Cyclical Fleece Growth in Cashmere Goats

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Abstract

Seasonal changes in fleece parameters were studied in mature feral doe goats, known to produce commercial quantities of cashmere and housed in natural light (NL) or continuous light (CL).

Circannual changes in volume growth rate (VGR) of cashmere in NL were asynchronous with those of hair, resulting in maxima in April and November respectively, indicating that follicle-specific mechanisms are controlling the rate of follicle activities.

Cycles of cumulative length of cashmere and hair in NL were synchronous. Cashmere maxima of 64·0 and 62·3 mm occurred in June and July respectively for two consecutive years. Distinct circannual cycles of linear growth (period, 365 days) were evident. While exposure to CL initially reduced the cycle period, after 2 years an extended cycle period emerged; this may have been due to photodesensitization.

In NL, cashmere fibre diameter minima occurred at June–July and February each year. Hair fibres underwent only one cycle of diameter change each year. The period of the cycles was reduced by CL.

An annual cycle of cashmere brush end fibre formation was apparent in NL. This cycle was associated with the cessation of growth in June–July, and a subsidiary event occurred between December and March. Continuous light accelerated brush end formation.

Cyclic fibre shedding produced a circannual rhythm in fleece composition with maximum cashmere: hair ratio (CHR) in April–May in non-breeding goats. The maximum CHR of 5·9:1 in NL did not reach its potential, as illustrated by the follicle S:P ratio of 6·9:1 in the skin. This suggests an irreversible loss of cashmere fibres from the fleece following the cycle of brush end formation in February.

The maximum mean length of cashmere and time of occurrence were similar in grazing and penned does, although grazing does were only sampled in 4 months of one year.

Introduction

The presence, macroscopic and microscopic morphology, and general dimensions of two distinct fibre types (cashmere and hair) in the fleece of the goat have been reported previously by Burns *et al.* (1962), Ryder and Stephenson (1968), Epstein (1969) and Smith *et al.* (1973).

The process of seasonal fibre shedding in Saanen, Toggenburg and Saanen × Angora goats was described by Ryder (1966). Holst *et al.* (1982) detailed changes in cashmere length in a group of goats for part of the growth cycle during the period April–September. These workers emphasized the problems associated with harvesting fleece at the appropriate time of the year to achieve maximum production.

Since the value of a cashmere fleece is determined by diameter, colour and weight of the cashmere fibre, circannual changes in diameter and other fleece components which contribute to weight will influence the financial return from each

goat. Accordingly, the present work was designed to measure in detail the changes in fleece components (except colour) for periods ranging from 5 months in a grazing study to 2 years 10 months under controlled conditions. The aim of this research was, firstly, to identify the combination of fleece components which maximize production and, secondly, to determine some aspects of the role of photoperiod in controlling the fleece growth cycle. A brief report on preliminary data on cashmere length, diameter and fleece composition was presented by McDonald (1985).

Materials and Methods

Pen Study

Ten mature feral does (*Capra hircus*), which were known to produce commercial quantities of cashmere and which had undergone pregnancy and lactation in the previous 12 months, were allocated to two groups of five by stratified randomization of their cashmere production at shearing. The goats were housed individually in pens and offered an above maintenance ration of 700 g pelleted lucerne daily. One group was located in a natural light (NL) environment where photoperiod was the normal light duration for latitude 27° 28' S. At this latitude the summer and winter solstice occurs on 22 December and 21 June respectively. The other group was located in continuous light (CL) which was provided by cool white fluorescent tubes and natural light. The minimum light intensity in this environment was 160 lux during ambient darkness. All does were exposed to ambient temperature.

Radioisotope (3·7 MBq L – [^{35}S] cysteine [Radiochemical Centre, Amersham]) was administered to each goat by intravenous injection every 28 days. Midside fleece samples were plucked 14 days after radioisotope administration, and the fibres were used to prepare autoradiographs (Downes *et al.* 1967). The volume growth rates of 100 cashmere and 100 hair fibres were measured by microprojection of the autoradiographs.

At the time of radioisotope administration, two fleece samples were cut at skin level and another sample was plucked. One hundred cashmere fibres and 100 hair fibres were randomly collected from one of the cut samples and their lengths measured against a rule. The diameters of 200 fibres (both cashmere and hair) were measured by the method of Chapman (1960), on snippets cut 5 mm from the proximal end of the other cut sample. Non-medullated fibres with a diameter of 28 μm or less were classified as cashmere. Cashmere:hair ratio (CHR) in the fleece sample was calculated by counting the number of fibres in each category of the fibre diameter measurements.

