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The allometric relationship between clean mohair growth and the fleece-free liveweight of Angora goats is affected by liveweight change

B.A. McGregor\textsuperscript{A,B,G}, K.L. Butler\textsuperscript{C} and M.B. Ferguson\textsuperscript{D,E,F}

\textsuperscript{A} Institute for Frontier Materials, Deakin University, Geelong, Vic., 3220, Australia.
\textsuperscript{B} Formerly Livestock Production Sciences, Future Farming Systems Research Division, Department of Primary Industries, Attwood, Vic., 3049, Australia
\textsuperscript{C} Biometrics Unit, Future Farming Systems Research Division, Department of Primary Industries, Werribee, Vic., 3030, Australia
\textsuperscript{D} Department of Agriculture and Food Western Australia, South Perth, W.A., 6151, Australia
\textsuperscript{E} Formerly, Livestock Production Sciences, Future Farming Systems Research Division, Department of Primary Industries, Hamilton, Vic., 3300, Australia
\textsuperscript{F} School of Veterinary and Biomedical Sciences, Murdoch University, Murdoch, WA
\textsuperscript{G} Corresponding author. E-mail address: bruce.mcgregor@deakin.edu.au

Short title: Allometric relationship for mohair growth
Abstract.

Clean fleece weight (CFWt) is affected by liveweight and change in liveweight in Merino sheep, Angora and cashmere goats. However, how these relationships progress as animals age has not been elucidated. Measurements were made over 12 shearing periods on a population of Angora goats representing the current range and diversity of genetic origins 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 does and castrated males (wethers) \((n=267\) animals). 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. The average of the FFLwt at the start of the period and the FFLWt at the end of the period was calculated (AvFFLwt). Liveweight change (LwtCh) was the change in FFLwt over the period between shearings. A restricted maximum likelihood (REML) model was developed for CFWt, after log10 transformation, which allowed the observations of the same animal at different ages to be correlated in an unstructured manner. A simple way of describing the results is: CFWt = \(\kappa (\text{AvFFLwt})^\beta\), where \(\kappa\) is a parameter that can vary in a systematic way with shearing age, shearing treatment and LwtCh; and \(\beta\) is an allometric coefficient that only varies with LwtCh. CFWt was proportional to FFLwt\(^{0.67}\) but only when liveweight was lost at the rate of 5 to 10 kg during a shearing interval of six months. The allometric coefficient declined to 0.3 as LwtCh increased from 10 kg loss to 20 kg gain during a shearing interval. A consequence is that, within an age group of Angora goats, the largest animals will be the least efficient in converting improved nutrition to mohair.

Additional keywords: age effects, efficiency, growth, mohair production, nutritional management.
Introduction

Sheep of wool breeds and Angora goats grow fibre even when chronically undernourished (SCA 1990; McGregor 2010a). Wool, cashmere and mohair production are related to liveweight and liveweight change of the producing animals (Sharkey and Hedding 1964; Allden 1969; Allden 1979; McGregor 1992a, 2010a). However, how these relationships progress as animals age has not been elucidated.

In our earlier work we reported that the lifetime change in mohair mean fibre diameter (MFD) was proportional to the cube root of the fleece-free liveweight (FFLwt) of Angora goats and this was true for three Angora goat genotypes (McGregor et al. 2012). Such allometric relationships are common in goat production and elsewhere in biology (Schmidt-Nielsen 1984, McGregor 1992b). However we can find no evidence that fleece weight of Angora goats or Merino sheep nor for any measurement of the pelage of mammals is allometrically related to liveweight of the animals in question (Gall 1981; Schmidt-Nielsen 1984; SCA 1990; Cottle 2010).

In the absence of objective information about lifetime changes in clean fleece weight as Angora goats age and grow, we investigated the relationship between clean mohair weight and age, liveweight and other lifetime factors on a population of Angora goats representing the current range and diversity of genetic origins in Australia. We aimed to use these relationships to define appropriate allometric relationships between clean mohair weight and goat size, and then discuss these results in terms of efficiency of mohair production between animals within a flock.

