drawn from the mid-side wool sample, and measures the length of the sampled staples, their strength, and the position at which the staples break.

Statistical analyses

All statistical analyses were carried out using SAS (Statistical Analysis System, version 8.2; SAS Institute Inc., Cary, NC, USA, 2001). The effect of mulesing on average daily liveweight gain (adg; calculated by live weight at d499 minus liveweight at d191 divided

by the number of days) and live weight at d191, d283, d359, d499 and d588 was analysed using the MIXED procedure with a linear model that included the fixed effects of mulesing treatment, dam shearing treatment, year of birth of ewe, wrinkle score, pregnancy rank, dag score at d283 d359, d499 and d588; and the random effect of the sire of the lamb. Live weight of ewes at d0, d79, d106, d141, d191, and d283; and live weight of lambs at d191, d283, d359 and d599 were fitted as covariates where indicated.

Dag score was analysed as a repeated measure using the MIXED procedure with a linear model. The fixed effects of mulesing treatment, day of measurement, wrinkle score, interactions of wrinkle score with treatment and day of measurement with treatment; and the random effect of ewe were considered.

The effect of mulesing on fleece fibre diameter, colour and yield at d360; and fleece weight, staple length and staple strength at d499 was analysed using the MIXED procedure with a linear model that included the fixed effects of mulesing treatment, dam shearing treatment, wrinkle score, year of birth of ewe and pregnancy rank, and the random effect of sire.

The effect of mulesing on fleece class at d499 was analysed using the GENMOD procedure with a linear model that considered the fixed effect of mulesing treatment.

Non-significant ($P>0.05$) variables were removed from each model to determine final solutions; significant effects are detailed in the results. Not all animals had records for all parameters, so analyses were conducted on as many records as were available (numbers in each analysis are shown).

Results

Liveweight gain and live weight

The liveweight gain from d191 through to d359 did not differ between mulesed and non-mulesed lambs (106 g/day ± 2 *vs.* 103 g/day ± 2) and the live weight at d283, d359 and at d499 of lambs did not differ ($P<0.05$) between mulesing treatments (Figure 4.1). Single-born lambs were heavier than their twin-born counterparts ($P<0.05$) at d191 (tailing) and d283 (weaning); following this there was no difference.

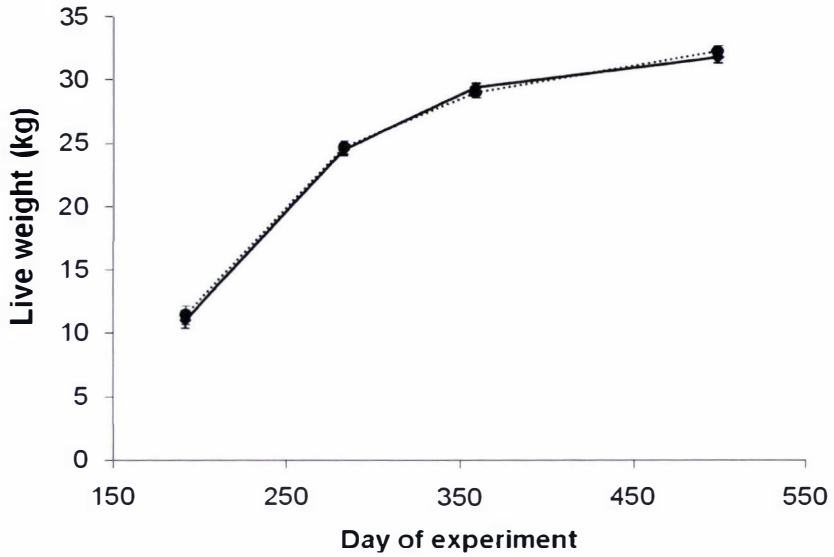

FIGURE 4.1 The live weight profile using least squares means and standard errors of the means at tailing (d191), weaning (d283), biopsy (d359) and shearing (d488) of Merino lambs that were mulesed (—♦—) or non-mulesed (···●···).

Dag and Wrinkle Score

Figure 4.2 shows a profile of dag scores of lambs throughout the experiment. Dag scores at d283 and d499 did not differ between mulesing treatments. Dag scores at d359 and d588 were greater in non-mulesed lambs than in mulesed lambs ($P<0.05$). There was a positive relationship between wrinkle score and dag score with dag score increasing with increasing wrinkle score. There was no interaction between mulesed treatment and wrinkle score for dag score.

