McGregor, B.A., Butler, K.L. and Ferguson, M.B. 2013, Variation in mohair staple length over the lifetime of Angora goats, *Animal production science*, vol. 53, no. 6, pp. 479-486.

DOI: [10.1071/AN12288](10.1071/AN12288)

Variation in mohair staple length over the lifetime of Angora goats

B.A. McGregor[A,B,G], *K.L. Butler*[C] *and M.B. Ferguson*[D,E,]

[A] Institute for Frontier Materials, Deakin University, Geelong, Vic., 3220, Australia.

[B] Formerly Livestock Production Sciences, Future Farming Systems Research Division, Department of Primary Industries, Attwood, Vic., 3049, Australia

[C] Biometrics Unit, Future Farming Systems Research Division, Department of Primary Industries, Werribee, Vic., 3030, Australia

[D] The New Zealand Merino Company Ltd. Christchurch, New Zealand

[E] Formerly, Livestock Production Sciences, Future Farming Systems Research Division, Department of Primary Industries, Hamilton, Vic., 3300, Australia

[F] Corresponding author. E-mail address: bruce.mcgregor@deakin.edu.au

Short title: Variation in mohair staple length

Abstract

Previous work has shown that, within an Angora goat flock, clean fleece weight is proportional to fleece-free liveweight (FFLwt)$^{2/3}$ and for goats of the same age and cohort, the mean mohair fibre diameter is proportional to FFLwt$^{1/3}$. This indicates that fibre length might not be related to the size of animals. This study examines how mohair staple length (SL) is related to FFLwt of Angora goats of different genetic origins over their lifetime and how the relationship varies with other lifetime factors. Measurements were made over 11 shearing periods on a population of Angora goats representing the current range and diversity of genetic origins in Australia, including South African, Texan and interbred admixtures of these and Australian sources. Records of breed, sire, dam, date of birth, dam age, birth weight, birth parity, weaning weight, liveweight, fleece growth and fleece quality were taken for castrated males (wethers) (n=94 animals). FFLwt were determined for each goat at shearing time by subtracting the greasy fleece weight from the liveweight recorded immediately prior to shearing. The average of the FFLwt at the start of the period and the FFLWt at the end of the period was calculated. Liveweight change (LwtCh) was the change in FFLwt over the period between shearings. A restricted maximum likelihood (REML) model was developed for SL, which allowed the observations of the same animal at different ages to be correlated in an unstructured manner. Average SL differed from about 12 cm to about 14½ cm, depending on age. There were no consistent effects of season. At any age, an increase of 10 kg LwtCh between animals results in about a 0.34 (s.e. = 0.087) cm increase in SL. There was no evidence of an effect of FFLwt on SL. The results confirm our hypothesis that within a single age cohort of Angora goats, there is very little, if any, relationship between the liveweight and staple length of individual animals. This implies that the biological determinants of size of fibres related to cross-sectional area are substantially different to the size determinants of fibre length.

Additional keywords: age effects, fibre morphology, liveweight, mohair production, nutrition management.

Introduction

The size of mohair fibres depends on the length of those fibres and the cross-sectional area along the length of the fibre. In Merino wool, fibre length is related to the length of cortical cells (Hynd 1994*a*) or to a change in the number of cells entering the fibre proper due to alterations in the rate of cell division or the distribution of cells to either the fibre or to the inner root sheath (Hynd 1994*b*). We have shown that mohair mean fibre diameter (MFD) is related to the size (liveweight) of animals within a flock, and thus the cross-sectional area will be related to the size of animal. In fact, for goats of the same age and cohort, the MFD is proportional to the cube root of animal size indicating that the mean cross-sectional area will be related to the liveweight$^{2/3}$ (McGregor *et al.* 2012). If fibres grow in a manner so that they maintain similar shape then fibre length would also be expected to be proportional to the cube root of liveweight, leading to an expectation of fleece weight being proportional to liveweight. On the other hand, if fibres respond to increased liveweight through increased cross sectional area but no change in fibre length, it would be expected that fleece weight would be proportional to liveweight$^{2/3}$.

Previous work has shown that, within an Angora flock, clean fleece weight (CFwt) is allometrically related to size of the animal, measured as fleece-free liveweight (FFLwt) (McGregor *et al.* 2013). In particular, with goats of the same age, CFwt is proportional to FFLwt$^{2/3}$ when the animal is not losing or gaining FFLwt. This indicates that fibre length might not be related to size of animals of the same age and cohort. This is different to the hypothesis discussed in McGregor *et al.* (2012) which was based on fibre length being proportional to the cube root of FFLwt.

Whan (1972) concluded that staple length (SL) may be a useful predictor of the average fibre length in wool tops. It has been shown that straight SL bears an approximately constant ratio to mean fibre length and to the crimped fibre length of the staple (Lang and Chaudhri 1948). The measurement of SL is an accepted measurement used by the wool textile processing industry to indicate the length of wool fibres (IWTO-30 2007). Thus, it would be reasonable to expect that the relationship between SL and FFLwt would be a reasonable proxy for the relationship between fibre length and FFLwt.