Percentage of brush end fibres in the fleece was determined from the plucked sample. Snippets approximately 2 mm in length were cut from the proximal end of the plucked sample, and a series of slides was prepared by mounting random subsamples of the snippets in liquid paraffin. Fibre root ends were examined under a projection microscope ($\times 112$). A higher magnification ($\times 500$) was used where necessary to differentiate between brush end and normal roots, the numbers of which were recorded separately. The total number of fibre roots counted for each sample varied between 225 and 330. Cut fibre ends were not counted.

A midside skin sample was taken from each goat with a 10 mm diameter trephine at the commencement of the experiment. The samples were fixed in isotonic neutral formalin and serial 8 μm thick transverse sections were cut distal to the sebaceous gland. The sections were stained with haematoxylin, eosin and picric acid, and examined under light microscopy. The secondary:primary ratio was calculated from counts of the respective follicles.

Paddock Study

A midside fleece sample was cut at skin level from each of 29 does in March, May, June and July 1985. The does were grazing native pasture at latitude 28° 13' S. Mean cashmere and hair fibre length was measured as in the pen study. Similarly, fibre diameter and CHR were determined on a cut midside fleece sample taken before shearing on 16 July. Fleeces were weighed individually and a random sample was collected from each. The proportion (yield %) of cashmere by weight was determined by separating cashmere and hair fibres in a Shirley Analyser (Australian Wool Testing Authority Limited, Guildford, N.S.W.). The cashmere produced by each animal was estimated from these values. The does were joined to bucks in April and all produced kids.

Results

Pen Study

Volume growth rate

Changes in volume growth rate (VGR) of cashmere in NL are presented in Fig. 1(a). During 1983, VGR declined from the end of April to the end of September. The period of greatest reduction in VGR was the month of June. There was no growth of cashmere in the 112 days from 2 September to 22 December, following which there was a rapid increase in VGR up to and including April. The period of greatest increase in VGR was from December to February (0–102·4 × 10^3 μm^3 day^{-1}). Maximum VGR of 153·7 × 10^3 μm^3 day^{-1} occurred in April 1984. This maximum exceeded that of 88·1 × 10^3 μm^3 day^{-1} in April 1983. The VGR of hair in NL (Fig. 1(b)) declined to a minimum in August. There was a rapid increase in October and again in November when the maximum of 4722·7 × 10^3 μm^3 day^{-1} occurred. Between November and April VGR of hair declined.
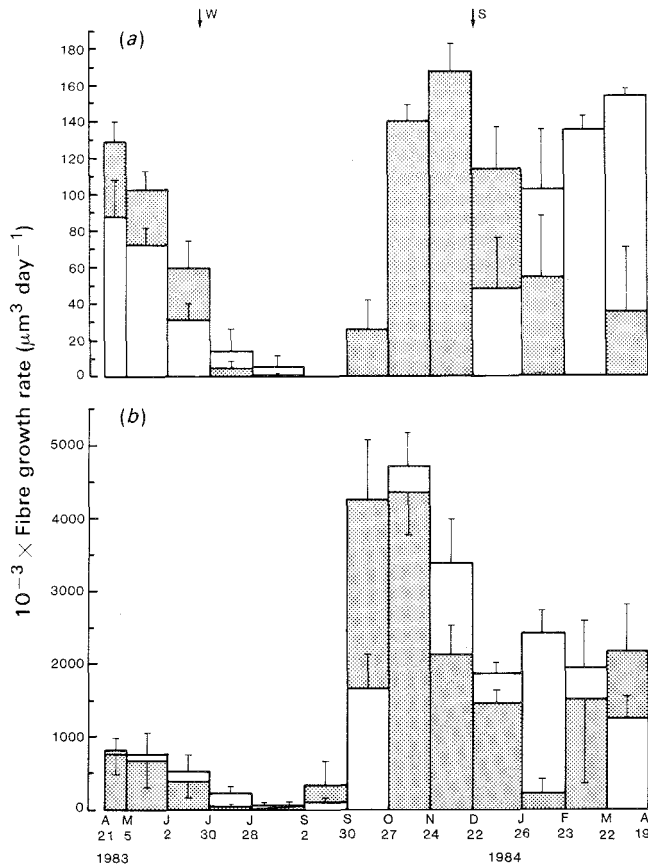

Fig. 1. Fibre volume growth rate of (a) cashmere and (b) hair in natural (□) and continuous (stippled) light. Winter (W) and summer (S) solstice. Vertical bars denote ± s.e.