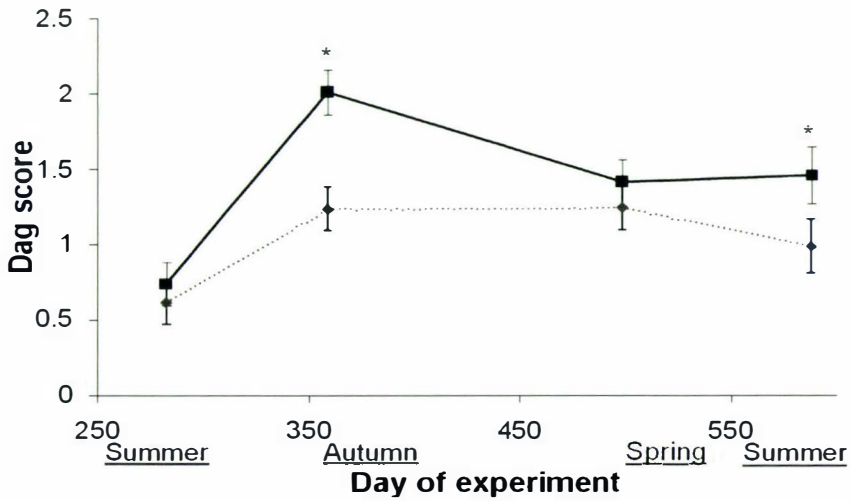

FIGURE 4.2 The effect of mulesing on dag score for mulesed (···♦···) and non-mulesed (—■—) Merino ewe lambs at weaning (d283), 7 months of age (d359), shearing (d499) and crutching (d588) (n=119) using least squares means and standard errors of the means. Data points with a * differ significantly ($P<0.05$).

Fleece characteristics

Mulesing had no effect on fibre diameter, colour, staple length, staple strength, fleece weight or fleece class (Table 4.1 and 4.2). Washing yield tended to be greater in non-mulesed lambs compared with mulesed lambs. There was a relationship between wrinkle score and fleece weight, with a general trend of an increase in wrinkle score giving an increase in fleece weight (see Chapter 3 – Table 3.3). Single-born lambs had heavier fleeces than twin-born lambs (see Chapter 3 – Table 3.3).

TABLE 4.1 The effect of mulesing Merino ewe lambs on the yield, fibre diameter and colour of fleece wool at d360.

Fibre measurement	n	Mulesed	Non-mulesed	Significance
Yield (%)	96	70.42 ± 0.78	72.01 ± 0.73	0.0861
Fibre Diameter (µm)	89	17.69 ± 0.34	17.68 ± 0.33	NS
Colour (y-z)	96	0.0089 ± 0.16	0.029 ± 0.15	NS

NS-Non-significant

TABLE 4.2 The effect of mulesing Merino ewe lambs at their first shearing (d499) on staple length, staple strength, fleece weight and fleece line.

Fibre measurement	n	Mulesed	Non-mulesed	Significance
Staple length (mm)	95	69.62 ± 1.23	68.57 ± 1.14	NS
Staple strength (N/kt)	95	39.12 ± 1.73	39.39 ± 1.61	NS
Fleece weight (kg)	95	2.44 ± 0.076	2.35 ± 0.074	NS
Fleece line	95	4.38 ± 0.31	3.76 ± 0.29	NS

NS-Non-significant

Discussion

The present study examined the effect of mulesing ewe lambs at tailing (d191) on their subsequent live weight, dag score and wool characteristics to d588.

Mulesing had no effect on liveweight gain or live weight. This suggests that any potential stress effect on liveweight gain from mulesing is a short-term effect that has been compensated for prior to weaning (d283). Rose *et al.* (1972) reported a depressed liveweight gain during the 10 days after the mulesing operation. Following this period however, mulesed sheep grew faster than non-mulesed animals and at 6 months of age there was only a slight difference in average live weight. Rose *et al.* (1972) found that a depressed liveweight gain as a result of mulesing was most marked in very wrinkled lambs. No such result was found in this experiment.

The aim of mulesing is to remove the skin around the crutch area to reduce dag formation in order to prevent flystrike. Therefore it should be expected that non-mulesed animals have a higher dag score than mulesed. The difference was not apparent in the current experiment until d359 (7 months of age). This result agrees with the findings of Richardson (1971). The difference had disappeared by d499, however, by crutching time (d588), the mulesed lambs were less daggy again. A potential explanation for this is related to nutrition due to the level of digestible fibre changing throughout the year. When digestible fibre is high, dag formation tends to be low (Davidson *et al.* 2006). Dag formation was higher in non-mulesed animals compared to mulesed animals in early-autumn and early-spring when the pasture is low in functional fibre (Binnie and Elliott 1986; Campion and Leek 1997).

The breech region of wrinkly sheep is highly prone to soiling by urine and faeces consequently attracting blowflies (Anson and Beasley 1975; Luff 1976). In the present experiment there was a positive correlation between wrinkle score and dag score. This agrees with farmer perception that suggests the wrinklier the lamb the higher the susceptibility to dags and thus to blowfly strike. This has resulted in many farmers only mulesing the "very wrinkly" lambs (wrinkle score of approximately 4-5). The findings of Heath and Bishop (2006) show that there is strong positive relationship between dags and blowfly strike. The lack of an interaction found in the present experiment suggests that mulesing reduces wrinkles around the breech and therefore the dags and potentially the susceptibility to flystrike. Whether mulesing only the very wrinkly lambs is justified will depend on the shape of the relationship between dag score and the susceptibility to flystrike.

In the present study there was a positive phenotypic relationship between wrinkle score and fleece weight, with an increasing wrinkle score corresponding to an increased fleece weight. This agrees with the findings of Walkley and Ponzoni (1984); Raadsma (1993); Cloete *et al.* (2005); and Scobie *et al.* (2005) who investigated phenotypic correlations between wrinkle score and greasy fleece weight. However, selection for increased wrinkles as a means of increasing fleece weight may not be desirable owing to the positive relationship between wrinkles and dag score, thus increasing the susceptibility of the animal to fly strike.

