

A multidimensional study on the impact of pre-weaning feeding and age after weaning on the follicle populations of Angora goats with implications on reproductive efficiency and financial returns from mohair.

by

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Certificate of Authorship

‘I declare that this submission is my own work and to the best of my knowledge and belief, understand that it contains no material previously published or written by another person except where due acknowledgement is made in this submission, as appropriate. Any contribution made to this submission by any person at Charles Sturt University or elsewhere is fully acknowledged.

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The thesis complies with University requirements for a thesis as set out in the related University policies and procedures (see [Policy Library](#))

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Ethics Approval

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Publications Resulting from the Research.

Chapter 6 of this thesis contains work accepted for publication which has been co-authored.

I developed the hypothesis formulation and experimental design. I conducted the fieldwork, data collection, statistical analysis and interpretation. I drafted the preliminary manuscript.

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Abstract

Australian mohair is a highly sought-after product in international natural fibre markets for its superior quality. To maintain this demand, substantial effort has been directed at understanding the factors that influence mohair quality and how to improve it. This thesis comprises of five short studies aimed to investigate the effect of pre-weaning feeding, and age after weaning, on the follicle populations of Angora goats, with implications on reproductive efficiency and financial returns from mohair.

In study one, pregnant Angora does were supplementary fed during days 60-90 or 120-180 post conception. Skin biopsies and fleece samples were taken from kids at birth, 1 week, 1 month, 2 months and 4 months of age. These samples were examined to determine the primary (P) and secondary (S) follicle densities and S:P ratio. Supplementary feeding during either time had no effect on follicle densities or S:P ratio.

In study two, the effect of age on follicle densities and S:P ratio was investigated by taking skin biopsies and fleece samples from 75 mature Angora goats aged from 6 months to 16 years. Although a significant correlation was found between age and S:P ratio, S follicle density, P follicle density and total follicle density, greater variation was explained by body weight than by age.

In study three, kids were selected at weaning and assigned to high and low postnatal nutrition groups with 12 and 13 replicates. Skin biopsies, fleece samples and body weight data were collected. Follicle densities and S:P ratio was similar between groups, however low nutrition status kids had lower body weights. Mean fibre diameter was also similar between nutritional groups but fleece weight was lower in kids from the low nutrition cohort.

In study four, reproductive records of a commercial Angora flock from 2017 to 2021 were examined to determine reproductive efficiency. Overall reproductive efficiency (kids weaned per 100 does bred) was 50%. Preweaning mortality was a major source of inefficiency, with starvation-mismothering-exposure being the primary cause of death.

In study five, gross margin scenarios were constructed to investigate the financial effect of feeding does for high or low S:P ratio progeny. Six scenarios were considered, in which does were fed for high or low S:P ratio progeny, with or without wethers and high and low stocking rates. Feeding does for high S:P ratio progeny and retaining wethers improved gross margins, while lower stocking rates did not. The major factors contributing to financial loss from an Angora enterprise were doe mohair quality and cost of supplementary feed.

While genetics has a marked effect on follicle development, nutrition during gestation and lactation enables the greatest potential of the follicle population to be achieved by maximising the number of follicles that initiate and mature respectively. Selection of replacement breeding animals should consider follicle density in conjunction with body weight and reproductive performance. This will improve the financial returns for an Angora enterprise.

Chapter 1 Introduction

Angora goats are famed for the long, luxurious locks of mohair produced by hair skin follicles. Mohair is valued based on the mean fibre diameter (MFD micron μm), staple length and greasy fleece weight (GFW) with genetics, environment and nutrition having a significant influence on these attributes (McGregor, 1998). The finest fleeces are produced by young animals but their overall smaller body size limits fleece weight. It has been suggested that increasing follicle density will improve fleece value despite the apparent biological cap on Angora skins' capacity to produce fibre (Galpin, 1948). Multiple studies suggest that the skin follicle population becomes fixed in the early postnatal period (Dreyer & Marincowitz, 1967; Lambert, Restall, Norton, & Winter, 1984; Margolena, 1974; Parry, Death, Dick, Miller, & Craven, 1993). Recent work on foetal programming of Australian Angora goats suggested that nutritional supplementation during the mid-pregnancy and early postnatal periods increased the follicle density of the offspring (McGregor, 2017, 2018b). Few histological studies have been conducted on skin follicle population development in Angora goats. Minimal information is available on the effects of age on skin follicle populations in fibre producing species including Angora goats. Furthermore, very little published reproductive data is available on commercial Angora goat flocks. The financial opportunities of feeding pregnant Angora does to improve follicle densities, S:P ratio and mohair quality of the progeny has not been investigated. This is the focus of the present work.

This paper is comprised of five short studies. Study one investigated the effects of supplementary feeding pregnant Angora does during gestation and lactation on the primary (P) and secondary (S) follicle densities and S:P ratio of the progeny from birth until 4 months of age.

Study two investigated the effect of age after weaning on the primary (P), secondary (S) and total follicle densities and S:P ratio to evaluate whether age after weaning has a relationship with these follicle population parameters.

In study three, the skin follicle development and mohair quality of kids poorly-grown and well-grown at weaning was assessed to determine if the poorly grown, tail end of a flock should be culled to improve the quality of the herd's clip.

In study four, the reproductive records of the research flock involved in studies one and two were analysed to describe the reproductive performance of a commercial Angora goat flock.

Finally, in study five six gross margin scenarios were constructed to assess the financial benefits of feeding Angora does to produce progeny of high or low S:P ratio, with and without wethers and at low and high stocking rates. The most substantial sources of financial loss were identified. Recommendations on breeding stock selection criteria to improve financial returns for an Angora enterprise were highlighted.

Chapter 2 Literature Review

The Angora goat was first introduced to Australia from Turkey in 1832 to Parramatta in Victoria (Clarke & Smith, 1975). With little recognition until the early 1970s (Clarke & Smith, 1975), Australia now hosts several thousand breeders and a national herd of over 200 000 goats (Mannion, 2018). Although Australian mohair contributes less than 5% of the world mohair clip, its quality gives this product a competitive edge with international buyers (Clancy, 2019).

To maintain this competitive edge, substantial effort has been directed at improving fleece quality. Fleece value is defined by three variables which determine the end use for particular fibre; mean fibre diameter (MFD micron μm), fleece staple length and fibre medullation (McGregor & Butler, 2014a; McGregor, Butler, & Ferguson, 2013a; Nixon, Saywell, & Bown, 1991). Other variables important in wool production, including vegetable matter, coting and staple strength do influence mohair quality, but are relatively minor factors in mohair production due to the lower quantities of mohair produced by the industry (McGregor & English, 2010). Generally, the most valuable fleece will have a low fibre diameter, high fleece weight and minimal to no fibre medullation. Overcoming the positive correlation between skin follicle density and fibre diameter while increasing fleece weight is poorly understood (Margolena 1974). Genetics, environment and nutrition have a profound influence on mohair quality (Allain & Roguet, 2003; McGregor, 1998; Taddeo, Allain, Mueller, & de Rochambeau, 1998a).

Foetal programming studies suggest that the prenatal environment has considerable influence on the postnatal production of an animal throughout its lifetime. Animals on higher planes of nutrition prenatally perform better than those on lower nutritional planes for lifetime body growth and reproductive performance (Short, 1955). For fibre producing species including sheep (Greenwood, Thompson, & Ford, 2010) and Angora goats (McGregor, 2016a),

plane of nutrition prenatally would have a similar effect on the initiation and development of skin follicles and on lifetime fibre production.

2.1 Factors Influencing Mohair Quality and Value

Fleece value is assessed and classed commercially using MFD, fleece staple length and fibre medullation. Similar to Merino wool, mohair is classed based on visual assessment of the fleece by certified classers (Clancy, 2007). Visual assessment during clip preparation is the accepted measure of assessing Merino fleece despite its poor correlation to measured fleece diameter with objective measurements of sale lots taken prior to sale (McGregor & Butler, 2014b). Guidelines to visually class mohair are less rigorously defined than those established for Merino wool. This explains why factors important in wool classing, for example staple strength, are not major drivers in classing mohair. However, it is not unreasonable to assume that an equally experienced mohair classer has the same measure of accuracy as a wool classer (McGregor & Butler, 2014b).

There are important differences between what constitutes top class mohair compared to top class wool. Table 2.1 provides a simplified summary of mohair classes which are used in the following discussion.

2.1.1 Fibre diameter

Based on previous Australian mohair auctions, fleece of a lower fibre diameter is inherently more valuable than a higher fibre diameter. During the B2021 auction, fibre classed as BFFK, BFK, BFFYG, BFFH and BFH was valued at \$59.20 /kg, \$57.40 /kg, \$48.20 /kg, \$38.70 /kg and \$34.20 /kg respectively (Clancy, 2021b). A similar trend is seen in the C, D and E-length classes for non-grower lots in this sale and previous years. Although this auction data is published for commercial rather than academic purposes, fine class mohair is

more valuable than coarser mohair although there is year to year variation of the specific value.

Table 2.1 Mohair classes based on staple length (A-E in mm) and fibre diameter (FF-H in μm). (Clancy, 2007; Macpherson, 2012; McGregor & English, 2010)

*Classes that can be subdivided with S.

	Kid ¹			Young Goat		Adult		
	FF* 22-25	F* 26-28	Kid* 28-30	FF* 28-30	F* 31-32	FF 32-34	F 35-36	H 37-42
A 150+	AFFKid	AFKid	AKid	AFFYG	AFYG	AFFH	AFH	AH
B 120-150	BFFKid	BFKid	BKid	BFFYG	BFYG	BFFH	BFH	BH
C 100-120	CFFKid	CFKid	CKid	CFFYG	CFYG	CFFH	CFH	CH
D 70-100	DFFKid	DFKid	DKid	DFFYG	DFYG	DFFH	DFH	DH
E 50-70	EFFKid	EFKid	EKid	EFFYG	EFYG	EFFH	EFH	EH

¹Kid mohair is usually from goats < 12 months of age.

2.1.2 Staple length

Different staple length mohair is required for specific textile applications. Referring to the A2021 auction mohair classed as FK but of different staple lengths, fibre class C, D, and E-length was valued at \$58.80 /kg, \$55.60 /kg and \$19.50 /kg respectively (Clancy, 2021a). However, looking at the same sale for FH classes, D-class mohair (70-100 mm) was valued at \$30.00 /kg while C-class (100-120 mm) was \$28.00 /kg. A similar trend was also seen for FFH class in the B2021 sale (Clancy 2021b). It is likely the preference for shorter fibres of different micron classes is a reflection on the versatility of fibres with those particular characteristics.

2.1.3 Fibre medullation

Fibre medullation refers to the occurrence of fibres with a central medulla core. Fibre medullation is an indicator of fibre variability and complicates determining fleece value. Medullated fibres are classed as either medullated fibre (med) or kemp. Med fibres have a medulla that is less than 60% of the diameter of the fibre while a kemp fibre has a medulla greater than 60% diameter. Fibres with an overall diameter less than 20 μm are not medullated (Lupton, Pfeiffer, & Blakeman, 1991). All medullated fibres with a diameter greater than 100 μm are kemp, while medullated fibres with a diameter 20-30 μm are all med. Kemp fibres are produced by primary central follicles while med fibres are produced by primary lateral follicles (Nixon et al., 1991).

These differences between med and kemp fibres are important when discussing the seasonal effect on mohair growth in a latter section. The presence of medullated fibres is undesirable since the medulla will not take up fabric dyes uniformly and cause a rougher, 'itchy' feel to the final product due to the coarser fibre diameter (Nixon et al., 1991). Even so, there is clear overlap between the diameters of med fibres and those of the desirable mohair fibres

between 20-40 μm (Lupton et al., 1991). Therefore, reducing the incidence of medullation is paramount in limiting its discount on fleece value.

2.2 Influences on Fleece Quality and Production

Fibre production is influenced by genetic and environmental factors (McGregor, 1998). Given that genetic potential is determined at conception, the environment subsequently determines the degree of the genetic potential achieved at any given time. This then determines the fleece phenotype quality for a given shearing. Limited reports are available on the genetic variation of fleece traits in Australian Angoras (Ferguson & McGregor, 2005). The following sections will discuss the heritability of fleece quality traits and the environmental and nutritional factors that influence mohair quality.

2.2.1 Genetics and heritability

Heritability estimates for MFD, staple length, clean fleece weight (CFW), greasy fleece weight (GFW) and kemp score have been reported by several researchers from different countries with mixed estimates. This is shown in Table 2.2.1.

Table 2.2.1 Heritability estimates (\pm standard error) for mean fibre diameter (MFD), staple length, clean fleece weight (CFW), greasy fleece weight (GFW) and kemp score.

Fleece Trait	Heritability	Reference
MFD	High	0.32 \pm 0.02 (Allain & Roguet, 2003) (Taddeo et al., 1998b) (Visser et al., 2009)
	Low	0.14 \pm 0.14 (Gifford et al., 1991)
Staple length	Moderate	0.18 \pm 0.02 (Allain & Roguet, 2003) (Taddeo et al., 1998b) (Visser et al., 2009)
	Low	0.13 \pm 0.11 (Gifford et al., 1991)
CFW	High	0.38 \pm 0.22 (Gifford et al., 1991)
GFW	Moderate	0.19 \pm 0.02 (Allain & Roguet, 2003) (Taddeo et al., 1998b) (Visser et al., 2009)
	High	0.45 \pm 0.23 (Gifford et al., 1991)
Kemp score	High	0.36 \pm 0.22 (Gifford et al., 1991)
	~	0.05 - 0.43 ¹ (Tiffany-Castiglioni, 1986)

¹Range was attributed to a sample selection bias.

Possible reasons for these differences include actual heritability differences in the different populations, differences in the genetic bases, sampling errors or biases in the sire selection for the genetic variation (Gifford, Ponzoni, Lampe, & Burr, 1991). Regardless, some degree of heritability for fleece quality traits exists with genetic improvement to mohair fibre traits possible and permanent.

2.2.2 Environmental effects

The environmental effect on mohair quality are caused by climatic, seasonal and year-to-year variation in pasture quality and quantity. This results in substantial nutritional variation in pasture. Photoperiod, a significant driver of plant growth, also reportedly influences mohair quality.

Using Merghoz goats individually penned under natural lighting conditions and fed a maintenance diet, Mirmahmoudi, Souri, Talebi, and Moghaddam (2011) took monthly skin biopsies to assess follicle density, percentages of active primary and secondary follicles and ratio of secondary to primary follicles (S:P ratio). This found the peak primary and secondary follicle activity and clean fibre growth occurred in winter and was lowest in summer, while fibre diameter was finest in spring and coarsest in autumn. These findings conflicted with the reports by Nixon et al. (1991) and Litherland, Toerien, Sahl, Lee, and Goetsch (2000) who sampled from Angora goats. Primary follicle fibre growth activity varied significantly ($p < 0.05$) with season, being reduced in the winter months. Secondary fibre activity varied negligibly with season. The reported effect of seasonal variation on fibre diameter in Angora goats is mixed (Bassett, 1986; Calhoun & Lupton, 1989; Dreyer & Marincowitz, 1967; Lupton et al., 1991). However, Mirmahmoudi et al. (2011) concluded that the variation in seasonal growth of fibre mirrored the seasonal variation in Dry Matter Intake (DMI) and not photoperiod per se. Arguably a similar conclusion would apply for Angora goats.

Photoperiod has been reported to affect the growth of Cashmere (B. J. McDonald & Hoey, 1987), merghoz hair (Mirmahmoudi et al., 2011) and mohair (Stapleton, 1978). Feeding Australian Angora wethers over 18 months, Stapleton (1978) found that mohair grew 55% more during the summer months than the winter, and that the proportion of medullated fibres varied in a similar way. However, it is unclear if this reflected a photoperiod effect or changes in liveweight as feed availability fluctuated throughout the year. Earlier research by Margolena (1974) found the proportion of non-growing follicles was higher in winter compared to summer and became progressively higher as a goat ages, although limited sample size complicates the validity of this finding. Regardless, both Stapleton (1978) and Margolena (1974) concluded that the influence of photoperiod on mohair growth is probably exaggerated but difficult to quantify.

Research conducted over a 15- year period in Argentina by Taddeo et al. (1998a) evaluated the effect of year, sex, age of dam and birth type on the characteristics of the fleece. For GFW at the first shearing, there was a significant difference due to year, sex, dam age and birth. Only year of production was significant for MFD and percentage medullation (med%) at first shearing. Year of production provided the greatest source of variation in GFW, MFD and med% although a specific trend could not be determined. For the second and subsequent shearings, year of production significantly affected GFW, MFD and med% although, a specific trend was not determined. A similar influence was seen in the more temperate environment of France by Allain and Roguet (2003) with large variations in fleece traits according to year of production. Clearly, variations in nutritional quality and quantity within and between years have a significant influence on mohair quality.

Pasture composition will inevitably change with the seasons and across years of production. The majority of Australian mohair producers graze their animals on improved or native grassland pastures in the wheat-sheep zone. These areas depend on pasture residues for summer grazing which are deficient in both energy and protein. Summer grazing results in a loss of liveweight and a decrease in fibre production in sheep (McGregor, 1998). In unpublished data by McGregor, castrated Angora goats grazed on annual temperate pastures over three consecutive years demonstrated a liveweight loss during summer and autumn. This loss was up to 21% of the previous maxima. Although fibre production was not assessed in Angoras, it is not unreasonable to expect a decrease in production similar to sheep given the liveweight loss (McGregor, 1998).

In conjunction with changes in energy and protein with pasture quality, trace element components also influence fibre production. Deficiencies in trace elements are known to have a large influence on fibre quality in practice, but little has been done to quantitatively measure this. The majority of trace

element requirements have been extrapolated from sheep for Angora goats. However, given the biological differences between mohair and wool this is unlikely to be accurate (McGregor, 1998). Work done by Qi, Lu, Owens, and Lupton (1992) supplemented sulphate to Angora goats and reported a positive response for mohair growth, staple length and staple strength. Certain areas of Australia have reported copper, selenium, iodine and cobalt deficiencies that influence wool production. This is likely to be true for Angora goats, although the severity may differ between the species (McGregor, 1998).

An individual farm factor also influences mohair production. Further research by Allain and Roguet (2003) in France, found the farm factor was highly significant for all fleece traits including GFW and MFD characteristics. This farm factor accounted for 8.4% and 7.4% variability respectively. The production system used by different producers including feeding systems, breeding methods and health management would explain these differences. The same is likely to occur in Australia although their impact remains unknown.

2.2.3 Nutrition

The influence of environmental factors on mohair quality can be explained by the effects of nutrition. However, additional factors including age, sex, physiological status, stocking rate, liveweight change and supplementary feeding have an effect on mohair quality. The following sections analyse each of these factors.

2.2.3.1 Age

Nutrient partitioning shifts as an animal ages (Taddeo, Allain et al. 1998a). Although age is commonly stated to increase MFD, several researchers under a variety of conditions have demonstrated this is unlikely to be reliable (Allain & Roguet, 2003; Ariturk, Yalcin, Imeryuz, Muftuoglu, & Singer, 1979; Gifford et al., 1991; McGregor, 1998, 2018a; Taddeo et al., 1998a). From 1979 to 1984,

Gifford et al. (1991) collected data on the fleece traits of Australian Angora goats to assess the environmental effects on mohair quality. Age was a significant source of variation for all fleece traits except med% and staple length in both wethers and does from 6-13 months old and in females only from 6-73 months of age. Body weight (BW) and MFD showed a marked increase between 13-18 months of age with a slower, but consistent increase with age thereafter (Gifford et al., 1991). Similar findings were reported by Allain and Roguet (2003), McGregor, Butler, and Ferguson (2012) and Stapleton (1978) with MFD increasing rapidly from 18-30 months of age. By contrast, Taddeo et al. (1998a) in Argentina found that MFD increased significantly from 2-5 years of age and then decreased rapidly thereafter. In Turkey, Ariturk et al. (1979) found the maximum value of MFD occurred at 4 years of age. Findings reported by Lupton et al. (1996) in Texas showed a linear effect of age on fleece traits with MFD and med% trending positively as an animal ages. As latter sections will discuss, these findings indicate it is difficult to distinguish whether MFD trends with age or with the BW change that comes with age.

The influence of age on staple length is ill defined (McGregor & Butler, 2014b). Earlier work by McGregor et al. (2013a) demonstrated that changes in liveweight influenced staple length but were small compared to the influence of age. The effect of age on staple length did not change in a simple systematic manner nor between the summer and winter shearing. It could be suggested that changes to the follicle population metabolism is the underlying mechanism (Taddeo et al., 1998a).

Age as a predictor of GFW is also unlikely to be reliable (McGregor, 1998). In a report by Lupton et al. (1996) GFW trended negatively with increasing age. In contrast, Taddeo et al. (1998a) and Ariturk et al. (1979) demonstrated a peak of GFW at 3-4 years of age. On the other hand, GFW demonstrated a marked increase between 6-13 months old, moderate increase until 3.5 years old and declining thereafter in a report by Gifford et al. (1991). Work completed by Allain and Roguet (2003) demonstrated similar findings, with GFW increasing

rapidly between 6-18 months of age and declining slowly thereafter. It is likely the early increase in fleece weight is due to a rapid expansion of skin surface area with the latter trends dependent on animal mature size and nutrition (McGregor, 1998).

Age of the dam has also been reported to play a role in the fleece quality of offspring. Studying a cohort of kids born in 2002, McGregor and Butler (2014b) recorded a range of subjective and objective fleece traits for nine different shearings. Those kids born to older dams had heavier CFW. Rather than the age of the dam influencing the fleece quality of the offspring, it is likely that those does that have been retained in the flock are inherently more productive both in terms of mohair production and reproduction and this is reflected in their offspring.

The influence of age may be attributed to differences in liveweight. Fleece free live weight (FFLwt) is positively correlated with both MFD and age (McGregor, 1998; McGregor et al., 2012). Under a variety of conditions including good and poor nutrition, mean liveweight accounted for four times more variation in fibre diameter than age (McGregor, 1998). When Angora wethers were grazed on annual pastures at three different stocking rates, mean liveweight accounted for twice as much variation in predicting fibre diameter as age (McGregor, 1998). Liveweight change, which is a reflection of long-term nutritional intake, will be discussed in detail elsewhere.

2.2.3.2 Sex

Both male and female animals utilise nutrients in biologically distinct pathways which is reflected in the mohair quality traits. Males consistently have reportedly heavier fleece weights compared to females by up to 26% (Allain & Roguet, 2003; Eppleston & Moore, 1990; McGregor & Howse, 2018; Taddeo et al., 1998a). Reports for the effect of sex on MFD and med% are conflicting (McGregor & Howse, 2018; Taddeo et al., 1998a). Females have a greater

density of primary and secondary follicles compared to males (Eppleston & Moore, 1990; McGregor & Howse, 2018). However, the allometric relationship between MFD and liveweight described by McGregor et al. (2012) demonstrated no sex difference when body weight was considered. Therefore, any trends for sex are likely attributed to differences in liveweight and skin surface area.

2.2.3.3 Physiological status

The nutritional requirement for reproduction is substantial, which is likely to reflect mohair quality. As the nutritional requirement of a working buck for joining is unknown, the mohair quality changes can only be estimated. However, pregnancy and lactation are known to have a significant effect on mohair quality of the doe. During the last 8 weeks of pregnancy, a foetus grows 85% of its final body weight (McGregor, 2016a). Most does are under energy stress during this time (Wentzel, Le Roux, & Botha, 1976). In a study by McGregor (2016a), pregnant Angora does were fed ad-libitum rations at three different levels based on energy requirements from day 47 of pregnancy until 4 days post-partum. Feeding levels were control (90% maintenance), maintenance (103% maintenance) and supplemented (120% maintenance). Supplemented does (S) grew 8% more fleece that was 1 μm coarser while maintenance (M) does grew 6% more fleece than control (C) does. There was no effect on med%. It was concluded that a pregnant doe can maintain fibre growth and quality if fed adequate energy during pregnancy (McGregor, 1998).

Further, McGregor (2016a) subsequently manipulated the nutrition of the aforementioned does during lactation (McGregor, 2017). Each treatment group C, M, and S was subdivided to be fed ad-libitum (AL) or restricted (R) during lactation. Those does that were better fed grew more mohair that was coarser. Single rearing does produced mohair 2.2 μm coarser than those raising twins. Twin rearing does produced 14% less mohair than those raising a single kid. It was concluded that there was a preferential partitioning of nutrients to

pregnancy and lactation rather than mohair, with a subsequent reduction in mohair growth (McGregor, 2017).

2.2.3.4 Stocking rate

Stocking rate is perhaps the most important decision producers make to determine the productivity and profitability of a farming enterprise (McGregor, 1998). Stocking rate determines the food available to each animal and has significant impact on future pasture production and composition. Optimal stocking rate is ideally determined using Dry Sheep Equivalent per hectare (DSE). The Ruminants Subcommittee from the Standing Committee on Agriculture Victoria (SCA, 1990) considered 1 DSE to be the maintenance energy requirements of a 45 kg wether sheep, which requires 7.6 MJ/day metabolisable energy (ME) per day. Historically, Angora goats were considered 0.75 DSE (Moylan, 1984) or 5.7 MJ/day. A retrospective analysis by Luo et al. (2004) found the maintenance energy requirements of a mature Angora goat was $473 \text{ kJ/kgBW}^{0.75}$. For a 45 kg goat, this is equivalent to 8.21 MJ/day. Using data established from the US National Research Council (2006), a 45 kg Angora wether would require a minimum of 10.2 MJ/day to maintain BW and grow mohair. Information on livestock planning produced by McLaren (1997) for producers compared sheep and cattle but did not consider goats. However, he suggested that the different eating habits of goats made direct comparisons difficult. Not only is 0.75 DSE grossly inadequate for Angoras, but substantial changes in the recommended energy requirements have occurred and the need for further assessment is recommended.

The grazing behaviour of goats is significantly different to sheep such that it has been suggested that grazing sheep and Angoras together would utilise different components of pasture and therefore increase production compared to each species grazed alone (McLaren, 1997). This was done by McGregor (1985). Increasing rates of stocking did have complimentary effects for moderate rates (10 animals/ha) but produced competitive effects at higher

stocking rates (12.5 animals/ha). At these higher rates, sheep were more productive for fleece and body growth but goats were less productive than those grazed at the same rate as a single species. It was concluded that Angoras should not be grazed at rates greater than sheep. This research was repeated later in greater depth with similar findings (McGregor, 2010a).

Initial studies on Angora goat stocking rates demonstrated significant effects of increasing stocking rate on pasture availability, structure and composition and on mohair quality parameters. Higher stocking rates reduced both MFD and fleece weight and increased medullation (Table 2.2.3.4). Earlier work by Lupton et al. (1991) found that medullated fibres increased with increasing stocking rates. However, when grazing pressure became intense, medullated fibre production was significantly depressed. Arguably, a reduced MFD would compensate for a reduced fleece weight at above recommended stocking rates. However, when concurrent changes in liveweight and reproduction are considered, it is unlikely that higher stocking rates are of any benefit.

Table 2.2.3.4 Main effects of stocking rate of Angora goats on mohair quality parameters. (McGregor, 1998)

Parameter	Effect of stocking rate
Mohair weight	High stocking rates reduces production per goat up to 20% but increased production per hectare.
Fibre diameter	Changes up to 5 μm . High stocking rates have finer mohair.
Kemp incidence	High stocking rates increased kemp.
Clean yield	Reduced by up to 5% at high stocking rates.
Mohair length	Reduced at high stocking rate.

2.2.3.5 *Liveweight change*

While stocking rate determines the feed available to an animal, liveweight change (LWtCh) is a reflection of how that nutrition status matches requirements. Average FFLwt and LWtCh reflect long and short term responses

to nutritional differences respectively. Both of these parameters are associated with MFD and CFW but are unlikely to influence medullation (McGregor, 2010a, 2010b; McGregor & Butler, 2014b; McGregor, Butler, & Ferguson, 2013b). Changes to liveweight confound the effects of age and sex on mohair quality. Using growing Angora goats grazed on pasture, McGregor (2010b) found that for every 10 kg increase in liveweight, fibre diameter increased by $3.48 \pm 0.28 \mu\text{m}$. Separate work by McGregor (2010a) found MFD increased by $4.7 \mu\text{m}$ for every 10 kg increase in FFLwt. He later established that MFD was proportional to $\text{FFLwt}^{1/3}$ (McGregor et al., 2013b). It is expected that older goats weigh more than growing goats and males to weigh more than females, which would be reflected in their coarser fleeces. Fleece weight follows a similar trend (McGregor & Butler, 2014b). Clean fleece weight is proportional to FFLwt (McGregor et al., 2013a) up to 50 kg BW with little response thereafter (McGregor & Butler, 2014b). In addition, the higher fleece weight may be due to an increase in staple length, with McGregor et al. (2013b) finding that at a given age every 10 kg increase in weight, increased staple length by 0.34 cm. In sheep, Hynd (1994) demonstrated that nutritional changes altered the size of cortical cells producing wool fibres and hence the fibre length. It would not be unreasonable to expect similar changes to mohair cortical cells. It is also suggested that conditions that cause a negative LWtCh may subsequently reduce fibre growth by increasing the numbers of non-growing follicles (McGregor et al., 2013b).

Given medullation is influenced by MFD, factors affecting the latter also have an effect on medullation (McGregor et al., 2012). A phenotypic relationship between MFD and FFLwt has been reported in many studies for Angora goats and Merino sheep (McGregor, Butler et al. 2012). Reports by McGregor, Butler et al. (2012) determined that mohair MFD is allometrically related to the cube root of FFLwt. Across 268 Merino genotypes, it was found that for each $1 \mu\text{m}$ increase in MFD, mature liveweight increased by 1.2% (McGregor et al., 2012). A separate paper by McGregor, Butler and Ferguson (2013a) demonstrated that for each $1 \mu\text{m}$ increase in MFD, there was a 1.5% increase in

med fibres when adjustments were made for FFLwt and a 2% increase without adjustment for FFLwt. It could be therefore concluded that the increase in medullation with FFLwt is due to the increase in MFD with increased body weight. However, the positive relationship of medullation to both FFLwt and MFD was unaffected when adjusting for the other variables (McGregor et al., 2013b). This indicates that the relationship between med and MFD is not affected by nutrition.

2.2.3.6 Supplementary feeding

Strategic use of supplementary feeding must balance the mohair quality and welfare gains with the feed and labour costs. Liveweight loss is expected in dry seasons when pasture quality and quantity is decreased. Goats fed to lose 5 kg BW over 12 weeks grew less mohair that is finer by 2-3 μm when compared to goats fed to maintenance. Goats fed to gain this weight grew mohair 2-3 μm coarser and reduced the incidence of medullated fibres compared to those fed to maintenance. It is unlikely that feeding adult non-breeding goats to gain BW would be economical given the increase in fibre diameter. However, it would be economical to feed kids to gain weight. Not only would this reduce medullation but improved body growth rates would hasten sexual maturity and subsequent reproduction (McGregor, 1998).

Liveweight loss can also be expected during late pregnancy and lactation. Supplementary feeding is beneficial to increase survival of the kids, improve lactation and kid mohair growth rates (McGregor, 1998). Any potential liveweight gain by the doe would be advantageous in the subsequent joining period to improve ovulation rates (McGregor, 1998).

The most common supplementary feed in Australia is cereal grains, especially wheat. Wheat compensates for the energy deficit in Australian pastures at times of liveweight loss (McGregor, 1998; McGregor & English, 2010). When weaner Angora goats were supplementary fed two levels of barley (115 or 230

g/day) in conjunction with grazing for 4 weeks, 8 weeks, 2 months or 3 months neither supplement quantity or duration influenced liveweight or mohair production (McGregor, Harris, & Denney, 2010). Offering 50:50 barley and lupins at 350 g/day for 4 months increased live weight, GFW, MFD and medullation (McGregor et al., 2010). However, this advantage became non-significant 6 weeks after supplementary feeding finished. This suggests that Angora weaners can be supplementarily fed to grow additional mohair during times of nutritional deficit but it must be prolonged and at relatively high levels. Further, the cost of supplementary feeding compared to the value of the additional mohair grown is unlikely to be advantageous when pasture is adequate (McGregor et al., 2010).

When Huston, Shelton, and Ellis (1971) fed yearling bucks different protein levels, those fed a diet of 18% crude protein (CP) grew 33% more mohair compared to those fed 12 or 15% CP. Fibre diameter increased linearly as protein level increased (Galbraith, 2000). Similar results had been found by Gregoire, Fahmy, Boucher, Tremblay, and Mercier (1996) and Throckmorton, Ffoulkes, Leng, and Evans (1982). When Galbraith (1998) supplemented rumen protected, intestinally available methionine fleece weight and MFD increased. This contrasts with their later work which found methionine increased yield without increasing fibre diameter (Galbraith, 2000). However, these differences became insignificant when adjusted for BW. This meant that additional methionine was used to increase all of its biological roles (Galbraith, 1998). Given the inherent difficulty in increasing 'protected' protein and its substantially higher cost, it is unlikely to be economical even if increases in mohair production could be achieved.

2.3 Follicle Development

The productive organ for wool and mohair is the hair follicle. Hair follicles are a uniquely mammalian structure and begin development in early foetal life as simple thickenings of the skin (Dyce, Sack, & Wensing, 2002). Follicles then

mature with an array of supportive structures in the late prenatal and early postnatal periods (Dyce et al., 2002). Later production of the hair follicle is influenced by the maternal environment during early development in sheep (Behrendt et al., 2006; Behrendt et al., 2011; Curnow, 2006; Thompson et al., 2011). This section will discuss the anatomical structure of hair follicles with particular reference to sheep and goats. The prenatal development of individual follicles and the complete follicle population will be described in detail, followed by the postnatal maturation of the follicle population.