The relationship between mohair SL and FFLwt is also of importance because mohair SL determines the processing route for mohair in textiles. Long mohair is required for worsted processing as longer staples produce tops with longer Hauteur allowing greater spinning speeds and producing higher quality yarns and fabrics (Hunter 1993). Consequently mohair SL comes second after MFD in importance as a fibre attribute and this is reflected in mohair auction prices over time (McGregor and Butler 2004). There are large premiums for mohair with longer SL compared with shorter SL, although the discounts for shorter length are less at lower MFD (McGregor and Butler 2004).

This study examines how mohair SL is related to liveweight of Angora goats of different genetic origins over their lifetime and how the relationship varies with other lifetime factors.

Materials and methods

General

Management details have been provided by McGregor and Butler (2008) and McGregor *et al.* (2012, 2013). In brief, Angora goats born in September 2002 in a progeny testing evaluation at Horsham, Victoria, (36º42'50"S, 142º18'30"E, altitude 180 m) with pedigree breeding records from known sires, were grazed on pasture from birth until 6 years of age. The goats were progeny of various genetic sources including sires of 100% South African origin (n = 2), 100% Texan origin (n = 4), and other interbred admixtures that included sires of South African, Texan and Australian origin (n = 4). These sires were representative of the genotypes available in Australia (Ferguson and McGregor 2004, 2005). Records of dam, birth weight, birth parity, liveweight, fleece growth and fleece quality were taken for castrated males (wethers). All animals were shorn every 6 months from 6 months of age, except as described below. One month after shearing in February 2004 the castrated male goats (n=94) were transported to Attwood, Victoria (37°40'S, 144°53'E, altitude 135 m) and grazed as a flock until November 2008.

Management

Goats were grazed as one flock, at near the recommended stocking rate on improved annual pasture (McGregor 2010*a*,*b*). Goats were moved between paddocks to match feed requirements. Shelter was available in the form of covered and enclosed shedding that was always accessible and could accommodate all goats. Fresh water was provided in all paddocks. During most years in autumn and winter, pastoral conditions were affected by drought and supplementary feeding was undertaken following Australian practice (McGregor 2005) from mid May to early September to maintain liveweight (McGregor and Butler 2008). A mineralised stock block was always available (Ridley AgriProducts Pty. Ltd., Melbourne) with the following content: Minimum content Ca 4.9%; P 1%; S 2%; Cu 600 mg/kg; Co 60 mg/kg; I 60 mg/kg; Zn 1000 mg/kg; Fe^{+2} 1100 mg/kg; Se 5 mg/kg; based on NaCl 75 to 85%.

The goats were given a full crutching and wigging three months prior to any shearing. Goats were vaccinated against 5 in 1 *Clostridia spp*. and "drenched" with an effective anthelmintic to control gastro-intestinal parasites no more frequently than once per year. All goats were weighed to the nearest 0.2 kg one day prior to any shearing except for the third shearing when the nearest liveweight prior to shearing was taken three months earlier at 15 months of age and following shearing one month later. All goats were fasted overnight prior to shearing or crutching. Goats were returned to pasture together following shearing.

Design

The goats studied were the castrated male progeny of a sire evaluation project (Ferguson and McGregor 2004, 2005). Between February 2004 and February 2006 the goats were part of a replicated experiment studying the influence of shearing treatments. There were four or eight individual goat replicates of 21 treatments arranged as a 7 Shearing treatments by 3 Genetic strains factorial (McGregor and Butler 2008). The shearing treatments were:

- Three different six month shearing intervals, each with different months of shearing: February-August, April-October, June-December;
- Two 12 months shearing intervals with different months of shearing: August-August, September-September;
- One 3 month shearing interval (Often treatment); and

- One seven-month winter shearing interval, February-September.

Genetic strain was based on sire line as follows:

- South African: Sires 100% South African bloodline;
- Texan: Sires 100% Texan bloodline; and
- Mixed: Sires of approximately 50% South African and 50% Texan bloodlines.

Some strains of wethers, whose breeding did not fit within these criteria, were culled.

Mohair measurement and testing

The practices were exactly as previously described (McGregor and Butler 2008). At crutching and shearing, fleeces, pieces, bellies and locks and samples were weighed to the nearest 1 g. Mid-side samples were taken at shearing, identified and stored in a plastic bag. Three staples from the mid side sample were measured for SL to the nearest 0.5 cm following the removal of adhesions and twists, and then stretched along a ruler to straighten the crimps. The assessed SL was not the longest fibres in the staple tip but was subjectively determined with the aim of measuring to the point where most of the fibres were present before any significant narrowing of the staple near the tip, as per industry selling broker practice.

Statistical methods

Fleece-free liveweights (FFLwt) were determined for each goat at shearing time by subtracting the greasy fleece weight from the liveweight recorded immediately prior to shearing. Average FFLwt between shearings (AvFFLwt) was determined as the average of the FFLwt at the start of the period and the FFLWt at the end of the period. Liveweight change (LwtCh) was the change in FFLwt over the period between shearings.

A restricted maximum likelihood (REML) model was developed for SL which allowed the observations of the same animal at different ages to be correlated in an unstructured manner. Thus, for individual animals, the variance was allowed to differ between ages and the covariance was allowed to differ between each pair of ages. Within this framework, a parsimonious model for fixed effects was developed using Wald *F*-tests (Payne 2011). Once a parsimonious fixed effects model had been established, random sire effects and random dam effects were examined for inclusion in the model but the sire effect was rejected based on a Chi-squared change in deviance test, and the dam effect was rejected based on the lack of numerical convergence when fitting a model with an extra term for a dam effect. Small random effects commonly lead to over –parameterization and this often leads to numerical convergence difficulties. Confidence intervals are constructed using asymptotic normal approximations.