Staple length, staple strength and fleece weight are affected by changes in nutrient allocation (stress) (Reis 1992; Butler 1994). As no growth check due to mulesing was observed, there would be no expectation of a staple length, staple strength or fleece weight difference between the two treatment groups. Although there was a tendency

for washing yield to be greater in non-mulesed lambs, the biological explanation for this is obscure; therefore this tendency is most likely to be a chance event. Colour was unaffected by mulesing, which is to be expected given that colour is largely influenced by season rather than stress effects as shown by Reid *et al.* (1976). Fleeces in this study were subjectively classed into sale lines based on fibre diameter, staple length, and colour. As none of these were affected by mulesing there would be no expectation of a difference in classed line.

In conclusion the practice of mulesing has been justified as a means of reducing dags in order to minimise or eliminate the risk of blowfly strike. In this experiment, mulesing Merino lambs appeared to have little effect on liveweight gain, live weights, and fleece characteristics. These results show little productive cost due to mulesing, but a reduced dag score was achieved throughout most of the initial year, which may reduce the incidence of blowfly strike. Based on the results of this experiment, mulesing could be justified only on the basis of protection against blowfly strike due to the reduction in dags. The less wrinkly the lamb, the lower its dag score. However, no interaction between mulesing and wrinkle score was apparent.

Chapter 5

Industry implications and recommendations

Three management practices that are currently influencing the New Zealand Merino Industry which can be manipulated are – shearing-time during pregnancy to manipulate wool growth, the management of live weight and body condition score to influence reproductive performance, and mulesing which is threatening the marketability of New Zealand fine wool. Manipulating wool growth through management as opposed to the use of genetics provides a relatively quick response and can be additional to the response from selection. The wool produced by Merinos is an important contributor to the New Zealand economy, with the wool clip from the 2007/2008 season valued at nearly 200 million dollars (Ovens Pers comm. 2008). The greater emphasis on meat production from Merinos in recent years is also of high importance with regards to reproductive performance. Profitability for Merino farmers comes from strong markets, low fibre diameter and lamb production. This section aims to discuss the potential financial implications of the experiments carried out to investigate these parameters.

Time of shearing

Lambs whose dam was shorn post-lambing had a greater follicle density, total skin follicle number index and secondary follicle number index than lambs whose dam was shorn mid- or late-pregnancy. These results suggest that there may be financial value to shearing ewes post-lambing providing the increase of secondary follicles was great enough to reduce the fibre diameter and at least maintain fleece weight. However, shearing time had no influence on fleece characteristics or live weight, possibly due to an absence of response in Merinos compared to coarse-wool breeds as previously suggested. It could potentially also have been due to the ewe not having the nutrients required to respond to shearing during foetal growth and fibre development, instead partitioning nutrients for her own benefit or not having additional nutrients for themselves and/or the fetus. This would be worth investigating in the future, particularly as there was a follicle response to shearing, suggesting some change in foetal development. A more controlled study with Merinos (possibly housed) to monitor intake and assess the fetal follicle development would clarify some of the questions raised by this research.

In the present study, the higher the wrinkle score of the animal, the higher the secondary to primary follicle ratio, total follicle density, secondary follicle density, secondary follicle number index, primary follicle number index, total follicle number index, and fleece weight. Therefore, increasing the wrinkliness of sheep in the flock may result in an increased fleece weight, and may potentially result in a reduced fibre diameter as indicated by the increased skin follicle number index.

Thus, shearing post-lambing and increasing wrinkles could increase profit by reducing fibre diameter and increasing fleece weight, thereby producing a wool clip of high value.

Ewe live weight and body condition

Maintaining high ewe live weight and body condition throughout pregnancy can result in high lamb survival to at least tailing and higher weaning weights compared to lighter ewes. The heavier ewes were at mating the higher the likelihood of them becoming pregnant with twins. Body condition of twin-bearing ewes began to decline in late-pregnancy although it recovered by weaning of their lambs.

Single-bearing ewes were 3 times more likely to be lactating at tailing (indicative of them rearing a lamb at this time), than twin-bearing ewes. Single-born lambs were also heavier at tailing and weaning and had heavier hogget (1 year old) fleeces than twin-born lambs.

This suggests separating twin-bearing ewes to enable preferential feeding levels in order to maintain body condition may be of a productive advantage. Having a high lamb live weight at weaning will ensure high prices paid for lambs and therefore increased value. Future investigations into the productivity of twin-born Merino lambs, and the use of terminal sires could be of value to the industry.

Mulesing

Merinos are mulesed in order to minimise the wrinkles over the breech, therefore reducing the susceptibility to urine staining, sweating and faecal staining which minimises the risk of blowfly strike (Luff 1976). There was no effect of mulesing lambs on liveweight gain, live weight or fleece characteristics; suggesting no productive cost to mulesing. Dag score increased with increasing wrinkle score, suggesting increased susceptibility to blowfly strike. Mulesing reduced dag score, although not consistently. Mulesing could be beneficial in reducing dags and therefore the susceptibility to blowfly strike, although not for any other productive gain. The advantages, previously discussed, for having animals with high wrinkle score may not actually be beneficial overall if they become struck more frequently. As mulesing is due to be phased out in 2010, future research should investigate alternative methods to blowfly strike control that are as effective as mulesing.