2.3.1 Anatomical structure of skin

The anatomical structure and function of skin is well described (Dyce et al., 2002; Galbraith, 1998). Hair follicles are a specialised modification of interdigitating papillae between the epidermal and dermal layers (Samuelson, 2007). The hair canal is lined with modified epidermal cells that form not only the canal itself, but supportive sebaceous and sudoriferous glands. The sebaceous glands produce an oily protective coating to the hair while the sudoriferous glands serve a thermoregulatory function (Dyce et al., 2002). Below the surface of the epidermis at the base of the hair canal is the hair bulb, which contains the dermal papillae and hair root. The dermal papillae contains blood vessels and nerves providing support to the hair root. Associated with the dermal papillae are the arrector pili muscles, which contract to erect hair shafts. The hair root is modified layers of epidermal cells that secrete the hair matrix. As the wool or mohair fibre grows, the epidermal cells mature to form the fibre medulla and secrete keratin to form the fibre cortex.

There are three different types of hair follicles, two of which are of most importance in fleece production as shown in Figure 2.3.1. Primary follicles produce straight, stiff fibres that tend to have a thick cortex and medulla, while secondary follicles produce fine, wavy fibres that tend to lack a medulla. Histologically, primary follicles always contain well developed sweat glands and arrector pili muscles. Secondary follicles have rudimentary supportive

glandular structures or lack them entirely (Hardy & Lyne, 1956). Primary follicles produce guard hair while secondary follicles produce the fibres recognised as wool and mohair. The third type produce vibrissae which include specialised sensory hairs such as whiskers on the face of most animals and have no contribution to fleece production (Dyce et al., 2002).

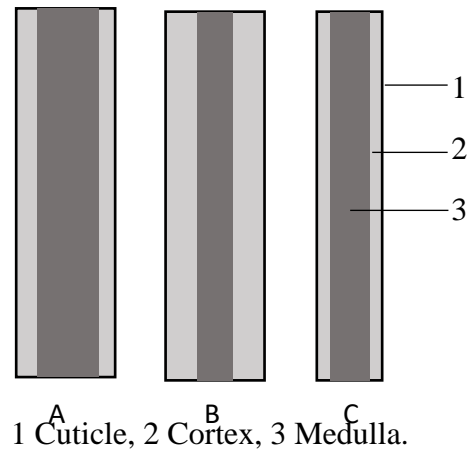


Figure 2.3.1 Schematic diagram of primary (A and B) and secondary (C) fibres (Dyce et al., 2002)

2.3.2 Individual follicle development

The definitions for the eight developmental stages of follicles were first proposed by Hardy and Lyne (1949) from mice studies. This initial proposal has since been adapted to apply to other rodents and sheep, and can be extrapolated to a variety of other mammals (Hardy & Lyne, 1956). The following summarises the developmental stages with respect to Merino sheep with particular emphasis on the differences between primary and secondary follicle development (Figure 2.3.2).

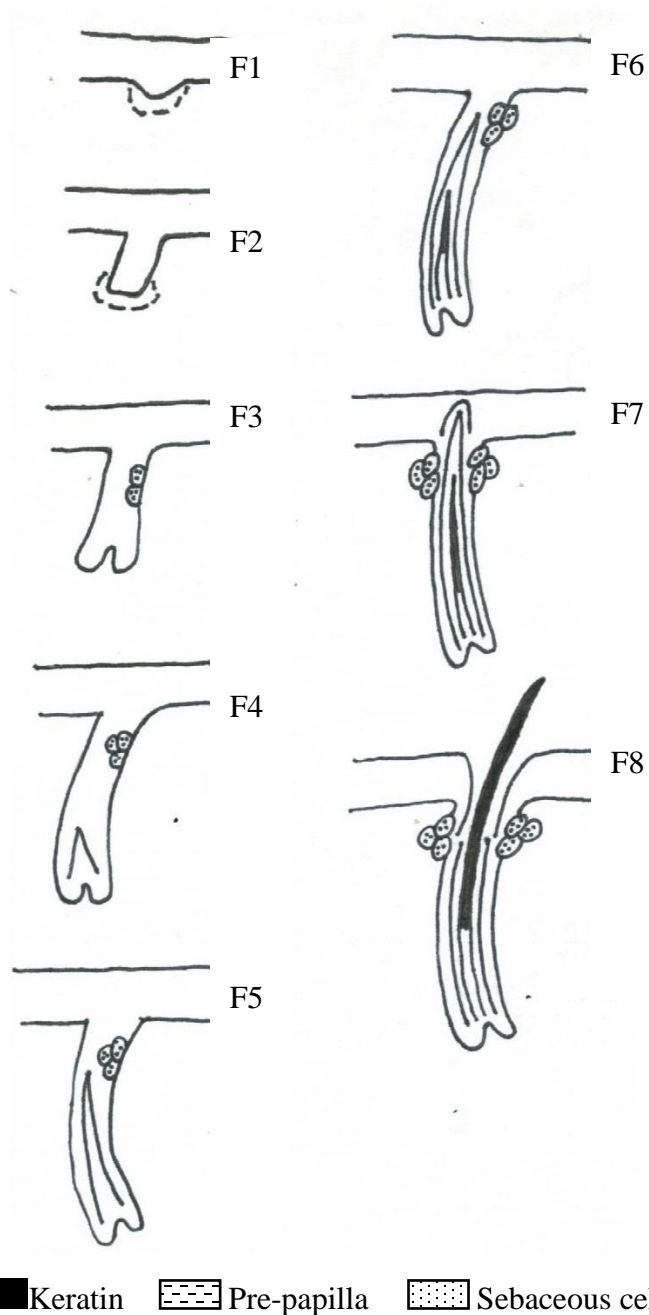


Figure 2.3.2 Schematic of stages F1-F8 in the development of secondary follicles in the Australian Merino sheep foetus (Hardy & Lyne, 1956)

Stage F1: *Follicle Plug*. Follicle development begins as a localised thickening of the epidermis that extends into the dermis. The adjacent layer of dermal cells thickens around the epidermal placode.

Stage F2: *Pre-papillae*. The base of the epidermal placode flattens. Primary follicles begin to develop a rudimentary sweat gland. Original Secondary (SO)

follicles are more elongated than primary follicles at this stage but have no rudimentary glands.

Stage F3: *Papillae*. The flattened epidermal placode becomes invaginated by the dermal cells to form the dermal papillae. Primary follicles begin to develop arrector pili muscles. Both follicle types begin to develop sebaceous glands. Some SO follicles begin to branch and invaginate to produce derived secondary (SD) follicles above the sebaceous gland.

Stage F4: *Hair Cone*. The outermost layer of the hair cone (Henle's layer), is formed. This is a cone-like structure pointed towards the epidermis. A distinct canal begins to form proximal to the advancing cone. The sweat glands and arrector pili muscle of the primary follicles begin to mature. More SD follicles form from SO follicles or the earliest SD follicles.

Stage F5: *Advanced Hair Cone*. The tip of the hair cone reaches the sebaceous gland of the primary follicles. The hair cones of primary follicles have distinct cuticles and cortices. The SD follicles begin to form hair canals proximal to immature hair cones.

Stage F6: *Hair Formation*. A tip of keratinised hair is seen in the advancing hair cone. The hair canal and sweat glands finish forming for the primary follicles. The hair canal of the secondary follicles continues to mature albeit slower than the primary follicles due to the extensive branching. Secondary follicles remain in this stage of development for longer than primary follicles.

Stage F7: *Hair in the Epidermis*. A tip of hair reaches the innermost layers of the epidermis for both types of follicles.

Stage F8: *Hair Emerges*. Hair tips penetrate the superficial epidermal layer of both primary and secondary follicles.

There appear to be distinct differences in the follicles between Merino sheep and Angora goats. Secondary follicles of Angora goats have distinctively larger sebaceous glands than the equivalent Merino follicle (Margolena, 1974).

Merino sheep display extensive secondary follicle branching with multiple fibres penetrating a single canal. While this does not occur in Angoras, each secondary follicle of an Angora penetrates the epidermis individually although

they do share supportive structures (Margolena, 1974). This probably explains why the sebaceous glands of Angora follicles are inherently larger than Merino follicles.

2.3.3 Follicle population development

Primary and secondary follicles form distinct groups (Hardy & Lyne, 1956). The first primary follicles (PX) to develop form trios of a central follicle (PCX) and lateral follicles (PLx). These follicles are relatively evenly spaced throughout the skin. Smaller primary trios (central PCY and lateral PLy) form between these earliest trios. Secondary original follicles (SO) and secondary derived (SD) follicles form in varying clusters between the primary trios.

There is significant overlap in the prenatal development of the follicle groups. As such, there are 18 recognised stages of development of the complete follicle population. Table 2.3.3 describes the stages of growth of the different follicle types and mean age of each developmental stage in Merino sheep foetuses (Hardy & Lyne, 1956).

Table 2.3.3 Summary of stages in the development of Merino sheep follicle groups and their relation to the growth of individual follicles.(Hardy & Lyne, 1956)

Mean Age of Foetus (days)	Follicle Group Stage	Most Advanced Stages Found in Each Follicle Type				
		PCX	PCY	PLx	Ply	SO
64	G1	F1	-	-	-	-
69	G2	F1	F1	-	-	-
71	G3	F2	F1	-	-	-
74	G4	F2	F2	F1	-	-
76	G5	F2	F2	F2, F1	F1	-
79	G6	F2	F2	F2	F2	-
82	G7	F3, F2	F2	F2	F2	-
86	G8	F3	F2	F2	F2	F1
90	G9	F3	F3	F3, F2	F2	F1
95	G10	F4	F4	F3	F3	F2
97	G11	F5	F5	F3	F3	F2
98	G12	F6	F6, F5	F5, F4	F4, F3	F2
99	G13	F6	F6	F5	F5, F4	F3
101	G14	F7	F7	F7, F6	F7, F6	F3
102	G15	F8	F8	F7	F7, F6	F3
107	G16	F8	F8	F8	F8, F7	F4, F3
115	G17	F8	F8	F8	F8	F7, F6
133	G18	F8	F8	F8	F8	F8

The mean age of the developmental stages do not directly correlate to Angora foetuses and it is likely these stages occur at an older age (Margolena, 1974). Follicular development in Angoras begins at approximately day 60 of gestation. Primary central follicles are first formed at approximately day 70 while PL follicles are initiated by day 80 (Margolena, 1974). Primary follicles regardless of type, take approximately 35 days to mature and pierce the skin about 10 days later at roughly 110 days gestation (Margolena, 1974).

The development of secondary follicles is less regular and significantly slower than primaries (Margolena, 1974). Secondary follicles are initiated at day 100. Secondary follicles will continue to be initiated until approximately 1 month after birth (Margolena, 1974). By 150 days gestation, there is extensive proliferation of the secondary follicles and penetration of the epidermis begins

to occur at about this time. All follicles appear to be mature by 2 months of age (Margolena, 1974).

2.3.4 Postnatal maturation of the follicle population

Follicle populations are most commonly described by S:P ratio and follicle densities (Short, 1954). The S:P ratio in young animals represent the proportion of the populations of both secondary immature (Si) and secondary mature (Sf) follicles compared to primary mature (Pf) follicles. High S:P ratios are desired, as this represents a follicle population with high densities of secondary follicles which results in lower mean fibre diameter.

It is well established that all secondary follicles are initiated by birth in many different breeds of sheep including Merinos (Short, 1954). Skin biopsies taken from Merino lambs every 7 days for the first 28 days postpartum demonstrated an average increase in mature follicles of 15% from birth to 7 days and 250% from birth to 14 days. This implies that the lag in body growth experienced after birth occurs similarly in follicle maturation and is likely related. Rate of secondary follicle maturation was highest between days 7-21 with 65% of secondary follicles producing fibres by 28 days old. The rate of maturation then declines between days 28-56, and slows further to near zero by 168 days. By tracking changes in the S:P and Sf:Pf ratios, Short (1954) determined that follicle maturation was complete by 168 days after birth. Therefore, the adult follicle population in Merino sheep is established by 6 months of age (Short, 1954).

Initiation and growth of hair follicles appears to be at a maximum during the 4th month of gestation in Angoras. Using 25 Angora goat foetuses and five live kids, Wentzel and Vosloo (1975) tracked the development of primary and secondary follicles and their rate of maturation. The S:P ratio increased sharply from 0 on day 90 to 7.0 by day 120 of gestation and remained constant until day 14 postpartum. The S:P ratio then gradually increased to 10.0 by 4 months post-

partum. The Sf:Pf ratio increased from 0 to 1.7 between days 110-130 post conception, remained constant until birth and then increased to 10.0 by 4 months of age. The similarity of S:P and Sf:Pf ratios at 4 months indicated that the follicle population was mature and functional by this age.

Similar findings were demonstrated by Parry et al. (1993) using a larger sample size and only live kids. The primary follicle density was highest at birth at 17.4 /mm² with a decline of over 50% during the first month postpartum (7.7 /mm²). This decline was less rapid thereafter to 2 months (5.7 /mm²), 4 months (3.7 /mm²) and stabilised at 6 months (3.0 /mm²) of age. This trend likely represents the change in animal size as the kid matures. The density of Sf and Si follicles at birth was 35.7 and 108 /mm² respectively. By 1 month of age over 90% of secondary follicles had reached maturity, with the density of Sf 60 /mm² and Si declining to 6.0 /mm². Few Si follicles were present at 2 months and none were seen at 4 months of age. The S:P ratio was 8.4, 8.8, 9.3, 10.9 and 9.9 at birth, 1, 2, 4 and 6 months of age respectively. The apparent increase in S:P ratio in the absence of immature primary follicles at birth demonstrates that some secondary follicles were initiated after birth (Parry et al., 1993). The maturation of secondary follicles occurs predominately after birth (Parry et al., 1993; Wentzel & Vosloo, 1975).

2.4 The Relationship between Follicle Density, Fibre Diameter and Fleece Weight

The previous sections explain how providing optimal nutrition at critical times of development is paramount to maximising the genetic potential for fleece production of an Angora goat. The ideal follicle population has a high S:P ratio of very small secondary follicle diameter with a high rate of growth. However, the biological capacity to produce such a population is limited. There is a highly negative curvilinear correlation between wool fibre diameter and follicle density (Adams & Cronje, 2003; Adelson, Hollis, & Brown, 2002; Scobie & Young, 2000). The dimensions of the follicular buds in the foetus do not correlate with the fibre diameter seen as an adult. However, the fibre diameter does correlate with the size of the hair dermal papillae at maturation. This

means that fibre diameter is determined after follicle initiation (Adelson et al., 2002). This relationship is useful because it suggests that two sets of genes control follicle density and fibre diameter. A negative correlation also occurs between S:P ratio and both fibre diameter and med (Adams & Cronje, 2003; McGregor, 2020). This is also useful in that selecting for reduced fibre diameter will concurrently result in an increase in secondary follicle density (Adams & Cronje, 2003).

There is an undesirable strong positive relationship between CFW and MFD (Allain & Roguet, 2003; McGregor & Butler, 2014b; Snyman, 2020; Visser, Snyman, van Marle-Koster, & Bovenhuis, 2009). These studies indicate that CFW increases 50-80 g for every 1 μm increase in fibre diameter. This positive relationship is undesirable. A highly significant negative correlation occurs between GFW and S:P ratio (Eppleston & Moore, 1990; McGregor, 2020). This negative relationship is undesirable. Early work by Galpin (1948) found that wool fibre can only occupy 2% of the total skin surface area. Skin can then either produce numerous small follicles or few large follicles, provided the 2% cap is not exceeded. Some evidence to this effect is provided by the follicle competition model. In Romney Marsh sheep, a strong negative correlation was found between the diameter of any single fibre and the number, size and displacement of the follicles surrounding it. The distance over which a follicle can effectively compete declines as the fibre diameter decreases (Bawden, Kleemann et al. 2010). There is some evidence to suggest that primary follicles do compete for fibre substrates more strongly than secondary follicles (Jackson, Nay, & Turner, 1975). It was observed by Short (1955) and McGregor (2020) that lower density fibres were coarser and longer than those of higher densities over a given growing period. This is undesirable in that it suggests that not only do primary follicles influence the development of the secondary follicles in later life, but can potentially be more productive in later life (Short, 1955). Therefore, producing fleeces of finer fibres and higher densities poses a biological problem. Given the asymptotic relationship, doubling density from 25 to 50, lowers MFD from 29 to 22 μm (Galpin, 1948). Doubling density

again to 100 reduces MFD to 17 μm . About 200 follicles/ mm^2 is needed for 14 μm fibres. It is unclear how high follicle density can be increased to lower fibre diameter and if this is beyond the biological capacity of skin (Galpin, 1948). Additionally, McGregor (2020) found that FFLwt is negatively associated with secondary follicle density. Animals with higher secondary densities will tend to be smaller with consequences on their survivability, reproduction and metabolic efficiency. Further research to understand the biological capacity of skin and how to exceed the 'density cap' is necessary if the relationship between CFW, MFD and follicle density is to be exploited.

2.5 Foetal Programming

Foetal programming refers to the phenomenon whereby the prenatal environment influences the postnatal productivity of offspring by the development of the physiological and metabolic pathways (Kenyon & Blair, 2014). Many factors influence the *in-utero* environment. These factors are classified by the extent, source and type of environmental variation caused and the potential for these factors to result in permanent or transient effects on offspring productivity (Greenwood et al., 2010). These sources of variation include dam age, parity, liveweight, prolificacy of the dam, genotype, nutrition, thermal environment, stress, toxins and teratogens (Greenwood et al., 2010). While there is no experimental evidence to support the concept of foetal programming in Angora goats, the abundant evidence in other domestic ruminants, suggests it is reasonable to assume it does (McGregor, 2016a).

2.5.1 Uncoupling the prenatal environment from postnatal maternal environmental influences

Given that offspring are reliant on their dams from conception until weaning, it is difficult to isolate the influence of the pre- and postnatal environments on later growth. Growth could be attributed either directly to treatments undertaken during pregnancy or indirectly from the influences of these

treatments on maternal performance in lactation. Artificially rearing offspring by a standardised protocol could be used to isolate the factors of the prenatal environment alone. This has been undertaken extensively in sheep and cattle but not in goats (Greenwood et al., 2010). Tables 2.5.1.1 and 2.5.1.2 summarises most studies that attempt to isolate the influence of prenatal environment on lambs reared artificially and maternally respectively.

Table 2.5.1.1 Summary of postnatal growth patterns of lambs feed restricted during pregnancy and reared artificially

Nutritional Event	Findings	Reference
Restricted nutrition during first 90 days gestation only. (Reduce doe BW 25% by 90 days gestation)	Minimal influence on postnatal growth provided nutrition adequate for the remainder of pregnancy.	Taplin and Everitt (1964) Everitt (1965)
Restriction during late pregnancy alone (Reduce doe BW 25% between 90-140 days gestation)	Difference of 1.5 kg persisted to 20 weeks of age compared to those well fed throughout gestation	Taplin and Everitt (1964)
Restricted during entire pregnancy (Reduce doe BW 25% by 140 days gestation)	Difference of 6 kg persisted to 20 weeks of age compared to those well fed throughout gestation	Taplin and Everitt (1964)
Severe chronic restriction throughout gestation or from mid-late gestation (Reduce doe BW 25% by 150 days gestation)	Compromised growth to mature size	Schinckel and Short (1961) Everitt (1967)
Adverse nutrition pre and postnatally. (Reduce doe BW 25% by 150 days gestation)	12 kg difference at 180 weeks old compared to those well fed both periods. 6kg attributed to pre or postnatal restriction alone compared to those well fed during both.	Schinckel and Short (1961)

Table 2.5.1.2 Summary of postnatal growth patterns of lambs feed restricted during pregnancy and reared on their dams.

Nutritional Event	Findings	Reference
Short term early restriction days 1-35 gestation (50% maintenance)	No effect on birth weight, post-weaning growth or adult liveweight at 2-3 years of age	Parr, Williams, Campbell, Witcombe, and Roberts (1986)
Adverse nutrition during the first 90 days of gestation (50% maintenance during days 1-35 gestation)	Overcome if adequately fed during late gestation	Parr et al. (1986)
Fed 70% nutritional requirements 30 days pre-conception to 100 days post conception	Lambs averaged 0.6 kg lighter and grew more slowly after weaning compared to those fed adequately	Nordy, Field, Riley, Johnson, and Kercher (1986) Nordy, Field, Riley M.L., and Kercher (1987)
Restriction during early- to mid-gestation (50% maintenance)	Heavier birth weight lambs than controls. Postnatal growth rates not significantly different	Gopalakrishnan et al. (2005)
Restricted to 50% requirements during days 28-78 of gestation	Lambs similar birth weight but heavier at 63 days old compared to controls Difference increased significantly to 120 days (weaning) and persisted until 8 months old	Ford et al. (2007)
Moderate underfeeding during last 6 weeks of gestation (70% maintenance)	Reduced birth weights. Persisted until weaning and 1 year old if ewe was also restricted during lactation Difference did not persist beyond 1 year old	Sibbald and Davidson (1998)

Continued.

Moderate underfeeding during last 6 weeks of gestation (Reduce doe BW 15% by 150 days gestation)	Similar findings to Sibbald and Davidson (1998) Significant difference in weight at 4 years old if dam also restricted during lactation No significant difference at 6 years old	Kelly, Greef, and Macleod (2006)
Enhanced nutrition first 100days gestation (Doe weight gain 75g/day)	Increased birth and weaning weights Did not persist at 18, 30 or 42 months old	Da Silva, Aitken, Rhind, Racey, and Wallace (2001)
Overfeeding throughout gestation (Feed refusal at 15% total ration/day)	Reduced placental development, lowered birth weight and growth to weaning	Da Silva et al. (2001)
Growth rate generally correlates with birth rate	For every 1 kg reduction in birth weight, lambs grew 46 g/day slower	Villette and Theriez (1983)
Lower birth weight lambs	Failed to catch up during lactation by 4 or 8 weeks of age but did post weaning by 2 years old	Louey, Cock, Stevenson, and Harding (2000) Louey, Cock, and Harding (2005)

2.5.2 Influence of the prenatal environment on productive characteristics

Birth weight, growth and mature size are important in the selection of animals (Greenwood et al., 2010). The following sections will discuss foetal environment and production traits including birth weight, reproductive and lactational performance and wool quality.

2.5.2.1 Birth weight

Birth weight is affected by genotype and nutrition (Gardner, Buttery, Daniel, & Symonds, 2007). It is likely that the maternal environment influences the

expression of growth and imprinting genes within the foetal genotype resulting in altered birth weights. Some evidence was provided by Sharma (2010) and Xiaopang et al. (2018). Embryos of Cheviot (small breed) sheep were transferred into Suffolk (large breed) dams and vice versa on day 8 of gestation. Cheviot embryos in Suffolk dams showed enhanced embryo length compared to non-transferred embryos. Suffolk embryos in Cheviot dams demonstrated a reduced embryo length, embryo width and heart bulge width and the resulting lambs were lighter at birth. This suggested that the maternal environment may suppress the expression of the foetal genotype before uterus size becomes an influence (Sharma, 2010).

The effect of nutrition on birth weight is most clearly demonstrated by the consistent difference between singleton and multiple births across a variety of species (SCA, 1990). Twins tend to be lighter than singletons under a variety of conditions (Gardner et al., 2007). Nutritional requirements of single and twin bearing sheep and goats is well established (SCA, 1990). The nutritional requirements of twin-bearing dams is universally greater than of singletons and while individual twins will have lower birth weights, the overall combined progeny weight is higher in twin-bearing animals (Gardner et al., 2007).

The influence of the timing, severity and duration of maternal nutritional restriction on offspring birth weight is demonstrated in Tables 2.5.1.1 and 2.5.1.2. Restriction during early gestation can have minimal influence on birth weight if the dam is fed adequately during the rest of gestation (Everitt, 1965; Parr et al., 1986; Taplin & Everitt, 1964). However, improved early nutrition is advantageous for growth rate of lambs to 12 months old (Bawden, Kleemann, McLaughlan, Natrass, & Dunn, 2010). Underfeeding during mid gestation alone produced mixed results (Ford et al., 2007; Gopalakrishnan et al., 2005; Nordy et al., 1986). It is likely that the severity, timing and duration of the nutritional restriction and how this influences the development of key metabolic pathways accounts for the differences in these results.

Feed restriction during late gestation consistently reduced lamb birth weights (Kelly et al., 2006; Louey et al., 2005; Louey et al., 2000; Moore, Millar, & Lynch, 1986; Sibbald & Davidson, 1998). The capacity to compensate for this setback depended on the persistence of the restriction into lactation. Lambs restricted during both periods took from 33 weeks to 4 years of age to compensate for this difference (Kelly et al., 2006; Moore et al., 1986). This indicates that the difference in body weight persisted after weaning and may reflect a difference in the development of key metabolic pathways.

2.5.2.2 Reproductive performance

Nutrition during gestation has the potential to influence offspring reproductive performance (Martin et al., 2012). They reported no effect of early gestation nutrition on offspring reproductive gonad organ size although mid to late gestation nutrition affected foetal ovary weight. Earlier work by Rae et al. (2002) found that the daughters of ewes underfed from mating to day 95 gestation had a reduced ovulation rate when mated at 20 months old despite similar body weight and BCS. This suggests that maternal under nutrition delayed foetal ovarian development without affecting ovary size as suggested by Bell (2006). Under-nutrition from days 21-140 of gestation had no effect on scrotal circumference, Sertoli cell count or semen characteristics in male offspring (Blair et al., 2011; Kari, 2014; Rae et al., 2002). Under nutrition during gestation has the potential to influence reproductive performance of the adult offspring especially females, but the restriction must be prolonged and include the mid-pregnancy period.

2.5.2.3 Lactational performance

Limited studies have been performed to assess the influence of prenatal nutrition on the lactational performance of the offspring. Further research by Blair et al. (2011) and Kenyon et al. (2011) found that above maintenance nutrition during days 21-140 had no influence of foetal mammary size.

However, foetuses from maintenance fed ewes did have heavier mammary glands without affecting the number of mammary ducts or their total area at day 100 of gestation compared to above maintenance ewes (van der Linden et al., 2009). For the live cohort, the maintenance group of lambs had a greater milk production with a greater lactose concentration during their entire first lactation at 2 years of age. The increase in milk yield did not persist in their second lactation but altered milk composition was still apparent (Blair et al., 2010). In a related study by Martin et al. (2012), ewes- fed maintenance rations during days 21-50 of gestation produced offspring with a greater milk yield at 2 years of age compared to those fed sub-maintenance or above maintenance. It is not unreasonable to suggest adverse nutrition during gestation would affect mammary gland development, given its influence on female reproductive organ growth.

2.5.2.4 Wool

In the Australian Lifetime Wool Project (Behrendt et al., 2006; Behrendt et al., 2011; Curnow, 2006; Thompson et al., 2011), a loss of 10 kg ewe liveweight (~1 BCS) between joining and day 90 of gestation increased the offspring's wool diameter by 0.35 μm and reduced fleece weight by 0.2 kg at hogget shearing due to reduced secondary follicle initiation (Greenwood et al., 2010). Improved maternal nutrition generally reduced fibre diameter and increased fleece weight in progeny up to 5 years of age. However, many of these studies on offspring fleece weight performed treatments during the lactational period, making it unclear to what extent this finding is due to foetal environment or lactational performance. Additionally, many studies did not adjust their findings for body weight which may confound these results (Behrendt et al., 2006; Behrendt et al., 2011; Curnow, 2006; Thompson et al., 2011).

Findings with regards to follicle characteristics are inconsistent. A report by Magolski et al. (2011) found that both under (60% maintenance) and over (140% maintenance) nutrition during the mid-late gestation period had no

influence on primary or secondary follicle number or fibre diameter. In contrast, Schinckel and Short (1961) found lambs from ewes fed less than half the control ration during the same period had reduced wool follicle numbers resulting in a lighter, coarser fleece. A review by Bell (2006) suggested reduced wool follicle numbers was because of retardation of the maturation of secondary follicles postnatally. Later sections will discuss the effect of maternal nutrition on wool production and quality in greater detail. Some attempt will be made to assess the confounding factors of prenatal and lactational influences and the influence of body weight on fleece characteristics.

2.6 The Influence of Pre-Natal Nutrition on Follicle Development and Future Production

The Australian Lifetime Wool Project investigated the influence of maternal nutrition on body weight, MFD and fleece weights, with few researchers investigating how nutrition altered the histological follicle population in the offspring (Behrendt et al., 2006; Behrendt et al., 2011; Curnow, 2006; Thompson et al., 2011). This project did not determine the influences of prenatal versus lactational nutrition on wool production. Neither the influence of pre- and/or postnatal nutrition on mohair characteristics or its effects on follicle populations has been studied extensively in Angora goats (McGregor, 2016a).

2.6.1 The influence of pre- and postnatal maternal nutrition on follicle populations

Primary follicles are mature at birth and no new secondary follicles are initiated after birth in the Merino (Schinckel, 1954). In an observational study by Schinckel (1954) a negative relationship between birth weight and primary follicle density was found. Given that the primary follicle population is complete by 90 days gestation, it is likely that lambs born with high birth weights but a low primary follicle density experienced a higher growth rate during days 90 to parturition. Major differences in birth weight occur at this

time and likely, on the rate of initiation of secondary follicles which occurs in the same period (Schinckel, 1954). Earlier work has established that lambs that undergo environmental challenges during gestation, such as maternal illness, reduced nutrient supply or competition from other foetuses have lower S:P follicle ratios at birth (Schinckel, 1953). Twins had a lower S:P fibre ratios from birth until 15 months old compared to their single born counterparts (Schinckel, 1954). Growth during the first month postpartum has a significant bearing on the proportion of secondary follicles that mature. When sampled at 1, 2, 3 and 4 weeks, 4 months and 15 months old, twins have a significantly reduced development of secondary follicles, predominately in the first month after birth. Although lactational performance is likely the underlying cause for the reduced development, milk production is established in the weeks leading up to parturition and therefore additionally reflects prenatal performance (Schinckel, 1954). Prenatal conditions influence the number of secondary follicles that are initiated while postnatal factors influence those that actually mature (Schinckel, 1954).

Prenatal and postnatal nutrition has significant effects on the maturation of the follicle population in lambs which persist into adult life (Schinckel & Short, 1961). Pregnant ewes were fed high (ad-libitum) and low (50% high nutrition group, sub maintenance) levels of nutrition (H- and L-) throughout gestation and the lambs subsequently fed high (ad-libitum) and low (50% high nutrition group, sub maintenance) levels of nutrition until weaning at 16 weeks old (HH, HL, LH and LL) by Schinckel and Short (1961). Low intake during the prenatal period produced lambs that were 34% smaller at birth and 9% smaller at maturity. A significant negative correlation ($r = -0.65$) was found between primary fibre density and birth weight and both S:P and Si:Pi ratios being lower in L- lambs (Schinckel & Short, 1961).

Lambs with low intake during the postnatal period had a slower growth rate and similar follicle number but delayed maturation of the follicle population. HH, HL and LH lambs demonstrated an increase in mature fibre density from birth to 4 weeks old, then a decline until 16 weeks old. LL lambs had a declining

density from birth to 16 weeks. After 24 weeks of age, HL and LL lambs had higher fibre density compared to HH and LH lambs. This indicates there was no permanent depression in follicle maturation by low postnatal nutrition. At the conclusion of the study, group mean density of mature fibres was not significantly different ($P>0.05$). Fleece growth was significantly different, being highest in HH and lowest in LL lambs ($P<0.05$). Low postnatal nutrition lambs produced smaller fibres at maturity. It is likely that while prenatal nutrition restricts the number of follicles at maturity, postnatal restriction does not but can permanently impair the capacity of follicles to produce fibre (Schinckel & Short, 1961).

Similar work was conducted more recently by Kelly et al. (2006) with comparable findings. Multiparous ewes were implanted with bisected embryos on day 6 and then each pair was fed maintenance (control) or sub maintenance (lose 15% liveweight) from day 50 gestation to lamb weaning at 12 weeks of age. Sub maintenance ewes lost weight during both pregnancy and lactation while maintenance ewes lost weight during pregnancy and gained during lactation. This resulted in sub maintenance lambs that were lighter body weight at birth, weaning and 4 months old. At birth, S:P fibre ratio was not significantly different between the intervention groups. However, sub maintenance lambs produced less clean wool by 0.24 kg per annum as adults. At the lamb and hogget shearings, wool fibre diameter was finer by 2.7 μm but then became broader by 0.3 μm thereafter. It is likely that the finer wool produced during early life by sub maintenance animals is a result of nutrition being diverted to compensatory body growth. It is only when growth rate of sub maintenance animals is similar to the control that the broader fibres becomes apparent (Kelly et al., 2006). This is further evidence that pre- and postnatal nutritional restriction has a permanent effect on liveweight, wool follicle population and functional capacity of wool follicles.

2.6.2 The influence of prenatal nutrition exclusively on follicle populations

Follicle populations were adversely affected by severe nutritional restriction of Merino ewes throughout gestation (Short, 1955). Ewes were penned individually and fed at high (1140 g/day), intermediate (690 g/day) and low (340 g/day) levels of a grain mix throughout gestation. Ewes were fed *ad libitum* after parturition. The high feeding ewes became inappetent in the 4th and 5th months of gestation and were abandoned. Ewes fed low level nutrition lost body weight and produced less wool than their better fed counterparts. Low fed lambs were significantly lighter (1.0-1.3 kg) and had an S:P fibre ratio 10% lower than the intermediate group. Secondary to primary follicle ratio was not significantly different at birth but were lower in low fed lambs at 3 years old. By 200 days old, low fed lambs produced the same CFW but fibres were broader (2.2 μm) and longer. Despite similar S:P follicle ratios at birth, low fed lambs resulted in a follicle population of lower productive density at 3 years old. It was suggested that any interference in the events of follicle development during gestation altered the cellular support structures and efficiency of wool synthesis (Short, 1955). Similar work by Taplin and Everitt (1964) and Everitt (1965) found secondary mature follicle density was lower only when underfed during late gestation. Fewer mature primary and secondary follicles were found in those fed low levels in late gestation until at least 18 months old. This suggests that poor nutrition in late gestation has a greater influence on the mature follicle population than early nutritional restriction.