The VGR of cashmere in CL (Fig. 1(a)) exceeded that in NL until July. There was little or no growth for the 56 days in August and September, following which VGR increased rapidly. Maximum VGR of 167·6 × 10^3 μm^3 day^{-1} was reached

in 84 days. This rate of growth occurred 112 days before the maximum in NL. Maximum VGR in CL occurred in December 1983, when there was no volume growth in NL. There was little difference between the maximum VGR in NL and CL. Exposure to CL produced no difference in the VGR of hair (Fig. 1(*b*)) when compared with that in NL up to the end of September. During the next 28 days there was a marked increase in VGR to a maximum of 4257·7 and 4355·3 × 10^3 μm^3 day^{-1} in October and November respectively. The VGR of hair in CL declined (from November to February) more rapidly than that in NL and reached a minimum in 84 days. While VGR in NL was still declining, in CL it began to increase following the minimum. Continuous light tended to synchronize the VGR of cashmere and hair by advancing the time at which cashmere commenced growth.
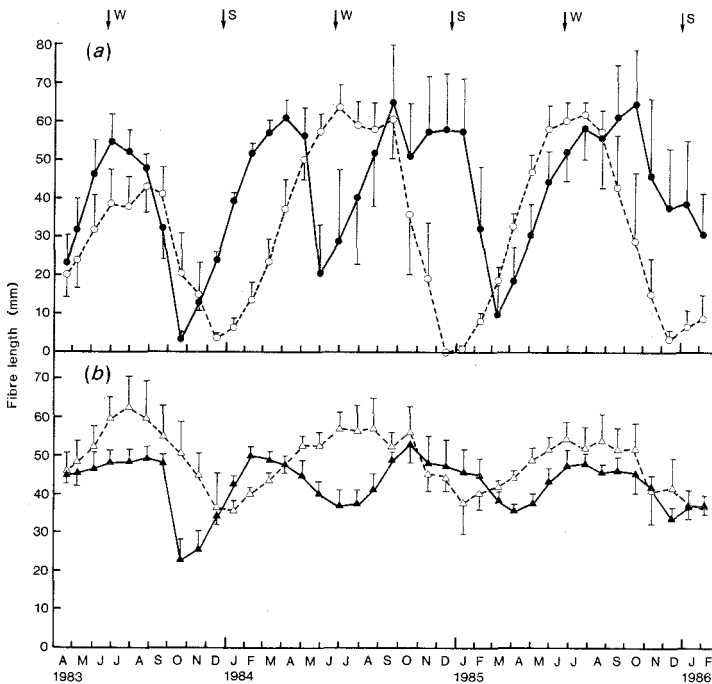

Fig. 2. Fibre length of (*a*) cashmere in natural (○) and continuous (●) light and (*b*) hair in natural (△) and continuous (▲) light. Winter (W) and summer (S) solstice. Vertical bars denote ± s.e.

Length

Throughout the experiment the length of cashmere in the fleece of goats in NL began to increase following the summer solstice in December 1983, 1984 and 1985 (Fig. 2(*a*)). Three growth cycles are delineated by minima in December. Maximum cashmere length of 43·1, 64·0 and 62·3 mm occurred in late August, June and July in 1983, 1984 and 1985 respectively. In 1984 the shape of the graph was somewhat bimodal, with little change in length for 84 days between June and September.

Linear growth rate (mean ± s.e.) of cashmere was greatest in March and April (0·51 ± 0·09 and 0·47 ± 0·07 mm day^{-1} respectively in 1984; 0·51 ± 0·03 and 0·49 ± 0·07 in 1985).

The amplitude of the rhythm of hair length (Fig. 2(b)) in NL was clearly less than that of cashmere. Maximum and minimum length occurred at the same time in both hair and cashmere. In 1983, hair length (62·3 mm) exceeded that of cashmere, whereas in 1984 and 1985, hair length (56·7 and 53·8 mm respectively) was less than cashmere length. Maximum length of hair in each growth cycle declined throughout the experiment.