References

Abbott K, McGowan M, Pfeiffer D, Sargison N (2003) Footrot in sheep. *Veterinary Record* **152**, 510-511.

Allen DM, Lamming GE (1961) Nutrition and reproduction in the ewe. *J. agric. Sci.* **56**, 69-79.

Anson RJ, Beasley PS (1975) Radical mulesing pays. *Queensland Agricultural Journal* **101**, 299-302.

Atkinson DS, Leathwick DM (1995) Evaluation of large scale trapping of flies as a means of reducing the incidence of flystrike in lambs. *Proceedings of the New Zealand Society of Animal Production* **55**, 193-195.

Austin AR, Young NE (1977) Effect of shearing pregnant ewes on lamb birth weights. *Veterinary Record* **100**, 527-529.

Behrendt R, Barber P, Oldham CM, Hocking Edwards JE, Hatcher S, Thompson A (2006a) Short Communication number 70: Lifetime Wool: Comparisons on commercial farms show the benefit of good nutrition in pregnancy on production and lamb performance of Merino ewes. In 'Working Papers: Australian Society of Animal Production 26th Biennial conference'. Perth, WA. (Eds K Croker, N Adams, D Lindsay).

Behrendt R, Barber P, Oldham CM, Hocking Edwards JE, Hatcher S, Thompson A (2006b) Short Communication number 91: Lifetime Wool: Comparisons on commercial farms demonstrate significant production potential for twin-bearing Merino ewes and their progeny. In 'Working Papers: Australian Society of Animal Production 26th Biennial conference'. Perth, WA. (Eds K Croker, N Adams, D Lindsay).

Belschner HG, Carter HB, Turner HN (1937) Fleece characteristics of stud Merino sheep in relation to the degree of wrinkliness of the skin of the breech. III. *Australian Veterinary Journal* **13**, 16-27.

Beveridge WIB (1984) The origin and early history of the mules operation. *Australian Veterinary Journal* **61**, 161-163.

Binnie DB, Elliott KH (1986) Implications of objective measurement of wool for sheep breeding. *Proceedings of the New Zealand Society of Animal Production* **46**, 202-207.

Blackwell GL, Potter MA, Cottam YH, Blair HT (1997) Susceptibility of Romney and Perendale sheep to flystrike by the Australian Green Fly, Lucilia cuprina (Wied.), and fly attractant trials. *Proceedings of the New Zealand Society of Animal Production* **57**, 37.

Brandsma JH, Blair HT (1997) Heritability of resistance to flystrike in New Zealand Perendale sheep. *Proceedings of the New Zealand Society of Animal Production* **57**, 41.

Brown GH, Turner HN, Young SSY, Dolling CHS (1966) Vital statistics for an experimental flock of Merino Sheep .3. Factors affecting wool and body characteristics including effect of age of ewe and its possible interaction with method of selection. *Australian Journal of Agricultural Research* **17**, 557-581.

Butler LG (1994) Factors affecting staple strength with particular reference to Australia. *International Journal of Sheep and Wool Science* **42**, 213-230.

Campion DP, Leek BF (1997) Investigation of a 'fibre appetite'. *Applied Animal Behaviour Science* **52**, 79-86.

Cloete SWP, Olivier JJ, Wyk JBv, Schoeman SJ, Erasmus GJ (2005) Genetic parameters and trends for hogget traits in Merino lines divergently selected for multiple rearing ability. In 'Application of new genetic technologies to animal breeding. Proceedings of the 16th Conference of the Association for the Advancement of Animal Breeding and Genetics, Noosa Lakes, Queensland, Australia, 25-28 September, 2005' pp. 24-27.

Coelli KA, Atkins KD (1995) Fleece weight and fibre diameter relationships within and between Merino flocks. *Proceedings of the Australian Society of Animal Breeding and Genetics* **11**, 587-590.

Colditz IG, Walkden-Brown SW, Daly BL, Crook BJ (2005) Some physiological responses associated with reduced wool growth during blowfly strike in Merino sheep. *Australian Veterinary Journal* **83**, 695-699.

Copping KJ, Hocking Edwards JE (2006) Short Communication number 67: Lifetime Wool: Managing nutrition during pregnancy of twin-bearing ewes. In 'Working Papers: Working Papers: Australian Society of Animal Production 26th Biennial conference'. Perth, WA. (Eds K Croker, N Adams, D Lindsay).

Corbett JL (1979) Variation in wool growth with physiological state. In 'Physiological & Environmental Limitations to Wool Growth'. (Eds JL Black, PJ Reis). (CSIRO: Sydney, Australia).

Corner RA, Kenyon PR, Stafford KJ, West DM, Oliver MH (2007) The effect of mid-pregnancy stressors on twin-lamb live weight and body dimensions at birth. *Livestock Science* **107**, 126-131.