Work conducted by Hutchison and Mellor (1983) in Scottish Blackface sheep further divided gestation into specific periods corresponding to follicle initiation and maturation. Table 2.6.2 describes the six different treatment periods of nutritional restriction and the corresponding predominate follicle activity. All treatments were fed control maintenance at all other times of gestation.

Table 2.6.2 Treatment periods used by Hutchison and Mellor (1983) to investigate prenatal nutritional restriction on follicle populations in Scottish Blackface sheep.

	Time of fed restriction during gestation (day)	Follicle activity	Nutritional effect	S:P ratio
A	Nil (control)			2.42
B	112-142	mid-late formation Sd follicles	severe short term	1.71**
C	112-131	mid-late formation Sd follicles	severe short term	1.42***
D	95-116	early-mid formation Sd follicles	severe short term	2.1NS
E	35-142	entire follicle initiation period	moderate long-term	1.79*
F	35-119	entire follicle initiation period	moderate long-term	2.06NS

Mean and Significance Differences from Control (Student's t-test) NS (not significant), *(p<0.05), **(p<0.1), ***(p<0.001).

Short- and long-term restriction was 0.3-0.6 and 0.6-0.8x recommended ME requirements respectively. Lambs were sacrificed at day 142 of gestation. Lambs from groups B, C and E had lower S:P follicle ratios as a result of moderate-severe underfeeding during late gestation. Given that both treatments B and C were significantly lower than other treatments, it appears that reduced early secondary follicle initiation cannot be resolved by good feeding after this period (Hutchison & Mellor, 1983). Similar reduced S:P ratio shown by B and E is indicative that a reduced placental size will influence nutrition available to the foetus at later critical times. Restoration of the S:P ratio was only possible if good nutrition was restored during early secondary follicle initiation. Overall, early nutritional restrictions on S:P ratio can be overcome if ewes are well fed from day 120 of gestation (Hutchison & Mellor, 1983).

Further studies by Kelly et al. (2006) using a live cohort of lambs supported these findings utilising similar reproductive procedures and diet. Lambs were lighter in the sub maintenance group at birth, 12 weeks and 4 months old.

Secondary to primary fibre ratio was lower in the sub maintenance progeny at birth and lamb shearing (0.4 years old) by 1-2.2 units. Between lamb and hogget shearing, S:P fibre ratio declined 2-10%. Clean fleece weight was reduced by 8% at lamb shearing and 3% at hogget shearing compared to control lambs. Interestingly, there was no difference in yield, staple length, staple strength or med% between treatments at any shearing. The effects of adverse mid-late gestation nutrition on follicle populations is apparent but when the adverse nutrition is extended into lactation, the effects are cumulative (Kelly et al., 2006; Kelly, Macleod, Hynd, & Greef, 1996; Schinckel & Short, 1961)

2.6.3 The long-term effects into adult life of gestational and lactational nutritional treatments

The effects of prenatal and early postnatal nutritional treatments in sheep are apparent until at least 18 months of age (Kelly et al., 1996). Given the potential mechanisms of foetal programming and the likely permanent dysregulation of key metabolic pathways, long-term effects into adult life would be expected. This has long been recognised in rats and humans (Barker & Clark, 1997; McMillen et al., 2001). The following describes the long-term effects of maternal gestational and lactational treatments on body composition and wool growth.

Merino lambs produced from sub maintenance fed ewes by Kelly et al. (2006) demonstrated adverse effects until at least 3.5 years old. Those lambs from ewes fed to lose 15% BW during pregnancy only, had a permanent and significant ($P < 0.01$) reduction in liveweight (1%), clean wool production (3%), wool follicle population (6%) and fibre diameter (1%). This effect was exacerbated if the poor nutrition was extended into lactation (BW loss of 15% during pregnancy and lactation), with reductions in liveweight (5%), clean wool production (5%) and wool follicle population (10%). Earlier work by Alden (1968) had implemented similar underfeeding treatments to lambs during the preweaning (birth to 206 days, H- and L-) and postweaning (206 to 380 days, -

H and -L) periods (HH, HL, LH, LL). This produced a less severe reduction in weaning weights (20% versus 44% in Kelly et al. (2006)) but over a longer period of time (6 months compared to 3 months). The adverse effects of preweaning underfeeding on fleece traits persisted until 2 years old while weight effects lasted for 5.5 years. Postweaning undernutrition had no influence on fleece traits and weight effects persisted for only 11 months. Although these effects are reportedly less than those of Schinckel and Short (1961), it is likely that the severity and duration of the nutritional restriction is paramount in determining the adverse effect on wool growth. It could be estimated that BW loss of the pregnant ewe by 15-25% will cause permanent restrictions on the wool production of the offspring (Kelly et al., 2006; Schinckel & Short, 1961). Undoubtedly, adverse early postnatal nutrition does have long-term permanent effects on offspring production.

Further work of Schinckel and Short (1961), assessed the follicle populations of offspring until 3.5 years old. Lambs that received low prenatal nutrition had 15% fewer wool follicles and produced 8.5% less wool as adults. Total follicle populations of HH and LH (62.6 and 61.8 million respectively) were significantly higher than HL and LL (57.8 and 48.3 million respectively) at 3 years old. Low postnatal nutrition did not affect the total number of fibres but reduced fibre diameter at maturity. This resulted in a 12% reduction in wool production. Therefore, postnatal restriction did not influence the number of follicles but did permanently affect the capacity of follicles to produce fibre (Schinckel & Short, 1961). However, animals with the highest densities at maturity were those with good prenatal nutrition, allowing the initiation of lots of follicles and restricted postnatal nutrition which reduced follicle size but did not prevent follicles from maturing.

2.6.4 The influence of maternal nutrition on follicle populations of the offspring in goats

Despite the differences in the prenatal development, postnatal maturation and hair product between sheep and Angora goats, general extrapolations are not unrealistic. However, limited data is available on the influence of maternal nutrition during gestation and lactation on the development of the follicle populations in goats (Bawden et al., 2010).

In a study by Lambert et al. (1984) unselected Australian feral goats were fed during different periods of gestation and for 1 month after kidding to assess hair follicle development in the offspring. Skin biopsies were taken at birth, 1 month and 4 months old from 50 kids. No difference between nutritional treatments was detected and therefore data was pooled. At birth, many primary but few secondary follicles were mature. Follicle densities increased rapidly after birth to 1 month old but declined slightly between 1 and 4 months of age. The S:P ratio also increased rapidly from birth to 1 month then more slowly until 4 months old indicating some postnatal initiation of secondary follicles. Single kids had higher S:P ratios at birth compared to twins but this difference became insignificant by 4 months old. Male kids also had higher S:P ratios at birth compared to females but not thereafter. Despite a failure to detect a significant difference in nutritional treatments, it is interesting that both single and male kids had a prenatal advantage over twins and female kids at birth. This advantage disappeared in the postnatal period indicating that prenatal advantages may be compensated by early postnatal conditions.

More recently, McGregor and Howse (2018) manipulated pre- and postnatal nutrition to permanently influence the skin follicle population and subsequent mohair quality in the offspring of Angora does. These were individually housed from day 47 post conception until 13 weeks postpartum. During days 47-104, they were fed control (C) (lose 67 g/day BW), maintenance (M) (maintain BW) or supplemented (S) (gain 102 g/day BW) rations. From day 105 of gestation

until 4 days postpartum does were fed *ad libitum*, then at *ad libitum* (AL) or restricted (R) (70% *ad libitum* fed treatment) levels until week 10 of lactation. Kids had skin biopsies taken at birth, 114, 180 and 420 days old. Improved mid pregnancy nutrition (MPN) increased kid liveweight. Improved postnatal nutrition (PNN) increased liveweight from 1-6 months old. At birth, MPN had no effect on skin follicle density or Sf:Pf ratio. Density of primary and secondary follicles was highest at birth and lowest at 15 months old. Secondary follicles were mature by 4 months. A significant interaction between MPN and PNN occurred on secondary follicle density, total number of secondary follicles and S:P ratio; S-AL, C-AL and M-R had higher values than all other treatments. The Sf:Pf ratio increased from 2.56 +/- 0.83 at birth to 9.32 +/- 1.41 at 4 months and then remained constant at 9.07 +/- 1.36 at 6 months and 9.11 +/- 1.53 at 15 months. Treatments C-R, S-R and M-AL had the lowest ratios. Improving MPN and PNN reduced the lifetime MFD. Only PNN improved GFW with -AL kids producing 14% more mohair at the first shearing and reduced incidence of medullation in subsequent shearings.

Both MPN and PNN had short and long-term effects on follicle populations and mohair production (McGregor, 2020; McGregor & Howse, 2018). Follicle development has a low priority for nutrients during the last month of gestation, as reflected in the similar secondary follicle populations across the different MPN treatments. Only when nutrients become available in the early postnatal period, does the influence of prenatal nutrition become apparent. Higher prenatal nutrition improved secondary follicle density, total number and S:P ratio to allow the highest growth of mohair and lowest MFD and med%. This effect persisted until at least 420 days old. Improved PNN allowed the greatest potential of the kids to be reached based on their prenatal nutrition restrictions. The ceiling for follicle population development is determined predominately by prenatal nutrition (Lambert et al., 1984). Postnatal nutrition then determines the follicle population that actually matures and the subsequent fibre characteristics as suggested by Schinckel (1954) in sheep.

2.7 Summary

Foetal programming is the phenomenon where the prenatal environment influences the postnatal productivity of offspring by the development of the physiological and metabolic pathways. Follicle type development *in-utero* is poorly understood in Angora goat foetuses. The influence of pre- and/or postnatal nutrition on the development and subsequent productivity of the follicle population has not been studied extensively in Angora goats. Further research to assess the effects of maternal environment on the development of hair follicle populations in Angora goats is paramount to improve mohair quality.

Chapter 3 The influence of nutritional supplementation of pregnant Angora does on the follicle density of their offspring.

3.1 Introduction

Skin follicles begin to be initiated in the foetal skin at about day 60 post conception (Margolena, 1974). While primary follicles are mature at birth, secondary follicles continue to be initiated for the first month post-partum in Angora kids (Margolena, 1974). Maturation of the follicle population is complete and fixed by 2 months of age (Margolena, 1974). Recent work on foetal programming of Angora goats suggests that nutritional supplementation of does during mid-pregnancy (days 47-105 post conception) and lactation (day 4 to week 13 post partum) can influence the follicle density of the progeny (McGregor, 2016a, 2017; McGregor & Howse, 2018). However, these studies did not target the periods of follicle initiation (days 60-90 post conception) or maturation (days 120-180 post conception). The aim of this study was to determine if primary and/or secondary follicle density could be influenced by *ad-libitum* feeding of pregnant Angora does at either 60-90 days or 120-180 days post conception.

3.2 Materials and Methods

3.2.1 Location and facilities

All procedures were approved by CSU Animal Ethics Committee (A19020). The project was completed on a 20.4 ha property in Humula, NSW, 130 km west of Canberra (147°77' E, 35°49' S, elevation 317 m) (Rasmussen, Rasmussen J.E, Gordon, & Ma, 2019). The area experiences a temperate climate, with warm summers (average daytime temperature 31 °C, 203 mm rainfall) and cold winters (average daytime temperature 12 °C, 239 mm rainfall) (Sahukar, Gallery, Smart, & Mitchell, 2003).

3.2.2 Design and nutrition treatments

For the purpose of this study, three feed treatments regimens were designed. Statistical input from the Quantitative Consulting Unit (CSU) indicated that 15 replicates of each feeding level were required to obtain statistical significance (45 does). Replicates of 15 were randomly assigned based on conception dates. Only 41 does were accepted into the study which included 5 twin bearing does. The feeding treatments based on metabolisable energy (ME) are outlined in Table 3.2.2. Supplementary feed was offered at 2 times maintenance requirements.

Table 3.2.2: Feed regimen of treatment groups at different stages of gestation and lactation.

Days post conception	Control		Treatment 1 Supplemented days 60-90 post conception		Treatment 2 Supplemented days 120-180 post conception	
	ME MJ/day		ME MJ/day		ME MJ/day	
	Single	Twin	Single	Twin	Single	Twin
42-59	Acclimatisation Period					
60-90	8.70	9.25	17.40	18.50	8.70	9.25
90-120	10.67	11.88	10.67	11.88	10.67	11.88
120-150	10.21	11.59	10.21	11.59	20.42	23.18
0-30 post partum	10.21	11.59	10.21	11.59	20.42	23.18

After day 28 post partum, does and kids were grazed on perennial ryegrass/subterranean clover/phalaris pasture. The project property was impacted by the Dunns Road Bushfire of December 2019, for which the goats were evacuated to a property 109 km north in Springdale, NSW 2666 on January 3rd 2020 (Rasmussen et al., 2019). During this time the goats were run in a feedlot situation with free access to oaten hay and reticulated, troughed fresh water. The goats were checked daily to ensure adequate food and water was available at all times. Body condition score of the does and kids did not appear to change when assessed at sampling at 4 months of age. The diet was adequate for maintenance at that time.

3.2.3 Animal management

3.2.3.1 Animal source and reproduction

The Angora goats in this study ranged in age from 18 months to 14 years and included 74 does and 2 bucks. The flock was established in 2015 with does sourced from three different breeders. The flock has since been self-replacing with sires sourced from one stud breeder. Each adult goat was individually tagged for identification.

Each doe in the study underwent an oestrus synchronisation regimen. Oestrus was synchronised using a 1 mL prostaglandin intramuscular injection (Ilium Estromil 250 µg/mL cloprostenol, Troy Animal Healthcare, Glendenning NSW) given in late March 2019 and again 11 days later. The flock underwent paddock mating for 63 days (three oestrus cycles) with two experienced bucks, beginning two days after the second prostaglandin injection. Each buck was fitted with a ram harness and the does were checked every day to record raddle marks and accurately determine conception dates.

Transabdominal pregnancy ultrasound scanning occurred at 12 weeks after buck introduction for pregnancy diagnosis. Foetal number and conception date were determined. Pregnant does were body condition scored (BCS) (Matthews, 2014), weighed and randomly allotted to their treatment group. Due to the low number of pregnant does and since some does were more than 60 days pregnant at ultrasound examination and did not qualify for Treatment 1, allotment to treatment groups did not take into account doe age or liveweight. Twin-bearing does were divided equally between treatments. Of the 74 does selected for breeding, only 41 were diagnosed as pregnant. Forty-one pregnant does were included in the study. Table 3.2.3.1 outlines the mean age and mean body weight and BCS of does on day 60 of gestation in each treatment.

*Table 3.2.3.1: Mean age (years) and body weight (kg) and body condition score (BCS) on day 60 post conception for does in three treatments fed maintenance or *ad libitum* during periods mid pregnancy (60-90 days) and late pregnancy/lactation (120-180 days).*

	Age (years)	Body weight (kg)	BCS
Supplemented days 60-90	6.1 ^a	34.4	3.0
Supplemented days 120-180	8.9 ^b	36.1	3.0
Control	7.2 ^c	36.2	3.0

^a Median age was 6 years.

^b Median age was 9 years.

^c Median age was 6 years.

3.2.3.2 General management

On day 42 after the raddle marks were noted, individual does were removed from pasture and paired with another of similar conception date (± 2 days). Does were penned together to allow acclimatisation to the pen environment and to allow a slow introduction to the change in feed. Each doe received 50 g of pellets (11.5 ME MJ/kg and Crude Protein (CP) 14%) and 0.54 kg of ryegrass hay on day 42 post conception. Pellets were increased by 50 g/day and hay reduced by 20 g/day until the target maintenance ration was received on day 60 post conception. Does were individually penned on day 60 of gestation (for 138 ± 3 days). Does were fed according to treatment from day 60 (Table 3.2.2). Fresh water was available at all times.

Does were released from their pens and into a paddock when the kid was 28 days (1 month) old and had unlimited access to pasture. Due to the Dunns Road Bushfire of December 2019, the flock were evacuated to a property 109km north in Springdale, NSW 2666 on January 3rd 2020 (Rasmussen et al., 2019). Average kid age at the time of evacuation was 87.7 days (range 71-95 days). The flock were run in a feedlot situation with unlimited access to oaten hay and reticulated, troughed fresh water. Due to this, the samples at 4 months were all taken on the same day when the kids were an average of 116.7 days old (range 100-124 days).

3.2.3.3 Health management

Normal health management practices were undertaken. Does were drenched with an effective anthelmintic (Q drench, Jurox Animal Health, Rutherford NSW, 3 mL/ 10 kg orally) and vaccinated (Ultravac 5 in 1, Zoetis Australia, Rhodes NSW, 1 mL subcutaneous injection) during oestrus synchronisation. Adult goats were shorn in March and November when kids were on average 59.7 days old (range 43-67 days). Kids were not shorn during the trial. Hooves were pared at each shearing.

3.2.4 Nutrition and feeding management

3.2.4.1 Pens

Individual pens of 3 x 3 m dimension were constructed in rows out of standard ringlock mesh in a holding paddock. Shelter was provided by shade cloth fastened to cover approximately 1/8th the area of each pen. Water and feed were provided in separate plastic containers that were cleaned and refilled daily. Goats were fed once daily in the morning and watered twice daily in the morning and evening.

3.2.4.2 Feeding regimen

A nutrition table, available in Appendix A (US National Research Council, 2006), was used to calculate the ME and CP requirements for goats at specific stages of pregnancy based on a 30 kg Angora doe bearing single or twin foetuses. Feed consisted of Ambos General Purpose PelletsTM (Appendix B) and ryegrass hay as a roughage source (16% total ration). Quantities were determined for individual does based on stage of pregnancy and foetal number according to the energy and protein requirements (Table 3.2.4.2). Double maintenance was considered an *ad libitum* ration based on the physical quantity of feed that the does could consume.

Table 3.2.4.2: Energy and protein maintenance requirements of single and twin bearing Angora does at different gestational stages.

Days post conception	Metabolisable energy (ME MJ/d)		Crude protein CP at 40% UIP* g/d	
	Single	Twin	Single	Twin
60-90	8.70	9.25	105	115
90-120	10.67	11.88	134	156
120-180	10.21	11.59	124	146

*Undegradable Intake Protein

During the periods of *ad libitum* feeding of Treatment 1 and Treatment 2, feed residues were weighed each morning prior to feeding. Total feed consumed during the treatments was calculated and feed consumed per kg BW was calculated for the average weight of the doe during the treatment period.

3.2.5 Animal and fleece measurements

Each doe was weighed and her BCS recorded on day 42, 60, 90, 120 and 150 of gestation and day 180 post conception (Matthews, 2014). For each treatment period, average body weight and total feed consumed was calculated to determine average feed consumed per kilogram BW per day. A fleece sample was taken from a 2.5 x 2.5 cm section on the mid-side at shearing in November during lactation. These samples were stored in labelled plastic bags and submitted to Riverina Wool Testers (Wagga Wagga, NSW) for measurement of mean fibre diameter (μm , Laserscan IWTO-12) (International Wool Textile Organisation, 2017). Every doe fleece was lightly skirted to remove the heavy stain and weighed.

Within 24 hours of parturition, kids were ear tagged for identification. Each kid was weighed at birth, 1 week, 1 month, 2 months and 4 months of age when a fleece sample and skin biopsy were also taken. A 4 mm full thickness skin biopsy was taken from the mid-side and stored in 10% formalin (Fossum et al., 2007). A local antibiotic and insect repellent spray was applied (Cetrigen, Virbac Australia, Milperra NSW) and a pain relief injection of tolfenamic acid (Ilium Tolfejec 40 mg/mL, Troy Animal Health, Glendenning NSW 0.1 mL/kg

SC) was given. A fleece sample was taken from the same position on the contralateral side and stored in airtight bags until submitted to Riverina Wool Testers for measurement of fibre diameter. Kid fleeces were lightly skirted to remove the heavy stain and weighed at shearing the following March at 6 months of age.

Skin biopsies and fleece samples for birth, 1 week, 1 month, 2 months and 4 months old were available for 21 kids born to 18 does. A further 16 kids were born to 12 does but did not survive to 1 month old. Therefore, samples for this subset were collected at birth only. Eight does were scanned pregnant but failed to kid (2 confirmed abortions) and 3 does died during the trial prior to kidding.

3.2.6 Skin histology

Skin biopsies were stored in 10% formalin pots until processed by the Veterinary Diagnostic Laboratory at CSU Wagga Wagga campus. A detailed description of the process is described elsewhere (Dey, 2018). In summary, samples were fixed in formalin for at least 24 hours prior to being transversely cut and placed into cassettes. These cassettes were passed through a series of dehydrating agents to replace the water with alcohol to enable embedding in paraffin wax. The wax blocks were sliced by a microtome, mounted onto glass slides and stained with haematoxylin and eosin (H&E). Primary mature (Pm), primary immature (Pi), secondary immature (Si) and secondary mature (Sm) follicles were manually counted by a trained assessor from 4 visual fields at 100x magnification.

3.2.7 Statistical analyses

Inferential statistics were used to calculate the density of primary and secondary, immature and mature follicle type and ratio of follicles. A ratio factor of fresh versus fixed samples was determined to account for shrinkage of samples during processing. This was used calculate the follicle parameters as

seen *in-situ* for each sample (Parry, Norton, & Restall, 1992; Scobie & Young, 2000).

Data were analysed using either SPSS software (IBM Corp, 2017) and R (R Development Core Team, 2010). Doe weight and BCS at day 60, 90, 120 and 150 of gestation and day 30 of lactation, gestational length, fleece weight and MFD were tested. Kid body weight, MFD, S:P ratio, primary follicle density, immature and mature secondary follicle densities at birth, 1 week, 2 months and 4 months of age and fleece weight at 6 months of age were tested. Non-significant terms were removed from the models. The variables of kid weight, micron, S:P ratio, primary follicle density, immature and mature secondary follicle densities at each time interval were tested with treatment and the appropriate doe co-variable using a linear mixed model with Pen/doe as the random effect. Three different models were used to determine the effects of the three covariates with treatment. These models were of the format:

$$\text{Kid Variable} \sim (1 \mid \text{Pen})$$
$$\text{Kid Variable} \sim \text{Treatment} + (1 \mid \text{Pen})$$
$$\text{Kid Variable} \sim \text{Treatment} + \text{DoeCo-variable} + (1 \mid \text{Pen})$$

Where a covariate was significant, an average covariate value was used to assess the standard errors of differences of means (s.e.d) to determine treatment differences by ANOVA with degrees of freedom d.f = 34 and least significant differences p=0.05. Given limited data was available at times 1 month, 2 months and 4 months and the change in variability across time, modelling was done at each time and ignored correlations between measurements on the same animal. Missing data was excluded. Additionally, birth type and sex were only considered at birth given the limited data at other time periods and making them confounding factors on the remaining findings.

3.3 Results

3.3.1 Feed intake

Feed consumption differed between treatments during each feeding period ($P < 0.005$). Does fed *ad libitum* during mid pregnancy consumed more feed than the remaining treatments during this feeding period. Similarly, does fed *ad libitum* during late pregnancy/lactation consumed more feed than the remaining treatments during this feeding period (Table 3.3.1). Birth type and kid sex did not influence the quantity of feed consumed per kg BW at the following time points.

Table 3.3.1 Mean feed intake (g/kg liveweight) for does in three treatments fed maintenance or *ad libitum* during periods mid pregnancy (60-90 days) and late pregnancy/lactation (120-180 days).

	Time period during pregnancy and lactation			
	Mid pregnancy (60-90 days)		Late pregnancy/lactation (120-180 days)	
	g/kg LW	MJ/kg LW	g/kg LW	MJ/kg LW
Supplemented days 60-90	28.19 ^a	0.292 ^a	25.25 ^b	0.261 ^b
Supplemented days 120-180	20.88 ^b	0.216 ^b	35.16 ^a	0.364 ^a
Control	20.99 ^b	0.217 ^b	25.60 ^b	0.265 ^b
P value	<0.005		<0.005	

a, b: Different superscripts within columns indicate means differ at $P < 0.05$

3.3.2 Doe live weight and fleece production

Doe weight, BCS, fleece weight, MFD or gestation length were not significantly different between treatments at any time of measurement (Table 3.3.2).

Table 3.3.2: Mean body weight (kg) and body condition score (BCS) for does in three treatments fed maintenance or *ad libitum* during periods mid pregnancy (60-90 days) and late pregnancy/lactation (120-180 days).

	Mid pregnancy (60-90 days)		Late pregnancy/lactation (120-180 days)	
	Body weight (kg)	BCS	Body weight (kg)	BCS
Supplemented days 60-90	36.4 (± 6.9)	3.0 (± 0.3)	25.2 (± 4.8)	3.0 (± 0.3)
Supplemented days 120-180	36.6 (± 4.8)	3.0 (± 0.3)	35.1 (± 8.4)	3.0 (± 0.4)
Control	36.6 (± 5.6)	3.0 (± 0.4)	25.6 (± 5.6)	3.0 (± 0.4)
P value	0.996	0.913	0.991	0.998

3.3.3 Kid production

A low number of kids born ($n = 38$) and surviving to 4 months of age ($n = 21$) for analysis (Table 3.3.3.1) and the low numbers in various categories made direct comparisons inexact. For does supplemented during days 60-90, days 120-180 and control only nine, six and six kids survived to 4 months respectively. Data limitation and large standard errors has prevented correlations between times to be determined.

Kid birth weight had a significant influence on mortality ($P=0.038$) with heavier kids more likely to survive (Table 3.3.3.2). Doe weight at 60 days indirectly influenced mortality due to its interaction with kid birth weight. Doe weight at 150 days had a significant influence on kid mortality to weaning ($P<0.003$) with heavier does more likely to raise kids to weaning.

Table 3.3.3.1: Prenatal and preweaning mortality of kids to 112 days (4 months) of age supplemented during days 60-90, 120-180 post conception and control in Angora goats.

	Does (expected kids)	Prenatal loss	Kids born	Preweaning loss	Kids weaned (singles/twin)	Kids weaned / doe (%)	Total kid mortality ² (%)
Supplemented days 60-90	12 (14)	1	13	4	5/4	75.0	35.7
Supplemented days 120-180	13 (15)	4 (6 ¹)	9	3	6/0	46.2	60.0
Control	13 (16)	2	14	8	2/4	46.2	62.5

¹Singles were born in 2 does when twins were expected

²Total kid mortality is prenatal and preweaning mortality / expected kids

Table 3.3.3.2. Mortality of kids by birth weight to 112 days (4 months) of age supplemented during days 60-90, 120-180 post conception and control in Angora goats

Birth weight (kg)	Kids born	Kids weaned	%Mortality
<1.5	3	1	66.7
1.5-2.0	8	1	87.5
2.0-2.5	9	3	66.7
2.5-3.0	10	8	20.0
>3.0	6	6	0.0

3.3.3.1 Live weight

Treatment influenced kid weight at 4 months ($P < 0.01$) with does supplemented during days 60-90 producing lighter kids than does supplemented during days 120-180 and control (11.1 (± 2.85 SEM) Vs 15.8 (± 2.11 SEM) and 12.9 (± 2.01 SEM) kg respectively) (Table 3.3.3.1). There was no significant difference between does supplemented during days 120-180 and control kids at 4 months of age ($P > 0.05$). Doe weight at 60 days gestation had a significant effect on kid birth weight and kid weight at 1 month, 2 months and 4 months old ($P < 0.01$). Doe weight at 60 days did not affect kid weight at 1 week old. However, there appears to be a non-linear relationship between kid weight and time (Figure 3.3.3.1). Kid live weight increases and becomes more variable with time. A peak kid weight appears to occur at approximately 80 days of age. There were no other interactions between the remaining variables and kid weight at any time measurement.

Table 3.3.3.1.1. Mean liveweight (kg \pm SEM) from birth to 112 days (4 months) of age for Angora kids born to does fed *ad libitum* between days 60-90 or 120-180 post conception and control does fed at maintenance.

	Birth		1 week		1 month		2 months		4 months	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Supplemented days 60-90	2.42	0.181	2.77	0.386	6.20	0.525	9.39	0.989	11.10	0.952
Supplemented days 120-180	2.44	0.278	2.87	0.739	8.01	0.980	13.72	1.215	15.81	0.861
Control	2.26	0.113	1.72	0.487	5.66	0.720	10.30	1.603	12.87	0.821

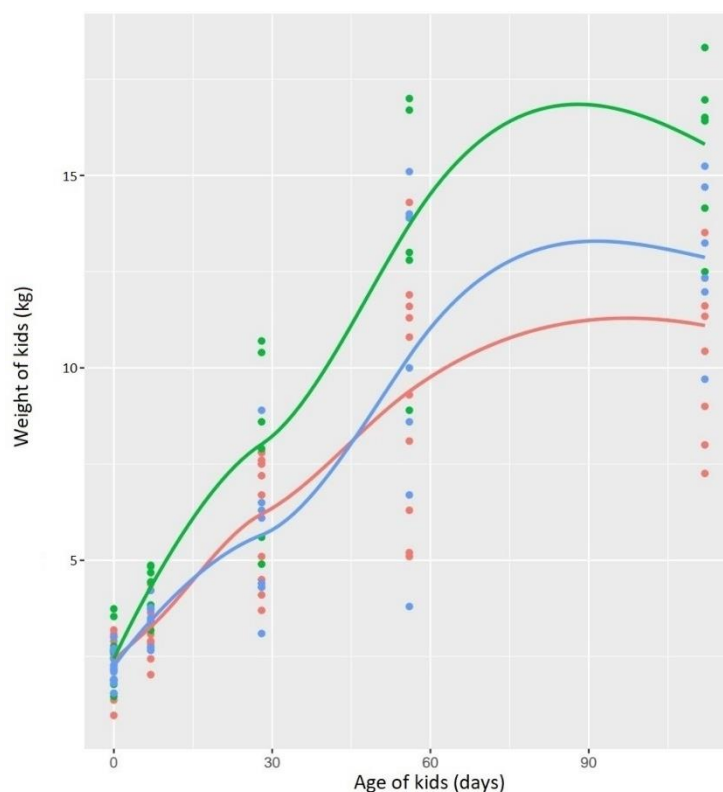


Figure 3.3.3.1: Mean liveweight (kg) from birth to 112 days (4 months) of age for Angora kids born to does fed *ad libitum* between days 60-90 (—●—) or 120-180 (—●—) post conception and control (—●—) does fed at maintenance.

3.3.3.2 Mean fibre diameter and follicle parameters

Treatment had no influence on fibre diameter at any time of measurement (Table 3.3.3.2.1). The fibre diameter of kids at birth was higher ($P < 0.02$) for twins than singles (26.6 vs 24.63 μm , respectively). Fibre diameter was highly variable at birth but became more consistent with time (Figure 3.3.3.2.1). Fibre diameter declined with time to a minimum of approximately 17 μm at 4 months of age. There were no other interactions between the remaining variables and fibre diameter at any time point measurement.

Table 3.3.3.2.1. Mean fibre diameter ($\mu\text{m} \pm \text{SEM}$) from birth to 112 days (4 months) of age for Angora kids born to does fed *ad libitum* between days 60-90 or 120-180 post conception and control does fed at maintenance.

	Birth		1 week		1 month		2 months		4 months	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Supplemented days 60-90	24.75	0.68	23.90	0.51	21.02	0.93	17.40	0.31	18.07	0.34
Supplemented days 120-180	25.94	1.03	24.47	0.59	20.88	0.63	19.52	0.84	18.78	0.37
Control	25.09	0.90	26.79	1.53	20.94	1.15	19.36	0.98	18.88	0.50

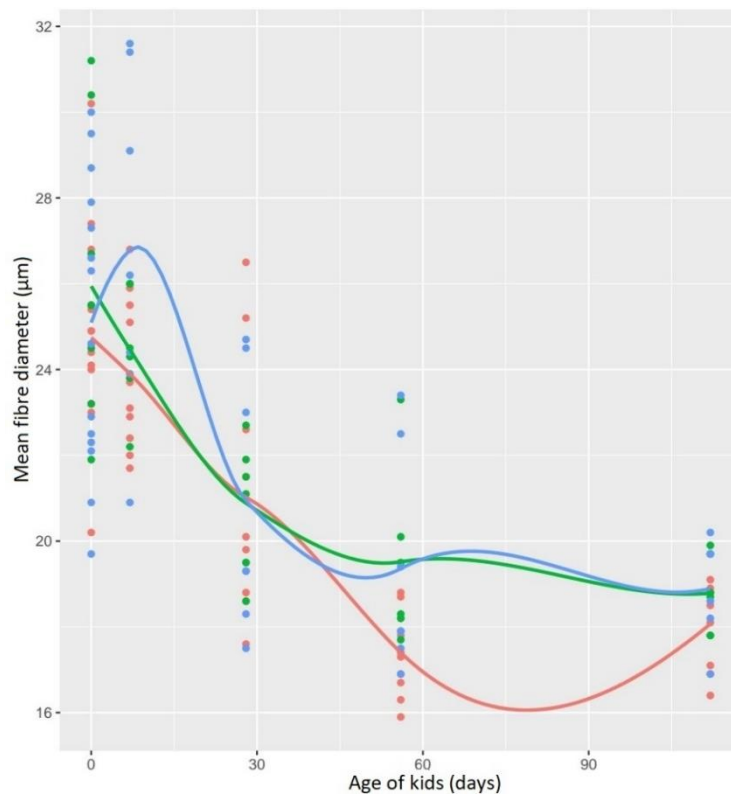


Figure 3.3.3.2.1: Mean fibre diameter (μm) from birth to 112 days (4 months) of age for Angora kids born to does fed *ad libitum* during days 60-90 (●), days 120-180 (●) post conception and control (●). Each dot represents a single measurement.