Exposure to CL altered the cycle of cashmere linear growth (Fig. 2(a)) when compared to that in NL. Growth cycles in CL were delineated by points of minimum fibre length of 3·3, 20·6 and 9·7 mm in October 1983, May 1984 and March 1985, respectively. The periods of cycles 2 and 3 were 224 and 280 days respectively. During the first growth cycle in CL in 1983 maximum cashmere length of 55·1 mm in June was 12·0 mm greater than that achieved in NL in August. Thereafter, little difference between maximum cashmere length in CL and NL was evident. The reduced cycle in CL during 1983 and 1984 was achieved by accelerated growth rate to maxima in June 1983 and April 1984, such that in the latter year the maximum in CL was achieved 84 days before the maximum in NL. The subsequent rapid decline in cashmere mean length (56·4 to 20·6 mm) in CL further contributed to the reduced cycle period, so that another length maximum was achieved 84 days after the maximum in NL. The shape of the graph of length in CL was similar to that in NL, as it tended to be bimodal. The interval between maximum length in 1984 and 1985 was 392 days for both NL and the third and fourth cycles of CL; however, the length maxima for NL and CL were 83° out of phase based on a NL cycle period of 365 days. As for NL, the amplitude of the rhythm of hair length was clearly less than that of cashmere length. Exposure to CL appeared to distort the relationship between cashmere and hair length maxima. Overall, hair length maxima were asynchronous with those of cashmere in CL. Under the influence of CL, hair length tended to be consistently less than both cashmere length in the same photoperiod and hair length in NL.

Diameter

In NL, cashmere fibre diameter was variable with minima in June–July and February (Fig. 3(a)). These points delineated two cycles of cashmere fibre diameter change with periods of 224 and 140 days for the July–February and February–June cycle respectively in 1983–84 and 1984–85. In these years the amplitude of the July–February cycle exceeded that of the February–June cycle. The amplitude of cycles declined towards the end of the experiment, and the changes became acyclic in late 1985. Between June 1983 and June 1984 changes in cashmere fibre diameter in CL (Fig. 3(a)) appeared to undergo three cycles (period, 112 days) compared with the two in NL. These were followed by a cycle of period 224 days which was completed in January 1985.

In contrast with NL, the amplitude of cashmere cycles in CL appeared to decline with time, and biannual cycles were not apparent. There was some similarity between cycle lengths, since a cycle of period 224 days was evident in each photoperiod.

Fig. 3(b) depicts cyclic changes in fibre diameter of the hair component of fleece. If September 1983 is chosen as time (t) = 0, two distinct cycles with similar amplitude occurred in NL and were completed in 728 days at September 1985. The cycles were not of equal length, being 308 and 420 days for the first and second

cycle respectively. If December 1983 is chosen as $t = 0$, the interval between maxima at December 1983 and January 1985 was 392 days with the minimum occurring in July on that interval. After September 1983 minimum hair fibre diameter in NL increased to 80 μm, while maximum occurred close to 118 μm. In contrast with NL, three distinct cycles occurred in CL. Amplitude declined markedly following completion of the first cycle. Maxima occurred in October 1983, June 1984, April 1985 and December 1985, and minima in August 1983, February 1984, October 1984 and July 1985. If February 1984 is $t = 0$, two cycles of period 252 and 280 days were completed by July 1985. If October 1983 is $t = 0$, then the two ensuing cycles were also of period 252 and 280 days.
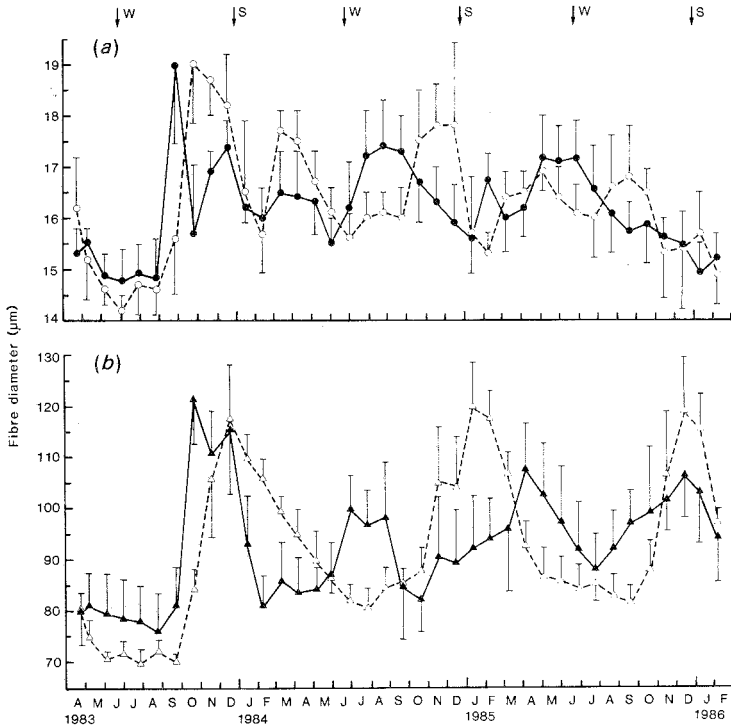