Cottam YH, Blair HT, Potter MA (1998) Monitoring some muscoid fly populations on Massey University sheep farms in the Manawatu. *Proceedings of the New Zealand Society of Animal Production* **58**, 220-223.

Cumming IA (1977) Relationships in the sheep of ovulation rate with liveweight, breed, season and plane of nutrition. *Australian Journal of Experimental Agriculture and Animal Husbandry* **17**, 234-241.

Davidson BS, Chaplin SJ, Laird C (2006) Effect of fibre supplementation on dag formation and flystrike in sheep grazing spring pastures. *Australian Journal of Experimental Agriculture* **46**, 783-786.

Denney GD (1990) Effect of pre-weaning farm environment on adult wool production of Merino sheep. *Australian Journal of Experimental Agriculture* **30**, 17-25.

Dolling CHS, Nicolson AD (1967) Vital statistics for an experimental flock of Merino sheep. 4. Failure in conception and embryonic loss as causes of failure to lamb. *Australian Journal of Agricultural Research* **18**, 767-788.

Ducker MJ, Boyd JS (1977) The effect of body size and body condition on the ovulation rate of ewes. *Animal Production* **24**, 377-385.

Duguma G, Schoeman SJ, Cloete SWP, Jordaan GF (2002) Genetic and environmental parameters for ewe productivity in Merinos. *South African Journal of Animal Science* **32**, 154-159.

Dun RB, Donnelly FB (1965) The effectiveness of the mules operation when carried out in conjunction with lamb marking. *Australian Journal of Experimental Agriculture and Animal Husbandry* **5**, 6-10.

Dun RB, Grewal RS (1963) A comparison of the productive performance of single and twin born Merino ewes. *Australian Journal of Experimental Agriculture and Animal Husbandry* **3**, 235-242.

Egan JK, Thompson RL, McIntyre JS (1977) Stocking rate, joining time, fodder conservation and productivity of Merino ewes. 2. Birth-weight, survival and growth of lambs. *Australian Journal of Experimental Agriculture* **17**, 909-914.

Ferguson KA, Wallace AL, Linder HR (1965) Hormonal regulation of wool growth. In 'Biology of the skin and hair growth'. (Eds AG Lyne, BF Short) pp. 655-677. (Angus and Robertson: Sydney, NSW).

Fozi MA, Van der Werf JHJ, Swan AA (2007) Inclusion of skin follicle traits in selection indices in breeding programs improves genetic gain in Australian fine-wool Merinos. *Australian Journal of Agricultural Research* **58**, 921-927.

Freer M, Moore AD, Donnelly JR (1997) GRAZPLAN: Decision support systems for Australian Grazing Enterprises - II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. *Agricultural Systems* **54**, 77-126.

Geenty KG, Dyson CB (1986) The effects of various factors on the relationship between lamb growth rate and ewe milk production. *Proceedings of the New Zealand Society of Animal Production* **46**, 265-269.

Gibb MJ, Treacher TT (1980) The effect of ewe body condition at lambing on the performance of ewes and their lambs at pasture. *Journal of Agricultural Science, UK* **95**, 631-640.

Gleeson DM, Heath ACG (1997) The population biology of the Australian sheep blowfly, *Lucilia cuprina*, in New Zealand. *New Zealand Journal of Agricultural Research* **40**, 529-535.

Gonzalez RE, Labuonora D, Russel AJF (1997) The effects of ewe live weight and body condition score around mating on production from four sheep breeds in extensive grazing systems in Uruguay. *Animal Science* **64**, 139-145.

Gootwine E (2005) Variability in the rate of decline in birth weight as litter size increases in sheep. *Animal Science* **81**, 393-398.

Gregory IP (1982a) Genetic-studies of South Australian Merino sheep .3. Heritabilities of various wool and body traits. *Australian Journal of Agricultural Research* **33**, 355-362.

Gregory IP (1982b) Genetic-Studies of South Australian Merino sheep .4. Genetic, phenotypic and environmental correlations between various wool and body traits. *Australian Journal of Agricultural Research* **33**, 363-373.

Guerrini VH (1988) Ammonia toxicity and alkalosis in sheep infested by *Lucilia cuprina* larvae. *International Journal for Parasitology* **18**, 79-81.

Hall DG, Fogarty NM, Gilmour AR (1995) Performance of crossbred progeny of Trangie Fertility Merino and Booroola Merino rams and Poll Dorset ewes. 1. Lamb birth weight, survival and growth. *Australian Journal of Experimental Agriculture* **35**, 1069-1074.

Hall M, Wall R (1995) Myiasis of humans and domestic animals. *Advanced Parasitology* **35**, 257-334.

Heath ACG, Bishop DM (2006) Flystrike in New Zealand: an overview based on a 16-year study, following the introduction and dispersal of the Australian sheep blowfly, *Lucilia cuprina* Wiedemann (Diptera: Calliphoridae). *Veterinary Parasitology* **137**, 333-344.

Hocking-Edwards JE, Birtles MJ, Harris PM, Parry AL, Paterson E, Wickham GA, McCutcheon SN (1996) Pre- and post-natal wool follicle development and density in sheep of five genotypes. *Journal of Agricultural Science* **126**, 363-370.