Materials and methods

General

Management details have been provided by McGregor and Butler (2008a) and McGregor et al. (2012). In brief, Angora goats born in September 2002 in a progeny testing evaluation at Horsham, Victoria, (36°42'50"S, 142°18'30"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 does and 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 wether goats 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 2010a,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 2008a). 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 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 treatments arranged as a 7 Shearing treatments by 3 Genetic strains factorial (McGregor and Butler 2008a). 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 2008a). 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. The mid-side samples were then tested to determine clean washing yield (CWY, %w/w, IWTO 2006).

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. Clean fleece weight at a shearing (CFWt) was determined as: total greasy fleece weight including weight of crutchings (kg) × CWY (as a proportion).

A restricted maximum likelihood (REML) model was developed for CFWt, after \( \log_{10} \) transformation, 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 Chi-square-tests (Payne 2010). The Wald Chi-square was used rather than the Wald F test because, as is common with more complicated REML models, the algorithm for calculating the numerator degrees of freedom needed for the Wald F tests failed numerically. Once a parsimonious fixed effects model had been established, random sire effects and random dam effects were examined for inclusion in the model by using chi-squared change in deviance tests. In the results the symbol, *, represents a crossing operator. Two outliers at age 4 and two outliers at age 5 were deleted on the basis that their greasy fleece weights were outliers. Confidence intervals are constructed using the asymptotic normal distribution of the logarithm of CFWt, and then back transforming.

Results
There was considerable variation in greasy and clean fleece weights during the study (Table 1; Fig. 1). Greasy fleece weight for a 6-month shearing interval averaged 2.21 kg and CWY averaged 85.3%. There was considerable variation in CFWt at any shearing (Fig. 1). The trend for CFWt was to fluctuate from shearing to shearing with an increase for the summer shearing (ages 1.5, 2.5, 3.5, 4.5, 5.5 compared with the previous winter shearing (Fig. 1). AvFFLwt varied from a lowest value of 10.4 kg at age 1 year up to a greatest value of 73.3 kg at age 6 years with LwtCh varying from a lowest value of -13.8 at age 6 years to a largest value of
+22.8 kg at age 5.5 years (Table 1, Fig. 2). The relationship between LwtCh and AvFFLwt differed considerably between shearing periods (Fig. 2).

The fixed effects in the model for the logarithm of CFWt can be represented as (Table 2, 3):

\[
\log_{10}(CFWt) = \text{Shearyears}\times\text{Shearregime} + \text{Age}\times\text{LwtCh} + \log(\text{AvFFLwt}) + \\
\log(\text{AvFFLwt})\times\text{LwtCh} + \text{Age}^2\times\log(\text{AvFFLwt})
\]

There was no evidence (P > 0.1, Table 3) for sire or dam effects, and thus terms for these effects are not included in the model.

Some of the complexity of the fixed effect component of the parsimonious model is specific to explaining variation at the 2-year shearing. For the remainder of the shearings, a simple way of describing the results is:

\[
\text{CFWt} = \kappa (\text{AvFFLwt})^\beta
\]

where \(\kappa\) is a parameter that can vary in a systematic way with shearing age, shearing treatment and LwtCh; and \(\beta\) is an allometric coefficient that only varies with LwtCh. Thus, for a given LwtCh, CFWt is allometrically related to AvFFLwt, although the constant of proportionality changes with shearing age, shearing treatment and LwtCh. Using the standard shearing interval for Angora goats of 6 months, the allometric coefficient declined from 0.70 at -10 kg LwtCh during the shearing interval to 0.27 at + 20 kg LwtCh during the shearing interval (Fig. 3).