Results

During the study SL varied between 7.2 and 18.0 cm (Fig. 1). Average SL for a six month shearing interval differed with age, ranging from 11.8 cm at 4 years to 14.7 cm at 6 years. For the animals in the study, average FFLwt was equal to 36.9 kg, standard deviation was equal to 14.0 kg, the minimum was equal to 8.3 and the maximum was equal to 72.0 kg . Average LwtCh was equal to 4.1 kg, standard deviation was equal to 5.9 kg varying from a lowest value of -13.8 to a largest value of +22.8 kg.

The fixed effects in the model for SL can be represented as (Table 1, 2):

$$SL = Shearyears*Shearregime + Age + LwtCh.$$

Although the date of birth was statistically significant ($P < 0.05$), date of birth was no longer statistically significant ($P < 0.05$) when one statistically influential kid that was born 5 days earlier than all the other kids used in the statistical analysis was excluded from analysis. Thus date of birth was not included in the chosen model (Table 2). There was no evidence ($P > 0.1$, Table 2) for a sire effect. The dam effect could not be tested because a model that included an extra term for dam did not numerically converge. This, in itself, is an indication of over-parameterization that can occur when there is little dam effect.

Average SL differed from about 12 cm to about 14½ cm, depending on age (Fig. 2). There were no consistent effects of season.

Angora goats which gained liveweight had longer SL than goats which lost liveweight but this effect was small compared with the age effect (Figs. 2 and 3). At any age, an increase of 10 kg LwtCh between animals results in about a 0.34 (s.e. = 0.087) cm increase in SL.

There was no evidence of an effect of FFLwt on SL (Table 2, Fig. 4). The narrow confidence intervals in Fig. 4 show, that not only is there no evidence of any effect, but also that any non-detected effect is small.

The residual standard deviation of SL was greater for 1.0 and 1.5 year olds than for older ages (Table 3). The residual standard deviation was relatively stable between ages 2.0 and 6.0 years old.

Generally, correlations declined between shearing ages further apart (Table 4). This trend is particularly evident when making shearing age comparisons with shearing ages 1, 1.5 and 2 years. The correlations for shearing ages 1 and 1.5 with shearing ages ≥ 3 years were ≤ 0.40, average 0.15, but at shearing ages ≥ 3 years the correlations at any older age averaged 0.40 (range 0. 16–0.67).

Discussion

The results confirm our hypothesis that within a single age cohort of Angora goats, there is very little, if any, relationship between the liveweight and staple length of individual animals. The lack of relationship we have found between SL and FFLwt, strongly contrasts with the relationship we previously found between MFD and FFLwt. This partially agrees with phenotypic correlations obtained from previous genetic studies with Angora goats (Shelton and Bassett, 1970; Yalçin *et al.* 1979; Gifford *et al*. 1991). In these 3 studies phenotypic correlations were small for SL and liveweight (0.04, 0.05 and 0.21), but larger for MFD and liveweight (0.13, 0.26 and 0.23). In two other genetic studies (Nicoll *et al*. 1989; Snyman and Oliver, 1996) the phenotypic correlations between MFD and liveweight were larger again (0.37and 0.55). One possible reason that a small positive phenotypic correlation between SL and liveweight was found in previous genetic studies is that in those studies it is likely that liveweight was not fleece free. Thus, the liveweight would include fleece weight which is likely to have a relationship with SL. Another possible reason is that in our modeling we have taken into account the effect of LwtCh, which has some positive relationship with

FFLwt (McGregor *et al.* 2013, Fig. 2). Thus, unadjusted, there will be some relationship between SL and liveweight caused indirectly by the direct relationship between LwtCh and SL.

If we assume that the relationships of SL with FFLwt and MFD with FFLwt are driven purely by morphological processes, then we can suggest mechanisms for the form of relationships. If as an animal gets larger it remains morphologically and compositionally similar, then the MFD will be proportional to FFLwt$^{1/3}$ (McGregor *et al.* 2012). If, despite an animal getting larger, the fibre follicle depth, or at least the depth of follicle involved in producing fibre cells, does not change then fibre length (and hence staple length) might be expected to be unrelated to FFLWt. These are the relationships observed in our studies.

A previous study (McGregor 1992) showed that skin weight of Angora goats was allometrically related to FFLwt, with an allometric constant not different from 1. That is, skin weight could be considered to be proportional to FFLwt. For this to occur by morphological process, then total skin depth would need to be proportional to FFLwt$^{1/3}$ in addition to MFD being proportional to FFLwt$^{1/3}$. This would occur if, at the macro level, the skin is morphologically similar for different size animals. Our suggested morphological mechanism for the relationship between SL and FFLwt is still possible, but it would imply that the depth of follicle involved in producing fibre cells is not related to the skin thickness. A consequence is that, in larger animals, a smaller proportion of the skin will be associated with producing fibre cells.