Treatment group had no influence on Si density, Sm density, Pm density, S:P ratio or fleece weight at any time point measurement (Table 3.3.3.2). However, there was a non-linear relationship for Si density with time (Figure 3.3.3.2.2). Similarly, Si density was highly variable at birth but stabilised at approximately 1 month old. Si density declined with time and approached 0 by 4 months old. There were no other interactions between the remaining variables and Si density, Sm density, Pm density, S:P ratio or fleece weight at any time point measurement.

Table 3.3.3.2.2: Mean Si, Sm and Pm density and S:P ratio and fleece weight of Angora goat kids of different ages from birth to 112 days (4 months) of age for all treatments.

	Si density		Sm density		Pm density		S:P ratio		Fleece weight	
	mean	SEM	mean	SEM	mean	SEM	mean	SEM	mean	SEM
Birth	15.387	9.471	15.282	6.699	3.935	1.353	7.33	1.852		
1 week	9.480	6.041	21.683	8.737	5.040	1.623	6.790	1.888		
1 month	1.730	2.057	23.877	8.615	3.823	1.574	6.09	1.756		
2 months	1.744	3.321	19.682	4.945	3.368	1.174	5.650	2.497		
4 months	0.216	0.247	18.839	5.948	3.405	1.193	6.00	1.924		
6 months									1.02	0.224

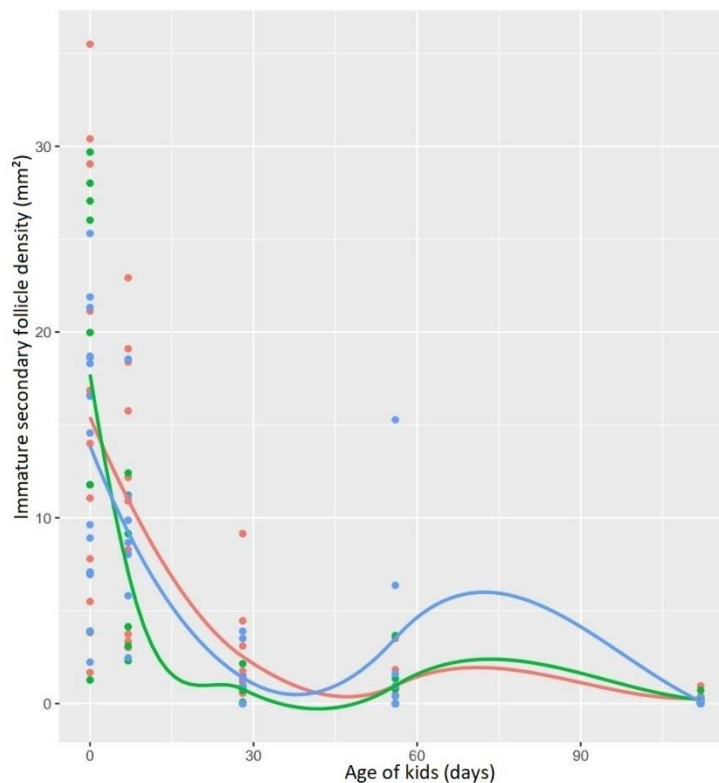


Figure 3.3.3.2.2: The effect of supplementation during days 60-90 (—●—), days 120-180 (—◆—) post conception and control (—●—) on kid immature secondary follicle density from birth to 112 days (4 months) of age in Angora goats.

3.4 Discussion

The results of this study were limited by kid mortality reducing the number of kids available for sampling. However, supplementary feeding of Angora does during days 60-90 gestation or days 120-180 post conception did not influence Si, Sm or Pm follicle density or S:P ratio in the surviving progeny. Although there was a significant difference of feed intake between treatments, this difference was small and unlikely to be meaningful in producing any biological difference in the progeny.

3.4.1 Feed intake

Feeding programs are designed primarily to provide sufficient energy, and secondarily protein based on the animal's production and physiological state. However, published recommendations on feeding Angora goats provide such differing values for energy and protein that formulating feed programs for pregnancy and lactation is challenging. Early gestation estimates of energy requirements for does of similar live weight range from 5.7MJ/day to 9.25MJ/day (US National Research Council, 2006) increasing to 10.36 MJ/day (McGregor, 2007) or between 13.36-15.04MJ/day (Huston et al., 1971) in late gestation. Similarly, published lactation requirements vary from 12.95MJ/day (McGregor, 2007) to 14.72-16.08MJ/day (Huston et al., 1971). Protein requirements are less variable with some agreement on early gestation recommendations (105-115g/day (US National Research Council, 2006)) greater variation in late gestation (108.9 Vs 124 g/day) and lactation (127 Vs 146 g/day) (Huston et al., 1971; US National Research Council, 2006) recommendations.

The three feed treatments were successful in differentially feeding during the specific periods of pregnancy and lactation. Control does were similar body weights post kidding compared to their day 60 body weights and maintained BCS throughout the trial. In this study, does fed above maintenance levels during days 60-90 consumed 11.5% more than the recommended energy and protein requirements (9.7MJ/day and 118.4g/day respectively), while the remaining treatment groups consumed below recommended levels (82% maintenance). Does fed above maintenance levels during days 120-180 consumed 22.3% more than the recommended energy and protein requirements (12.13MJ/day and 147g/day respectively) while the remaining treatment groups consumed below the recommended levels (76% maintenance). Refusals were high during *ad-libitum* feeding but negligible at all other times. Despite the restriction of energy and protein at different stages of pregnancy and lactation, doe BCS, body weight, fleece weight and kid birth weight did not differ between treatment groups. While the maintenance requirements of the does

increases as pregnancy and lactation progresses, the consistency of doe BCS and body weight across treatment groups suggests that maintenance requirements were achieved regardless of feeding treatment.

Several factors may explain why there was no difference in doe BCS, body weight, fleece weight and kid birth weight between groups. Calculated body weight changes from the feed treatments when the entirety of the ration was consumed are minimal and could be attributed to inaccuracy in measuring live weight. The body weight changes would be insufficient to produce changes in BCS. This can be overcome by acclimatising does to the ration over a greater time period or by utilising feedstuffs with a greater concentration of energy and protein. Given the body weight and BCS changes were minimal, the feeding treatments were unlikely to have an impact on the foetal programming of the progeny.

There are three possible reasons why intake was not increased when more feed was on offer. Firstly, it was suspected that the pellet feed had low palatability. The does were often observed consuming hay in preference to the pellets, and stealing from the adjacent pens despite the availability of pellets. However, pellet residues were negligible after 24 hours on offer and therefore palatability was acceptable to the does. Secondly, hay (16.8% of ration) was provided as a means to prevent ruminal acidosis. However, Huston et al. (1971) recommended that hay be offered as 20% of a complete ration. Therefore, the behaviours observed could be the result of a craving for more fibre. Finally, given the does were individually housed in pens, their energy use was low and therefore all energy could be invested into kid growth that would otherwise be used for physical movement. It seems likely that the apparent energy restriction is overcome by limitations in energy use. Any apparent restrictions in energy consumption are therefore likely to be statistical rather than biological.

Foetal number and kid sex did not appear to influence feed intake of the doe. It is well established that foetal sex, uterine environment, doe size and nutrition influence foetal development after 130 days gestation (Huston et al., 1971).

Therefore, it would be expected that twin-bearing does would consume more feed similar to that seen by McGregor (2017) where single and twin bearing does consumed 3.25 times and 3.72 times maintenance respectively. In the present study, a greater proportion of the kid cohort were singles (26 singles and 10 twins) and does (21 does and 15 bucks) across all treatment groups. It is likely that the apparent lack of influence of kid sex and foetal number on feed intake is because of insufficient numbers in various categories within the kid cohort.

3.4.2 Doe live weight and fleece production

Feeding treatment did not influence doe live weight, BCS, fleece weight, MFD, kid birth weight or gestational length. All does gained liveweight throughout pregnancy with a decline during lactation. The live weight changes of these does differs from those reported by others (McGregor, 2016a). In McGregor (2016a), supplemented does were fed 1.35 maintenance and gained throughout the feeding period from day 47-105 of gestation. Although the does in the present study supplemented on days 60-90 were fed above maintenance, the remaining treatment groups were fed 0.82 maintenance and still gained weight (~1.05kg). Similarly, the does supplemented on days 120-180 were fed above maintenance while the remaining treatment groups were fed 0.76 maintenance and still gained weight. Given BCS was maintained, this likely reflect a gain in conceptus weight and not maternal body weight. However, McGregor (2016a) frequently readjusted feeding levels to compensate for liveweight changes to achieve projected weight outcomes. They also recalculated what 'maintenance' was based on how the does were performing on the particular feed. In the present study, no adjustments were made and therefore it is likely that feeding did not reflect what was maintenance for these particular goats. This demonstrates an inherent challenge with formulating a feeding program; it is vital to monitor responses to feeding so that adjustments can be made to account for differences in metabolism, activity, feed palatability and digestibility to achieve feeding goals.

There was no influence of treatment group on doe fleece weight or MFD. Does in this project were shorn prior to mating but fleece measurements were only taken from the following shearing after the project was complete. Although these fleece measurements reflect feeding throughout gestation and lactation, the effects of short-term supplementary feeding on live weight and fibre diameter are diluted. In contrast, does better fed during gestation produced more, albeit coarser fleece than those fed below or at maintenance by (McGregor, 2016a) and this effect was exacerbated if better fed during lactation. Comparing this project to McGregor (2016a) and McGregor (2017) is therefore difficult because fleece measurements were taken before, during and after their research reflecting baseline production, gestation feeding treatments and lactational feeding treatments respectively. However, it can be ascertained that the feeding treatments did not adversely affect fleece measurements of the project does for this particular shearing.

3.4.3 Kid production

3.4.3.1 Kid live weight

Despite attempts to feed maintenance requirements with periods of above maintenance feeding, the results of this project are more consistent with underfeeding throughout gestation and lactation (control), underfeeding in late gestation and lactation (does supplemented days 60-90 gestation) or underfeeding in early to mid gestation (does supplemented days 120-180 gestation). This provides a better understanding on the influence of the feeding treatments on the resulting kids.

Treatment group influenced kid weight at 4 months old only with does fed above maintenance during days 60-90 (but restricted in late gestation and lactation) producing lighter kids than the remaining groups. In work done by Sibbald and Davidson (1998) with sheep, moderate undernutrition (70%

maintenance) in the last 6 weeks of gestation reduced birth weight that continued to be evident at weaning and 1 year old if this was extended into lactation. Similar findings by Kelly et al. (2006) found these differences persisted until 4 years of age but were overcome by 6 years of age. Interestingly, when Moore et al. (1986) restricted ewes to <70% maintenance during the last 6 weeks of gestation, birth weights were reduced but were not significantly different at 33 weeks of age. While there was no difference in birth weight in the present study, this effect was seen at weaning (4 months). It is likely that does fed poorly in late gestation and lactation do not have the body reserves to provide a high level of lactational output and hence, kid growth is restricted. Variability of kid weight increased with time and appeared to plateau at 80 days postpartum (Figure 3.3.3.1). Differences in kid body weight at 4 months is a reflection on the lactational output of the dam but also the uptake of solid feeds by the kid (McGregor, 2017; McGregor & Howse, 2018). This would also explain the apparent plateau at 80 days old. Lactational output begins to decline after day 9 postpartum, with obvious rumination occurring in kids from 3 weeks of age (Matthews, 2014; McGregor, 2018b). Weaner ill-thrift, a temporary setback in growth rate around weaning, is a well-recognised phenomenon in both sheep and goats (Campbell, Vizard, & Larsen, 2009; Matthews, 2014).

It is unsurprising that kids from does fed maintenance throughout gestation and lactation (control) and does under-fed in early gestation (supplemented days 120-180 gestation) were heavier compared to those restricted in late gestation (supplemented days 60-90 gestation). Poor nutrition to reduce ewe live weight by 25% in early gestation can be compensated if ewes are adequately fed beyond day 90 (Everitt, 1965; Taplin & Everitt, 1964). Further, if restrictions prior to 90 days are severe (50% maintenance) but adequate after 90 days, lambs can be heavier at birth and weaning than those adequately fed throughout gestation indicating significant compensatory growth (Parr et al., 1986). Although the restrictions were not so severe in this project (80% maintenance) and kid birth weights were similar across treatments, it seems unlikely that

significant compensatory growth occurred in late gestation. More likely, these does were better fed in the period leading up to lactation and therefore had greater lactational performance and subsequent kid growth compared to the remaining treatment group.

Doe weight on day 60 of gestation influenced kid weight at birth, 1 month, 2 months and 4 months of age. Heavier does produced heavier, faster growing kids. Doe age was not a significant variable. It is likely that the heavier does are either inherently larger or have greater body reserves to compensate for gestational and lactation demands.

3.4.3.2 Mean fibre diameter and follicle parameters

Mean fibre diameter was not different between treatments because the differences in feed intake were not large. Mean fibre diameter was broader in twins than singles at birth but sex had no effect. Reports on the differences of MFD between twins and singles are mixed. Work conducted by Gifford, Ponzoni, Burr, and Lampe (1990) and Taddeo et al. (1998a) reported no effect of birth type on MFD while both McGregor and Howse (2018) and Cimen (2006) found a higher fibre diameter in singles compared to twin kids. The Australian Lifetime Wool Project (Behrendt et al., 2006; Curnow, 2006; Thompson et al., 2011) found that a loss of 10 kg ewe body weight between joining and day 100 of gestation using 5 different levels of feed on offer reduced progeny fleece weight by 0.2 kg and increased fibre diameter 0.3-0.4 μm . These results were consistent across birth type (Greenwood et al., 2010). Therefore, given twinning produces a natural form of intrauterine growth retardation, twins would be expected to produce less, coarser wool than singletons. In the present study, mean fibre diameter was highly variable at birth but became finer and more consistent as the kids grew. This likely reflects the shedding of the coarse birth coat and the maturation of the secondary follicles (Parry et al., 1992). However, given the level of kid mortality, it is

possible that decline in variability of MFD at older ages is due to reduction in sample numbers that was insufficient to detect any variability.

Treatment group, birth type or kid sex had no significant influence on follicle development or fleece weight at birth or any time measurement. It was expected that kids from control does would have lowest densities and S:P follicle ratio because of maintenance feeding for their physiological state during the entirety of gestation and lactation limiting the initiation and maturation of secondary follicles (Greenwood et al., 2010). Does supplemented during days 60-90 were expected to have moderate densities and S:P follicle ratio given that the periods of restriction corresponded to S:P follicle initiation and maturation (Greenwood et al., 2010; Schinckel, 1954). Does supplemented during days 120-180 would have highest follicle densities and S:P ratio given that early restriction can be compensated if better fed in late gestation and lactation (Thompson et al., 2011). There was likely no treatment effect because differences in feed intake were not substantial.

Postnatal follicle maturation as indicated by S:P ratio did not follow the expected pattern in the present study. As demonstrated in Figure 3.3.3.2.2, secondary immature follicle density was highly variable at birth, becoming more uniform over time. This was unexpected given other reports, in which variability increased with time (McGregor & Howse, 2018). Work completed by Short (1954) demonstrated in sheep that secondary follicle maturation rate follows a curvilinear relationship and reaches a maximum at 7-21 days postpartum with a subsequent reduction as maturation is complete by 60 days postpartum. Similar findings were indicated by McGregor and Howse (2018) and Parry et al. (1993) in Angora goats although further secondary follicles were initiated after birth with maturation complete at 2 months. Given variability of Si density declined after birth, this would seem to indicate that no further secondary follicles were initiated after birth. Similarly, maturation was complete by 4 months when Si density approached zero (Figure 3.3.3.2.2).

While complicated by the low number of experimental units, these results generally demonstrate that S:P ratio was highest at birth and either slowly decreased or remained constant over time. It has been well established in both sheep and Angora goats that primary follicle initiation starts at 70 days post conception and maturation is complete by day 110 (Bawden et al., 2010; Margolena, 1974; Parry et al., 1993). Therefore, with a constant primary follicle population, a reduction in S:P ratio can occur if the secondary follicle population is declining. Total secondary follicle density did decline as kids grew but this would be expected given the increase in body surface area. Total secondary follicle number indicators (SFNI), which describe the total number of follicles over the entire skin surface area, would be a better parameter to describe changes in follicle populations (Parry et al., 1992). However, natural competition between adjacent secondary follicles for metabolic substrates has been demonstrated by Adams and Cronje (2003) which would inevitably result in attrition of secondary follicles less capable of competing. This would similarly explain why S:P ratio remained constant for some kids. If competition between follicles was minimised then all follicles would be equally capable of maturing without any changes to the overall proportions of secondary and primary follicles (Adams & Cronje, 2003).

The number of follicles that mature is significantly influenced by birth weight and growth to 1 month old, when kid nutrition is reliant on the dam (Schinckel, 1954). Treatment group did not influence birth weight but arguably did influence growth at 4 months of age. The maturation of the follicle population is influenced by the gestational nutrition in three ways: the prenatal initiation of follicles, development of hormonal pathways of mohair synthesis within the foetus, and preparation of the dam for lactation (Greenwood et al., 2010; Schinckel & Short, 1961). Differences in body weight at 4 months of age between treatments are likely the result of lactational output but this did not translate into any discernible difference in the follicle populations. This is because differences in feed intake between treatments were not substantial. However, feeding during the critical times of gestation and lactation will

culminate in determining how many follicle precursors form, the proportion that mature and the development of the support structures that determine future hair production (Schinckel, 1954; Wentzel & Vosloo, 1975).

3.4.3.3 Kid mortality

This study was not designed to compare treatment effects on reproduction and perinatal mortality which will be discussed in greater detail in Chapter 6. Kid mortality proved to be a significant limitation on this study, reducing the number of kids available for fleece sampling and skin biopsy. However, it is unsurprising that heavier kids were more likely to survive and heavier does more likely to raise a kid to weaning (McGregor, 2016a; Robertson, Atkinson, Friend, Allworth, & Refshauge, 2020; Snyman, 2010a, 2010b).

Hypocuprosis (enzootic swayback) and/or hypovitaminosis E (Matthews, 2014) were considered the most likely cause of prenatal and early postnatal losses. Postnatal losses were likely complicated by mismothering-starvation-exposure disease complex. Although this region is not known for copper deficiency (Grains Research and Development Corporation, 2016), Angora goats are particularly susceptible to copper and selenium status (Matthews, 2014).

3.5 Conclusion

Kid mortality was a significant problem in this study and therefore any conclusions from these results are limited. Differences in feed consumed by the treatment groups were small and did not produce any significant difference in doe weight, BCS, MFD or fleece weight. Treatment influenced kid weight at 4 months of age with does fed *ad-libitum* during days 60-90 post conception having lighter kids than other treatments. This was likely due to a lower lactational output. Doe weight at 60 days post conception had an effect on kid weight at birth, 1 month, 2 months and 4 months of age. Heavier does produced heavier kids at these ages. Treatment had no effect on kid MFD, follicle density

or S:P ratio at any age. These findings indicate that supplementary feeding during mid pregnancy and late pregnancy/lactation can influence kid growth at 4 months of age and that small differences in feed intake did not influence skin follicle populations in any meaningful way. Future studies would require a greater number of samples initially to allow for some losses throughout the experiment but still result in an adequate sample size for significance.

Chapter 4 The relationship between secondary to primary follicle ratio, primary and secondary follicle densities and age in Angora goats.

4.1 Introduction

The skin follicle is the productive organ for all fibre producing mammals including the Angora goat (Dyce et al., 2002). Age-related microscopic changes to hair follicle populations are a well-recognised phenomenon in several species, including humans (Galbraith, 1998). However, the influence of age on skin follicle populations is poorly understood in fibre producing animals including goats, sheep, camelids and Angora rabbits. While some research is available on the skin follicle populations of Angora kids from birth to weaning when skin follicles are maturing, little data exists for Angoras at older ages. The aim of this study is to determine the relationship between S:P follicle ratio, S and P follicle density and age in mature Angora goats.

4.2 Materials and Methods

4.2.1 Animal source and location

This study was conducted on the Humula property with the same flock involved in the study in Chapter 3. For the purpose of this study, skin biopsies and fleece samples were taken from Angora goats of different ages. Ages ranged from 6 months to 16 years and included 79 does, 24 castrated males (wethers) and 6 bucks. Animals less than 5 years old with any structural impairments were excluded from the study. Animals older than 5 years with major structural impairments were excluded from the study. Goats were randomly selected based on order of shearing. A total of 75 samples were collected based on statistical input from the Quantitative Consulting Unit (CSU) and included all remaining bucks, does and kids involved in the study in Chapter 3. The distribution of samples from each age group and sex is described in Figure 4.2.1.

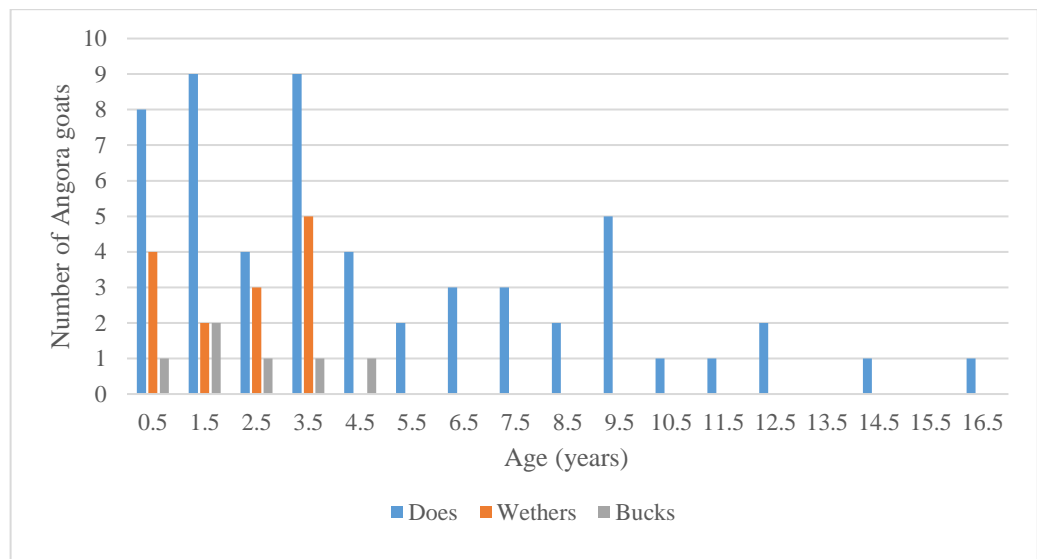


Figure 4.2.1: Distribution by age and sex of Angora goats sampled to investigate the relationship between secondary to primary follicle ratio, secondary and primary follicle density and age.

4.2.2 Fleece measurement

Fleece samples were taken as outlined in Chapter 3.2.5. The fleece samples were submitted to Riverina Wool Testers to determine mean fibre diameter (μm , Laserscan IWTO-12), standard deviation of fibre diameter (μm , Laserscan IWTO-12), coefficient of variation of fibre diameter (CV%, Laserscan IWTO-12) and %fibres >30micron (% , Laserscan IWTO-8) (International Wool Textile Organisation, 2017).

4.2.3 Skin histology

Likewise, a 10 mm skin biopsy was taken as outlined in Chapter 3.2.5. Biopsy samples were stored and processed by the Veterinary Diagnostic Laboratory at CSU Wagga Wagga campus.

4.2.4 Statistical analyses

Inferential statistics were used to calculate the density of each follicle type and follicle ratio for each sample. Shrinkage of samples was similarly accounted for to calculate the follicle densities of the fresh samples (Chapter 3.2.6).

Data were analysed using SPSS software (IBM Corp, 2017). Correlation coefficients (r) were determined between age and FFLwt, GFW, MFD, fibre diameter variation, standard deviation, coefficient of variation, >30micron%, comfort, spinning fineness, S:P ratio and primary, secondary and total follicle densities with sex as a random effect. Non-significant terms were removed from the models. Multiple linear regression analysis was performed to determine the relationships between age and the significant attributes. These models were:

$$a + (b + cx) / (1 + dx + nx^2) \text{ for BW}$$

$$a + (b + cx)r^x \text{ for MFD and } >30\text{micron}\%$$

$$a + b/(1+d*x) \text{ for S density, P density and Total density.}$$

The effects of those attributes with a significant correlation ($P < 0.05$) were plotted using R (R Development Core Team, 2010) with confidence intervals and local regression fits applied.

4.3 Results

4.3.1 Body weight

A significant correlation was present between age and fleece free live weight ($P < 0.001$). Fleece free live weight follows a simple linear model when sex is accounted for, although the slope for males (wethers and bucks pooled) is steeper than females (11.81 Vs 7.02) at ages less than 5 years ($P < 0.0005$, $r = 0.855$). This model can be represented as:

$$BW = 31.2546 + (-15.1878 + 7.0152x) / (1 + (-0.6036x) + 0.1609x^2)$$

where x is age in years. No males were present whom were older than 5 years of age. Maximum body weight of 37.32kg occurred at 3.85 years old with a final weight of 31.25kg (Figure 4.3.2 A) at older ages.

4.3.2 Fleece weight

There was no correlation between age and fleece weight ($P=0.805$). Sex had no influence at ages less than 5 years. No coefficients were significant in linear modelling for fleece weight indicating a high degree of variability in the model (Figure 4.3.2 B).

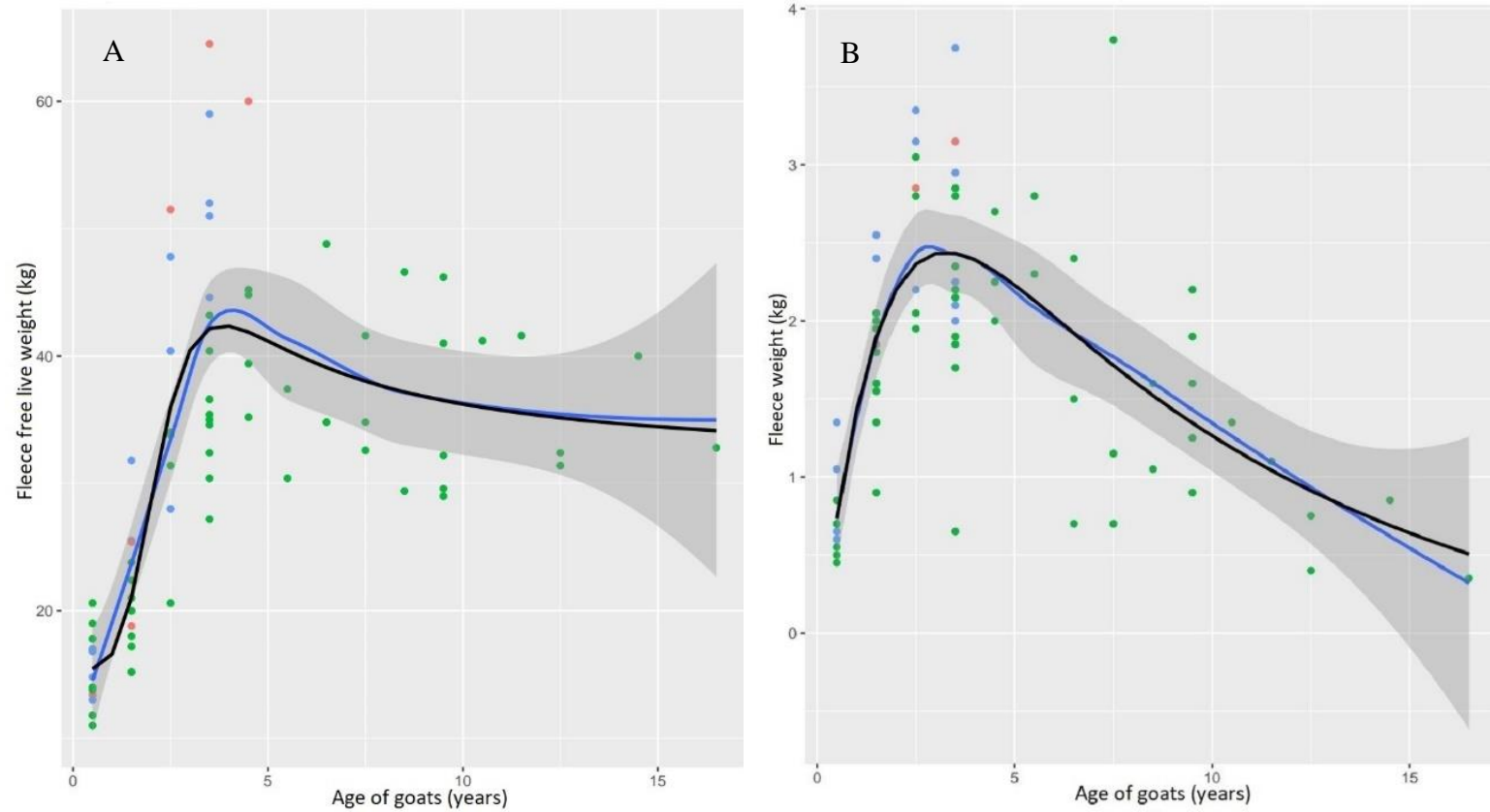


Figure 4.3.2: The effect of age on fleece free live weight (A) and fleece weight (B) of Angora goats. Symbols: bucks (●), does (●) and wethers (●), confidence interval (■), line of best fit (—), linear regression (—).

4.3.3 Fibre characteristics

Significant correlations were found between age and fibre characteristics and are shown in Table 4.3.3. Sex had no apparent influence on any variable.

Table 4.3.3: Correlation between fibre characteristics and age in one Angora goat flock (n=75)

Fibre characteristic	Correlation P-value
Mean fibre diameter	<0.0005
Fibre diameter variation	<0.0005
Standard deviation	<0.0005
Coefficient of variation	<0.011
>30micron%	<0.0005
Comfort	<0.0005
Spinning fineness	<0.0005

Mean fibre diameter, >30micron% and spinning fineness were explained by linear regression (Figure 4.3.3). No other variables were explained by linear regression models. The model for MFD can be represented as:

$$\text{MFD} = 28.92479 + (-14.30382 + 6.20005x)0.67832^x$$

where x is age in years. Mean fibre diameter increased from 21.0 μm at 6 months old to peak at 32.5 μm at 5 years old before plateauing at older ages to 28.9 μm .

The model for >30micron% can be represented as:

$$\text{>30micron\%} = 31.59006 + (-47.12798 + 25.11465x)0.74983^x$$

where x is age in years. Percentage >30 μm increased from 5% at 6 months old to peak at 50% at 5 years old before plateauing at older ages to 31%.

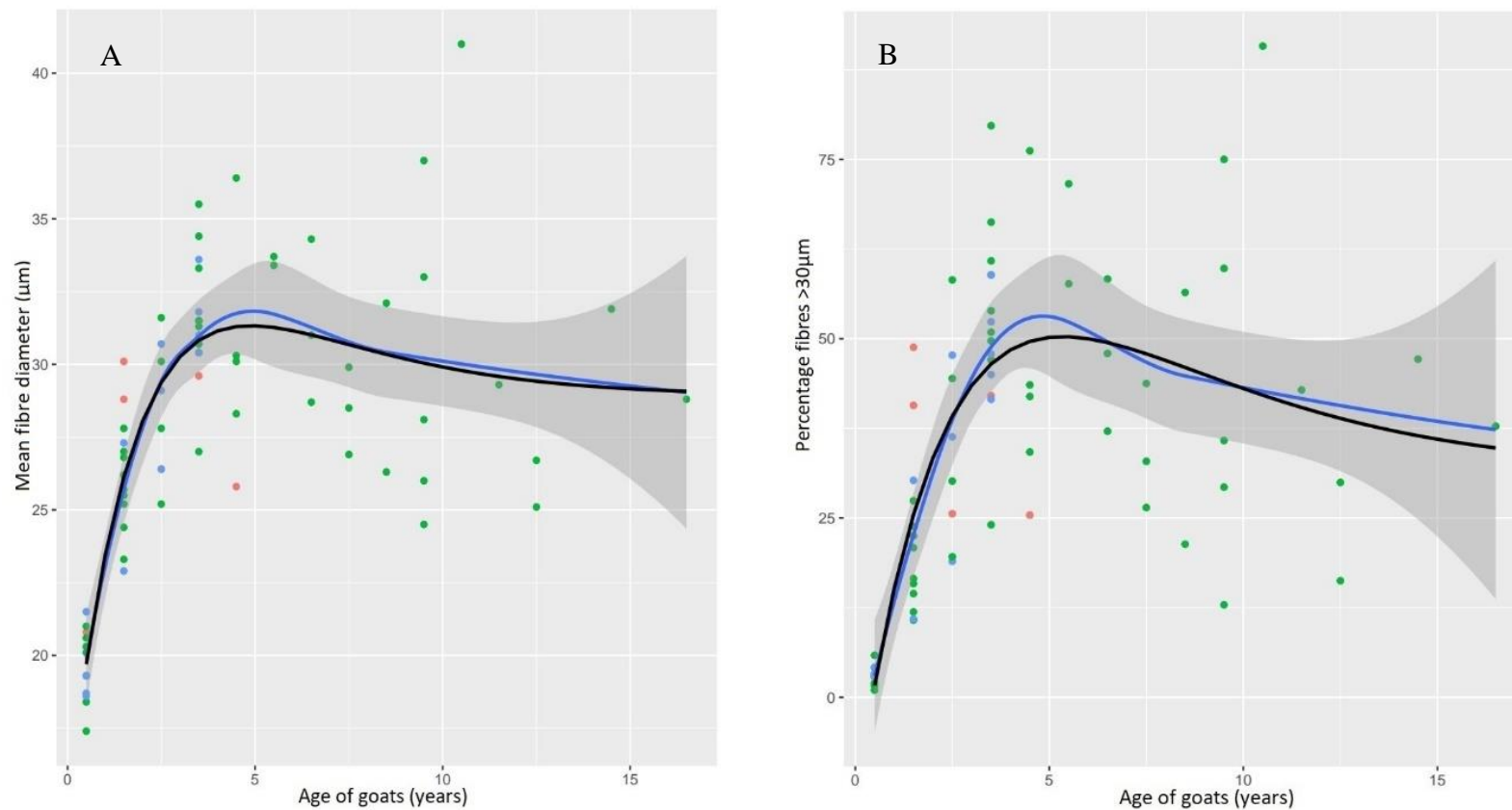


Figure 4.3.3: The effect of age on mean fibre diameter (A) and percentage of fibres $>30\mu\text{m}$ (B) of Angora goats. Symbols: bucks (●), does (●) and wethers (●), confidence interval (■), line of best fit (—), linear regression (—).