Angora goats that had high liveweight gain during the period of fleece growth grew more CFWt than goats that had low liveweight gain or liveweight loss (Table 3; Fig. 4). At any shearing age, the differences in CFWt were greater at lower liveweights (up to 0.25 kg) compared with higher liveweights (Fig. 4).

The residual standard deviation of the logarithm of CFWt was relatively stable between 1 year old to 4.5 years old (Table 4). The residual standard deviation was somewhat greater at ages 5, 5.5 and 6.0 years old compared with younger ages.

Generally, correlations declined between shearing ages further apart (Table 5). 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, 1.5 and 2 with shearing ages > 4 years were ≤ 0.36, but at shearing ages ≥ 2.5 years the correlations at any older age were 0.51–0.87.
Discussion

Influence of AvFFLwt and LwtCh

The results indicate that there is an allometric relationship between clean mohair growth and the AvFFLwt of Angora goats during a shearing interval. As an animal increases in size, the cross sectional area of each fibre will increase proportionally with the cross sectional area of its follicle (Hynd 1994), which in turn is likely to be proportional to the skin surface area (Black 1987). To the extent that goats of different sizes are morphologically similar (i.e. have the same geometric shape), the skin surface area will be proportional to (animal volume)\(^{0.67}\) (Schmidt-Nielsen 1984); the general allometric relationship between surface area and volume of similar three-dimensional objects. In turn, to the extent that goats of different sizes are compositionally similar (i.e. have the same density = weight ÷ volume), animal volume will be proportional to liveweight (FFLwt). It follows that, to the extent that the implied assumptions are true, the cross sectional area of each fibre will be proportional to (FFLwt)\(^{0.67}\) (Turner 1959).

The number of fibres produced by an Angora goat is determined by the number of fibre follicles produced pre- and post natally (Margolena 1974), and excepting for follicle shutdown, does not change as an animal becomes larger. Thus we might expect that the cross-sectional area of all fibres (on the fleece) combined is also proportional to (FFLwt)\(^{0.67}\). It follows that to the extent that fibre length and fibre density (weight to volume) do not change with animal size, then we might expect that clean mohair growth (CFWt) will be proportional to (FFLwt)\(^{0.67}\).

What we have found is that, for animals of the same age, CFWt was proportional to FFLwt\(^{0.67}\) but only when liveweight was lost at the rate of 5 to 10 kg during a shearing interval of six months (Fig. 3). Furthermore, the relationship at maintenance and positive rates of liveweight change was proportional to AvFFLwt\(^{k}\), where \(k\) is considerably less than 0.67. This implies that factors, other than the simple geometric relationships described, are affecting mohair growth resulting in clean fleece growth being proportional to AvFFLwt\(^{(0.67-x)}\), where \(x\) relates to these other factors. Possible factors affecting the fleece growth to liveweight proportionality constant include: the assumption that body
density is constant as liveweight increases; smaller and larger animals are morphologically similar and
thus the allometric relationship between volume and weight holds; the assumption that the specific
density of fibres is constant as liveweight increases; the assumption that fibre length does not change
with animal size; and the assumption that the number of growing fibres is constant as liveweight
increases.

An alternative, but perhaps equivalent, interpretation of the results is that Angora goats are
only fully efficient with respect to converting nutrients into mohair when those goats are losing
liveweight. This implies that circulating substrates supplied from catabolism and nutrients digested at
that time are preferentially diverted to mohair growth. What this implies is that, from the animals
perspective, growing fibre is a core survival function. This agrees with previous work that under good
nutrition Angora goats tend to store fat (McGregor 1992b) whilst with poorer nutrition animals tend to
store more energy in growth, both of the body and in the fibre. This preferential diversion of nutrients
co-exists with the generally observed results that mohair production increases as size of animal
increases and as animal growth increases (McGregor 2010a). Our conclusion is in accord with
Ferguson (1962) who found that, in Merino sheep, animals that are growing are much less efficient in
converting intake into wool than are sheep that are below maintenance. The conclusion is not in
accord with Pattie and Williams (1967), who concluded the opposite to Ferguson (1962).