There were differences of more than 2.5 cm between ages in SL (Fig. 2). While the differences between ages shown in Fig. 2 are to a small extent confounded with the effects of LwtCh, the differences been ages are much too large to be explained by this confounding (Figs. 2 and 3). The effect of age on SL are likely to be environmental because the effect does not change in a simple systematic way as the goats age or between the summer and winter half year. This indicates that there are major environmental effects that affect SL, which are not reflected in the average liveweight or changes in liveweight of the animal.

Influence of LwtCh

Both AvFFLwt and LwtCh should reflect differences in nutrition over the longer and shorter term respectively. That these indices of nutritional status had little effect suggests that other factors were in play. Hynd (1994*a*) has shown that changes in nutrition affect the size of cortical cells in wool fibres and hence the length of wool fibres. It is likely that changes in nutrition in Angora goats have similar effects on the length of mohair fibres. It is also possible that negative LwtCh may reduce average SL by affecting the number of growing fibres. This effect may operate as a relative increase in the number of non-growing fibres when liveweight declines, leading to marginally reduced SL (Fig. 3).

Influence of other factors

There may be differences in season which affect nutritional intake, perhaps related to pasture structure, such as proportion of green and dead herbage, which may have affected the ease of dietary selection and so grazing time, or digestion of forage as described for sheep (Birrell 1989). However in the present work, season of fibre growth had no consistent effect on SL (Fig. 2).

At the time of the shearing experiment (fleeces harvested from 2 year old to 3.5 years old) there were major nuisance effects of shearing regime (Table 2). This relates to the previous results that shearing interval has a major effect on fleece weight, SL and other fleece attributes (McGregor and Butler 2008).

Neither birth weight, dam age, nor single births versus multiple births had an effect once other terms in the model had been accounted for (Table 2). On farms, the main effect of these factors is to alter weaning weight. Weaning weight also had no effect, most probably because we directly measured liveweight during the course of this study.

Surprisingly, there was no evidence of any genetic effects of breed, sire identity or dam identity in the model (Table 2). This suggests that the genetic effects on SL are quite small. While a positive phenotypic relationship between liveweight and mohair SL has been reported in previous studies of Angora goats from Texas, Turkey and Australia, the correlations are small and in two cases not significantly different from zero: 0.04 (Shelton and Bassett 1970); 0.05 (Yalçin *et al*. 1979); 0.21 (Gifford *et al*. 1991). Taken together with the present work, it appears that SL is not associated with the size of the Angora goat. Wool SL is also phenotypically positively related to liveweight of Merino sheep (Huisman and Brown 2008). In their study, the highest correlations occurred between staple length and liveweight taken at the same time with lower correlations when these measures were compared at different times.

It is unlikely that differences in fibre crimp would bias our measure of SL as the staples were straightened prior to measurement.

Random variation

The higher residual standard deviation of SL between animals at ages 1 and 1.5 years may reflect the effects of drought conditions which existed between weaning and 1.5 years of age. During the last year of this study, the wear of 30% of the first permanent incisors was associated with a 7.5% decline in SL (McGregor and Butler 2011) but this effect has not increased the residual standard deviation above that seen between 2 to 5 years of age (Table 3). Variation in mohair SL differs over the body of Angora goats, and there are differences between farms, and between age of goats (McGregor and Butler 2009).

The within animal correlation generally declined to levels well below 0.3 when comparing shearings at <2 years old with shearings at older ages (Table 4). This indicates that ranking of animals for SL can change substantially as the goats become older.

Conclusion

Despite the cross-sectional area of mohair fibres being related to the size of animals within a flock, the SL and thus presumably fibre length is not related to the size of the animals. This implies that the biological determinants of size of fibres related to cross-sectional area are substantially different to the size determinants of fibre length. As an animal grows, the skin surface area increases, skin follicle density declines and skin follicle bulb size increases. This results in increased fibre cross-sectional area but the larger skin surface area does not give any advantage in relation to mohair fibre length growth.

Acknowledgements

The Rural Industries Research and Development Corporation and the Victorian Department of Primary Industries funded this project. Robert and June Liddy and Rowena and Glen Doyle provided their property, animals and labour for the initial two years of the project. The participating mohair breeders who supplied their genetic material and other DPI colleagues are gratefully thanked (see Ferguson and McGregor 2005). Terry Couzens, Attwood, is thanked for assisting with animal management.

References

Birrell HA (1989) The influence of pasture and animal factors on the consumption of pasture by grazing sheep. *Australian Journal of Agricultural Research* **40**, 1261-75.

Ferguson MB, McGregor BA (2004) An evaluation of Angora sires through progeny testing- A progress report. *South African Journal of Animal Science* **34** (5), 7-9, http://www.sasas.co.za/journal/843

Ferguson MB, McGregor BA (2005) ‘Selecting high performing Angoras’. RIRDC Research Report No 05/141. (Rural Industries Research and Development Corporation: Barton, ACT). https://rirdc.infoservices.com.au/items/05-141 [Verified 31 July 2012]

Gifford DR, Ponzoni RW, Lampe RJ, Burr J (1991) Phenotypic and genetic parameters of fleece traits and live weight in South Australian Angora goats. *Small Ruminant Research* **4**, 293-302.

Huisman AE, Brown DJ (2008) Genetic parameters for bodyweight, wool, and disease resistance and reproduction traits in Merino sheep. 2. Genetic relationships between bodyweight traits and other traits. *Australian Journal of Experimental Agriculture* **48**, 1186-1193.