4.3.4 Follicle density and S:P ratio

Significant correlations were found between age and S:P ratio ($P < 0.012$), secondary follicle density ($P < 0.0005$), primary follicle density ($P < 0.003$) and total follicle density ($P < 0.0005$). Sex had no apparent influence on any variable. Secondary to primary ratio could not be explained by a linear regression model. Secondary, primary and total follicle densities demonstrated linear by linear responses to age (Figure 4.3.4).

The model for S density can be represented as:

$$S \text{ density} = 2.9156 + 16.2256 / (1 + 0.5858x)$$

where x is age in years. Maximum secondary follicle density is 19.1412 with an estimated final density of 2.9156.

The model for P density can be represented as:

$$P \text{ density} = 1.2012 + 2.0176 / (1 + 1.0095x)$$

where x is age in years. Maximum primary follicle density is 3.2191 with an estimated final density of 1.2012.

The model for total density can be represented as:

$$\text{Total density} = 4.1397 + 18.1537 / (1 + 0.6178x)$$

where x is age in years. Maximum total follicle density is 22.2934 with an estimated final density of 4.139.

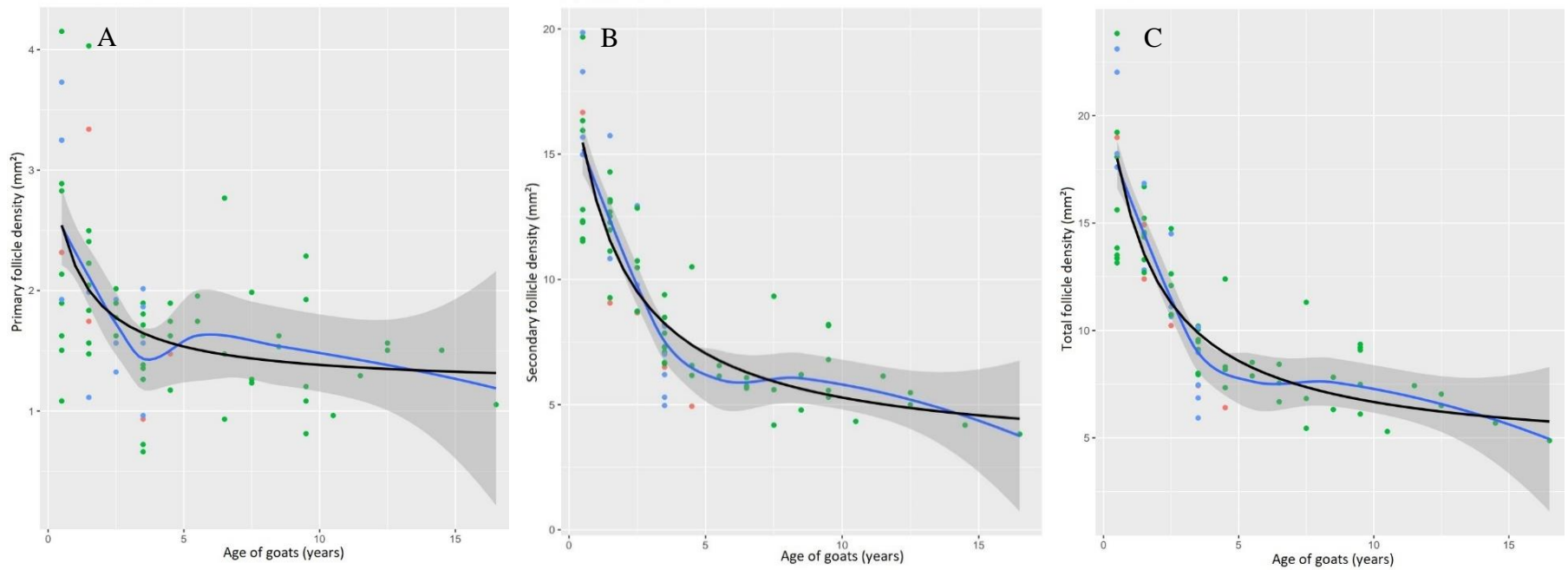


Figure 4.3.4: The effect of age on primary (A), secondary (B) and total (C) follicle densities of Angora goats. Symbols: bucks (●), does (●) and wethers (●), confidence interval (■), line of best fit (—), linear regression (—).

4.3.5 Histological observations

Primary follicles are identified by a large follicle opening containing a medullated fibre, bilobed sebaceous gland and arrector pili muscle (Figure 4.3.5). Secondary follicles contain smaller unmedullated fibres and no or rudimentary supportive structures (Figure 4.3.5). Skin follicles were arranged in wedges with rows of 4-6 secondary follicles between the primary follicles. These follicle groups were arranged in rows interspersed with connective tissue.

Follicle group arrangement was poorly organised in younger skins, very distinct by 5 years old but became less organised at older ages. This was associated with an apparent reduction in the number of secondary follicles, increase in primary follicle size and increase in surrounding connective tissue (Figure 4.3.5).

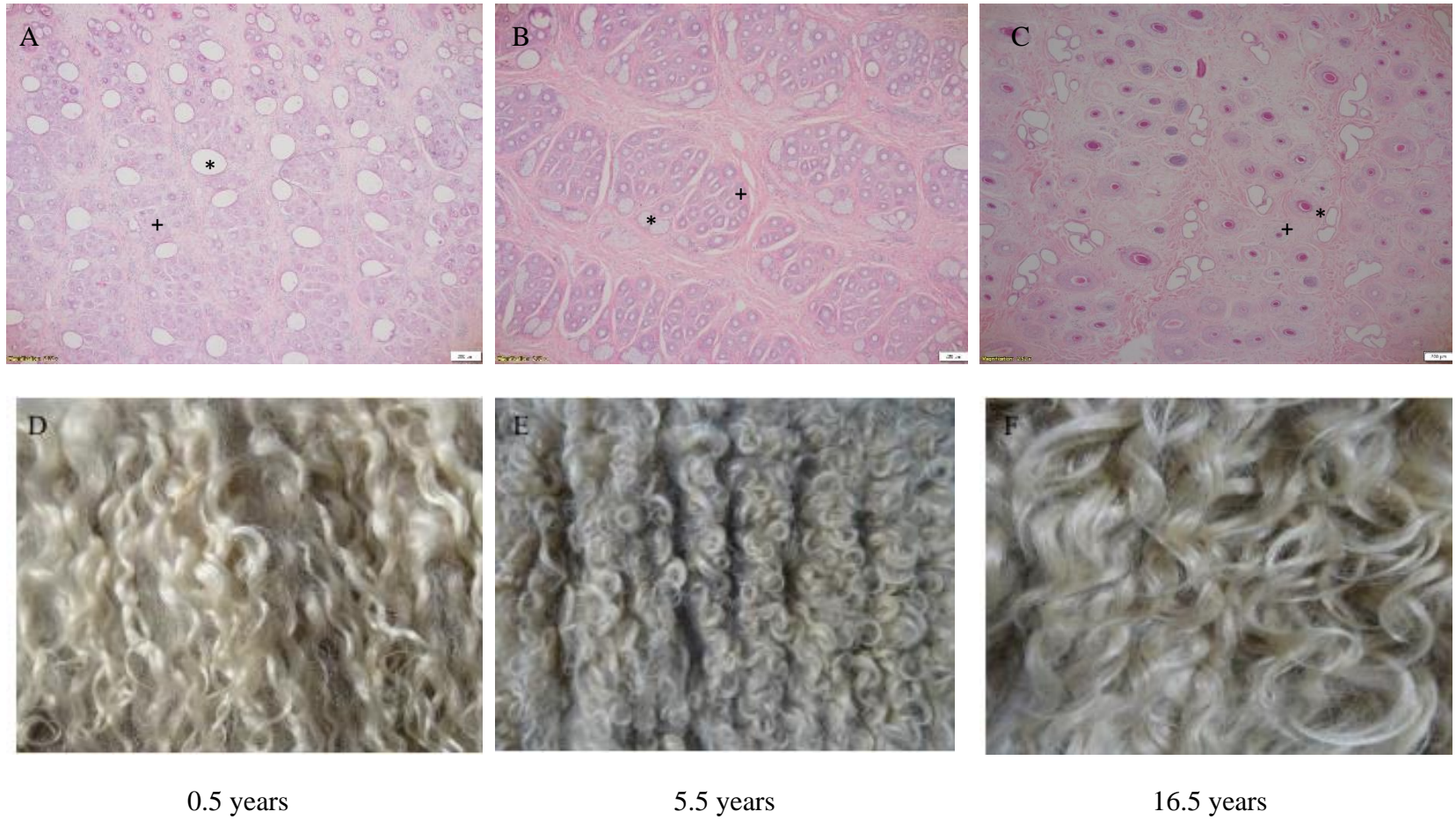


Figure 4.3.5*: Photomicrograph (x 100) showing arrangement of the hair follicles and support structures of Angora goat skin (Images A, B and C) and the corresponding macroscopic mohair (Images D, E and F) at 0.5, 5.5 and 16.5 years old. Symbols: Primary follicles (*), Secondary follicles (+). (Westphalen, 2022a)

*Full size images available in Appendix C

4.4 Discussion

4.4.1 Body weight and fleece weight

The reports of age at which maximum fleece production occurs is highly variable. Work by Taddeo et al. (1998a), Gifford et al. (1991), Hunter (1993) and Ariturk et al. (1979) describe maximum GFW occurring at 3-4 years old and declining at older ages in Angora goats. A similar trend was seen in this study with a maximum fleece weight for does that were 5 years old. Further measurements from both does and wethers older than 5 years is necessary to verify this trend in this flock. Other reports describe peak GFW occurring at 1.5-2.5 years old, remaining constant until 4.5 years old and declining thereafter (McGregor, 1981). Fleece weight is proportional to \log_3 fleece free live weight (McGregor et al., 2013a) and mean live weight and age are reasonably correlated (McGregor, 1998). Therefore, it would be expected that maximum fleece production would occur at maximum body weight. At what age maximum body weight occurs is a matter of marked variability within and between flocks (McGregor et al., 2012). Genetic and environmental factors are the likely reason why age and fleece weight have no discernible relationship.

The determinants of body weight and therefore fleece weight could be broadly categorised into four factors; feed quality, the capacity to prehend feed, the ability to digest feed and ability to utilise digested feed.

The capacity to consume food is reliant on the ability to get to food and to prehend it. Energy utilisation for mobility is likely higher in younger animals because of their small size relative to distance is greater (Pontzer, 2007). It is well recognised that incisor wear increases as Angoras' age and the rate of wear can vary within the same age cohort. Work by McGregor and Butler (2011) found that 30% wear of the first permanent incisors reduced greasy fleece weight by 20%. Interestingly, this degree of wear did not influence body weight for Angora goats but did in sheep (McGregor & Butler, 2011). This

demonstrates a noteworthy relationship between the capacity to consume food and fleece weight.

Ruminant digestion of plant material is dependent on microbial fermentation. It is well recognised that different feedstuffs will alter the ruminal microbiota (P. McDonald, Edwards, Greenhalgh, & Morgan, 2002). However, evidence is emerging that age-related changes occur in the ruminal microbial community. Significant correlations occur between age to weaning, microbial genera and concentrations of volatile fatty acids (VFAs) and microbial crude protein in sheep (Magolski et al., 2011) and goats (Kari, 2014). Interestingly, dairy cows in their 1st-3rd lactations have a greater abundance of ruminal microflora when compared to cows in the 5th or greater lactation on the same base ration (Louey et al., 2005). These changes reduced the fermentation of carbohydrate and lipid metabolism and increased protein metabolism causing a reduction in milk yield and milk lactose in older cows. This provides some tangible evidence that not only does the ruminal microbiota change with age but will influence the productive output. Although not defined in Angora goats, it is possible that the ruminal microbial population in goats may similarly change with age, and could be one cause of reduced body weight or fleece weight at ages above 5 years.

Finally, utilisation of the metabolites of digestion are dependent on the physiological state of the animal and its productive output. Glucose utilisation and fat deposition is dependent on insulin and cortisol, while fat mobilisation is dependent on growth hormone (Blair et al., 2011; Cunningham & Klein, 2007). Work conducted by Behrendt et al. (2011) with goats and sheep demonstrated a decreasing tolerance to glucose and an increase in secretion of insulin as the animals' aged. This results in a reduction in muscle mass and overall body weight, as seen in older animals and reflected in this data. Limited evidence suggests that young goats are 25% more efficient at using dietary energy to produce mohair compared to older goats likely due to the greater tolerance to glucose (McGregor, 1981). Further, the additional metabolic demands of pregnancy and lactation are well recognised to suppress wool growth and

reduce body weight (Couchman & McGregor, 1983). Metabolite utilisation in young goats shifts from body growth to reproduction as they age. Variability in fleece weight could reflect how metabolite use is shifting with age.

4.4.2 Fibre characteristics

The reported influence of age on MFD are variable. This study appears to have maximum MFD occurring at 5 years old which is later compared to other reports. It was demonstrated by Gifford et al. (1991) and Gifford et al. (1990) that MFD increased markedly to 13-18 months old, while Allain and Roguet (2003) and McGregor et al. (2012) found that MFD increased to 18-30 months old. Reports by Hunter (1993), Ariturk et al. (1979) and Taddeo et al. (1998a) each found MFD was broadest at 4-5 years old which is more consistent with this data. Similarly, the pattern of decline after this maximum varied with some finding the decline was rapid (Taddeo et al., 1998a), others found it slow (Gifford et al., 1991) and still others found MFD trended positively without reaching a maximum (Lupton et al., 1996). However, both Taddeo et al. (1998a) and Allain and Roguet (2003) concluded that year of production was the greatest source of variation for MFD. Therefore, it seems likely that the variable reports of the influence of age on MFD are a reflection of the different environments and years from which these reports are made. The results of this dataset also reflect the environment and particular year and therefore repeat measures over several years are required to substantiate these findings.

The influence of age on med% is more consistent. It is generally accepted that med% increases with age although some contention exists in the linear model that can be applied to this correlation (Gifford et al., 1990; Gifford et al., 1991; Lupton et al., 1996; Taddeo et al., 1998a). Direct comparisons to this data are difficult because different measurements of medullation have been used by different reports. As aforementioned, there is overlap in the diameter of fibres classified as med compared to unmedullated fibres (Lupton et al., 1991). It is inevitable that some fibres greater than 30 μm are not medullated and therefore

using >30micron% as a measure of medullation in this study will overestimate the degree of medullation. However, high percentages of fibres broader than 30 μm are undesirable regardless of the presence of medullation and therefore >30micron% remains a valuable reported trait (Adams & Cronje, 2003; McGregor, 2020).

It is interesting that >30micron% increases to 5 years old and then declines at older ages although variability increases. There appears to be two likely reasons for this. Firstly, there are fewer data sets for does older than 5 years, and particularly does older than 10 years. Additionally, males are not represented beyond 5 years old. Although both factors bias the measures for older animals and overestimates their significance, this was done to ensure that the sample population was representative of the entire flock. Secondly, the genetic variation is greater in those animals over 5 years old. All animals that were 1, 2, 3 and 5 years old were sired by bucks from the same stud. The 4 year old cohort is a mix of these same genetics and a second source. It is interesting to note that the variability appears greater for the 4 year old cohort and those greater than 5 years old. It is well established that med% has a high heritability (Gifford et al., 1991; Lupton et al., 1991) and the increased variation is likely a representation of different genetic lines.

The mixed results for the influence of age on fibre characteristics is caused by the difficulty of separating age as its own variable to body weight and the body weight changes that occur as Angora's age. In this data, more variation could be attributed to body weight than to age for most fibre characteristics, confounding the results. It is interesting to note that different age cohorts appeared to behave differently from the neighbouring cohorts indicating a seasonal variation similar to McGregor et al. (2012) and McGregor and Butler (2014b). The seasonal variation of this data likely reflects the different preweaning conditions each age cohort was reared under and a different metabolic efficiency in later life. The differences between different age cohorts also reflects different physiological life stages and production.

Differences in fibre characteristics between light and heavy Angora goats may be the result of differences in metabolism. It has long been recognised that smaller animals have higher metabolic rates because each cell expends more energy than the equivalent cell type in a large animal. However, large animals inherently have more cells therefore their overall energy requirements are higher (Speakman, 2005). Recent work by Makarieve et al. (2008) found that basal metabolic rates converged onto a very narrow range of 0.3-9 W/kg. This means that despite the vastly different physiological and biochemical pathways, mass-specific metabolic rates are relatively uniform. This means that the metabolic rate of small and large Angora goats is likely to be very similar.

A second difference in metabolism between light and heavy Angora goats may be the rate of metabolic turnover. The most energy expensive metabolic process is the synthesis and breakdown of protein (Cunningham & Klein, 2007). Very limited data exists on the effects of body size on protein turnover. In a review by Garfano, Czernichow, and Breant (1998), no clear evidence was found to suggest that larger animals have different rates of protein turnover compared to small animals in maturity. They speculated that protein turnover across different species was very similar at the same body weight. This was confirmed in aging humans by Gardner et al. (2007). It is likely that Angora goats regardless of size have similar rates of protein turnover.

A final difference in metabolism between light and heavy Angora goats could be their susceptibility to fluctuations in metabolic supply. It is well recognised that larger goats have a greater maintenance energy requirements and adverse fluctuations in energy supply have more severe effects. Both McGregor et al. (2013b) and Adams and Cronje (2003) demonstrated that energy restriction led to a greater med% in heavier goats, similar to this dataset. Skin protein synthesis accounts for approximately 15% of total body protein synthesis in sheep and therefore any changes in protein supply will have a marked effect on wool growth (Adams & Cronje, 2003). Fluctuations in energy and protein

supply also explains why heavier Angoras have a greater fibre diameter variation and standard deviation in this dataset. Differences in fibre characteristics between light and heavy Angora goats are likely a result of different susceptibility to metabolic supply rather than differences in metabolic rate or turnover.

4.4.3 Follicle density and S:P ratio

Many reports focus on how S:P ratio and follicle densities are established in early postnatal life with few reports on how the ratio and densities change as Angoras' age. Both Dreyer and Marincowitz (1967) and McGregor (2020) found that S:P ratio was lowest at birth and increased to 3 months old, remaining constant thereafter (2.3 to 9.1 and 2.56 to 9.07 respectively). According to Hunter (1993), Texan Angora goats have a weaner S:P ratio of 6.5-8.3 while South African goats average 9.1 and Australian Angoras have an S:P ratio of 8.8. This is consistent with the findings of Margolena (1974), whom determined a mature S:P ratio of 8.0. Although a significant correlation was found between age and S:P ratio, no discernible trend was determined. Total follicle density is reported as 10-15 mm² by Hunter (1993), similar to McGregor (2020). Research by Parry et al. (1993) found that mature P and S density was 3 /mm² and 28.8 /mm² respectively. Secondary follicle density was lower in McGregor (2020) at 14.8 /mm². These results are comparable to this dataset for young goats.

Secondary, primary and total follicle densities were highest at 6 months old, declined rapidly to 5 years old and slowly declined thereafter into old age. The rate of decline of primary follicles was less rapid than secondary follicles. Although correlations between age and S:P ratio, S density, P density and total follicle density were all significant, more variability was explained by body weight than by age. This is unsurprising. It is well established that no new follicles are formed after 2 months of age and the follicle population matures by 4 months old (Parry et al., 1993). Any changes to density thereafter are a

reflection of body growth and expansion of the skin surface area which is proportional to body weight (McGregor, 2016b; McGregor & Butler, 2016). This explains the rapid decline between 6 months and 5 years old, when most body growth is occurring and the slower decline thereafter when body weight is relatively constant.

Although a well-recognised phenomenon of the aging process, how skin and hair follicles age is not completely understood. No papers are available on this process in Angora goats. In a paper by Galbraith (1998), progressive loss of hair follicle dermal stem cells was mapped over 24 months in humans. It was found that although these cells are a central progenitor, aging skin demonstrated impaired renewal of this cell type and reductions in the differentiation pathways. This would explain not only the dermal thinning seen with encroaching age but also age-related hair loss. Although the precise biochemical mechanisms are likely to be different across species, the inherent nature and role of hair follicle dermal stem cells means that depletion with age and the resulting change in skin characteristics is possible in other species including Angora goats.

4.4.4 Histological observations

Histological studies of Angora goat skin are limited and conflicting regarding the changes that occur with age. Primary follicles are identifiable by a wide follicle opening containing a large medullated fibre, bilobed sebaceous gland and arrector pili muscle (Dreyer & Marincowitz, 1967; Parry et al., 1992). In older skins, there appears to be a loss in the amount of sebaceous gland tissue, increase in width of the hair canal with additional dead space around the fibre and an increase in diameter of said fibre (Figure 4.3.5). Sebaceous gland size is known to be inversely proportional to the size of its associated hair (Samuelson, 2007). These changes in follicle size appear to correspond with changes in the associated connective tissue and are likely related to it. These differences in

older skin would also explain the decline in follicle densities seen in older goats.

Secondary follicles contain small non-medullated fibres without arrector pili muscles and small or non-existent sebaceous glands (Dreyer & Marincowitz, 1967; Parry et al., 1992). Interestingly, secondary follicles tend to have proportionately wider root sheaths than primary follicles in contrast to Wentzel and Vosloo (1975), in which primary follicles were proportionately wider than secondary follicles. Further measurements would be necessary to explore this in greater detail. Secondary follicles tended to increase in size and reduce in number in older skins to become more similar in appearance to primary follicles (Figure 4.3.5). This made distinguishing primary from secondary follicles in older skins difficult and therefore calculated primary and secondary follicle densities may be inaccurate. Regardless, the changes in total follicle density in older skins is reflective of a genuine decrease in all follicle types with age.

The most dramatic changes in the microscopic appearance of Angora skin are to the arrangement of the follicles and supportive connective tissue. Follicle groups contained 3 primary follicles surrounded by a variable number of secondary follicles in rows in a wedge-shaped cluster. These groups are then arranged in rows with thin connective tissue between groups and thicker connective tissue between rows (Dreyer & Marincowitz, 1967; Parry et al., 1992). The arrangement within groups appeared less organised in the youngest skins but became very distinct at maturity (Parry et al., 1992). In the older skins, the organisation and arrangement of within and between follicle groups was non-existent (Figure 4.3.5). Additionally, the associated connective tissue became thicker in older animals as follicles became more disorganised. Those animals with higher secondary follicle densities tend to contain similar numbers of follicle groups but with more secondary follicles within those groups that were smaller in area (Figure 4.3.5). This observation supports the statistical

trend between fibre diameter and both S:P ratio and secondary follicle density found in this report and others (Adams & Cronje, 2003).

These observations seem to conflict with other reports. A paper by Margolena (1974) concluded that there was very little difference in the skin of young and old animals aside from a general loosening of the dermal structures. This seems very unlikely for several reasons. Firstly, as demonstrated in Figure 4.3.5, there are distinct macroscopic differences in the appearance of young and older Angora skins which must have corresponding changes microscopically. Secondly, “loosening” implies that the number and structure of follicles is similar in young and older animals but spread over a greater area. While this is likely true during growth to mature size, it does not explain the changes between maturity and old age. As Figure 4.3.5 demonstrates, there are clear changes in the number and structure of follicles without a significant change in body surface area. Thirdly, Margolena (1974) had very few numbers of samples from each age group and sampled only to 9 years old. The more extensive sampling of this study is likely more representative of the trends that occur.

These observations present a conundrum if attempts are to be made to increase secondary follicle density and maintain this population for greater productivity. Follicle arrangement becomes more organised as Angoras’ age to maturity and a number of secondary follicles are lost even when changes in body surface area are taken into account. How a greater number of secondary follicles can be maintained is presently unknown but almost certainly relates to competition for nutrients between follicles (Taddeo et al., 1998a). Differences between mature and older skins demonstrates not only a loss of more secondary follicles but a trend for the remaining to produce thicker fibres. The viability of maintaining older animals in a commercial setting is complex. With the limited knowledge available, retaining doe goats to 5 years old for their fleece production is feasible in a commercial setting and justified based on the results of this data. At what age does become unsustainable for their own fleece production is unknown although retaining older does for their reproductive potential will be

discussed in Chapter 6. While this study is limited by the sample size, representation of various groups and failure to track these changes as an individual goat ages, differences in young, mature and older skins are clear.

4.5 Conclusion

Representation of different cohorts particularly male goats and goats over 10 years of age, was a substantial limitation of this study. There was a significant correlation between age and MFD, fibre diameter variation, standard deviation, coefficient of variation, >30micron%, comfot and spinning fineness. However, more variation could be attributed to differences in body weight than to age. A significant correlation occurred between age and S:P ratio, S follicle density, P follicle density and total follicle density. Similarly, more variation could be explained by body weight than by age. Histological observations suggest that there are differences in the arrangement of follicles and the follicle groups between young goat skin and that at older ages. Differences in metabolism with age and body weight likely explains these findings.

Chapter 5 Should orphan and tail-end kids be culled from an Angora goat flock?

5.1 Introduction

Many farmers will wean their flocks based on a specific time rather than kid size, and therefore will inherently produce a cohort of younger, smaller animals due to the spread of the kidding period. A variety of dam and environmental factors can contribute poor nutrition in the early postnatal period (Snyman, 2010a). Reports by McGregor and Howse (2018) and McGregor (2017) have found that kids on low planes of nutrition in the pre- and postnatal periods have lower follicle densities and S:P ratio. These kids subsequently produced coarser fleeces compared to their well-fed counterparts. Given these kids produce fleeces of lower value, whether these kids should be kept for future breeding or culled from the flock is of interest to farmers aiming to produce high quality mohair. This aim of this study was to determine the relationship between skin follicle development and mohair characteristics at 18 months old in kids identified as well- and poorly-grown at weaning.

5.2 Materials and Methods

5.2.1 Location and facilities

Goats were sourced from two Angora goat studs in Western Victoria and transported to the Animal Research Institute, Werribee, Victoria and managed as a single flock. Details of the rainfall, environment and pasture composition are described elsewhere (McGregor, 2010b). Goats were grazed on annual pasture with fresh water available at all times. Shelter consisted of enclosed shedding that could accommodate all goats and was constantly accessible to them.

5.2.2 Animal reproduction and experimental design

Does were naturally mated in autumn (March – May) and kidding occurred on August 6 +/- 2 weeks. Does were run as one mob from joining until weaning. Where possible, records were taken on the day of kidding, dam, birth parity, birth weight and doe liveweight. Some of these records are incomplete due to orphaned, mismothered or unknown doe identities despite rigorous observation. Kids were weaned at over 4 months old in December and run as one mob until 5 months old. Kids were separated into doe and buck flocks and managed on a rotational grazing program to ensure similar nutritional conditions.

Using liveweight records from birth to weaning, kids were selected from the flock as poorly grown or well grown and designated to either low or high postnatal nutritional treatments respectively. This provided 12 or 13 replicates of individual kids respectively for each treatment. The majority of kids in the low nutrition group were twins and a number of orphans. Kids in the high nutrition treatment were predominately singles.

5.2.3 Animal and fleece measurements

Each goat was weighed once a month, and one day before shearing to the nearest 0.5 kg. All goats were shorn every 6 months from 6 months old. At shearing, fleeces, pieces, bellies, locks and samples were weighed to the nearest 1 g. Clean fleece weight at shearing (CFW) was calculated as a proportion: total greasy fleece weight (kg) × clean wash yield % (CWY). Staple length was measured as the average of 3 staples of the midside to the nearest 0.5 cm. Number of crimps along a staple were recorded using a crimp gauge. A grid sample (~50 g) was taken from the midside to represent the entire fleece, identified and stored. These samples were then tested by the Australian Wool Testing Authority laboratory for clean washing yield (% w/w, with 16% regain, IWTO-19), MFD (μm , IWTO-28) and incidence of medullated fibre and kemp fibre (% by number, IWTO-8) (International Wool Textile Organisation, 2017).

Total medullated fibre was calculated by adding incidences of medullated and kemp fibres.

5.2.4 Skin histology

Skin biopsies were taken from the selected kids under local anaesthetic on January 31 1991 when the mean age was 177 days (range 153-189). Samples were stored in 10% formalin pots until processed similarly to those described in Chapter 3 by a diagnostic laboratory using haematoxylin and eosin (H&E) stain. Slides were then given to an independent investigator and the primary and secondary follicles manually counted. Primary and secondary follicle densities and S:P ratio was determined for each sample. Although all selected kids were sampled, only slides from 18 kids were available for interpretation. Table 5.2.4 describes the sample population by kid sex and parity.

Table 5.2.4: Sex and parity of kids fed high or low nutrition from birth to weaning.

	High Nutrition		Low Nutrition	
	Male	Female	Male*	Female
Single	4	4	1	0
Twin	0	1	1	6

*Three male kids were represented in the low nutrition group. For one male kid, parity was unknown.

5.2.5 Statistical analyses

Inferential statistics were used to calculate the S:P ratio and primary, secondary and total follicle densities. Adjustment for shrinkage of the samples was considered when determining the aforementioned parameters.

Data were analysed using GenStat 15.1 (VSN International, 2007). Missing data was excluded. Correlation coefficients (r) were determined between greasy fleece weight and kid weight, clean fleece weight, MFD, staple length, incidence of medullation, incidence of kemp, staple crimps, S:P ratio and

primary and secondary follicle densities. The effects of nutritional group on kid weight, clean fleece weight, MFD, incidence of medullation, S:P ratio and primary and secondary follicle densities were assessed ANOVA with d.f. = 23. Standard errors of differences in means (s.e.d) were used to detect differences between treatments with least significant differences at $P=0.05$. The effect of sex was tested but found to be not significant for any attribute so was excluded from the models.

5.3 Results

5.3.1 Body weight effects

Daily weight gain was significantly different between the high nutrition, well grown kids and low nutrition, poorly grown kids (61 vs 148 g/d, $P<0.001$) resulting in high nutrition kids being heavier at 5 months of age compared to low nutrition kids (27.6 kg v 18.5 kg, $P<0.001$). The high nutrition kids had higher daily weight gain and remained heavier until at least 18 months old (32.6 kg vs 24.9 kg, $P<0.001$) (Table 5.3.1).

Table 5.3.1: Mean body weight at 5 months and 18 months old (kg) and mean daily weight gain (g/d) of kids fed high or low nutrition from birth to weaning.

	5 months body weight (kg)	18 months body weight (kg)	Daily weight gain (g/d)
High Nutrition	27.60	32.60	148
Low Nutrition	18.50	24.90	61
LSD 5%*	1.93	2.66	29
P value	<0.001	<0.001	<0.001

*Least significant difference 5%

5.3.2 Fleece effects

Greasy fleece weight was significantly different between nutritional treatment groups ($P=0.05$) with high nutrition kids producing fleeces 13% heavier. No other fleece measurements were significantly different between groups. Mean fibre diameter, staple length, clean washing yield, incidence of med and kemp were similar between treatments ($P>0.20$). Staple crimp was also similar ($P=0.07$) (Table 5.3.2).

Table 5.3.2: Mohair characteristic measurements for kids fed high or low nutrition from birth to weaning.

	Greasy fleece weight (kg)	Mean fibre diameter (μm)	Staple length (cm)	Clean washing yield (%w/w)	Incidence of med (% by number)	Incidence of kemp (% by number)	Staple crimps /cm
High Nutrition	1.51	32.80	11.70	91.20	2.0	1.30	0.64
Low Nutrition	1.33	32.70	12.30	91.90	1.80	1.30	0.54
LSD 5%*	0.17	1.90	1.15	1.60	1.26	0.39	0.105
P value	0.050	0.920	0.230	0.360	0.760	0.90	0.070

*Least significant difference 5%

When the data for all nutritional groups was pooled, there was positive correlation between liveweight and GFW (pearson correlation 0.49, $P=0.013$). A negative correlation was present between GFW and both clean washing yield (pearson correlation -0.42, $P=0.035$) and incidence of medullation (pearson correlation -0.46, $P=0.020$).