Practical Implications
An important practical finding is that, in any given year, the difference in fleece production between
the animals growing the most and those growing the least, is larger in smaller animals than in larger
animals (Fig. 4). This is evidence that smaller Angora goats were more responsive to nutrition than
larger animals, since liveweight change is an indicator of the nutrition of the individual.

Thus in relation to flock structure, the results indicate that, within an age group of Angora
goats, the largest animals will be the least efficient in converting improved nutrition to mohair (Fig.
4). Our previous report indicated that the largest animals are also likely to grow the coarsest and
therefore least valuable mohair (McGregor et al. 2012). These findings together indicate that if
animals are to be culled from a flock that is likely to have good quality nutrition, then it is the largest
animals which should be culled first. Conversely, when nutrition is below maintenance, there are larger differences in mohair production between small and large animals. In this case, it is possibly beneficial to cull small animals because animal costs are normally on a per head basis and this would reduce cost per unit of mohair production.

If the efficiency of mohair growth declines as liveweight increases, as will happen with good nutrition, then a consequence is that for the same total of feed a larger number of animals consuming a lower amount of feed each will produce more mohair than fewer animals consuming a larger amount of feed each. This leads to a rule of thumb that smaller Angoras will tend be more economically productive in more biologically productive environments, while larger goats will tend to be more economically productive in less biologically productive environments. However, we caution that increasing stocking rate of Angora goats to levels above those recommended for Merino sheep is not advised (McGregor and Butler 2008b; McGregor 2010a,b).

For animal health and reproductive reasons, it is often recommended to selectively concentrate nutrition on the smaller animals of a sheep or goat flock. Our results indicate that this is also likely to be beneficial for mohair production.

Influence of other factors

There was a difference between shearings in CFWt, even after accounting for the effects of liveweight and liveweight change (Fig. 4). These effects are likely to be environmental because the effect does not change in a simple systematic way as the goats age (Fig. 4). This indicates that there are major environmental effects that affect fleece weight, which are not reflected in the liveweight or changes in liveweight of the animal.

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 3). This relates to the previous results that shearing interval has a major effect on fleece weight and other fleece attributes (McGregor and Butler 2008a).

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 3). 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 3). This suggests that the genetic effects on CFWt are mostly intermediated via differences in liveweight as has been suggested for Merino sheep (Thompson and Barlow 1986). A positive phenotypic relationship between liveweight and mohair CFWt has been reported in previous studies of Angora goats from South Africa, Texas, Turkey, Australia and New Zealand (Shelton and Bassett 1970; Yalçin et al. 1979; Nicoll et al. 1989; Gifford et al. 1991; Snyman and Olivier 1996). Wool CFWt is also phenotypically positively related to liveweight of Merino sheep (Huisman and Brown 2008).

For any specified liveweight change, at the fourth shearing (2.0 years old) the allometric coefficient was 0.4 (se = 0.07, \( P = 1 \times 10^{-7} \)), less than the coefficient at other shearings. We suggest that these effects are artefacts of no reliable pre-shearing liveweight for the third shearing. For all other shearings a liveweight was taken within two days of shearing. For the third shearing the nearest liveweight prior to shearing was taken three months earlier at 15 months of age and following shearing one month later. During this time period the goats experienced drought and liveweight loss averaging 1 kg but varying from -7 to +7 kg between goats. Following their third shearing the goats were also transferred to the research farm over a distance > 300 km.

Random variation

The increase in the residual standard deviation of the logarithm of CFWt at ages 5, 5.5 and 6.0 years old may reflect two differing effects. All animals in this study grew typical “solid” mohair fleeces until age 5 when several fleeces “blew up” in the sense that they lost their mohair crimping structure (character) and became fluffy. This may reflect changes in follicle activity as reported by Margolena (1974). The second effect was the impact of incisor wear on CFWt during the last year of this study. The wear of 30% of the first permanent incisors was associated with a 20% decline in CFWt (McGregor and Butler 2011).
The within animal correlation generally declined to levels well below 0.5 when comparing shearings at < 2 years old with shearings at older ages (Table 5). This could indicate that ranking of animals in their efficiency of producing mohair can change substantially as the goats become older.