Fig. 3. Fibre diameter of (*a*) cashmere in natural (○) and continuous (●) light and (*b*) hair in natural (△) and continuous (▲) light. Winter (W) and summer (S) solstice. Vertical bars denote ± s.e.

Brush ends

Fig. 4(*a*) depicts cycles of brush end formation in cashmere fibres. The first cycle in NL reached a maximum of 100% in September and was completed in December. A minor event occurred between December and March with a maximum of 20% in February. No brush end cashmere fibres were present in the fleece in March and April, after which the proportion rose rapidly to 68·9% in July 1984.

In comparison, exposure to CL accelerated cashmere brush end formation with 99·7% reached in July 1983. This level was maintained for 56 days in CL before it fell rapidly to 0·1% in November. No brush ends were formed for the next 56 days. Within the following 84 days the brush end component of the fleece rose to a maximum of 80·6% in April, then declined rapidly. The major difference between the cycles in NL and CL was the absence of a minor event between the

two cycles in CL. In NL, the formation of brush end hairs (Fig. 4(*b*)) reached a maximum in August with a minimum in February. This contrasted with the changes in CL, where the second maximum occurred in February following minima in November and December.
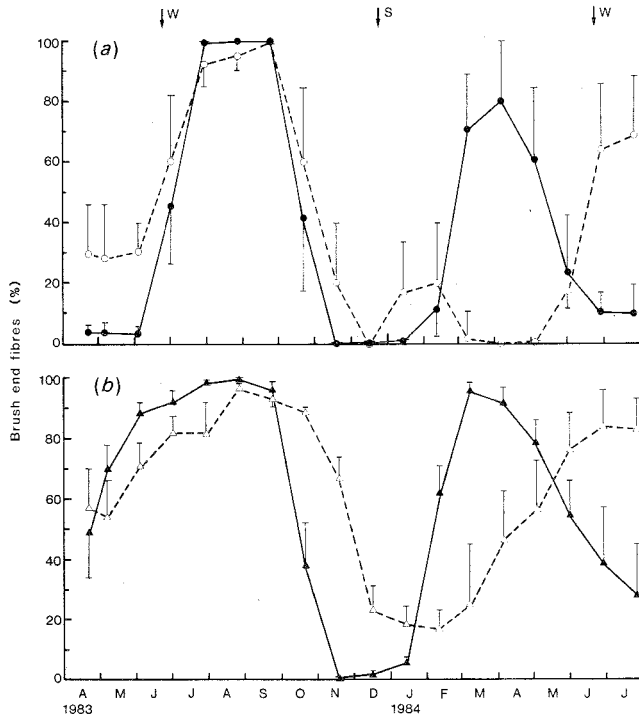

Fig. 4. Brush end fibre component of (*a*) cashmere in natural (○) and continuous (●) light and (*b*) hair in natural (△) and continuous (▲) light. Winter (W) and summer (S) solstice. Vertical bars denote ± s.e.
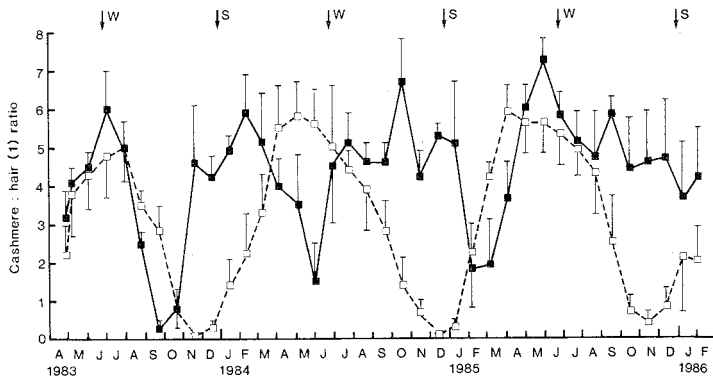

Fig. 5. Cashmere:hair ratio in natural (□) and continuous (■) light. Winter (W) and summer (S) solstice. Vertical bars denote ± s.e.