Hocking Edwards JE (1999) Reduction in wool follicles prior to birth in Merino sheep. *Reproduction, Fertility and Development* **11**, 229-234.

Hocking Edwards JE, Hynd P (1992) Cellular characteristics of wool follicles and fibres in finewool and strongwool Merinos. *Australian Journal of Agricultural Research* **43**, 355-365.

Hocking Edwards JE, Starbuck TM (2006) Short communication number 79: Growth from weaning to one year of age affects maiden ewe fertility. In 'Working Papers: Australian Society of Animal Production 26th Biennial conference'. Perth, WA. (Eds K Croker, N Adams, D Lindsay).

Hynd PI (1995) Skin and follicle-based selection for wool production and quality. *Wool Technology and Sheep Breeding* **43**, 15-23.

IWTO (1998) Specification IWTO-47-98. Measurement of the mean and distribution of fibre diameter using an optical fibre diameter analyser (OFDA). (International Wool Secretariat London.

Jefferies BC (1961) Body condition scoring and its use in management. *Tasmanian Journal of Agriculture* **32**, 19-21.

Kelly RW, Macleod I (1991) Nutritional regulation of follicle initiation. In 'Wool Biology'. (Ed. P Hynd) pp. 42-48. (Australian Wool Corporation: Melbourne).

Kelly RW, Macleod I, Hynd P, Greeff J (1996) Nutrition during fetal life alters annual wool production and quality in young Merino sheep. *Australian Journal of Experimental Agriculture* **36**, 259-267.

Kenyon PR, Morel PCH, Morris ST (2004) Effect of ewe liveweight and condition score at mating and mid-pregnancy shearing on twin lamb birthweights and growth rates to weaning. *New Zealand Veterinary Journal* **52**, 145-149.

Kenyon PR, Morris ST, McCutcheon SN (2002a) Does an increase in lamb birthweight through mid-pregnancy shearing necessarily mean an increase in lamb survival rates to weaning? *Proceedings of the New Zealand Society of Animal Production* **62**, 53-56.

Kenyon PR, Morris ST, Revell DK, McCutcheon SN (2002b) Maternal constraint and the birthweight response to mid-pregnancy shearing. *Australian Journal of Agricultural Research* **53**, 511-517.

Kenyon PR, Morris ST, Revell DK, McCutcheon SN (2003) Shearing during pregnancy - review of a policy to increase birthweight and survival of lambs in New Zealand pastoral farming systems. *New Zealand Veterinary Joumal* **51**, 200-207.

Kenyon PR, Sherlock RG, Morris ST, Morel PCH (2006) The effect of mid- and late-pregnancy shearing of hoggets on lamb birthweight, weaning weight, survival rate, and wool follicle and fibre characteristics. *Australian Journal of Agricultural Research* **57**, 877-882.

Kenyon PR, Sherlock RG, Parkinson TJ, Morris ST (2005) The effect of maternal shearing and thyroid hormone treatments in mid pregnancy on the birth weight, follicle and wool characteristics of lambs. *New Zealand Journal of Agricultural Research* **48**, 293-300.

Kenyon PR, Webby RW (2007) Pastures and supplements in sheep production systems. In 'Pasture and supplements for grazing animals'. (Eds PV Rattray, IM Brookes, AM Nicol) pp. 255-274. (New Zealand Society of Animal Production: Hamilton).

Kleemann DO, Grosser TI, Walker SK (2006) Fertility in South Australian commercial Merino flocks: aspects of management. *Theriogenology* **65**, 1649-1665.

Kleemann DO, Walker SK (2005) Fertility in South Australian commercial Merino flocks: relationships between reproductive traits and environmental cues. *Theriogenology* **63**, 2416-2433.

Larsen JWA, Anderson N, Vizard AL, Anderson GA, Hoste H (1994) Diarrhoea in Merino ewes during winter: association with trichostrongylid larvae. *Australian Veterinary Journal* **70**, 365-372.

Lax J, Brown GH (1967) Effects of inbreeding maternal handicap and range in age on 10 fleece and body characteristics in Merino rams and ewes. *Australian Journal of Agricultural Research* **18**, 689-706.

Leathwick DM, Atkinson DS (1998) Influence of different proportions of Lotus corniculatus in the diet of lambs on dags, flystrike and animal performance. *Wool Technology and Sheep Breeding* **46**, 353-359.

Lee C, Fisher AD (2007) Welfare consequences of mulesing of sheep. *Australian Veterinary Journal* **85**, 89-93.

Luff AF (1976) Mulesing sheep saves losses from flystrike. *Agricultural Gazette of New South Wales* **87**, 32-37.

McCloghry CE (1997) Histological technique for the determination of wool follicle density. *Wool Technology and Sheep Breeding* **45**, 129-145.

McInnes P, Smith MD (1966) The effect of nutrition before mating on the reproductive performance of Merino ewes. *Australian Journal of Experimental Agriculture and Animal Husbandry* **6**, 455-459.

Meikle HE, Wickham GA, Rae AL, Dobbie JL, Hickey SM (1988) Follicle and fleece characteristics of Merinos, Romneys and Merino-Romney crossbreds. *Proceedings of the New Zealand Society of Animal Production* **48**, 195-200.