Conclusion

CFWt was proportional to FFLwt^{0.67} but only when liveweight was lost at the rate of 5 to 10 kg during a shearing interval of six months. Furthermore, the relationship at maintenance and positive rates of liveweight change was proportional to AvFFLwt^k, where k is considerably less than 0.67. A consequence is that, within an age group of Angora goats, the largest animals will be the least efficient in converting improved nutrition to mohair.

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. John Hornweg is thanked for his dedicated shearing services. Mrs Val Park, Riverina Fleece Testing Services, formerly at Albury, provided fleece testing services.

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Fig. 1. The range in clean fleece weight for each shearing age for shearing intervals of 6 months.
Fig. 2. The relationship between fleece-free liveweight change (y-axis) and the average fleece-free liveweight (x-axis) of Angora wether goats for each shearing age. Ages are a) 1 year; b) 1.5 years; c) 2 years; d) 2.5 years; e) 3 years; f) 3.5 years; g) 4 years; h) 4.5 years; i) 5 years; j) 5.5 years; k) 6 years of age.
**Fig. 3.** Relationship between the allometric coefficient ($\beta$), relating clean fleece weight to average fleece-free liveweight, and fleece-free liveweight change during a fleece growing period of 6 months for Angora goats aged between 1 year and 6 years of age. Bars show 95% confidence limits.
Fig. 4. Relationship between clean fleece weight and average fleece-free liveweight at different ages for animals that have high and low fleece-free liveweight change during the period of fleece growth (6 months). Low fleece-free liveweight change is -5.0 kg at 4, 4.5 and 5 years of age; -2.5 kg at 1 and 3 years of age; 0 kg at 2 and 6 years of age; + 2.5 kg at 1.5, 2.5 and 3.5 years of age; and 10 kg at 5.5 years of age. High fleece-free liveweight change is 2.5 kg at 1 and 3.5 years of age; 5 kg at 4, 4.5 and 5 years of age; 10 kg at 2 and 3.5 years of age; 12.5 kg at 1.5 years of age, and 20 kg at 5.5 and 6 years of age. Symbols: dotted line, high liveweight change; solid line, low liveweight change. For 2 to 3.5 years of age values are equally weighted, on the log scale for clean fleece weight, for each shearing treatment occurring at that age. Bars represent 95% confidence intervals. Ages are a) 1 year; b) 1.5 years; c) 2 years; d) 2.5 years; e) 3 years; f) 3.5 years; g) 4 years; h) 4.5 years; i) 5 years; j) 5.5 years; k) 6 years of age.
Table 1. Mean, standard deviation (s.d.) and range in greasy and clean fleece weight, clean washing yield, average fleece-free liveweight and average fleece-free liveweight change for Angora wether goats shorn every six months from ages 1 to 6 years of age ($n = 872$).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>s.d.</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greasy fleece weight (kg)</td>
<td>2.21</td>
<td>0.641</td>
<td>0.79</td>
<td>4.64</td>
</tr>
<tr>
<td>Clean washing yield (% w/w)</td>
<td>85.3</td>
<td>5.33</td>
<td>63.6</td>
<td>97.7</td>
</tr>
<tr>
<td>Clean fleece weight (kg)</td>
<td>1.89</td>
<td>0.562</td>
<td>0.66</td>
<td>3.85</td>
</tr>
<tr>
<td>Average liveweight (kg)</td>
<td>38.7</td>
<td>14.26</td>
<td>10.4</td>
<td>73.3</td>
</tr>
<tr>
<td>Average liveweight change (kg)</td>
<td>4.0</td>
<td>5.86</td>
<td>-13.8</td>
<td>22.8</td>
</tr>
</tbody>
</table>
### Table 2. Fixed terms in parsimonious growth curve model for the $\log_{10}(\text{clean fleece weight, CFWt})$