Hunter L (1993) ‘Mohair: a review of its properties, processing and applications.’ (CSIR: Port Elizabeth).

Hynd PI (1994*a*) Follicular determinants of the length and diameter of wool fibres. I. Comparison of sheep differing in fibre length/diameter ratio at two levels of nutrition. *Australian Journal of Agricultural Research* **45**, 1137-47.

Hynd PI (1994*b*) Follicular determinants of the length and diameter of wool fibres II. Comparison of sheep differing in thyroid hormone status. *Australian Journal of Agricultural Research* **45**, 1149-57.

IWTO-30 (2007) Determination of staple length and staple strength. Ilkley, Yorkshire: International Wool Textile Organisation.

Lang WR, Chaudhri AM (1948) A note on the interpretation of Merino staple length measurements. *Journal of the Textile Institute* **39**, T249-T252.

McGregor BA (1992) Body composition, body condition scores and carcass and organ components of grazing Angora goats. *Proceedings of the Australian Society of Animal Production* **19**, 273-276.

McGregor BA (2005) 'Nutrition and management of goats in drought.' Research Report No 05/188. (Rural Industries Research and Development Corporation: Barton, ACT). https://rirdc.infoservices.com.au/items/05-188 [Verified 31 July 2012]

McGregor BA (2010*a*) The influence of stocking rate and mixed grazing of Angora goats and Merino sheep on animal and pasture production in southern Australia. 3. Mohair and wool production and quality. *Animal Production Science* **50**, 168-176.

McGregor BA (2010*b*) The influence of stocking rate and mixed grazing of Angora goats and Merino sheep on animal and pasture production in southern Australia. 2. Live weight, body condition, carcass yield and mortality. *Animal Production Science* **50**, 149–157.

McGregor BA, Butler KL (2004) Contribution of objective and subjective attributes to the variation in commercial value of Australian mohair: Implications for mohair production, genetic improvement, and mohair marketing. *Australian Journal of Agricultural Research* **55**, 1283-1298.

McGregor BA, Butler KL (2008) The effect of frequency and timing of shearing on the growth of fibre and objective and subjective attributes of Angora goat fleeces. *Journal of Agricultural Science Cambridge* **146**, 351-361.

McGregor BA and Butler KL (2009). Variation of staple length across mohair fleeces: implications for animal selection and fleece evaluation. *Journal of Agricultural Science Cambridge* **147**, 493-501.

McGregor BA, Butler KL (2011) The relationship between permanent incisor wear and mohair production and attributes in grazing adult Angora goats. *Small Ruminant Research* **100**, 37-43.

McGregor, B.A., Butler, K.L. and Ferguson, M.B. (2012). The allometric relationship between mean fibre diameter of mohair and the fleece-free live weight of Angora goats over their lifetime. *Animal Production Science* **52**, 35-43.

McGregor, B.A., Butler, K.L. and Ferguson, M.B. (2013). The allometric relationship between clean mohair fleece weight and the fleece-free liveweight of Angora goats over their lifetime varies with season and liveweight change. *Animal Production Science* **53**, 154-162.

Nicoll GB, Bigham ML, Alderton MJ (1989) Estimates of environmental effects and genetic parameters for live weights and fleece traits of Angora goats. *Proceedings of the New Zealand Society of Animal Production* **49**, 183-189.

Payne RW (Ed.) (2011) 'The Guide to GenStat®; Release 14. Part 2: Statistics.' (VSN International: Hertfordshire, UK)

Shelton M, Bassett JW (1970) 'Estimate of certain genetic parameters relating to Angora goats.' Texas Agricultural Station Research Reports (PR-2750), 38-41. (Texas Agricultural and Mechanical University: College Station, Texas)

Snyman MA, Olivier JJ (1996) Genetic parameters for body weight, fleece weight and fibre diameter in South African Angora goats. *Livestock Production Science* **47**, 1-6.

Whan RB (1972) Fibre-length variation in greasy wool. *Journal of the Textile Institute* **63**, 84-90.

Yalçin BC, Ariturk E, Imeryuz F, Sincer N, Muftuoglu, S. (1979). Genetic and environmental aspects of Angora goat production. 2. Phenotypic and genetic parameters for the important production traits. *Instanbul University Vet. Fak. Derg.* **5**, 19-34.

Figure captions

Fig. 1. The range in mohair staple length at each age of shearing during the study, adjusted to a 6-month growing period.