Cashmere:hair ratio

Changes in fleece composition expressed as cashmere:hair ratio (CHR) are shown in Fig. 5. Three distinct cycles of similar amplitude are apparent in NL. The

cycles are delineated by minima in November, December and November of three consecutive years. Maxima of 5·0:1, 5·8:1 and 5·9:1 were achieved in July 1983, May 1984 and April 1985 respectively. There was little between-month or between-year difference in CHR for April, May and June and 1984 and 1985 respectively.

Overall, changes in CHR in CL were rapid compared with those in NL where the graph was rhythmic in appearance. The CHR maximum in CL (7·2:1) was higher than the maximum in NL (5·9:1).

Secondary:primary ratio

The mean ($\pm$ s.e.) ratio of secondary:primary (S:P) follicles in the skin of goats in NL was 6·86 $\pm$ 0·51:1 and in CL 7·36 $\pm$ 0·60:1.

Paddock Study

Changes in the mean length of cashmere and hair in the fleeces of 29 does are depicted in Fig. 6. There was no difference between the length of cashmere and hair in March. The rate of growth of cashmere between 26 March and 7 May was 0·60 mm day^{-1}, which exceeded that of hair in the same period. Both cashmere and hair achieved maximum length in June (63·2 and 43·9 mm respectively). The length of cashmere had declined to 53·7 mm at shearing on 16 July.
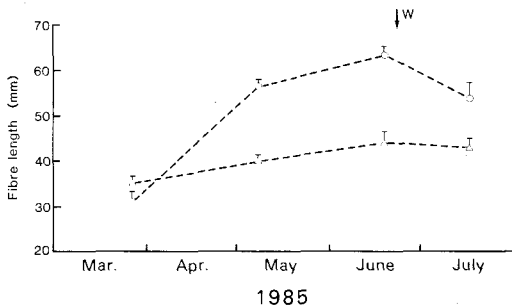

Fig. 6. Fibre length of cashmere ($\bigcirc$) and hair ($\triangle$) of goats grazing at 28° 13′ S. Winter (W) solstice. Vertical bars denote $\pm$ s.e.

At shearing, the mean weight ($\pm$ s.e.) of fleece was 241·5 $\pm$ 15·4 g, and of its cashmere component 79·0 $\pm$ 7·6 g. This resulted from a mean ($\pm$ s.e.) yield of 32·2 $\pm$ 2·5%. The mean ($\pm$ s.e.) diameter of cashmere in the fleece was 14·7 $\pm$ 0·4 μm and of hair 84·5 $\pm$ 2·5 μm. The mean ($\pm$ s.e.) CHR in the fleece was 5·3 $\pm$ 0·8:1 at shearing.

Discussion

Rhythms of fibre volume growth rate, length, diameter, and brush ends are apparent in the fleece of cashmere goats in NL. Some of these cycles are composed of stages of anagen, catagen and telogen as described for the hair follicle of mammals by Ebling and Hale (1970). The same parameters (amplitude and period) of each cycle of a fleece component are not always of the same magnitude; however, the results show synchronization at some points in time. Exposure of goats to CL modifies the cyclic changes in all fleece components in terms of the amplitude, phase and period.

Since VGR of cashmere is derived from changes in length and diameter, this fleece parameter illustrates the composite effect of independent cycles of the two components. Telogen in NL is shown by no volume growth between 2 September and 22 December. This is followed by anagen from the summer solstice in

December to the autumn equinox in April. Follicles proceed through catagen into telogen between April and September as shown by the decline in growth rate.

Changes in VGR of cashmere in NL are asynchronous with those of hair, with cashmere reaching a maximum in April and hair in November. Maximum growth rate of hair is achieved while cashmere is in telogen. This reflects a major difference between the control of cashmere-bearing secondary follicles and hair-bearing primary follicles. Obviously, follicle-specific mechanisms are controlling activity in this situation since these differences are expressed by seemingly adjacent follicles in the skin.