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Factor/Variate</th>
<th>Number of levels</th>
<th>Description</th>
</tr>
</thead>
</table>
| Shearyears    | Factor         | 5                | 4 if CFWt measured at 2 - year - old shearing  
5 if CFWt measured at $2\frac{1}{2}$ - year - old shearing  
6 if CFWt measured at 3 - year - old shearing  
7 if CFWt measured at $3\frac{1}{2}$ - year - old shearing  
NA otherwise  
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   | $\log_{10}$ (average of the fleece-free liveweight at the start of the period and end of period)                                           |
| Age2          | Factor         | 2                | The change in fleece-free liveweight over the period between shearing                                                                  |
| Age           | Factor         | 11               | Indicator of whether measurement taken at 2-year-old  
Age (years) at shearing (1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6)                                                                 |
Table 3. Tests for including and excluding effects in the model (see Table 2 for definitions)

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

<table>
<thead>
<tr>
<th>Adjustment to model</th>
<th>Type of test</th>
<th>$\chi^2$ value</th>
<th>Degrees of freedom</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terms included</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shearyears by Shearregime interaction</td>
<td>Wald</td>
<td>439.58</td>
<td>12</td>
<td>$1.5 \times 10^{-6}$</td>
</tr>
<tr>
<td>LwtCh effect differs with Age</td>
<td>Wald</td>
<td>37.74</td>
<td>10</td>
<td>$4.2 \times 10^{-5}$</td>
</tr>
<tr>
<td>LogAvFFLwt effect is different at Age2</td>
<td>Wald</td>
<td>27.97</td>
<td>1</td>
<td>$1.2 \times 10^{-7}$</td>
</tr>
<tr>
<td>Product of LogAvFFLwt and LwtCh</td>
<td>Wald</td>
<td>18.58</td>
<td>1</td>
<td>$1.6 \times 10^{-5}$</td>
</tr>
<tr>
<td>Terms excluded</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Square of LwtCh</td>
<td>Wald</td>
<td>0.05</td>
<td>1</td>
<td>0.82</td>
</tr>
<tr>
<td>Square LogAvFFLwt</td>
<td>Wald</td>
<td>2.20</td>
<td>1</td>
<td>0.14</td>
</tr>
<tr>
<td>LogAvFFLwt differs with each Age</td>
<td>Wald</td>
<td>8.22</td>
<td>9</td>
<td>0.51</td>
</tr>
<tr>
<td>Product of LogAvFFLwt and LwtCh differs at Age2</td>
<td>Wald</td>
<td>0.14</td>
<td>1</td>
<td>0.71</td>
</tr>
<tr>
<td>LogAvFFLwt differs with Shearregime</td>
<td>Wald</td>
<td>6.11</td>
<td>7</td>
<td>0.53</td>
</tr>
<tr>
<td>LwtCh differs with Shearregime</td>
<td>Wald</td>
<td>13.98</td>
<td>6</td>
<td><strong>0.030</strong></td>
</tr>
<tr>
<td>Weaningwt</td>
<td>Wald</td>
<td>0.59</td>
<td>1</td>
<td>0.44</td>
</tr>
<tr>
<td>Birthwt</td>
<td>Wald</td>
<td>0.87</td>
<td>1</td>
<td>0.35</td>
</tr>
<tr>
<td>Breed</td>
<td>Wald</td>
<td>2.41</td>
<td>2</td>
<td>0.30</td>
</tr>
<tr>
<td>DOB</td>
<td>Wald</td>
<td>25.29</td>
<td>16</td>
<td>0.065</td>
</tr>
<tr>
<td>Single vs Twins</td>
<td>Wald</td>
<td>0.57</td>
<td>1</td>
<td>0.45</td>
</tr>
<tr>
<td>Dam age</td>
<td>Wald</td>
<td>0.80</td>
<td>1</td>
<td>0.37</td>
</tr>
<tr>
<td>Sire effect</td>
<td>Deviance</td>
<td>0.43</td>
<td>1</td>
<td>0.51</td>
</tr>
<tr>
<td>Dam effect</td>
<td>Deviance</td>
<td>0.65</td>
<td>1</td>
<td>0.42</td>
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Table 4. Residual standard deviation (r.s.d.) of the logarithm of clean fleece weight at each age