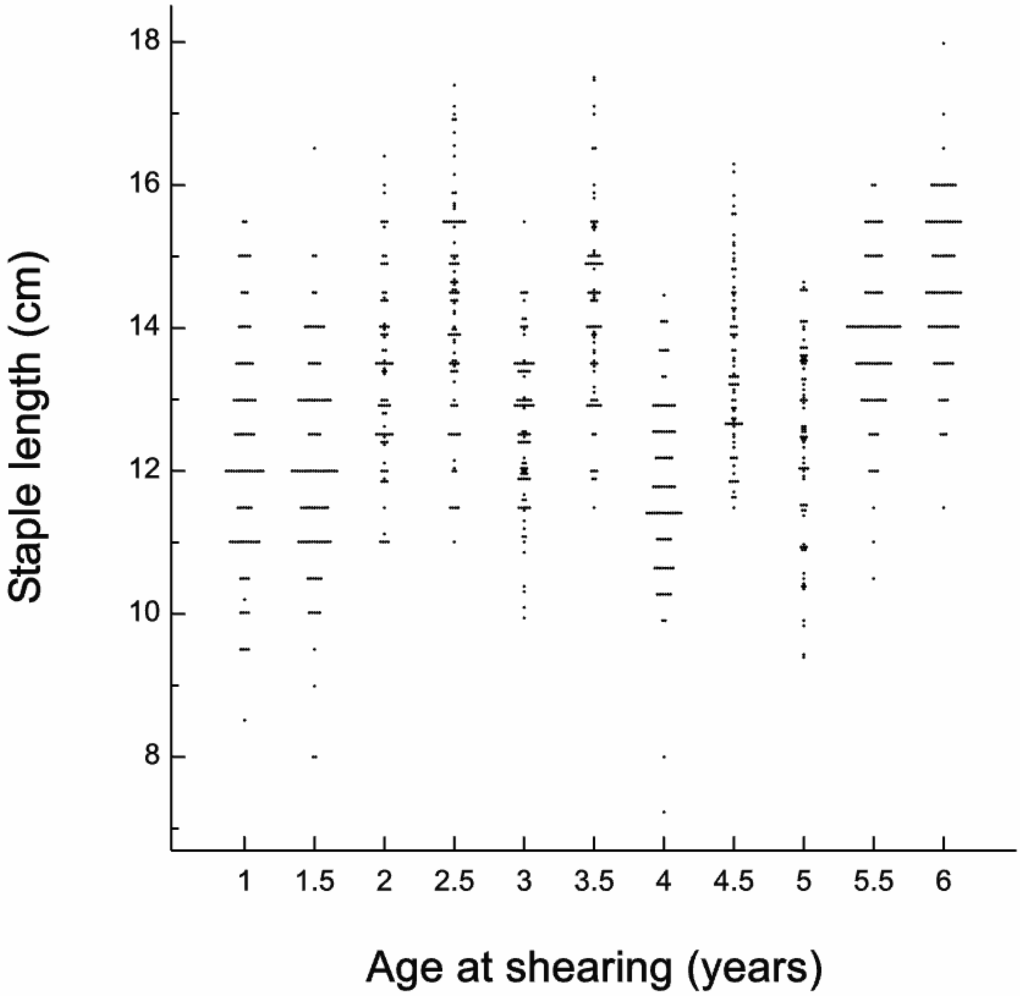

Fig. 2. Effect of age at shearing on average staple length. Values are given for the average liveweight change (kg) of goats during the growing period. These liveweight change values are presented as numbers on the graph. During the shearing experiment years, predicted means are equally weighted for shearing regimes occurring at each particular age. The error bars represent the 95% confidence intervals.

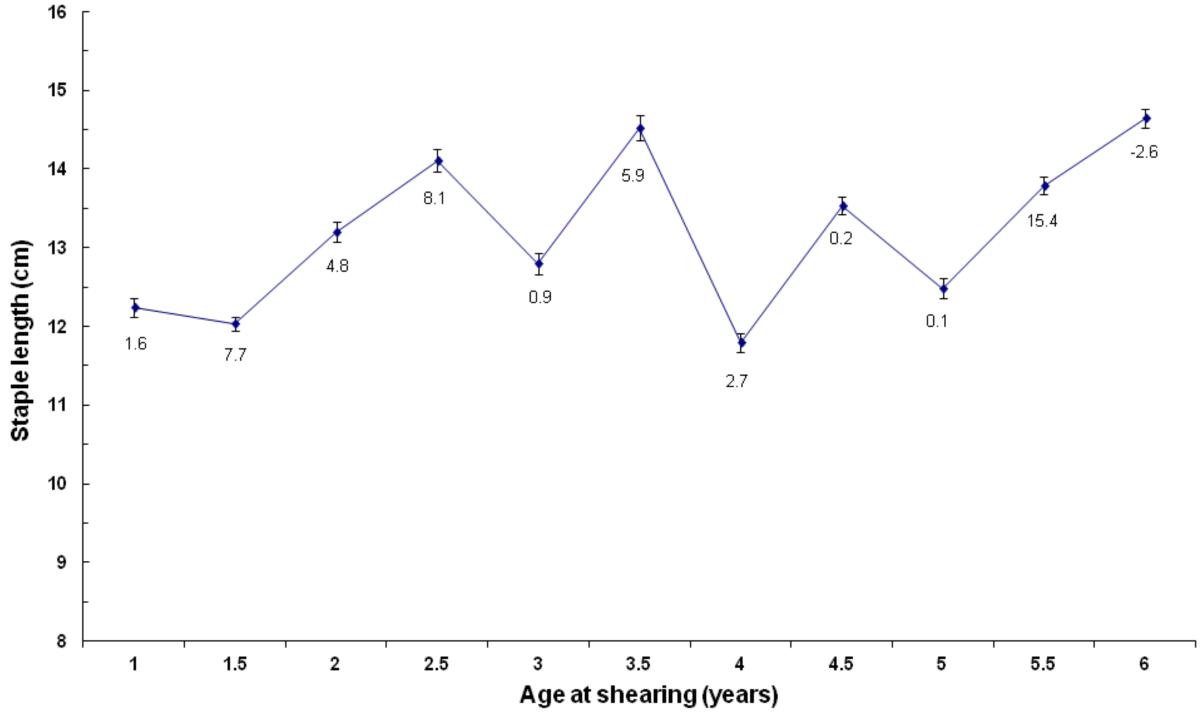

Fig. 3. Effect of deviation of fleece-free liveweight change from average fleece-free liveweight change on staple length deviation, at a given age. Error bars show the 95% confidence intervals. The y-axis covers the same range in staple length as Fig. 1. Effect is adjusted for other terms in the model.