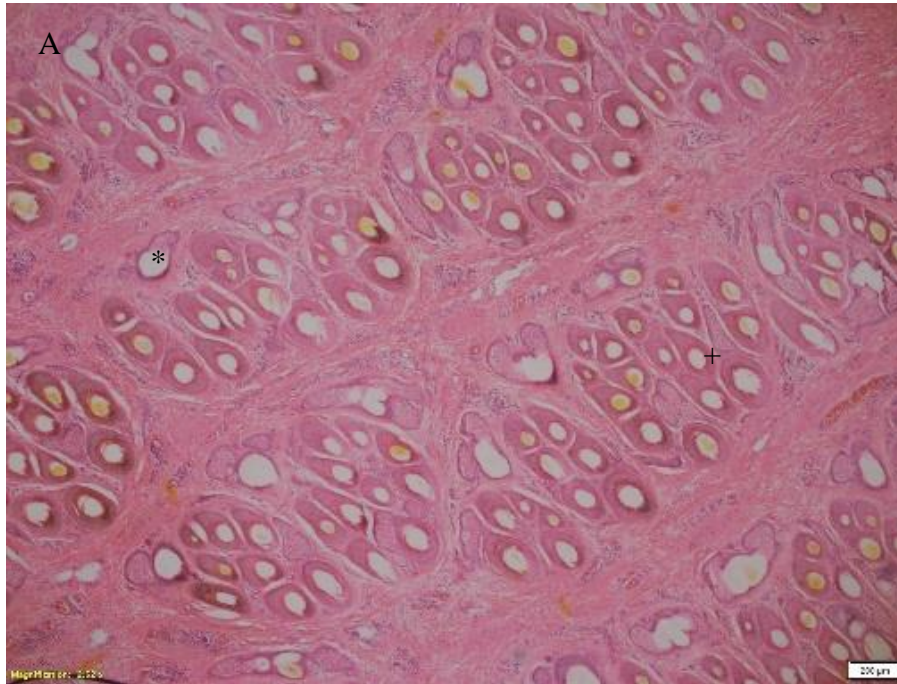
5.3.3 Follicle densities, S:P ratio and histological observations

There was no significant difference between groups for primary, secondary or total follicle density or follicle ratio (Table 5.3.3). Sex and birth type did not significantly influence the follicle variables.

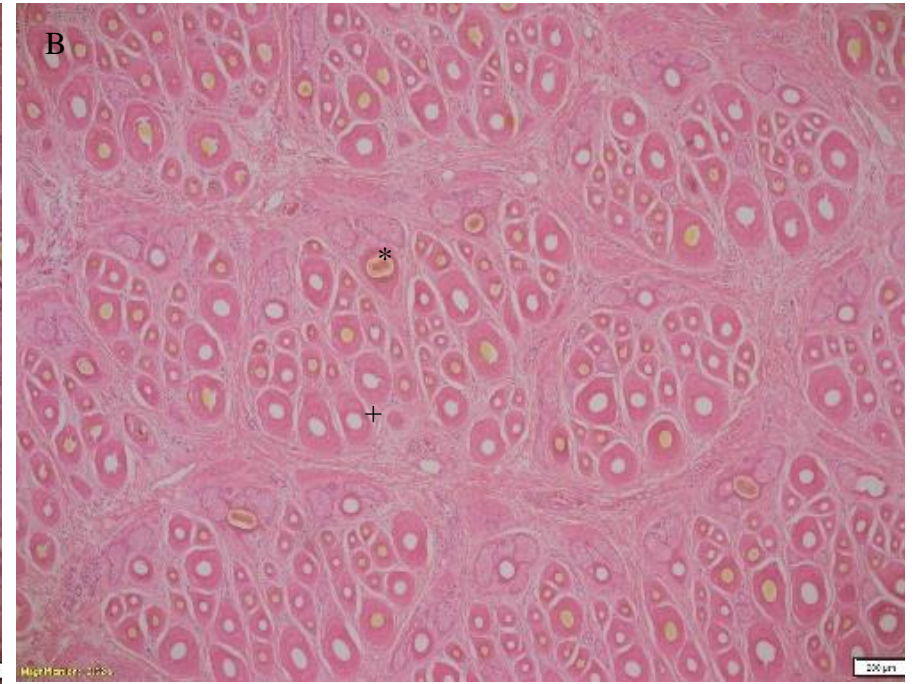
Table 5.3.3: Mean (\pm SEM) primary, secondary and total follicle density (/mm²) and S:P ratio of kids fed high or low nutrition from birth to weaning.

	Primary follicle density (/mm ²)	Secondary follicle density (/mm ²)	Total follicle density (/mm ²)	S:P ratio
High Nutrition	1.954 (\pm 0.158)	12.248 (\pm 0.828)	14.091 (\pm 0.837)	6.306 (\pm 0.692)
Low Nutrition	2.029 (\pm 0.228)	11.748 (\pm 0.862)	14.811 (\pm 1.264)	6.683 (\pm 0.544)
Variance	0.316	0.589	0.036	0.890
P value	=0.791	=0.681	=0.641	=0.674

Despite the similarities in follicle densities and S:P ratio of high and low nutrition kids, the microscopic appearance of their skin illustrated some marked differences. Figure 5.3.3 demonstrates the microscopic arrangement of follicles in low and high nutrition kids. The arrangement of the follicle groups into rows is less organised in the low nutrition group and the connective tissue between the rows is thicker compared to the high nutrition group. The root sheaths of the secondary follicles appear wider while the supportive structures of the primary follicles are smaller and less developed in the low nutrition group.



Low nutrition group



High nutrition group

Figure 5.3.3: Photomicrograph (x 100) showing arrangement of the hair follicles and support structures of Angora goat skin of low (Image A) and high (Image B) nutrition kids. Symbols: Primary follicles (*), Secondary follicles (+). (Westphalen, 2022b)

5.4 Discussion

5.4.1 Body weight effects

Kids in the high nutrition group had a higher daily weight gain that persisted to at least 18 months of age. This is unsurprising, given the dams were managed as one flock during kidding and up to weaning. The difference between the high and low nutrition groups is likely due to quantity rather than quality of the feed on offer to the kids. Differences in daily weight gain and body weight can be attributed to birth type. The high nutrition cohort were predominately singletons, while the low nutrition cohort were twins and orphans. The high nutrition group had dam's with better mothering ability and did not need to compete with a sibling for milk. Therefore, high nutrition kids had an inherent advantage over the low nutrition cohort which persisted until at least 18 months of age (Greenwood et al., 2010; Kenyon & Blair, 2014; Thompson et al., 2011). This would similarly explain the greater fleece weight of the high nutrition kids (McGregor, 2020).

5.4.2 Fleece effects

It has generally been accepted that improved nutrition during gestation reduces progeny MFD, increases fleece weight and reduces incidence of med (Bawden et al., 2010; Behrendt et al., 2006; Behrendt et al., 2011; Curnow, 2006; Greenwood et al., 2010; McGregor & Howse, 2018; Schinckel & Short, 1961; Short, 1955; Thompson et al., 2011). However, MFD, staple length and incidence of medullation were not significantly different between the high and low nutrition cohorts. Given the allometric relationship between MFD and body weight, it is expected that smaller animals would have finer fleeces (McGregor et al., 2012). Work conducted by Kelly et al. (1996) found no difference in MFD of progeny from sub maintenance and control fed Merino ewes at the lambing shearing. However, sub maintenance fed progeny did produce coarser and lighter fleeces at the hogget shearing and remained lighter by 1.3 kg BW.

This was attributed to statistically significant differences in body weight, follicle densities and S:P ratio (Kelly et al., 1996). Only the kid shearing has been assessed in this data. Given the significant difference in body weight at 18 months of age, it seems likely that a similar trend would occur if further measurements had been taken at shearing at 12 and 18 months of age.

5.4.3 Skin histology

If comparisons at the same size rather than age are made, differences in follicle densities and S:P ratio between high and low nutrition kids are likely. Follicle initiation is complete by 1 month of age and therefore total follicle number does not increase after this age (Lambert et al., 1984; Parry et al., 1993). Further changes in follicle density are the result of skin expansion as the kid grows (McGregor, 2016b). Kids from the low nutrition cohort have a similar follicle density over a smaller surface area (Adams & Cronje, 2003). This implies that low nutrition kids have fewer total follicles, and when compared to their better fed counterparts at the same size, would actually have lower follicle densities.

It is not surprising that lower nutrition kids likely had reduced follicle densities when skin surface area was considered. Naturally restricted Cashmere kids (twins) demonstrated lower SFNI, PFNI and Sf:Pf ratio compared to their singleton counterparts (Parry et al., 1992). In a study by McGregor and Howse (2018), Angora kids better fed during gestation and lactation had the highest S:P ratio, secondary and total follicle densities. This is likely because higher nutritional planes allow the initiation of more follicles prenatally and more of the follicles to mature postnatally. Similar findings were demonstrated in Scottish Blackface, Romney and Merino sheep (Greenwood et al., 2010; Hutchison & Mellor, 1983; Kelly et al., 2006; Kelly et al., 1996; Short, 1954). Likewise, given S:P ratio describes the structure of the follicle population, circumstances in which both S and P follicle densities are high or low but in the same proportion would result in similar values. Therefore, similar S:P ratios can be expected when follicle densities are markedly different.

It is interesting to note that the apparent histological differences in low and high nutrition kid skin are similar to those observed between young and older Angora goat skins discussed in Chapter 4. One possible explanation is the attrition of follicles that fail to mature in low nutrition kids produces a similar microscopic arrangement to the aging attrition effect seen in older skins. Attrition of follicles would disrupt the arrangement of the follicle groups and cause the resulting dead space to be occupied by connective tissue (Samuelson, 2007). Follicle attrition was observed by Margolena (1974) in histological samples from kids as young as 75 days old. Further, underdevelopment of the follicle supportive structures would be expected if follicle maturation is inhibited. This could also explain why low nutrition kids also produce lighter fleeces compared to their better fed counterparts similar to the older versus younger goats in Chapter 4.

These results provide some insight into practical implications on flock structure. Not only are low nutrition kids smaller than their better fed counterparts, but they can be expected to produce lighter and coarser fleeces at hogget and subsequent shearings. Follicle densities and S:P ratio are likely lower in the low nutrition cohort due to a reduced follicle population size. Follicle characteristics are strongly heritable in Merino sheep (Jackson et al., 1975) and although not established in Angora goats, can be expected to be similar. Although it can be expected that some low nutrition doe kids have the same genetic potential for follicle characteristics as the high nutrition kids, the cause of their poor performance must be considered when determining if they should remain in the flock. This would particularly apply to mismothered or orphaned low nutrition kid does and the potential ramifications on their own reproductive performance. Therefore, it is unlikely that tail-enders will be beneficial to the long-term productivity of a flock in terms of both mohair quantity and reproductive performance and should be culled after the kid shearing.

5.5 Conclusion

Well grown kids at weaning were heavier at 5 and 18 months old and produced higher fleece weights. Mean fibre diameter, S:P ratio, S follicle density, P follicle density and total follicle density were not different between groups. However, when differences in skin surface area are considered, low nutrition kids would have lower follicle densities and would likely produce coarser fleeces. While it is reasonable to suggest that follicle density parameters are heritable in Angora goats, tail-enders are unlikely to contribute positively to the long-term mohair productivity of the flock. With the potential of the poor performance of low nutrition kids to be demonstrated in their reproductive performance at maturity, tail-enders are unlikely to contribute positively to the reproductive performance of a flock. Therefore, tail-enders should be culled.

Chapter 6 Reproductive efficiency in Angora goats: A cohort study in south eastern New South Wales

Note An abstract presenting the results of Chapter 6 has been accepted for publication (Appendix D (Westphalen et al 2022))

6.1 Introduction

Very little data is published on the reproductive efficiency of Australian Angora goats in a commercial setting. Kid fleece constitutes the most valuable product in a mohair clip due to its finer diameter and poor reproductive performance has a substantial impact on the financial returns (McGregor, 2010c). In an Australian trial by Ritar, Robertson, and Evans (1994) comparing young Angora and Cashmere goats, the Angoras grew more slowly, started ovulating later and had lower ovulation rates. Similar results were seen in a South African trial comparing Angoras to Angora x Boer mixes (Snyman, 2004). It has long been suspected that Angora goats have poor reproductive performance compared to other breeds of goats, but the causes of reproductive loss are poorly defined under Australian conditions. This study aims to identify the major sources of reproductive loss between joining and weaning in Angora goats.

6.2 Materials and Methods

6.2.1 Animal source and location

This study was conducted over a four-year period on the Humula property and flock described in Chapter 3. The Angora goat does in this study ranged in age from 2 years to 16 years old. Reproductive records from 2017-2021 (excluding 2018) were assessed. No data was available in 2018 due to extremely low buck fertility. A total of 228 records were available over the 4-year period with some does data from more than one year. Of these, 33 were maidens (first joining at 2

years old) and 195 were adults (second and subsequent joining). Flock structure by age over the reported years is presented in Table 6.2.1.

Table 6.2.1: Doe flock structure by age between 2017-2021 (excluding 2018) in one Angora goat flock.

Age (years)	2017	2019	2020	2021
2	4	14	6	9
3	5	7	13	6
4, 5, 6	23	14	13	22
7, 8, 9	16	15	16	10
10+	7	13	7	7
	56*	63	55	54

*For one doe in 2017, age was unknown

6.2.2 Animal reproduction and management

The flock grazed on perennial ryegrass/subterranean clover/phalaris pasture throughout the year except in 2019. The producer does not routinely provide supplementary feed but low stocking rates (<4 DSE/ha) on fertilised pasture allows does to maintain body condition throughout the year. Chapter 3 outlines in detail the management of pregnant does throughout gestation and lactation in 2019. In brief, does were joined on the aforementioned pastures. From 42 days post conception, does were individually penned and differentially fed a pelleted/hay ration during early and late pregnancy to investigate the effects of feeding on the follicle density of the offspring. In all years does physically fit, weighing >25 kg and in BCS 3 prior to joining were selected for breeding. Each year, 40-60 does were mated with two bucks for a 9 week joining starting in early April. Different oestrus synchronisation protocols were undertaken each year. In 2017, no oestrus synchronisation protocol was used. In 2019, 250 µg cloprostenol prostaglandin (PG) (Ilium Estromil 1mL, Glendenning NSW) was administered intramuscularly (IM) to each doe and a repeat injection given 11 days later. In 2020 and 2021, an intravaginal controlled internal drug release device (CIDR) (Zoetis EAZI-BREED CIDR, West Ryde NSW) was inserted for 21 days and 250 µg cloprostenol IM administered at removal. Transabdominal ultrasonography for pregnancy diagnosis and foetal number

was conducted each year from 2019, 8 weeks after removal of the bucks. Daily monitoring of the flock began 2 weeks prior to the first expected kidding date in early September and continued for 9 weeks after the first birth. For each birth, the dam was identified and the number of kids and kid sex was recorded. Kids were marked (vaccinated, drenched, males castrated) at weaning at 4 months old and the breeding outcome for each doe recorded. In 2019 and 2021, dead kids (n=15 and n=16 respectively) were necropsied and categorised into probable cause of death. Only data from the 2021 necropsies is presented because these are representative of the on-farm scenario.

6.2.3 Statistical method

Pregnancy rate (pregnant doe per doe bred), conception loss (does not scanned pregnant per doe bred), foetal loss (does failed to kid per doe scanned pregnant), kidding rate (kids born per doe bred), postnatal loss and reproductive rate (kids weaned per doe bred) were determined for adults and maidens each year and the flock average over the 4-year period calculated. No pregnancy data was available for 2018. Descriptive statistics for year and doe age with pregnancy rate, foetal loss, kidding rate, postnatal loss and reproductive rate were conducted using SPSS statistical analysis software (IBM Corp, 2017).

6.3 Results

Reproductive performance parameters are outlined in Table 6.3.1. Average pregnancy rate was 72%, and 80% when excluding maiden does. Foetal loss from scanning to birth was 17.6-26.9% (Table 6.3.1). Reproductive rates (kids weaned per doe bred) were highest in does over 7 years old (52.7% Vs 47.6% 3-6 years old) and lowest in maidens (12.1%) and the very old (0.0%, >15 years) (Table 6.3.2). This indicates that first parity does had lower conception rates, that improve to parity 5 and then decline thereafter. Kidding rates (kids born per doe bred) were 67-87% for adult does but only 24.2% for maidens. Single female kids were most common (50/153) while female kids born as

twins (female or male sibling) were more likely to be weaned (78.1%) than single females (72%), single males (52.4%) or twin males (62.1%). Losses from birth to weaning were up to 47%. Therefore, overall reproductive efficiency was 50% (50 kids weaned to 100 does bred).

The primary cause of kid mortality in 2021 between birth and weaning was starvation-mismothering-exposure complex (Table 6.3.3). All kids except one had been born alive and most perinatal deaths occurred within hours of birth. Many kids had not sucked prior to death. Stillbirths and dystocia did not appear to be major contributors to perinatal mortality.

In 2019 and 2020, copper deficiency was suspected to play a role in postnatal kid mortality. Clinical signs and limited blood sampling (n = 2) were highly suggestive of copper deficiency. Response to copper supplementation substantiated these findings

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Table 6.3.1. Reproductive performance parameters of adult Angora does from 2017-2021 (excluding 2018) and mean reproductive parameters for adults and maidens.

Year	Does	Oestrus Sync	Preg / doe bred	Foetus / preg	Doe kid/ preg	Kid born/ doe bred	Kid born/ preg	Kid wean/ born	Kid wean/ doe bred	Kid wean/ preg
2017	52	Nil ¹	~	~	~	0.830	~	0.860	0.711	~
2019	49	PG ²	0.69 4	1.147	0.824	0.673	0.971	0.515	0.350	0.50
2020	49	CIDR + PG ³	0.83 7	1.220	0.780	0.796	0.951	0.538	0.429	0.512
2021	45	CIDR + PG ³	0.88 9	1.225	0.775	0.867	0.975	0.615	0.533	0.60
Adult mean	195		0.80 4	1.20	0.791	0.790	0.965	0.643	0.508	0.539
Maiden mean	33		0.38 6	1.111	0.867	0.242	0.867	0.50	0.121	0.622

¹Nil: No reproductive hormones given.

²PG: Administered 250 µg cloprostenol IM (Ilium Estromil 1mL, Glendenning NSW), repeated 11 days later.

³CIDR + PG: CIDR (Zoetis EAZI-BREED CIDR, West Ryde NSW) inserted for 21 days. Administered 250 µg cloprostenol IM at removal.

Table 6.3.2 Reproductive rate, conception loss (joining – scanning) and foetal loss (scanning – kidding) between 2017-2021 (excluding 2018) by age in one Angora goat flock.

Age (years)	Does bred	Does scanned	Scanned pregnant	Kidded	Conception loss (%)	Foetal loss (%)	Reproductive rate (%)
2	33	29	9	7	69.0	22.20	12.12
3	31	26	17	13	34.60	23.50	51.61
4, 5, 6	72	48	41	34	14.60	17.0	45.83
7, 8, 9	57	41	33	26	19.50	21.20	52.63
10+	34	27	24	18	10.10	25.0	52.94

Table 6.3.3 Primary causes of mortality of Angora kids in 2021 in one flock.

Likely cause of mortality	Kid ID	Birth type and sex ¹	Age at death	Clinical signs ²		
Starvation mismothering exposure complex	1	TD	< 24 hours	Lungs inflated, stomach empty.		
	4	SD	?			
	10	SB	< 24 hours			
	13	TB	< 24 hours			
	Pneumonia +/- exposure	5	TD		4 days	Lungs pneumonic changes.
		16	TB		4 days	
	+/- Predation	2	SB		< 24 hours	Evidence of predation. Full necropsy not possible
3		?	?			
6		SD	?			
11		SB	4 days			
14		TB	2 days			
Gastro- enteritis	7	TD	< 24 hours	No thoracic pathology. Intestinal pathology +/- peritonitis		
	9	SD	2 days			
Dystocia	8	TB	< 24 hours	Lungs inflated, stomach empty. Bruising/trauma to abdominal musculature		
	12	TD	< 1 hour			
Stillborn	15	SB	< 1 hour	Lungs not inflated, stomach empty.		

¹Birth type (S single, T twin) and sex (B buck, D doe)

²(Matthews, 2014)

Kid mortality by birth weight is demonstrated in (Table 6.3.4). A majority (52.78%) of kids weighed between 2.0 – 3.0 kg at birth. Kid mortality was highest in kids that weighed less than 2.0 kg at birth (81.8%).

Table 6.3.4. Mortality of kids by birth weight in 2019 in one Angora goat flock.

Birth weight (kg)	Kids born	Kids weaned	%Mortality
<1.5	3	1	66.7
1.5-2.0	8	1	87.5
2.0-2.5	9	3	66.7
2.5-3.0	10	8	20.0
>3.0	6	6	0.0

6.4 Discussion

Identifying the major areas of reproductive loss is key to improving reproductive outcomes in Angora goats. Reports on the reproductive efficiency of Angora goats are scarce. The overall reproductive efficiency of this flock was 50%, far lower than other reports for Angoras internationally (McGregor & English, 2010; Snyman, 2002, 2010b). For Angora goats, Snyman (2010b) reported weaning percentages of 54.4-105.3% across different flocks over several years similar to McGregor and English (2010) (90-120%) while, Snyman (2002) found weaning rates of 70-78.8%.

The mean pregnancy rate for all years of this dataset was slightly lower than other reports in a recent review (Robertson et al., 2020) even when maiden does were excluded. In several South African surveys, between 14-18% of Angora does fail to conceive by pregnancy scanning at 42 days (Snyman, 2010b; van der Westhuysen, 1979). Pregnancy rates in goats can exceed 93% but be as low as 60% (Robertson et al., 2020). It is recognised that first parity does and sheep have lower conception rates, that improve to parity 5 and then decline thereafter (Gonzalez-Garcia & Hazard, 2016; Robertson et al., 2020). This dataset demonstrated a similar pattern.

The poor pregnancy rate in maiden does found in this dataset could be attributed to a delay in the onset of puberty. In a report by Ritar et al. (1994) in Australia, 58.3% of Angora does were naturally ovulating at 6 months of age (12.4 kg BW) compared to 94.1% of Cashmere goats (15.4 kg BW) at the same age. Ovulation rate was also higher in Cashmere does (2.44 V 1.57 ovulations per doe). Natural ovulation was highest in Angora does at 15 months old at 80% and lowest at 19 months at 50%. Body weight was 16.2 kg and 22.3 kg respectively (Ritar et al., 1994). It is likely the decline in natural ovulation rate seen between 15 months and 19 months of age is a result of the seasonal oestrus seen in goats. Given the maiden does in this dataset were first joined at 18

months old, 25.0 kg BW and BCS 3, delayed onset of puberty is an unlikely cause of failure to conceive.

Body weight before mating and at scanning has a strongly positive correlation with reproductive outcome and contributes to the poor conception and weaning rates seen in maiden does (Snyman, 2010b, 2020). It is recommended that maiden does obtain > 60% of mature BW before breeding which is about 25 kg for an Angora doe (Matthews, 2014). Only does > 25 kg were selected for breeding. However, pregnancy rate for maiden does across all years was very low (< 40%). Based on this data, 25 kg BW is insufficient for obtaining good reproductive rates in this cohort of maiden does. This is corroborated by the low ovulation rates seen in Ritar et al. (1994) for Angora does < 25 kg BW. Similarly, Snyman (2010b) in South Africa found that multiparous Angora does less than 32 kg had poor reproductive efficiency. It seems likely that the recommendations on minimum BW of maiden Angora does prior to breeding is too low and does should be over 32 kg before breeding (Ritar et al., 1994; Snyman, 2010b). This is unlikely to be achieved by 18 months of age but early cyclicity and fertility should be considered in the selection of replacement does if improvements to reproductive efficiency are to be made. Does that successfully breed at 24 months of age should be retained in this flock while does that do not successfully breed until after 36 months of age may be considered for culling on a reproductive basis.

Angora goats do not appear to have the fecundity of other breeds in a review by Robertson et al. (2020). Kids born per pregnancy in this dataset was ~0.9 while reports of 1.3-1.4 for Angora goats are found elsewhere (Robertson et al., 2020). This is low compared to other breeds including Kalahari Red (1.6), Boer (2.0) and Australian Rangeland (2.17) goats (Robertson et al., 2020). Surprisingly, twins had higher survival rates compared to singles and females higher than males in this dataset. This is in contrast to Snyman (2010a) who reported mortality was lowest in single born (10%), then twin (13%) and triplet (22%) kids. Birth weight and survivability have a strong positive correlation

(Kenyon & Blair, 2014; Robertson et al., 2020; Snyman, 2010a). Given the low numbers of twins and no triplets in the present dataset, a cohort bias likely accounts for the apparent greater survival of twins.

Foetal loss is a hidden source of reproductive wastage if pregnancy scanning is not performed to identify it. Fewer than 10% of goat producers pregnancy scan their flocks and therefore prenatal inefficiency has not been determined (Greenwood & Thompson, 2007). It appears that foetal loss is higher in goats than sheep (Robertson et al., 2020). Several factors appear to influence foetal loss. Firstly, nutrition during pregnancy plays a significant role. In a research trial by McGregor (2016a) in Australia, does fed to mimic pasture allowances resulting in 2 kg weight loss in mid pregnancy had foetal loss of 17% between scanning and kidding while those better fed only had 2%. Earlier work by Ritar et al. (1994) found does with BCS 3 or more had only 7% foetal loss while BCS 2 had 20% loss. South African reports across different management systems found does supplementary fed to include the pre-joining period did not have improved conception, but did have lower foetal loss than those not supplemented (Snyman, 2010b). It is unclear why this occurred given nutrition in early gestation and plasma progesterone concentrations are inversely related (Williams & A.I., 1982) in sheep and possibly goats. A decline in pasture quality typically results in periods of energy restriction during joining and pregnancy, therefore the findings of this dataset are consistent with the higher foetal losses seen by McGregor (2016a), Ritar et al. (1994), Snyman (2010b) and Scheurmann (1983).

Parity also has a role in foetal loss. Does over 7 years old performed better than all other cohorts. in this study. Further, Snyman (2010b) found does 11-12 years old had high pregnancy scanning percentages but lower kidding rates indicating substantial foetal loss between scanning and kidding compared to does 4-9 years old. This trend was present regardless of management system (Snyman, 2010b). Foetal losses were also highest in does > 10 years old in this dataset. It is difficult to ascertain why certain age cohorts of does have greater

foetal loss if the reason for the foetal loss is not determined. Other factors that can affect pregnancy rate in all goats but particularly older goats include season, pre-joining body weight and nutrition. Interestingly, Greyling (2000) did not find a positive relationship between progesterone levels and multiple pregnancies in Boer goats. Therefore, it seems unlikely that parity in itself has an adverse effect on progesterone production as a source of foetal loss.

Other factors that can contribute to foetal loss included previous foetal loss, > 2 foetuses and pregnancy from the third or later oestrus (Robertson et al., 2020). At this time, insufficient data is available on this cohort to assess whether previous foetal loss or multiple foetuses increases the risk of loss in subsequent pregnancies. Without being able to determine how many does return to service after the first or second oestrus, it is difficult to determine if pregnancy from the third cycle increases the risk of foetal loss. Strategic use of ram harnesses or similar marking devices would be useful to this end.

Losses in the postnatal period to weaning are the most noteworthy source of kid mortality in this study and others (Snyman, 2002, 2010a, 2010b; van der Westhuysen, 1979). Postnatal loss of 16-48% is reported in the present study, markedly higher than those reported elsewhere. Preweaning mortality is surprisingly similar between research pen trials and field surveys. In several Australian research flocks in which does were penned for 13 weeks post kidding, reports of preweaning mortality between 6.4-21% and up to 25% have been found in Angora and Cashmere goats (McGregor, 2016a; Robertson et al., 2020). Similar results were seen in South African Angoras on research stations (Snyman, 2002). For field surveys, postnatal losses of 7-19.4% have been reported (Snyman, 2010a, 2010b; van der Westhuysen, 1979).

Unsurprisingly, starvation-mismothering-exposure complex was the most common cause of death in the present study. Although starvation, mismothering and exposure are interconnected in causing kid mortalities, exposure is the catalyst in this particular flock. Mean minimum temperatures at Humula during

kidding are 3.2-7 °C with 27% of the annual rainfall occurring during September-November (Sahukar et al., 2003). Primary hypothermia in goats can occur at temperatures as high as 23 °C in windy, wet conditions (Robertson et al., 2020). Cold, wet conditions result in kids that fail to suck and are subsequently abandoned. Although predation appeared to be a major contributor to kid loss, its primary role is likely overexaggerated. More likely, weak semi-comatose kids are predated shortly before or soon after death with insufficient remains to determine the primary cause of mortality. This is in contrast to Snyman (2010a) who identified predation as the primary cause of kid death on veld in South Africa. Geography and farm management practices would explain this difference and highlight the importance of targeted study in the causes of kid mortality across multiple flocks.

Copper deficiency was strongly suspected to play a role in the mortality of kids in 2019 and 2020. This disease can present as a congenital form in kids and a delayed form in both kids and adults (Matthews, 2014). Clinical signs of the congenital form are predominately neurological including muscle tremors, head shaking and progressive paralysis but can cause death without precipitating signs (Matthews, 2014). Similar signs are seen in the delayed form, but also include anaemia, diarrhoea, discoloured and poor-quality fleece and failure to thrive. Gross necropsy changes are not usually present (Matthews, 2014). Although the Humula area is not known for copper deficient soils (Grains Research and Development Corporation, 2016), resolution of clinical signs in response to copper supplementation supports the likelihood of this diagnosis.

Reduction in preweaning mortality from the primary cause, starvation-mismothering-exposure complex, may be achieved by improving kid birth weight in this flock. In this dataset, kids over 2.5 kg were more likely to survive than kids less than 2.5 kg. The relationship between kid birth weight and survival is curvilinear (McGregor, 2016a; Robertson et al., 2020; Snyman, 2010a). Reports by Scheurmann (1983) found that kids weighing more than 2.2 kg could be expected to survive provided the mother-kid bond was established.

It is likely this is the critical weight at which kids have sufficient reserves to cope with short periods of inappetence after birth and thermal stress. It could also be the critical weight which induces sufficient hormonal and mechanical stimulus to the vagina/cervix to induce mothering behaviour and induce lactation in the doe (Snyman, 2010a). This implies that improving kid birth weight would have a direct effect on improving kid mortality across most flocks.

Different oestrus synchronisation protocols were used each year in the studied flock. In a paper by Ritar et al. (1994), Angora goats were treated with 200 or 400 IU PMSG after treatment with a progestogen-impregnated control internal drug release device for 16-18 days in the natural breeding season. Ovulation rates were lower in Angora compared to Cashmere goats similarly treated. For Angoras, 38% remained anovulatory after treatment while only 10% of Cashmere goats were anovulatory. The sample size of this dataset is insufficient to comment on the effects of different oestrus synchronisation protocols on reproductive outcomes in this flock of Angora goats.

6.5 Conclusion

This study provides a detailed examination of the reproductive performance of an Australian commercial Angora goat flock. The major area of reproductive inefficiency for the studied flock was preweaning mortality within the first 24 hours after birth. Starvation-mismothering-exposure was identified as the primary cause of death between birth and weaning. Copper deficiency played a role in some years but could be resolved with supplementation. Foetal loss is a second area of concern but without identifying the cause of loss, it is difficult to manage. Poor reproductive performance of maiden does was also identified as a source of reproductive inefficiency. In this mob, insufficient doe body weight and kid birth weight are the primary drivers of reproductive inefficiency. Management of maiden does prior to their first joining and of pregnant does

during lactation to improve both dam and kid body weights is likely to markedly improve reproductive efficiency in this Angora goat flock.

Chapter 7 Theoretical gross margins for different flock structures when feeding pregnant does to produce progeny of high and low S:P ratio.

7.1 Introduction

Feeding pregnant Angora does to receive adequate nutrition during gestation and lactation has a long-lasting effect on the future production of the offspring into adult life (Bawden et al., 2010; Greenwood et al., 2010; McGregor, 2020; McGregor & Howse, 2018). Reports produced by McGregor and Howse (2018) have demonstrated that feeding during gestation and lactation can increase S:P ratio and improve the value of the kid fleece. However, supplementary feeding is often the most significant cost incurred by producers (McGregor, 2010c; McGregor & English, 2010). It is unclear if the cost of additional feeding is outweighed by gains in fleece value. Gross margin describes the profit made from the net sale of goods minus the costs incurred and is used to benchmark the profitability of an enterprise (Chaffey, 2006). The most recent reports on benchmarking of Angora enterprises is from 2010 (Chaffey, 2006; McGregor & English, 2010). While no recent published gross margins for an Angora enterprise were found, gross margins for merino sheep enterprises are readily available. This study aims to construct gross margins for Angora enterprises to determine the financial benefit of feeding pregnant Angora does for improved S:P ratio progeny.

7.2 Materials and Methods

7.2.1 Gross margin scenarios

For the purpose of this study, six scenarios were constructed in which does were differentially fed during pregnancy and lactation. Gross margins were calculated on a per farm, per doe, per total flock DSE and per ha basis. In all scenarios, all doe kids were kept for replacement stock. Cull doe hoggets (12-

18 months old) and cull for age (CFA) does and bucks were sold at 5 years old. In scenario one (HnW: High S:P ratio, no Wethers) does were fed to produce progeny of high S:P ratio and wether kids were sold after their first shearing. In scenario two (LnW: Low S:P ratio, no Wethers) does were fed to produce progeny of low S:P ratio and wether kids were sold after their first shearing. Stocking rate in scenarios HnW and LnW was 8.85 total flock DSE/ha. In scenario three (HWH: High S:P ratio, Wethers, High stocking rate) and four (LWH: Low S:P ratio, Wethers, High stocking rate) does were fed to produce progeny of high and low S:P ratio respectively and wether hoggets were sold after their third shearing. Stocking rate in scenarios HWH and LWH was 10.55 total flock DSE/ha. In scenario five (HWL: High S:P ratio, Wethers, Low stocking rate) and six (LWL: Low S:P ratio, Wethers, Low stocking rate) does were fed to produce progeny of high and low S:P ratio respectively and wether hoggets were sold after their third shearing. The proportion of does in the flock was reduced to maintain the same stock rate as scenarios HnW and LnW (8.85 total flock DSE/ha). The flock parameters for each scenario are outlined in Table 7.2.2.1.