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<tr>
<th>Age</th>
<th>r.s.d.</th>
<th>s.e.(r.s.d.)</th>
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<tbody>
<tr>
<td>1</td>
<td>0.058</td>
<td>0.0023</td>
</tr>
<tr>
<td>1.5</td>
<td>0.060</td>
<td>0.0023</td>
</tr>
<tr>
<td>2</td>
<td>0.063</td>
<td>0.0029</td>
</tr>
<tr>
<td>2.5</td>
<td>0.062</td>
<td>0.0025</td>
</tr>
<tr>
<td>3</td>
<td>0.048</td>
<td>0.0022</td>
</tr>
<tr>
<td>3.5</td>
<td>0.058</td>
<td>0.0022</td>
</tr>
<tr>
<td>4</td>
<td>0.061</td>
<td>0.0025</td>
</tr>
<tr>
<td>4.5</td>
<td>0.064</td>
<td>0.0024</td>
</tr>
<tr>
<td>5</td>
<td>0.080</td>
<td>0.0026</td>
</tr>
<tr>
<td>5.5</td>
<td>0.113</td>
<td>0.0026</td>
</tr>
<tr>
<td>6</td>
<td>0.090</td>
<td>0.0025</td>
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</table>
Table 5. Within animal correlation between ages, after adjusting for fixed terms in the model

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<tr>
<th>Age (years)</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
<th>3.5</th>
<th>4</th>
<th>4.5</th>
<th>5</th>
<th>5.5</th>
</tr>
</thead>
<tbody>
<tr>
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<td>–</td>
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<td>–</td>
</tr>
<tr>
<td>2</td>
<td>0.66</td>
<td>0.66</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<td>–</td>
</tr>
<tr>
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<td>0.48</td>
<td>0.75</td>
<td>0.47</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>3</td>
<td>0.50</td>
<td>0.63</td>
<td>0.60</td>
<td>0.69</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>3.5</td>
<td>0.41</td>
<td>0.69</td>
<td>0.55</td>
<td>0.87</td>
<td>0.82</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>4</td>
<td>0.42</td>
<td>0.54</td>
<td>0.53</td>
<td>0.65</td>
<td>0.75</td>
<td>0.79</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>4.5</td>
<td>0.36</td>
<td>0.58</td>
<td>0.49</td>
<td>0.71</td>
<td>0.67</td>
<td>0.78</td>
<td>0.73</td>
<td>–</td>
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<td>–</td>
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<tr>
<td>5</td>
<td>0.34</td>
<td>0.43</td>
<td>0.38</td>
<td>0.46</td>
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<td>0.54</td>
<td>0.42</td>
<td>0.63</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>5.5</td>
<td>0.18</td>
<td>0.35</td>
<td>0.34</td>
<td>0.63</td>
<td>0.54</td>
<td>0.62</td>
<td>0.52</td>
<td>0.69</td>
<td>0.55</td>
<td>–</td>
</tr>
<tr>
<td>6</td>
<td>0.18</td>
<td>0.31</td>
<td>0.33</td>
<td>0.51</td>
<td>0.57</td>
<td>0.54</td>
<td>0.47</td>
<td>0.58</td>
<td>0.69</td>
<td>0.85</td>
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</table>