Exposure to CL has a greater impact on cashmere VGR than on hair. Cashmere telogen (little or no VGR) is reduced by 84 days in CL, while hair telogen is reduced by only 28 days. This tends to synchronize the cycles of VGR of cashmere and hair.

The results of measurement of cashmere fibre length (Fig. 2(a)) clearly illustrate circannual rhythms of this fleece parameter. The growth cycle in NL is always completed at the summer solstice and a new cycle of growth begins immediately. These static minima delineate a cycle with period of 365 days. Cashmere linear growth in NL ceases around the winter solstice. In the controlled conditions of the second (1984) and third (1985) cycles, cashmere grew to 62 and 64 mm respectively.

Comparison of the three cycles shows a small lateral distortion of the maxima. The latest maximum, which occurred during August in the first cycle, may reflect a different physiological state caused by previous pregnancy and lactation. If this is correct, then other factors such as mating, shearing, parasitism and severe undernutrition may also produce distortion of the maxima. The effect of photoperiod on this cycle appears to be related primarily to the summer solstice.

Changes in the length of cashmere and hair in NL are synchronized, suggesting that a common mechanism controls the rhythmic activity of both primary and secondary follicles. This contrasts with the asynchronous behaviour of the rhythms of VGR. The reduced amplitude of the cycle of hair length compared with that of cashmere length means that the goat maintains a protective hair coat when little or no cashmere is present.

Comparison of cashmere linear growth from April 1983 to March 1985 shows that CL induced three growth cycles compared with two induced by NL. This resulted from a reduction in the length of anagen and catagen with generally no difference in maximum fibre length. The greater linear growth rate of cashmere in CL in the first cycle in 1983 enhanced fibre length when compared with the length achieved in NL. This suggests that CL will increase fibre length in the presence of a physiological constraint on growth such as lactation; however, the effect is generally expressed as a reduction in the period of the cycle. It appears that the response to CL diminishes with time, since the period of cycle 2 was 223 days and that of cycle 4 was greater than 336 days. This lengthening of the cycle period after 2 years' exposure to CL could be due to the absence of alternating photo-stimuli which tends to induce a refractory state.

The initial response to CL shows that the cashmere growth cycle (anagen, catagen and telogen) is not influenced by natural light/dark events. Since exposure to CL does not ablate the fibre growth cycle, then an exogenous light stimulus is not necessary to induce basal rhythmic activity. Such endogenous cycles obviously utilize humoral mechanisms of control which are either systemic, local or a

combination of these, to effect cyclicity. Seasonal rhythms may therefore arise from the interaction of a pineal-mediated stimulus and endogenous mechanisms.

In the NL environment the time around the summer solstice appears to be an important photoperiodic event, since follicle activity changes from the telogen to anagen phase. Around both the summer and winter solstices, the rate of change of day length is minimal. Similarly, the rate of change of day length in CL is zero, and in this environment light-independent growth cycles are evident. This suggests that minimal rate of change of day length allows transition of follicle activity and the direction of the activity (e.g. anagen) is determined simply by the previous activity (e.g. telogen). In CL this transition is not constrained by photoperiodic events.

In the absence of any known constraints on cashmere linear growth, it appears that growth ceases at a given length of fibre. This length is independent of photoperiod since it occurs in both NL and CL. The results in 1983 (Fig. 2(a)) suggest that continued growth is terminated at the spring equinox, which is the beginning of the period of maximum rate of change of photoperiod. It is not known how fleece removal at shearing will modify this linear growth pattern.

The rhythm of cashmere fibre diameter in NL (Fig. 3(a)) is different from that of length, since diameter tends to undergo two cycles in 365 days. The cycles toward the end of 1983 and 1984 show an increase in fibre diameter which appears to be associated with a decrease in fibre length. Since the decrease in length can only occur by the loss of longer fibres from the population measured (fibre shedding), then the changes in fibre diameter may result from a change in the fibre population rather than progressive linear changes in diameter within fibres. This proposition does not explain the consistent increase in fibre diameter in February–March of each year, since there is no apparent decrease in fibre length around this time of the year.