7.2.2 Flock parameters

In order to determine the financial outcome of feeding does to produce progeny of high or low S:P ratio, gross margins were constructed based on the published gross margins for a self-replacing, 20 µm Merino flock with 1000 breeding ewes (Department of Primary Industries, 2019). This flock comprised of 1000 breeding does run on 232 ha with a mature doe body weight of 45 kg. Dry sheep equivalent was calculated for each class of Angora in order to calculate stocking rates (Appendix E) (US National Research Council, 2006). The flock parameters and DSE for each class of Angora goat are outlined in Table 7.2.2.1 and 7.2.2.2 respectively.

Table 7.2.2.1: Flock parameters for Angora goats when does are fed for high and low S:P ratio without (scenarios HnW and LnW) and with wether hoggets at high (scenarios HWH and LWH) and low (scenarios HWL and LWL) stocking rates.

	Scenarios HnW and LnW	Scenarios HWH and LWH	Scenarios HWL and LWL
Breeding doe flock size (head)	1000	1000	583
Flock mortality (%)	4	4	4
Productive life (years)	5	5	5
Total mob stocking rate (DSE/ha)	8.85	10.55	8.85
Buck to doe ratio (%)	2	2	2
Marking (%)	89	89	89
Weaning (%)	86	86	86
Weaning age (months)	4	4	4
Age wethers when sold (months)	6	18	18

Table 7.2.2.2 Dry sheep equivalent (DSE) ratings of different Angora goat classes used for the gross margin scenarios

	Doe	Doe Hogget	Doe kid	Wether kid	Wether hogget	Buck
DSE rating (/head)	1.20	0.80	0.67	0.75	1.0	1.80

7.2.3 Income

Fleece production was based on published values for does and their progeny fed for high and low S:P ratio (McGregor, 2020; McGregor & Howse, 2018). The mohair values of bucks and hoggets were calculated based on the allometric relationship between MFD and body weight (McGregor et al., 2012) and the expected difference in skin surface area between does and wethers (McGregor, 2020). Given stocking rate increased in scenarios HWH and LWH, changes in fleece parameters and body weight were calculated. Using stocking rate data of McGregor (2010a) and (McGregor, 2010b), the increase in stocking rate would

be expected to reduce fibre diameter by 2 μm in adults and 1 μm in hoggets, and reduce fleece weight by 0.1 kg per shearing. Fleece parameters of the different classes of Angora goats in each scenario is demonstrated in Table 7.2.3. These were used to calculate the income from mohair based on \$40 /kg for 25 μm mohair and the expected depreciation in value as fibre diameter increased (McGregor, 2004; McGregor & English, 2010). Relative values were calculated elsewhere from mohair auctions between 2004-2007 (McGregor, 2004). More recent relative value data is not available and would not be representative of the long-term trends in mohair value since mohair is presently at record highs (Clancy, 2021b).

Similarly, body weight losses of 3.6 kg, 1.8 kg and 0.9 kg were expected for adults, hoggets and kids respectively in scenarios HWH and LWH. Carcass values were based on 2019 eastern Australia over-the-hook returns recently published by Meat and Livestock Australia (2020) (44% carcass yield, 750 c/kg) (McGregor, 2010c). Lower body weight of does would be expected to incur lower kidding performance and lower growth rate of kids. This information is not available and therefore is a limitation on the study.

7.2.4 Variable costs

Variable costs were calculated based on the values for a breeding ewe flock (Department of Primary Industries, 2019) with adjustments made specific to an Angora enterprise (Table 7.2.4). Overhead fixed costs were not included in the gross margins. The replacement costs for bucks are based on a commercial enterprise purchasing from a stud (Scattergood, 2015). Costs of shearing and crutching reflect the twice-yearly shearing that is required for Angoras. Similarly, goat health practices are indicative of the differences between sheep and goats and reflect present retail costs to producers (Department of Primary Industries, 2019). The costs for selling mohair and livestock are the same as those for sheep (Department of Primary Industries, 2019).

Table 7.2.3 Mean greasy fleece weight (GFW) (per 6-monthly shearing), fibre diameter (MFD) and body weight (BW) parameters of different classes of Angora goats when does are fed for high and low S:P ratio without (scenarios HnW and LnW) and with wether hoggets at high (scenarios HWH and LWH) and low (scenarios HWL and LWL) stocking rates. Abbreviations: GFW, greasy fleece weight; MFD, mean fibre diameter; BW, body weight.

		Doe	Doe hogget	Doe kid	Wether kid	Wether hogget	Buck
Scenario HnW	GFW (kg)	1.54	1.2	1.11	1.11	~	3.0
	MFD (μm)	39.7	25	27.3	27.3		34
	BW (kg)	45	21	16	16		55
Scenario LnW	GFW (kg)	1.38	1.2	1.01	1.01	~	3.0
	MFD (μm)	36.3	24	28.9	28.9		34
	BW (kg)	36	18	14	14		55
Scenario HWH	GFW (kg)	1.54	1.1	1.11	1.11	1.2	2.9
	MFD (μm)	39.7	23	27.3	27.3	23	32
	BW (kg)	45	19.2	16	16	23.8	51.4
Scenario LWH	GFW (kg)	1.38	1.1	1.01	1.01	1.2	2.9
	MFD (μm)	36.3	22	28.9	28.9	22	32
	BW (kg)	36	16.2	14	14	20.8	51.4
Scenario HWL	GFW (kg)	1.54	1.2	1.11	1.11	1.3	3.0
	MFD (μm)	39.7	25	27.3	27.3	25	34
	BW (kg)	45	21	16	16	25.6	55
Scenario LWL	GFW (kg)	1.38	1.2	1.01	1.01	1.3	3.0
	MFD (μm)	36.3	24	28.9	28.9	24	34
	BW (kg)	36	18	14	14	22.6	55

Table 7.2.4 Variable costs of Angora goats when does are fed for high and low S:P ratio without (scenarios HnW and LnW) and with wether hoggets at high (scenarios HWH and LWH) and low (scenarios HWL and LWL) stocking rates.

Replacement stock	Bucks	\$300.00 /head
	Cartage	\$51.00 /head
Mohair harvesting and selling	Shearing	\$7.42 /head
	Crutching	\$2.74 /head (bucks) \$1.56 /head (all other classes)
	Mohair tax	1.5%
	Commission	\$40.50 /bale
	Mohair cartage/packing	\$24.00 /bale
Goat health	Drenching	\$0.80 /head/dose (adults) \$0.29 /head/dose (kids)
	Lice control	\$1.47 /head/dose
	Vaccination	\$0.36 /head/dose
	Marking	\$0.23 /head (doe) \$0.46 /head (wether)
	Pregnancy scanning	\$1.00 /head
Livestock selling	Cartage	\$2.10 /head
	Commission	4.5%
	Levies	\$2.60 /head
Pasture maintenance	Scenarios HnW, LnW, HWL and LWL	\$38.00 /ha
	Scenarios HWH and LWH	\$44.00 /ha

7.2.5 Variable feeding costs

Feed requirements were calculated from McGregor (2017) which formed the basis of the fleece values published in McGregor and Howse (2018) and McGregor (2020). Does were fed from day 47 post conception until week 13 of lactation by (McGregor, 2017) and therefore does in the scenarios were supplementary feed during the same time frame. In scenarios LnW and LWL, does were fed for low S:P ratio progeny which was considered pasture only with no additional fodder. In scenario HnW and HWL, does were fed for high S:P ratio progeny. The additional energy required over the baseline flock diet (scenarios LnW and LWL) was calculated to feed the entire doe flock (1019.5

MJ/head). Using values from New South Wales Department of Primary Industries 2022) and CEIC Data (2021) for barley (\$274/t), the total additional feed costs on an as-fed basis was calculated.

In scenario LWH, does were fed to gain 3.6 kg prior to mating (133.92 MJ/head) (Luo et al., 2004) in order to produce similar low S:P ratio progeny. In scenario HWH, does were fed to gain 3.6 kg prior to mating and produce high S:P ratio progeny (1153.42 MJ/head). Pasture maintenance costs were adjusted to account for the increase in stocking rate in scenarios HWH and LWH (Department of Primary Industries, 2019).

7.3 Results

The full details of the gross margin for scenarios HnW, LnW, HWH, LWH, HWL and LWL are found in Appendices F – K respectively. Gross margins are illustrated in Table 7.3.1. Feeding for high S:P ratio improved the gross margin compared to feeding for lower S:P ratio. Maintaining wethers for three shearings at higher stocking rates improved gross margin but not at lower stocking rates regardless of feeding regimen. The difference in gross margin between feeding for high or low S:P ratio was similar when the doe flock remained the same size (scenarios HnW Vs LnW and scenarios HWH Vs LWH) at approximately \$6100. Likewise, the difference in gross margin between feeding for high or low S:P ratio was similar on a per doe (~\$6.10), per head (~\$2.51), per total flock DSE (~\$2.70) and per ha (~\$26.38) basis. When the doe flock size was reduced to maintain a lower stocking rate (scenarios HWL Vs LWL), the difference in gross margin between feeding for high and low S:P ratio decreased to \$2513.61. The difference in gross margin between feeding for high or low S:P ratio was similarly decreased per doe (\$4.31), and per ha (\$10.83). Gross margin per total flock DSE increased (\$6.39). When stocking rates were the same (scenarios HnW Vs HWL and scenarios LnW Vs LWL), feeding for high S:P ratio resulted in a larger difference in gross margin of \$19 865.40. This was slightly lower when feeding for low S:P ratio (\$17 404.59).

Table 7.3.1 Gross margins of an Angora enterprise when does are fed for high and low S:P ratio without (scenarios HnW and LnW) and with wether hoggets at high (scenarios HWH and LWH) and low (scenarios HWL and LWL) stocking rates.

	Gross Margin \$/farm	\$/Doe	\$/Head	\$/Total flock DSE	\$/ha
Scenario HnW	88 241.25	88.24	39.73	42.98	380.35
Scenario LnW	83 266.83	83.27	37.49	40.55	358.91
Scenario HWH	113 662.41	113.66	43.48	46.44	489.92
Scenario LWH	106 394.73	106.39	40.70	43.47	458.60
Scenario HWL	68 375.85	117.28	45.10	33.30	294.72
Scenario LWL	65 862.24	112.97	43.44	26.91	283.89

Doe mohair income was a major source of poor financial returns when feeding for high S:P ratio compared to low S:P ratio regardless of flock structure (Table 7.3.2). Does fed for high S:P ratio produced coarser, higher volume fleece compared to does fed for low S:P ratio but due to discounts for fibre diameter, the mohair was approximately half as valuable (\$2.29 Vs \$4.37 /kg respectively). Therefore, the income for doe fleece was higher for does fed for low S:P ratio. However, progeny from high fed does produced finer, more valuable fleece (\$35.42 Vs \$25.59 /kg) than their low fed counterparts and this compensated for the loss incurred by the does. Hoggets were the most productive class per head producing very fine, high-volume fleece.

Income from carcass sales was highest in scenario HWH when total carcass volume was also highest (Table 7.3.3). Carcass income per head was highest in scenario HWL, followed by scenarios HWH, LWL, HnW, LWH and LnW.

Table 7.3.2 Mohair income (\$/head) from different classes of Angora goats when does are fed for high and low S:P ratio without (scenarios HnW and LnW) and with wether hoggets at high (scenarios HWH and LWH) and low (scenarios HWL and LWL) stocking rates.

	Doe	Doe Hogget	Doe kid	Wether kid	Wether hogget	Buck
Scenario HnW	9.10	98.00	79.63	79.63	~	45.50
Scenario LnW	14.24	95.60	52.69	52.69	~	45.50
Scenario HWH	9.10	90.00	79.63	79.63	98.00	74.09
Scenario LWH	14.24	87.60	52.69	52.69	98.00	74.09
Scenario HWL	9.10	98.00	79.63	79.63	106.00	45.50
Scenario LWL	14.24	95.60	52.69	52.69	106.00	45.50

Table 7.3.3 Carcass volume, total income and income per head from Angora goats when does are fed for high and low S:P ratio without (scenarios HnW and LnW) and with wether hoggets at high (scenarios HWH and LWH) and low (scenarios HWL and LWL) stocking rates.

	Number sold	Carcass volume (kg)	Total income	Income /head
Scenario HnW	798	8356.48	62 673.60	78.54
Scenario LnW	798	7030.32	52 727.40	66.07
Scenario HWH	772	9405.52	70 541.46	91.37
Scenario LWH	772	7924.48	59 433.66	76.99
Scenario HWL	437	5580.78	41 855.88	95.78
Scenario LWL	437	4745.22	35 589.18	81.44

The major source of differences in variable cost was in the cost of feeding including pasture maintenance (Table 7.3.4). Pasture maintenance costs were higher when stocking rate was high (scenarios HWH and LWH). Feed costs were highest to lowest in scenario HWH, HnW, HWL, LWH and LnW/LWL respectively. All remaining variable costs were very similar between the different scenarios.

Table 7.3.4 Pasture and supplementary feed costs (\$/farm) of an Angora enterprise when does are fed for high and low S:P ratio without (scenarios HnW and LnW) and with wether hoggets at high (scenarios HWH and LWH) and low (scenarios HWL and LWL) stocking rates.

	Energy (MJ/head)	Feed volume (t)	Feed cost (\$)	Pasture cost (\$)	Total (\$)
Scenario HnW	1019.5	83.65	22 920.00	8816.00	31 736.00
Scenario LnW	0	0	0	8816.00	8816.00
Scenario HWH	1153.42	94.64	25 931.00	10 301.00	36 232.00
Scenario LWH	133.92	10.99	3011.00	10 301.00	13 312.00
Scenario HWL	1019.5	48.80	13 370.00	8816.00	22 186.00
Scenario LWL	0	0	0	8816.00	8816.00

7.4 Discussion

Differences in gross margin when feeding for high or low S:P ratio were not large. Feeding for high S:P ratio has the advantage of producing offspring with reduced MFD and increased fleece and carcass weights (McGregor, 2017, 2020; McGregor & Howse, 2018). While genetics will have a role in reducing MFD and increasing fleece weight (Allain & Roguet, 2003; Gifford et al., 1991; Taddeo, Allain, Mueller, Rochambeau, & Manfredi, 1998b; Visser et al., 2009), multiple reports have found feeding during gestation to be as important (Bell,

2006; Greenwood et al., 2010; McGregor, 2016a, 2020; McGregor & Howse, 2018; Schinckel & Short, 1961).

Focusing on reducing MFD of progeny alone is unlikely to have a considerable effect on income. Despite MFD accounting for 59% of the variability in mohair value, there is little monetary advantage to producing mohair < 25 μm (McGregor & Butler, 2004). Therefore, the advantage of feeding for high S:P ratio applies until MFD declines to 25 μm and then relies on increasing fleece weight of the progeny. Changes to the marketability of the finest mohair by commercial agents or selling to niche (hand spinning) consumers is necessary for producers to achieve the full benefits of feeding for high S:P ratio progeny (Lupton et al., 2008).

Progeny from better fed does can be expected to have higher birth weights, weaning weights and mature live weights (Greenwood et al., 2010; McGregor, 2016a, 2020; McGregor & Howse, 2018). Improved kid weights can reduce kid mortality (McGregor & Butler, 2008) and susceptibility to disease or stress (McGregor, 2010a). For hogget replacement does, improved body weight is advantageous for reproductive performance during their first joining. Improved body weight in mature does can reduce foetal losses. This is beneficial in improving weaning rates and thereby the income from kid fleece. Even for cull goats, improved liveweight can produce greater returns on carcass volume (McGregor, 2010c).

Retaining wethers improved gross margin at high stocking rates. Increased stocking rate results in a reduction in live weight if no additional feed is provided (McGregor, 2010a). Live weight accounts for 4 times more variability in MFD than age and can be expected to decrease as stocking rate increases (McGregor, 2018a). Increasing stocking rate increased gross margin per DSE by reducing MFD with a concurrent reduction in fleece weight per head in these scenarios and McGregor (2018a). However, reports by McGregor and English (2010) and McGregor (2010c) found that mohair gross margin was not related

to either stocking rate or weaning performance but instead to mohair income and supplementary feeding expenses.

Several reasons could account for this difference. Firstly, the main driver of mohair profit is doe MFD (McGregor, 2010c). In these scenarios, better fed does produced mohair of higher MFD. This indicates that not only were the does producing less profitable mohair but were incurring higher feed costs. It is likely that the reduction in mohair MFD incurred by the remaining goat classes compensated for the reduced value of the doe mohair. Secondly, the flock parameters for mortality% while reflecting the situation in sheep enterprises, may not be representative of Angora flocks. It is likely an underestimate of the situation for Angora enterprises, given the findings of McGregor (2018a) and McGregor and Butler (2008). Their reports while under research conditions, indicate that Angora goats have an increased mortality compared to sheep at the same stocking rate. Mortality rates for the on-farm scenario are unknown. Higher mortality rates would inevitably lower mohair income and reduce income from meat sales. Finally, labour costs were included in McGregor and English (2010) and McGregor (2010c). Labour costs were not considered in the hypothetical scenarios because most Angora enterprises are small-scale, family run businesses that farmers operate themselves. If this were to be taken into account, the labour costs would be considerably higher in the high-fed scenarios because of the time to put out supplementary feed. This would explain why the gross margin per DSE and per ha are much greater in these hypothetical scenarios than the on-farm reports (McGregor & English, 2010).

When the size of the doe flock was reduced in order to retain wethers at the same stocking rate, overall gross margin did not improve. This is surprising given wethers produce fine, high-volume fleece at minimum cost while does produce poor quality fleece at a higher cost. In these scenarios, the flock is self-replacing and therefore the proportion of wether hoggets is dependent on the number of does (Department of Primary Industries, 2019). If the doe flock is reduced in size, the wether flock would decline in a similar proportion. This would have ramifications on the mohair income. However, income from

livestock sales was increased on a per head basis. This is likely due to the increase in wether carcass weight at lower stocking rates compared to the remaining scenarios.

While the primary driver of the doe flock is reproduction, improving the fleece quality of does will have a significant effect on mohair income. Significant price discounts occur for high diameter fibre, with premiums paid for 24-25 μm and discounts of up to 90% for mohair $> 36 \mu\text{m}$ (McGregor, 2010c; McGregor & Butler, 2004; McGregor et al., 2012). When feeding for high S:P ratio, doe MFD and fleece weight increased (McGregor, 2017, 2020; McGregor & Howse, 2018). Gross margin reports by McGregor and English (2010) found that income from mohair sales declined as the proportion of does increased (\$22.74 per kg at 36% does to \$17.68 per kg at 43% does in the flock) similar to these scenarios. Additional penalties would occur for the poor character, poor style and increased stain expected in doe fleece. These were not considered in these scenarios (McGregor, 2010c; McGregor & English, 2010). However, these penalties should be considered in the management practices of the doe flock to minimise the financial loss incurred.

Reproduction presents the greatest opportunity to improve the mohair income by producing kids of superior quality that have lower MFD and increased fleece weights. Does fed for low S:P ratio progeny also had lower body weights and would be expected to have lower kidding performance. Reproductive performance on commercial Angora properties is poorly described and how body weight would influence both kidding and weaning rates is a limitation of this study. While recognising that Angora goats have an average weaning percentages of only 80% (Chaffey, 2006; McGregor, 2010c; Snyman, 2002, 2010b), selecting for reproductive capacity alone will not improve gross margin (McGregor & English, 2010). Breeding programs for superior mohair quality are hampered by a failure to implement industry wide standards on objective, rather than subjective quality traits when selecting replacement breeding stock (McGregor & English, 2010). In France, this has been achieved with positive

results (Allain & Roguet, 2003). Given the multitude of environmental and nutritional factors that influence MFD, selecting breeding stock for MFD alone is unlikely to improve fleece quality. An appropriate objective selection criterion would be secondary follicle density (Adams & Cronje, 2003; Adelson et al., 2002; Scobie & Young, 2000). An increase in follicle density is correlated with a higher fleece value at each shearing and in the total value of a mohair clip (McGregor, 2020). At present, measuring secondary follicle density is expensive and time-consuming. Developing other selection indices that are easily measured in the field is paramount if this criterion is to be used. However, there was growing suspicion that in selecting for increased follicle density, poor mothering ability and increased lamb mortality had inadvertently been selected in superfine merino sheep because no consideration was given to other selection indices (Kuchel & Lindsay, 1999). This would have a substantial impact on gross margin by reducing weaning percentage and the proportion of lamb fleece in the wool clip. While it is unclear if a similar situation is developing in Angora goats, breeding animals should be selected for reproductive performance and the capacity to thrive with minimal intervention. In conjunction with selection for increased follicle density, substantial improvements to gross margins can be made.

Unsurprisingly, variable costs were driven by the cost of pasture maintenance and supplementary feed (Lupton et al., 2008; McGregor & English, 2010). Feeding for high S:P ratio incurred the highest feed costs particularly at high stocking rates. In reports by McGregor (2010c), increased feed costs reduced mohair gross margins. However, it was concluded that improper use of selective supplementary feeding likely resulted in significant financial waste. These hypothetical scenarios are providing additional feed to does for only the gestational period only. Extending the feeding period into lactation or providing supplementary feed to kids after weaning has the potential to improve gross margins by increasing kid weaning weights and subsequent growth to maturity. This is beneficial to both mohair, meat and reproductive outcomes. While these

feeding plans are beyond the scope of this study, it is apparent that proper use of selective feeding can improve gross margins.

7.5 Conclusion

Feeding does for high S:P ratio progeny improved gross margins. Retaining wethers until their third shearing improved gross margin regardless of feeding treatment. However, differences in gross margins when feeding for high or low S:P ratio were not large except when doe flock size was reduced. Reducing the size of the doe flock to maintain a similar stocking rate did not improve gross margins. The doe mohair clip was the major source of poor financial return, with does being fed for high S:P ratio offspring producing fleece that was half as valuable as fleece from does being fed for low S:P ratio. Hoggets were the most productive goat class, producing highly valuable fleece. Variable costs were driven by the cost of supplementary feed and pasture maintenance. The financial advantage of feeding does for high S:P ratio progeny is minimal unless the value of the doe mohair clip can be improved.

Chapter 8 General discussion

8.1 Discussion

Mean fibre diameter is the primary driver of mohair value and financial return for an Angora enterprise (McGregor, 2010c). Replacement breeding stock selection has heavily emphasised reducing MFD and to a lesser extent increasing fleece weight (Allain & Roguet, 2003; McGregor et al., 2012). Little consideration has been given to other production characteristics such as body weight, reproductive performance or survivability (Allain & Roguet, 2003; Gifford et al., 1991; Taddeo et al., 1998b; Visser et al., 2009). However, there is growing suspicion that in selecting for reduced MFD, poor survivability is inadvertently being selected, similar to the situation in ultrafine Merino sheep (Kuchel & Lindsay, 1999). Not only does poor survivability reduce the overall number of goats within a flock and reduces income but also increases the cost of maintaining less thrifty animals. Therefore, breeding selection criteria must balance reducing MFD while maintaining or increasing survivability. This can be done with the development of selection indices so multiple traits can be improved simultaneously.

A multitude of environmental and nutritional factors influence MFD at a given shearing (McGregor, 1998). Selection of breeding animals based on MFD at a set age will remove the least productive animals from the flock but not necessarily select those of improved fleece quality traits (Allain & Roguet, 2003; Greenwood et al., 2010). Genetic factors at conception and nutrition during gestation and lactation determine the optimal production in postnatal life through the development of the skin follicle population (Bawden et al., 2010; McGregor & Howse, 2018). While the study in Chapter 3 did not successfully differentially feed each treatment cohort during set periods of pregnancy and lactation and therefore failed to produce any discernible change in S:P ratio or follicle density in progeny, other reports have had more success. In the work of (McGregor, 2016a, 2017; McGregor & Howse, 2018), improved nutrition from

mid gestation and throughout lactation increased S:P ratio and fleece value in the progeny. Selecting breeding animals with increased secondary follicle densities and S:P ratio rather than MFD is an objective measure that represents improved fleece quality traits.

While selection of breeding animals based on secondary follicle density and S:P ratio will objectively improve MFD, selection on these characteristics alone can also inadvertently select for lower body weight and survivability (Adams & Cronje, 2003; Adelson et al., 2002; Kuchel & Lindsay, 1999; Scobie & Young, 2000). The study conducted in Chapter 5 found that low nutrition kids had similar follicle densities and MFD compared to high nutrition kids but were significantly smaller at 5 and 18 months old. Low nutrition kids also had lower fleece weights. If breeding stock were to be selected solely on secondary follicle density and S:P ratio, it would be expected that some small, poorly grown animals would be included. Selection for secondary follicle density is limited by the cost incurred to measure secondary follicle density. Development of cost-effective method of measuring secondary follicle density is paramount if secondary follicle density is to be used as part of breeding selection. At present, selection for the profit drivers of fleece value (fibre diameter and CFW), weaning rate and progeny growth rate will have a positive effect on profit.

While selection for improved secondary follicle density and S:P ratio will increase the quality of the kid fleece, the relationship between both secondary follicle density and S:P ratio and age are unclear. The study in Chapter 4 attempted to determine how follicle densities and S:P ratio changes as Angora goat's age. It was found that follicle densities and S:P ratio were negatively correlated with age but more variability could be attributed to body weight than to age. Mean fibre diameter was positively correlated with age but similarly, more variability can be attributed to body weight than age. However, repeat measures on the same goat as they age will substantiate this finding and overcome the confounding factors of the study including genetic variation and

nutrition. If body weight can be maintained through good nutrition, it seems likely that improvements in follicle density and S:P ratio can persist throughout the productive lifespan. This will improve the quality of the adult mohair clip and increase financial returns.

While emphasis has been placed on selection for MFD, there is a marked potential to improve financial returns through increased reproductive efficiency. Very little published information is available on the reproductive performance of commercial Angora goat flocks (Robertson et al., 2020; Snyman, 2010a, 2010b). While reports of weaning percentages of 54.4-120% (McGregor & English, 2010; Snyman, 2010a, 2010b) have been made, the reproductive efficiency of the flock studied in Chapter 6 was only 50% (50 kids weaned per 100 does bred). The major source of inefficiency was postnatal mortality to weaning. While predation has been reported as a major cause of postnatal mortality in South Africa (Snyman, 2010a), starvation-mismothering-exposure was identified as the primary cause of mortality in the study. Birth weight and survivability were positively correlated in the study of Chapter 6 and other reports (McGregor, 2016a; Robertson et al., 2020; Shelton & Groff, 1984; Snyman, 2010a) although this is in contrast to McGregor (2017), McGregor (2016a) and McGregor and Howse (2018). It can be expected that improving kid birth weight will reduce a kid's susceptibility to exposure, enable them to cope with short periods of starvation and induce mothering behaviour in the dam. The cost of feeding during gestation and lactation to improve kid birth weight and postnatal mortality would be outweighed by the increase returns from kid fleece and cull carcass weight. Additionally, if more kids survive until weaning, selection for replacement breeding stock can be more rigorous and greater steps to improve production traits can be made (Greenwood et al., 2010). This can directly improve financial returns for a given Angora flock.

Increasing financial returns by increasing mohair quality and income has been emphasised, but reducing costs in mohair production is also important (Lupton et al., 2008; McGregor & English, 2010). As demonstrated in Chapter 7,

variable costs were driven by the cost of supplementary feed. It has been demonstrated that selective supplementary feeding during gestation and lactation can improve performance of the progeny but result in substantial financial losses from increases in doe MFD (McGregor, 2004, 2010c; McGregor et al., 2012; McGregor & English, 2010). However, the scenarios constructed in Chapter 7 did not take into account additional effects of improved feeding on doe performance. Supplementary fed does can be expected to have increased body weight, kid birth weights and kidding performance (Ritar et al., 1994). Improved body weights will have additional consequences on the subsequent joining (Snyman, 2010b). This will have positive effects on reducing flock mortality and increasing kid marking %, kid weaning % and reproductive efficiency. Selective use of supplementary feed may have negative effects on the dam mohair quality but the gains from other production benchmarks would be substantial and provide significant improvements to financial returns.

8.2 Summary

The main driver of mohair price is MFD and the focus of Angora goat producers has been on selecting for finer MFD. However, in doing so poor survivability may have inadvertently been selected (Kuchel & Lindsay, 1999). While follicle density and S:P ratio of the progeny can be increased by nutrition during gestation and lactation, the mohair value of the dams will decline due to an increase in MFD on higher nutrition (McGregor, 2004, 2010c, 2016a, 2017; McGregor et al., 2012; McGregor & Howse, 2018). Greater emphasis should be placed on selecting animals, particularly replacement breeding does, that have relatively low MFD at high growth rate and body weights. On higher planes of nutrition, these does can be expected to produce progeny of higher follicle densities, S:P ratio and fleece value due to greater follicle initiation and maturation (McGregor, 2016a, 2017; McGregor & Howse, 2018). The effects of improved nutrition will have substantial effects on other production characteristics including body weight, kidding performance and flock mortality (Greenwood et al., 2010). Increases in kid birth weight and survivability can be

expected on higher planes of nutrition, thereby improving the reproductive efficiency of any given Angora goat flock (Ritar et al., 1994; Snyman, 2010b). There is a marked potential to improve financial returns by selective feeding of Angora goat does and developing objective selection criteria of replacement breeding stock.

Chapter 9 Conclusion

Supplementary feeding during gestation and lactation did not produce a significant difference in follicle densities or S:P ratio in the progeny because the feeding treatments were not significantly different between the groups. Other researchers that have successfully differentially fed during pregnancy and lactation have found differences in follicle densities and S:P ratio of the progeny. However, in a separate study, kids that received low nutrition in the postnatal period had similar follicle density and S:P ratio compared to kids receiving high nutrition although they were smaller. Low nutrition kids also had similar MFD compared to high nutrition kids but reduced fleece weight. Follicle densities and S:P ratio was negatively correlated with age, although more variability was explained by body weight than by age. Feeding for improved S:P ratio in the progeny did not substantially improve gross margins regardless of flock structure or stocking rate. Doe MFD was the primary source of lost income due to improved feeding during gestation and lactation causing dams to produce coarser mohair. While genetics plays a role in follicle population parameters, selection of replacement breeding stock that demonstrate a low MFD at high body weights will minimise the financial loss from doe fleece while enabling improvements to be made to follicle density and S:P ratio in the progeny. Postnatal kid mortality to weaning was a major source of reproductive inefficiency in the studied flock. The primary cause of kid mortality was starvation-mismothering-exposure complex. Improved feeding during gestation will not only enable follicle density and S:P ratio to increase but will also address the primary cause of reproductive inefficiency by improving kid birth weight and survivability in the postnatal period.

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Appendix A – Nutrition table (US National Research Council, 2006)

Class/Age/Other	BW (kg)	Daily Gain (g/day)	Mohair Fibre Growth (g/day)	Energy Requirements (ME Mcal/day)	Protein Requirements CP @ 40% UIP g/day
Growing Female kids	10	20	4	1.00	44
	20	20	4	1.45	62
Growing Male kids	10	20	4	1.10	44
	20	20	4	1.62	62
Maintenance Mature Female	30	0	10	1.82	84
Breeding Mature Female	40	0	10	2.39	109
Maintenance Mature Male	40	0	10	2.44	99
Breeding Mature Male	50	0	15	3.31	137
Early gestation (Single kid)	40	16	10	2.47	123
Early gestation (Twin kids)	40	26	10	2.61	134
Late gestation (Single kid)	40	63	10	3.02	157
Late gestation (Twin kids)	40	106	10	3.34	182
Early lactation (Single kid)	40	-22	10	2.83	145
Early lactation (Twin kids)	40	-44	10	3.20	165

Appendix B – Ambos all purpose pellets nutritional specifications (Riverina Stockfeeds, 2019)

9189 Oct20



ALL PURPOSE PELLETS

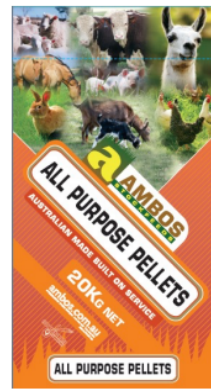
A convenient and economic multi-species pellet feed formulated for supplementary feeding to a wide range of farm animals such as Cattle, Sheep, Goats, Alpacas, Deer, Horses, Rabbits, Poultry and Pigs.

FEATURES: A unique pellet feed especially suited to farms with multi-species feeding requirements. It is particularly useful as a supplement feed for Alpacas.

INGREDIENTS: Cereal grains (Barley, Wheat) and cereal co-products, Almond co-products, Oilseed Protein meals, Lucerne meal, Limestone, Bentonite, Salt, Trace minerals and vitamins.

NUTRIENT SPECIFICATIONS: Dry Matter basis:	
Protein	14%
Fat	3%
Crude Fibre	9%
NDF	31%
Starch	30%
Energy (Ruminant ME)	11.5 MJ/kg
Calcium	2%
Phosphorus	0.5%

SPECIAL INCLUSIONS, MEDICATIONS: None
 This product is antibiotic free and does NOT contain ionophores.
 This product does NOT contain urea.
 This product does not contain restricted animal material.



HOW TO FEED: Animals should be fed according to the guidelines below.