Milligan KE, Broadbent JS (1974) Condition scoring of sheep. *Proceedings of the New Zealand Society of Animal Production* **34**, 114.

Morris MC (2000) Ethical issues associated with sheep fly strike research, prevention, and control. *Journal of Agricultural & Environmental Ethics* **13**, 205-217.

Morris ST, Kenyon PR, Burnham DL, McCutcheon SN (1999) The influence of pre-lamb shearing on lamb birthweight and survival. *Proceedings of the New Zealand Grassland Association* **61**, 95-98.

Morris ST, McCutcheon SN (1997) Selective enhancement of growth in twin foetuses by shearing ewes in early gestation. *Animal Science* **65**, 105-110.

Morris ST, McCutcheon SN, Revell DK (2000) Birth weight responses to shearing ewes in early to mid gestation. *Animal Science* **70**, 363-369.

Munoz C, Carson AF, McCoy MA, Dawson LER, O'Connell NE, Gordon AW (2008) Nutritonal status of adult ewes during early and mid-pregnancy. 1. Effects of plane of nutrition on ewe reproduction and offspring performance to weaning. *Animal* **2**, 52-63.

Nancarrow MJ, Nagorcka BN, Purvis IW (1998) Skin and follicle attributes contribute to differences in clean fleece weight in superfine Merino sheep. *Animal Production in Australia. Proceedings of the Australian Society of Animal Production* **22**, 253-356.

Ovens K (Pers comm. 2008) Value of the New Zealand Merino clip. (New Zealand Merino Co).

Palmer J (2004) The mulesing debate. *Australian Veterinary Journal* **82**, 663.

Pattie WA, Williams JJ (1967) Selection for weaning weight in Merino sheep: 3. Maintenance requirements and the efficiency of conversion of feed to wool in mature ewes. *Australian Journal of Experimental Agriculture and Animal Husbandry* **7**, 117-125.

Pearse BHG, Peucker SKJ (1991) Comparison of a liquid and a powder insecticidal dressing to aid healing and prevent flystrike of mulesing wounds in lambs. *Australian Veterinary Journal* **68**, 163-164.

Peart JN (1967) The effect of different levels of nutrition during late pregnancy on the subsequent milk production of Blackface ewes and on the growth of then lambs. *Journal of Agricultural Science, UK* **68**, 365-371.

Raadsma HW (1993) Fleece Rot and Body Strike in Merino Sheep. 6. Experimental evaluation of some physical fleece and body characteristics as indirect selection criteria for fleece rot. *Australian Journal of Agricultural Research* **44**, 915-931.

Reid RND, Jones AL (1976) The effectiveness of mulesing in flystrike control in Corriedale and crossbred sheep in Tasmania. *Proceedings of the Australian Society of Animal Production* **11**, 185-188.

Reis PJ (1992) Variations in the strength of wool fibres - A review. *Australian Journal of Agricultural Research* **43**, 1337-1351.

Revell DK, Main SF, Breier BH, Cottam YH, Hennies M, McCutcheon SN (2000) Metabolic responses to mid-pregnancy shearing that are associated with a selective increase in the birth weight of twin lambs. *Domestic Animal Endocrinology* **18**, 409-422.

Revell DK, Morris ST, Cottam YH, Hanna JE, Thomas DG, Brown S, McCutcheon SN (2002) Shearing ewes at mid-pregnancy is associated with changes in fetal growth and development. *Australian Journal of Agricultural Research* **53**, 697-705.

Richardson G (1971) A comparison of mulesed and un-mulesed sheep in the Western District. *Journal of Agriculture. Victorian Department of Agriculture.* **61**, 10-11.

Roberston DE (1987) Are big sheep best? In 'Merino Improvement Programs in Australia. Proceedings of a National Symposium'. Leura, New South Wales. (Ed. BJ McGuirk). (Australian Wool Corporation).

Rogers GE (2006) Biology of the wool follicle: an excursion into a unique tissue interaction system waiting to be re-discovered. *Experimental Dermatology* **15**, 931-949.

Rose M, McMeniman NP, Anson RJ (1972) Effect of the radical mules operation performed at lamb marking on subsequent lamb growth rates. *Queensland Journal of Agricultural and Animal Sciences* **29**, 1-7.

Rothwell J, Hynd P, Brownlee A, Dolling M, Williams S (2007) Research into alternatives to mulesing. *Australian Veterinary Journal* **85**, 94-97.

Safari A, Fogarty NM (2003) Genetic parameters for sheep production traits: Estimates from the literature. Technical Bulletin 49. NSW Agriculture, Orange, Australia.

Safari E, Fogarty NM, Gilmour AR (2005) A review of genetic parameter estimates for wool, growth, meat and reproduction traits in sheep. *Livestock Production Science* **92**, 271-289.

Sandeman RM, Collins B, Carnegie P (1987) A scanning electron microscopy study of *L. cuprina* larvae and the development of blowfly strike in sheep. *International Journal for Parasitology* **16**, 69-75.

SANZ (1984) Method for the measurement of the colour of wool, NZS 8707:1984. (Standards Association of New Zealand: Wellington, NZ).