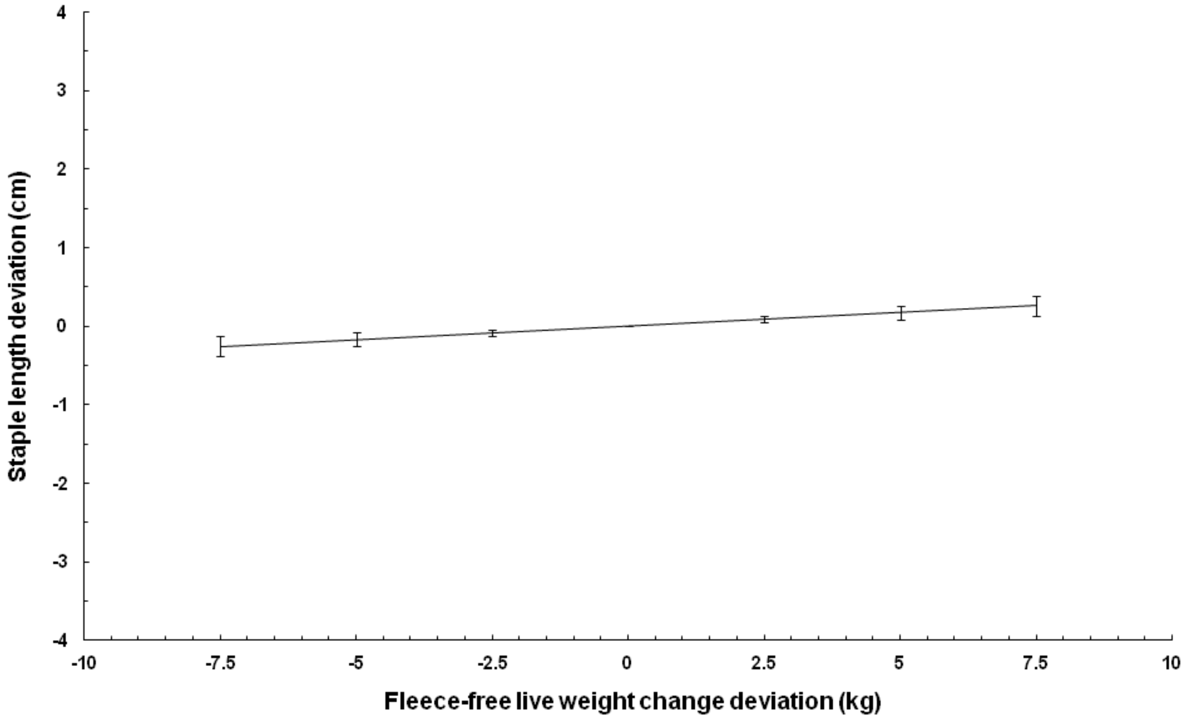

Fig. 4. Effect of deviation of average fleece-free liveweight from average fleece-free liveweight on staple length deviation, at a given age. Error bars show the 95% confidence intervals. The y-axis covers the same range in staple length as Fig. 1. Response is adjusted for all terms in the model (i.e. using parsimonious model with extra term for fleece-free liveweight).