<i>Species</i>	<i>Daily maintenance feeding rate</i>
Cattle, Sheep, Goats, Alpacas, Deer	1% of bodyweight plus forage
Horses	1% of bodyweight plus forage
Pet Rabbits	1% of bodyweight plus fresh forage, chaff etc
Poultry and Pigs	Free choice without restriction

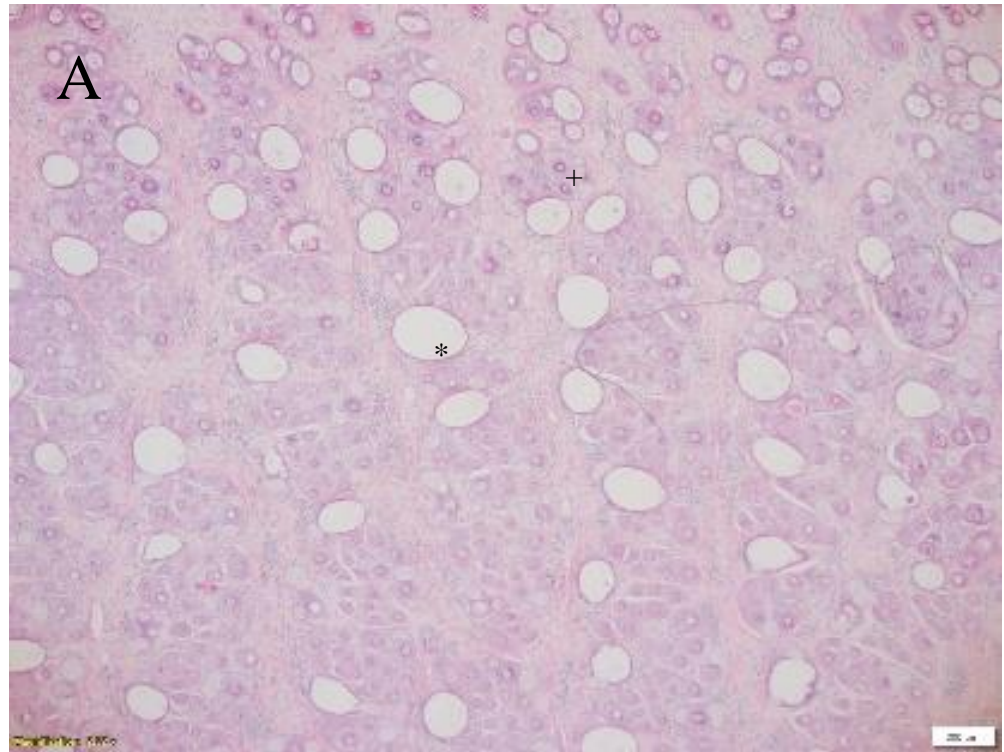
Controlled and gradual feeding of pellets is important to introduce animals to a change in their diet. Give special attention to introducing excessively hungry or drought-affected animals. Over the first 10 days, feed small controlled amounts of pellets, starting with 0.2% of bodyweight per day, and gradually increase the amount fed per day.
 For Ruminants (Sheep, Goats, Cattle, Deer, Alpacas etc) and Horses, always ensure they have access to an adequate volume of an effective fibre forage source such as hay, straw, mature pasture, etc.
 Ensure that clean fresh water is available at all times.

OTHER INFORMATION: Products are available in Bulk, Bulka Bags and 20kg bags

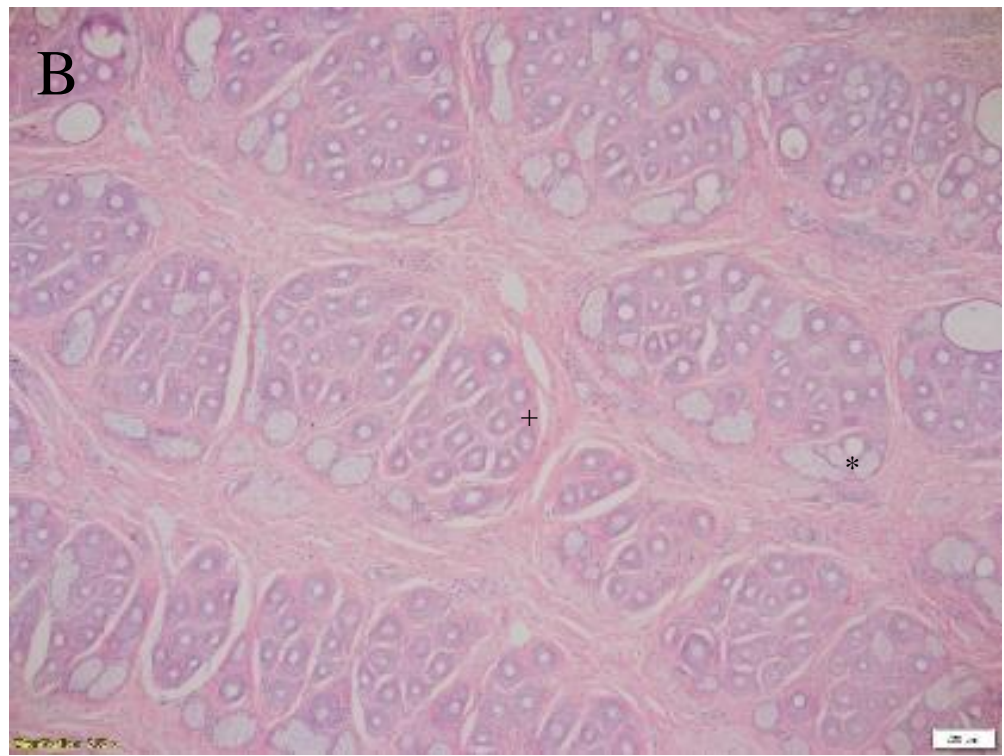
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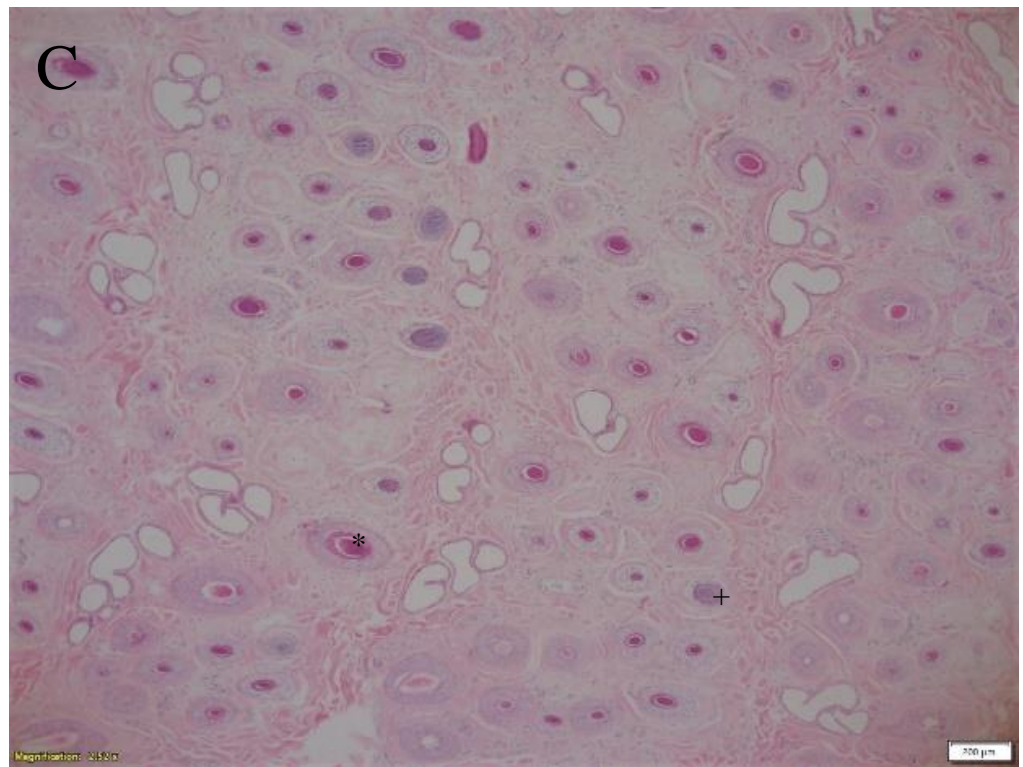
Appendix C – Full size images from Figure 4.3.5



0.5 years



5.5 years



16.5 years

Appendix D – Annual Australian Animal Sciences Conference publication, Cairns Qld, 5-7 July 2022.

Reproductive efficiency in Angora goats: A cohort study in southern New South Wales

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Poor reproductive efficiency is a well-recognised phenomenon of the Angora goat. However, reproductive performance in Australian Angora goats on commercial properties is inadequately described and the causal factors of reproductive inefficiency difficult to ascertain. We present a cohort study conducted in one flock of Australian Angora does in south eastern NSW aiming to identify the major sources of reproductive loss between joining and weaning.

This study was conducted over a four year period on a 20.4 ha property in Humula, NSW, 130km west of Canberra. The flock was established in 2015. Comprehensive reproductive performance records were collected between 2017 and 2021 by the owner. A total of 228 records were available. The flock grazed pasture throughout the year except in 2019. In 2019, a pen research trial was conducted in which pregnant does were fed differentially during different stages of pregnancy to determine the effects of feeding on the skin follicle density of the progeny. These results are presented elsewhere. Does weighing >25kg prior to joining were selected for breeding. Each year 40-60 does were mated with 2 bucks for a 9 week joining starting in early April. Each year a different oestrus synchronisation protocol was undertaken. Transabdominal ultrasonography for pregnancy diagnosis and fetal number occurred 8 weeks after removal of the bucks. Daily monitoring of the flock began two weeks before the first expected kidding date in early September. For each kid born, the dam was identified and birth type (single, twin) and sex of kid was recorded. Kids were marked at weaning and breeding outcome for each doe recorded. In 2021 only, dead kids (n=16) were necropsied to identify likely causes of death. Descriptive statistics were conducted using SPSS statistical analysis software.

The overall conception rate (pregnant does/does bred) was 72% or 80% excluding maiden does. Foetal loss from scanning to birth was 17.6-26.9%, although this is likely an overestimation if kids dying during or after birth were not found. Reproductive rates (kids weaned/doe bred) were lowest in maidens (12.1%) and does >15 years (0.0%). Highest rates were observed in does between 3-9 years old (50.9 Vs 42.3% >10 years). Kidding rates (kids born per doe bred) were 67-87%. The majority of births were single female kids (50/153) but females born as twins were more likely to be weaned (78.1%) than single females (72%), single males (52.4%) or twin males (62.1%). Losses between birth and weaning were up to 48% with an overall reproductive efficiency of 50% (50 kids weaned per 100 does bred). Starvation-mismothering-exposure complex was the primary cause of death between birth and weaning. Copper deficiency was suspected to play a role in postnatal mortality based on clinical signs and response to copper supplementation; limited blood sampling (n=2) substantiated this observation.

Table 1. Reproductive performance of adult does 2017-2021 and mean performance of adults and maidens in one Angora goat flock.

Year	Number of Does	Oestrus Sync	Preg/ doe bred	Foetus/ preg	Doe kidded/ preg	Kid born/ doe bred	Kid born/ preg	Kid wean/ born	Kid wean/ doe bred	Kid wean/ preg
2017	52	Nil ^a	~	~	~	0.830	~	0.860	0.711	~
2019	49	PG ^b	0.694	1.147	0.824	0.673	0.971	0.515	0.350	0.50
2020	49	CIDR + PG ^c	0.837	1.220	0.780	0.796	0.951	0.538	0.429	0.512
2021	45	CIDR + PG ^c	0.889	1.225	0.775	0.867	0.975	0.615	0.533	0.60
Adult mean	195		0.804	1.20	0.791	0.790	0.965	0.643	0.508	0.539
Maiden mean	33		0.386	1.111	0.867	0.242	0.867	0.50	0.121	0.622

^aNil: No reproductive hormones given.

^bPG: Given 250mcg cloprostenol IM (Ilium Estromil 1mL, Glendenning NSW), repeated 11 days later.

^cCIDR + PG: CIDR (Zoetis EAZI BREED CIDR, West Ryde NSW) inserted for 21 days. Given 250mcg cloprostenol IM at removal.

Conception rates were lower than expected (86-89% (Robertson *et al* 2020)). Fetal losses were higher than those reported elsewhere (10.1-20% (Snyman 2010)). Postnatal kid mortality was the major source of reproductive inefficiency similar to other reports (Robertson *et al* 2020). Based on a limited number of necropsies, starvation-mismothering-exposure and copper deficiency were the major causes of mortality although the area is not known for copper deficient soils. It is suspected that inadequate pre-joining liveweight is the cause of poor conception rates particularly for maidens. Although this study was conducted in only one flock, there is considerable potential to improve reproductive efficiency. Further research on the wider Angora industry is necessary to develop benchmarks for producers to utilise this potential.

References

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Appendix E – Dry sheep equivalent for different classes of Angora goats (US National Research Council, 2006)

	Doe ^a	Doe hogget ^b	Doe kid ^c	Wether kid ^c	Wether hogget ^d	Buck ^e
January	1.2	0.8	0.67	0.75	1.0	1.8
February	1.2	0.8	0.67	0.75	1.0	1.8
March	1.2	0.8	0.67	0.75	1.0	1.8
April	1.26	0.8	0.67	0.75	1.0	1.8
May	1.26	0.8	0.67	0.75	1.0	1.8
June	1.26	0.8	0.67	0.75	1.0	1.8
July	1.54	0.8	0.67	0.75	1.0	1.8
August	1.54	0.8	0.67	0.75	1.0	1.8
September	1.45	0.8	0	0	1.0	1.8
October	1.42	0.8	0	0	1.0	1.8
November	1.42	0.8	0	0	1.0	1.8
December	1.42	0.8	0	0	1.0	1.8
Total	16.17	9.6	5.36	6.0	12.0	21.6
DSE/head/year						

^a Calculated to maintain body weight and mohair fibre growth 4 g/day. (45 kg BW January – March). Calculated for single kid early gestation with 16 g/day daily BW gain and 5 g/day mohair fibre growth (April – June). Calculated for single kid late gestation with 63 g/day daily BW gain and 5 g/day mohair fibre growth (July – August). Calculated for single kid early lactation with 22 g/day daily BW loss and 5 g/day mohair fibre growth (September). Calculated single kid late lactation with 22 g/day daily BW gain and 5 g/day mohair fibre growth (October – December).

^b Calculated to grow from 25 kg BW to 35 kg BW at daily gain 20 g/day and mohair fibre growth 4 g/day

^c Calculated to grow from 15 kg BW to 25 kg BW at daily gain 20 g/day and mohair fibre growth 4 g/day.

^d Calculated to grow from 25 kg BW to 45 kg BW at daily gain 20 g/day and mohair fibre growth 4 g/day.

^e Calculated to maintain 55 kg BW and mohair fibre growth 4 g/day.

Appendix F – Gross margin when feeding does for high S:P ratio and wethers sold as kids (Scenario HnW)

Flock size: 1000 does

Flock parameters					
Flock mortality	4%		Buck %	2%	
Productive life	5 years		Marking %	89%	
Doe body weight	45 kg		Weaning %	86%	
DSE rating/doe	1.2		Weaning age	4 months	
Stocking rate/ha	8.85 DSE/ha				
Pasture maintenance	90 kg/ha single super @ \$350 t + \$6.50 /ha application				
Supplementary Feed (Barley)	13MJ/kg Dry Matter – 90% Dry Matter 11.7MJ/kg as fed @ \$274/t				

Income						
	Class	Number	Kg/head/year	\$/kg	\$Income	
Mohair	Does	960	3.1	2.29	6771.07	
	Doe hoggets	404	2.4	40.00	38 784.00	
	Doe kids	413	2.22	35.42	32 475.18	
	Wether kids	430	2.22	35.42	33 811.93	
	Bucks	20	6.0	7.25	870.00	
	Crutch	Adults	1384	0.4	5.00	2768.00
		Kids	413	0.2	5.00	413.00
Total			6554.06		115 893.19	
Sales	Class	Number	\$/head			
	Doe hoggets	187	69.30		12 959.10	
	Wether weaners	430	52.80		22 704.00	
	CFA does	177	148.50		26 284.50	
	CFA bucks	4	181.50		726.00	
	Total					62 673.60
Income Total					178 566.79	

Variable Costs					
Replacements	Class	Number		\$/head	\$Cost
	Bucks	4		300.00	1200.00
Cartage				51.00	204.00
Total					1404.00
Mohair harvesting and selling	Class	Number	Reps	\$/head	
Shearing	Adults/hoggets/doe kids	1797	2	7.42	26 667.48
	Wether kids	430	1	7.42	3190.60
Crutching	Does/hoggets/doe kids	1777	2	1.56	5544.24
	Bucks	20	2	2.74	109.60
Mohair Tax	1.5%				1738.40
Commission etc		33		40.50	1336.50
Cartage		33		11.00	363.00
Packs		33		13.00	429.00
Total					39 378.82
Goat health	Class	Number	Reps	\$/head	
Drenching	Adults/hoggets	1384	2	0.80	2214.40
	Doe kids	413	2	0.29	239.54
	Wether kids	430	1	0.29	124.70
Lice control	Adults/hoggets	1384	2	1.47	4068.96
	Doe kids	413	2	1.47	1214.22
	Wether kids	430	1	1.47	632.10
Vaccination 5 in 1	Adults	1384	2	0.36	996.48
	Doe kids	413	2	0.36	297.36
	Wether kids	430	1	0.36	154.80
Marking	Doe kids	413	1	0.23	94.99
	Wether kids	430	1	0.46	197.80
Scanning	Does	1000	1	1.00	1000.00
Total					11 235.35
Livestock selling		Number		\$/head	
Cartage		798		2.10	1675.80

Continued

Commission on goat sales	4.5%			2820.31
Levies Total		798	2.60	2074.80 6570.91
Pasture maintenance	232ha	@	\$38.00/ha	8816.00
Fodder	83.65t	@	\$274.00/t	22 920.53
Costs Total				90 325.53
<hr/>				
Gross margin				
	/farm			\$88 241.25
	/doe			\$88.24
	/head			\$39.73
	/dse			\$42.98
	/ha			\$380.35

Appendix G – Gross margin when feeding does for low S:P ratio and wethers sold as kids (Scenario LnW)

Flock size: 1000 does

Flock parameters					
Flock mortality	4%	Buck %	2%		
Productive life	5 years	Marking %		89%	
Doe body weight	45 kg	Weaning %		86%	
DSE rating/doe	1.2	Weaning age		4 months	
Stocking rate/ha	8.85 DSE/ha				
Pasture maintenance	90 kg/ha single super @ \$350 t + \$6.50 /ha application				
Supplementary Feed (Barley)	13MJ/kg Dry Matter – 90% Dry Matter 11.7MJ/kg as fed @ \$274/t				
Income					
Mohair	Class	Number	Kg/head/year	\$/kg	\$Income
	Does	960	2.8	4.37	11 578.75
	Doe hoggets	404	2.34	40.00	37 814.40
	Doe kids	413	2.02	25.59	21 348.71
	Wether kids	430	2.02	25.59	22 227.47
	Bucks	20	6.0	7.25	870.00
	Crutch	Adults	1384	0.4	5.00
Kids		413	0.2	5.00	413.00
Total			6054.02		97 020.34
Sales	Class	Number	\$/head		
	Doe hoggets	187	59.40		11 107.80
	Wether weaners	430	46.20		19 866.00
	CFA does	177	118.80		21 027.60
	CFA bucks	4	181.50		726.00
	Total				
Income Total					149 747.74

Variable Costs					
Replacements	Class	Number		\$/head	\$Cost
	Bucks	4		300.00	1200.00
Cartage				51.00	204.00.
Total					1404.00
Mohair harvesting and selling	Class	Number	Reps	\$/head	
Shearing	Adults/hoggets/doe kids	1797	2	7.42	26 667.48
	Wether kids	430	1	7.42	3190.60
Crutching	Does/hoggets/doe kids	1777	2	1.56	5544.24
	Bucks	20	2	2.74	109.60
Mohair Tax	1.5%				1455.31
Commission etc		30		40.50	1215.00
Cartage		30		11.00	330.00
Packs		30		13.00	390.00
Total					38 902.23
Goat health	Class	Number	Reps	\$/head	
Drenching	Adults/hoggets	1384	2	0.80	2214.40
	Doe kids	413	2	0.29	239.54
	Wether kids	430	1	0.29	124.70
Lice control	Adults/hoggets	1384	2	1.47	4068.96
	Doe kids	413	2	1.47	1214.22
	Wether kids	430	1	1.47	632.10
Vaccination 5 in 1	Adults	1384	2	0.36	996.48
	Doe kids	413	2	0.36	297.36
	Wether kids	430	1	0.36	154.80
Marking	Doe kids	413	1	0.23	94.99
	Wether kids	430	1	0.46	197.80
Scanning	Does	1000	1	1.00	1000.00
Total					11 235.35
Livestock selling		Number		\$/head	
Cartage		798		2.10	1675.80

Continued

Commission on goat sales	4.5%			2372.73
Levies		798	2.60	2074.80
Total				6123.33
Pasture maintenance	232ha	@	\$38.00/ha	8816.00
Fodder	0	@	\$274.00/t	0
Costs Total				66 480.91

Gross margin	
/farm	\$83 266.83
/doe	\$83.27
/head	\$37.49
/dse	\$40.55
/ha	\$358.91

Appendix H – Gross margin when feeding does for high S:P ratio and wethers sold as hoggets (Scenario HWH)

Flock size: 1000 does

Flock parameters					
Flock mortality	4%	Buck %	2%		
Productive life	5 years	Marking %		89%	
Doe body weight	45 kg	Weaning %		86%	
DSE rating/doe	1.2	Weaning age		4 months	
Stocking rate/ha	10.55 DSE/ha				
Pasture maintenance	108.3 kg/ha single super @ \$350 t + \$6.50 /ha application				
Supplementary Feed (Barley)	13MJ/kg Dry Matter – 90% Dry Matter 11.7MJ/kg as fed @ \$274/t				
Income					
Mohair	Class	Number	Kg/head/year	\$/kg	\$Income
	Does	960	3.1	2.29	6771.07
	Doe hoggets	404	2.2	40.00	35 552.00
	Doe kids	413	2.22	35.42	32 475.18
	Wether kids	413	2.22	35.42	33 811.93
	Wether hoggets	404	2.4	40.00	38 784.00
	Bucks	20	5.8	12.43	1441.88
Crutch	Adults	1786	0.4	5.00	3576.00
	Kids	826	0.2	5.00	826.00
Total			6713.46		153 238.07
Sales	Class	Number	\$/head		
	Doe hoggets	187	63.36		11 848.32
	Wether hoggets	404	78.54		31 730.16
	CFA does	177	148.50		26 284.50
	CFA bucks	4	169.62		678.48

Continued

Total					70 541.46
Income					223 775.53
Total					
Variable Costs					
Replacements	Class	Number	\$/head		\$Cost
	Bucks	4	300.00		1200.00
Cartage			51.00		204.00
Total					1404.00
Mohair harvesting and selling	Class	Number	Reps	\$/head	
Shearing	All	2614	2	7.42	38 791.76
Crutching	Does/hoggets/ kids	2594	2	1.56	8093.28
	Bucks	20	2	2.74	109.60
Mohair Tax	1.5%				2298.57
Commission etc		34		40.50	1377.00
Cartage		34		11.00	374.00
Packs		34		13.00	442.00
Total					51 486.21
Goat health	Class	Number	Reps	\$/head	
Drenching	Adults/hoggets	1788	2	0.80	2860.80
	Kids	826	2	0.29	479.08
Lice control	Adults/hoggets	1788	2	1.47	5256.72
	Kids	826	2	1.47	2428.44
Vaccination 5 in 1	Adults	1788	2	0.36	1287.36
	Kids	826	2	0.36	594.72
Marking	Doe kids	413	1	0.23	94.99
	Wether kids	413	1	0.46	189.98
Scanning	Does	1000	1	1.00	1000.00
Total					14 192.09
Livestock selling		Number	\$/head		
Cartage		772	2.10		1621.20
Commission on goat sales	4.5%				3174.37
Levies		772	2.60		2007.20
Total					6802.77

Continued

Pasture maintenance	232ha	@	\$44.40/ha	10 300.80
Fodder	94.64t	@	\$274.00/t	25 931.25
Costs Total				110 117.11

Gross margin		
	/farm	\$113 662.41
	/doe	\$113.66
	/head	\$43.48
	/dse	\$46.44
	/ha	\$489.92

Appendix I – Gross margin when feeding does for low S:P ratio and wethers sold as hoggets (Scenario LWH)

Flock size: 1000 does

Flock parameters					
Flock mortality	4%		Buck %	2%	
Productive life	5 years		Marking %	89%	
Doe body weight	45 kg		Weaning %	86%	
DSE rating/doe	1.2		Weaning age	4 months	
Stocking rate/ha	10.55 DSE/ha				
Pasture maintenance	108.3 kg/ha single super @ \$350 t + \$6.50 /ha application				
Supplementary Feed (Barley)	13MJ/kg Dry Matter – 90% Dry Matter 11.7MJ/kg as fed @ \$274/t				
Income					
Mohair	Class	Number	Kg/head/year	\$/kg	\$Income
	Does	960	2.8	4.37	11 578.75
	Doe hoggets	404	2.14	40.00	34 582.40
	Doe kids	413	2.02	25.59	21 348.71
	Wether kids	413	2.02	25.59	21 348.71
	Wether hoggets	404	2.4	40.00	38 460.80
	Bucks	20	5.8	12.43	1441.88
Crutch	Adults	1786	0.4	5.00	3576.00
	Kids	826	0.2	5.00	826.00
Total			6179.08		153 234.07
Sales	Class	Number	\$/head		
	Doe hoggets	187	53.46		9997.02
	Wether hoggets	404	68.64		27 730.56
	CFA does	177	118.80		21 027.60
	CFA bucks	4	169.62		678.48
Total					59 433.66

Continued

Income	192 596.92
Total	

Variable Costs					
Replacements	Class	Number	\$/head		\$Cost
	Bucks	4	300.00		1200.00
Cartage			51.00		204.00
Total					1404.00
Mohair harvesting and selling	Class	Number	Reps	\$/head	
Shearing	All	2614	2	7.42	38 791.76
Crutching	Does/hoggets/ kids	2594	2	1.56	8093.28
	Bucks	20	2	2.74	109.60
Mohair Tax	1.5%				1997.45
Commission etc		31		40.50	1255.50
Cartage		31		11.00	341.00
Packs		31		13.00	403.00
Total					50 991.59
Goat health	Class	Number	Reps	\$/head	
Drenching	Adults/hoggets	1788	2	0.80	2860.80
	Kids	826	2	0.29	479.08
Lice control	Adults/hoggets	1788	2	1.47	5256.72
	Kids	826	2	1.47	2428.44
Vaccination 5 in 1	Adults	1788	2	0.36	1287.36
	Kids	826	2	0.36	594.72
Marking	Doe kids	413	1	0.23	94.99
	Wether kids	413	1	0.46	189.98
Scanning	Does	1000	1	1.00	1000.00
Total					14 192.09
Livestock selling		Number	\$/head		
Cartage		772	2.10		1621.20
Commission on goat sales	4.5%				2674.51
Levies		772	2.60		2007.20
Total					6302.91
Pasture maintenance	232ha	@	\$44.40/ha		10 300.80

Continued

Fodder	10.99t	@	\$274.00/t	3010.80
Costs Total				86 202.19

Gross margin	
/farm	\$106 394.73
/doe	\$106.39
/head	\$40.70
/dse	\$43.47
/ha	\$458.60

Appendix J – Gross margin when feeding does for high S:P ratio with reduced doe flock size and wethers sold as hoggets (Scenario HWL)

Flock size: 583 does

Flock parameters					
Flock mortality	4%	Buck %	2%		
Productive life	5 years	Marking %	89%		
Doe body weight	45 kg	Weaning %	86%		
DSE rating/doe	1.2	Weaning age	4 months		
Stocking rate/ha	8.85 DSE/ha				
Pasture maintenance	90 kg/ha single super @ \$350 t + \$6.50 /ha application				
Supplementary Feed (Barley)	13MJ/kg Dry Matter – 90% Dry Matter 11.7MJ/kg as fed @ \$274/t				
Income					
Mohair	Class	Number	Kg/head/year	\$/kg	\$Income
	Does	560	3.1	2.29	3949.79
	Doe hoggets	231	2.4	40.00	22 176.00
	Doe kids	241	2.22	35.42	18 950.41
	Wether kids	241	2.22	35.42	18 950.41
	Wether hoggets	231	2.6	40.00	24 024.00
	Bucks	12	5.8	12.43	894.96
Crutch	Adults	1034	0.4	5.00	2068.00
	Kids	482	0.2	5.00	482.00
Total			3931.24		91 495.57
Sales	Class	Number	\$/head		
	Doe hoggets	105	69.30		7276.50
	Wether hoggets	231	84.48		19 514.88
	CFA does	99	148.50		14 701.50
	CFA bucks	2	181.50		363.00

Continued

Total	41 855.88
Income	133 351.45
Total	

Variable Costs					
Replacements	Class	Number	\$/head	\$Cost	
	Bucks	2	300.00	600.00	
Cartage		2	51.00	102.00	
Total				702.00	
Mohair harvesting and selling	Class	Number	Reps	\$/head	
Shearing	All	1516	2	7.42	22 497.44
Crutching	Does/hoggets/ kids	1504	2	1.56	4692.48
	Bucks	12	2	2.74	65.76
Mohair Tax	1.5%				1372.43
Commission etc		20		40.50	810.00
Cartage		20		11.00	220.00
Packs		20		13.00	260.00
Total					29 918.11
Goat health	Class	Number	Reps	\$/head	
Drenching	Adults/hoggets	1034	2	0.80	1654.40
	Kids	482	2	0.29	279.56
Lice control	Adults/hoggets	1034	2	1.47	3039.96
	Kids	482	2	1.47	1417.08
Vaccination 5 in 1	Adults	1034	2	0.36	744.48
	Kids	482	2	0.36	347.04
Marking	Doe kids	231	1	0.23	55.43
	Wether kids	231	1	0.46	110.86
Scanning	Does	583	1	1.00	583.00
Total					8231.81
Livestock selling		Number	\$/head		
Cartage		437	2.10	917.70	

Continued

Commission on goat sales	4.5%			1883.51
Levies		437	2.60	1136.20
Total				3937.41
Pasture maintenance	232ha	@	\$38.00/ha	8816.00
Fodder	48.80t	@	\$274.00/t	13 370.26
Costs Total				64 975.60

Gross margin		
	/farm	\$68 375.85
	/doe	\$117.28
	/head	\$45.10
	/dse	\$33.30
	/ha	\$294.72

Appendix K - Gross margin when feeding does for low S:P ratio with reduced doe flock size and wethers sold as hoggets (Scenario LWL)

Flock size: 583 does

Flock parameters			
Flock mortality	4%	Buck %	2%
Productive life	5 years	Marking %	89%
Doe body weight	45 kg	Weaning %	86%
DSE rating/doe	1.2	Weaning age	4 months
Stocking rate/ha	8.85 DSE/ha		
Pasture maintenance	90 kg/ha single super @ \$350 t + \$6.50 /ha application		
Supplementary Feed (Barley)	13MJ/kg Dry Matter – 90% Dry Matter 11.7MJ/kg as fed @ \$274/t		

Income					
Mohair	Class	Number	Kg/head/year	\$/kg	\$Income
	Does	560	2.8	4.37	6754.27
	Doe hoggets	231	2.4	40.00	22 176.00
	Doe kids	241	2.02	25.59	12 457.72
	Wether kids	241	2.02	25.59	12 457.72
	Wether hoggets	231	2.6	40.00	24 024.00
	Bucks	12	6.0	12.43	894.96
Crutch	Adults	1034	0.4	5.00	2068.00
	Kids	482	0.2	5.00	482.00
Total			3655.64		81 314.68
Sales	Class	Number	\$/head		
	Doe hoggets	105	59.40		6237.00
	Wether hoggets	231	74.58		17 227.98
	CFA does	99	118.80		11 761.20
	CFA bucks	2	181.50		363.00

Continued

Total	35 589.18
Income	116 903.86
Total	

Variable Costs

Replacements	Class	Number	\$/head	\$Cost
	Bucks	2	300.00	600.00
Cartage			51.00	102.00
Total				702.00

Mohair harvesting and selling	Class	Number	Reps	\$/head	
Shearing	All	1516	2	7.42	22 497.44
Crutching	Does/hoggets/ kids	1504	2	1.56	4692.48
	Bucks	12	2	2.74	65.76
Mohair Tax	1.5%				1219.72
Commission		18		40.50	729.00
etc					
Cartage		18		11.00	198.00
Packs		18		13.00	234.00
Total					29 636.40

Goat health	Class	Number	Reps	\$/head	
Drenching	Adults/hoggets	1034	2	0.80	1654.40
	Kids	482	2	0.29	279.56
Lice control	Adults/hoggets	1034	2	1.47	3039.96
	Kids	482	2	1.47	1417.08
Vaccination 5 in 1	Adults	1034	2	0.36	744.48
	Kids	482	2	0.36	347.04
Marking	Doe kids	241	1	0.23	55.43
	Wether kids	241	1	0.46	110.86
Scanning	Does	583	1	1.00	583.00
Total					8231.81

Livestock selling	Number	\$/head	
Cartage	437	2.10	917.70

Continued

Commission on goat sales	4.5%			1601.51
Total				3655.41
Pasture maintenance	232ha	@	\$38.00/ha	8816.00
Fodder	0	@	\$274.00/t	0
Costs Total				51 041.62

Gross margin		
	/farm	\$65 862.24
	/doe	\$112.97
	/head	\$43.44
	/dse	\$26.91
	/ha	\$283.89