SAS (2001) Statstical anlaysis system 8.2. (SAS Institute Inc.: Cary, North Carolina, USA).

Scales GH, Bray AR, Baird DB, O'Connell D, Knight TL (2000) Effect of sire breed on growth, carcass, and wool characteristics of lambs born to Merino ewes in New Zealand. *New Zealand Journal of Agricultural Research* **43**, 93-100.

Schinckel P, Short BF (1961) Influence of nutritional level during pre-natal and early post-natal life on adult fleece and body characters. *Australian Journal of Agricultural Research* **12**, 176.

Scobie DR, Saville DJ (2000) The misuse of ratios and percentages in wool research. Proceedings of the 9th Congress of the Asian-Australian Association of Animal Production Societies and the23rd Biennial conference of the Australian Society of Animal Production. Asian-Australian Journal of Animal Sciences. **13**, 461-464.

Scobie DR, Young SR (2000) The relationship between wool follicle density and fibre diameter is curvilinear. *Proceedings of the New Zealand Society of Animal Production* **60**, 162-165.

Scobie DR, Young SR, O'Connell D (2005) Skin wrinkles affect wool characteristics and the time taken to harvest wool from Merino and Halfbred sheep. *New Zealand Journal of Agricultural Research* **48**, 177-185.

Sherlock RG, Kenyon PR, Morris ST (2002) Does mid-pregnancy shearing affect lamb fleece characteristics? *Proceedings of the New Zealand Society of Animal Production* **62**, 57-60.

Sherlock RG, Kenyon PR, Morris ST, Parkinson TJ (2003) Metabolic changes in ewes shorn during mid-pregnancy. *Proceedings of the New Zealand Society of Animal Production* **63**, 144-148.

Short BF (1955) Developmental modification of fleece structure by adverse maternal nutrition. *Australian Journal of Agricultural Research* **6**, 863-872.

Smeaton DC, Webby RW, Tarbotton IS, Clayton JB (2000) The effects of shearing Finnish Landrace x Romney ewes in mid-pregnancy on lamb survival, birth weight and other weights. *Proceedings of the New Zealand Society of Animal Production* **60**, 58-60.

Steinheim G, Mysterud A, Holand O, Bakken M, Adnoy T (2002) The effect of the initial weight of the ewe on later reproductive effort in domestic sheep (Ovis aries). *Journal of Zoology* **258**, 515-520.

Symonds ME, Bryant MJ, Lomax MA (1989) Lipid metabolism in shorn and unshorn pregnant sheep. *British Journal of Nutrition* **62**, 35-49.

Thompson GE, Goode JA (1981) Lactogenesis in ewes exposed to neutral and cold environmental temperatures during the last week of gestation. *Animal Production* **32**, 245-250.

Thompson KF, Sedcole JR, O'Connell D, Geenty KG, Skyes AR (1990) Spring and summer pasture feeding and ewe reproduction and wool growth. *Proceedings of the New Zealand Grassland Association* **52**, 123-127.

Toland Thompson AC, Hebart ML, Penno N, Hynd P (2007) Perinatal wool follicle attrition coincides with elevated perinatal circulating cortisol concentration in Merino sheep. *Australian Journal of Agricultural Research* **58**, 748-752.

Townend C (1987) Sheep strike and mulesing. *Parasitology Today* **3**, 68-69.

Turner HN (1961) Relationships among clean wool weight and its components .2. Effect of maternal handicap and its influence on selection. *Australian Journal of Agricultural Research* **12**, 974-991.

Underwood EJ, Shier FL (1942) Studies in sheep husbandry in Western Australia. 2. The influence of feeding during late pregnancy on the birth-weight, growth rate, and quality of the lamb. *Journal of the Department of Agriculture. Western Australia* **19**, 37-47.

Walkley JRW, Ponzoni RW (1984) An application of selection index theory to Merino breeding: a case study. *Wool Technology and Sheep Breeding* **32**, 21,41-43.

Wallace JM, Aitken RP, Cheyne MA (1996) Nutrient partitioning and fetal growth in rapidly growing adolescent ewes. *Journal of Reproduction and Fertiility* **107**, 183-190.

Waters CM, Coelli KA, Lee GJ, Atkins KD (2000) Reproduction effects on annual fleece production, liveweight and body condition of grazing Merino ewes. *Australian Journal of Experimental Agriculture* **40**, 931-937.

Willams SH, Brightling A (1999) The Australian wool industry's repsonse to the issue of pesticides residues. In 'Proceedings of the Australian Sheep Veterinarian Society Conference, Australian Veterinary Association'. Hobart. (Ed. B Besier) pp. 77-84.

Wolfe R (2006) 'A short history of sheep in New Zealand.' (Random House New Zealand: Auckland).

Wuliji T, Dodds KG, Andrews RN, Turner PR (1998) Mature Merino ewe performance in an ultrafine fibre diameter selected and a control flock. *Proceedings of the New Zealand Society of Animal Production* **58**, 284-287.

Young SSY, Brown GH, Turner HN, Dolling CHS (1965) Genetic and phenotypic parameters for body weight and greasy fleece weight at weaning in Australian Merino sheep. *Australian Journal of Agricultural Research* **16**, 997-1009.