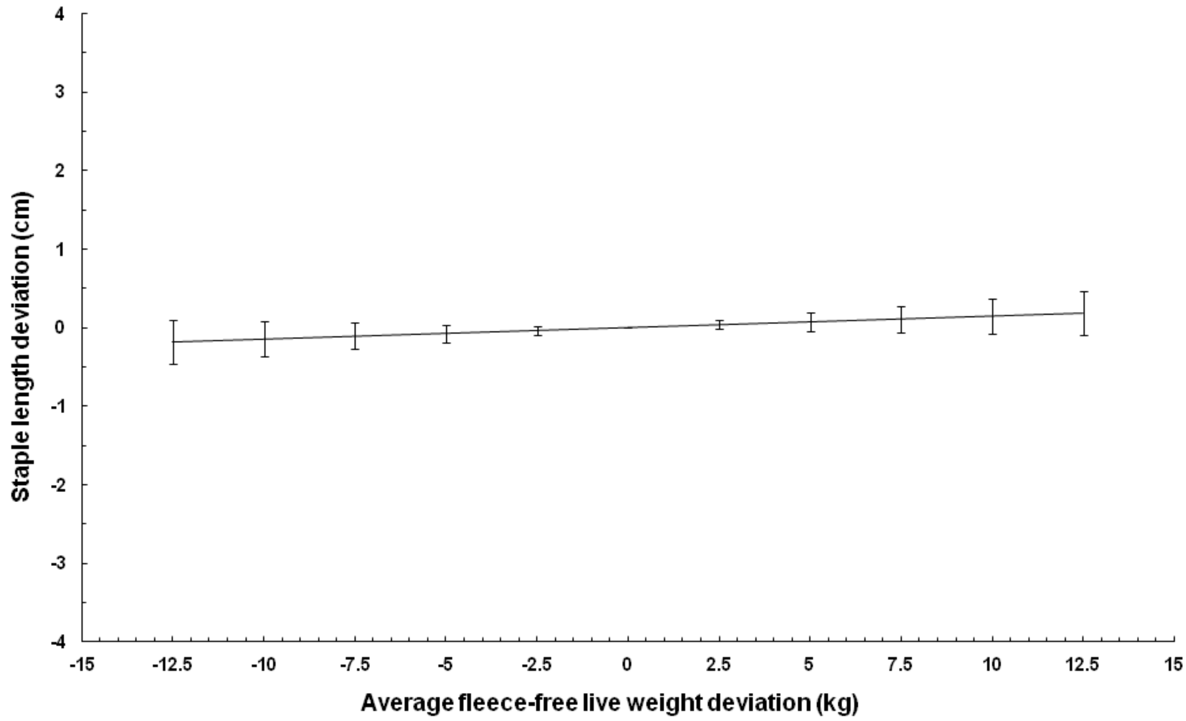

Table 1. Fixed terms in parsimonious model for mohair staple length

Acronym	Factor/variate	Number of levels	Description
Shearyears	Factor	5	4 if CFWt measured at 2 - year - old shearing 5 if CFWt measured at 2½ - year - old shearing 6 if CFWt measured at 3 - year - old shearing 7 if CFWt measured at 3½ - year - old shearing NA otherwise
Shearregime	Factor	8	FebAug if animal was in February and August shearing regime and measured in Shearyears 4 to 7 FebSept if animal was in February and September shearing regime and measured in Shearyears 4 to 7 AprOct if animal was in April and October shearing regime and measured in Shearyears 4 to 7 JunDec if animal was in June and December shearing regime and measured in Shearyears 4 to 7 AugAug if animal was in August and August shearing regime and measured in Shearyears 4 to 7 SeptSept if animal was in September and September shearing regime and measured in Shearyears 4 to 7 Often if animal was in every 3 months shearing regime and measured in Shearyears 4 to 7 NA if measurement taken in other Shearyears
LwtCh	Variate	Not applicable	The change in fleece-free liveweight over the period between shearings
Age	Factor	11	Age (years) at shearing (1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6)

Table 2. Tests for including and excluding effects in the model

P-values in bold are significant at the 5% level

Adjustment to model	Type of test	χ^2/*F*-value	Degrees of freedom	*P*-value
Terms included				
Shearyears by Shearregime interaction	Wald F	13.27	12, 108.1	**2.2×10^{-16}**
Age effect outside Shearing experiment years	Wald F	98.88	6, 98.8	**1.7×10^{-39}**
LwtCh	Wald F	15.47	1, 254.6	**0.00011**
Terms excluded				
Square of LwtCh	Wald F	0.03	1, 227.0	0.87
LwtCh differs with age	Wald F	0.97	10, 252.4	0.47
LwtCh differs with Shearregime	Wald F	1.67	7, 131.3	0.12
Liveweight	Wald F	1.60	1, 233.1	0.21
Single v. Twins	Wald F	0.84	1, 88.8	0.36
Dam age	Wald F	0.18	1, 90.9	0.67
Weaning weight	Wald F	0.56	1, 89.4	0.46
Birth weight	Wald F	0.24	1, 86.8	0.63
Breed	Wald F	0.37	2, 85.3	0.69
Date of birth	Wald F	2.05	16, 69.2	**0.021**
Date of birth when animal born 5 days earlier than all others omitted	Wald F	1.68	15, 70.2	0.075
Sire effect	Deviance	2.58	1	0.11
Dam effect	Deviance	Did not converge		

Table 3. Residual standard deviation (r.s.d.) of staple length (cm) at each age

Age	Residual standard deviation	s.e.(r.s.d.)
1	1.572	0.0304
1.5	1.504	0.0279
2	1.173	0.0247
2.5	1.009	0.0221
3	0.941	0.0203
3.5	1.327	0.0268
4	1.250	0.0249
4.5	1.178	0.0232
5	1.278	0.0255
5.5	1.096	0.0220
6	1.127	0.0228

Table 4. Within animal correlation between ages, after adjusting for fixed terms in the model

Age (years)	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5
1	–	–	–	–	–	–	–	–	–	–
1.5	0.42	–	–	–	–	–	–	–	–	–
2	0.46	0.24	–	–	–	–	–	–	–	–
2.5	0.30	0.43	0.38	–	–	–	–	–	–	–
3	0.16	0.28	0.40	0.37	–	–	–	–	–	–
3.5	0.04	0.17	0.38	0.26	0.50	–	–	–	–	–
4	0.16	0.09	0.26	0.26	0.35	0.51	–	–	–	–
4.5	0.15	0.21	0.30	0.41	0.41	0.53	0.67	–	–	–
5	0.10	0.08	0.31	0.25	0.34	0.28	0.24	0.50	–	–
5.5	0.11	0.25	0.24	0.16	0.32	0.32	0.16	0.50	0.49	–
6	0.15	0.16	0.20	0.21	0.45	0.31	0.23	0.39	0.41	0.56