The occurrence of maximum cashmere length was accompanied by mean fibre diameter minima of 16 μm or less, indicating that the growth of fine fibres occurs towards the end of anagen. Since cashmere length maxima are followed by fibre diameter rises after completion of anagen, fine fibres must be cast from the fleece earlier than coarse cashmere. Again, prior gestation and lactation appeared to influence fibre diameter, which reached a minimum of 14 μm in the first cycle and around 16 μm in later cycles.

In contrast with cashmere, hair fibres undergo only one cycle of fibre diameter change each 365 days. Maximum diameter of hair occurs when length is at a minimum, indicating that the coarse fibres are retained in the fleece following casting.

Exposure to CL altered the cyclic changes in the diameter of cashmere and hair. This alteration was consistent with that seen in other fleece parameters, in that the period of cycles was reduced by CL.

Discussion of characteristics of the cycles of cashmere linear growth and diameter allows further development of the role of these in the rhythm of VGR. The apparently asynchronous VGR of cashmere and hair in NL from 21 April 1983 to 19 April 1984 is not a function of linear growth rate, since that characteristic is minimal for both fibre types in November when hair VGR is at a maximum. Fig. 3(b) shows that the increase in hair VGR at this time of the year in NL is due largely to increasing fibre diameter. The subsequent decline in hair VGR is again

a function of reduced diameter. In contrast, maximum VGR of cashmere occurs under the influence of maximum linear growth and declining cashmere fibre diameter in March–April. These differences in VGR again illustrate the function of follicle-specific mechanisms controlling cutaneous events.

It is known that brush end fibre formation occurs before a fibre is shed from the follice and that this phenomenon precedes fleece casting or moulting in mammals which exhibit seasonal fleece growth cycles (Ebling and Hale 1970; Ryder 1977). In the present work these processes in the goat are illustrated by circannual rhythms of brush end formation (Fig. 4) and fleece composition (Fig. 5). In NL, 92·3% of cashmere fibres had formed brush ends by the end of July 1983. This was associated with the maximum CHR of 5·0:1 at the same time. Although these events occurred before maximum cashmere length in August, some of these fibres were lost from the fleece, as shown by the decline in CHR after July. A similar reduction in the percentage of cashmere fibres in the fleece was described by Holst *et al.* (1982); however, this followed maximum cashmere fibre length in July. In the present work when maximum cashmere length occurred in July 1985, CHR was already declining. The relationship between the occurrence of maximum cashmere length and cashmere fibre loss from the fleece appears somewhat variable.

Catagen is again highlighted by the rise in the brush end fibre component of the cashmere fleece during the period March–September. Initiation of catagen thus follows the period of maximum linear growth rate in March–April. Since CHR does not begin to decline until July 1983, brush end fibres which are formed as early as May must be either retained in their respective follicles or in the fleece until at least the following August.

Ebling and Hale (1970) suggest that fibres which have formed brush ends are not shed from the follicle until a new hair commences growing. This does not appear to be the sequence of events in the goat. There is no evidence of follicle activity when fibre shedding occurs in the goat because cashmere VGR in NL in 1983 is zero from 2 September to 22 December, when CHR is declining. In fact, a pronounced period of telogen is apparent in cashmere-bearing secondary follicles following fibre shedding. There is no obvious mechanism by which the fibre is lost from its follicle.

It was shown in Fig. 4(*a*) that around 20% of the cashmere fibre population present in January–February form brush end roots. This was not evident in CL. In Fig. 5, the CHR of 7·2:1 in CL in 1985 tends to approach the theoretical maximum as illustrated by the ratio of S:P follicles in the skin (7·36:1). In contrast, the CHR in NL does not achieve its maximum potential, as shown by a value of 5·9:1 in 1985, compared with a follicle S:P ratio of 6·86:1 in the skin. This suggests that cashmere fibres which form brush ends in January–February in NL are shed from follicles and lost from the fleece and are not replaced by new fibres. Since this secondary event does not occur in CL, all fibres grow in a continuous and coordinated pattern until the end of the cycle.

There was no deflection in the graph of cashmere fibre length in NL (Fig. 2(*a*)) after the time of brush end formation in January–February; however, a major increase in cashmere fibre diameter consistently occurred in February–March each year. This suggests that fibres which are shed from the fleece at this time have a mean length close to the mean of the total population at that time, but the mean diameter of shed fibres is considerably lower than that of the population. This further supports the hypothesis that changes in the mean fibre diameter of the

cashmere component of the fleece result from changes in the fibre population rather than linear changes within fibres.

It is apparent that the absence of brush end formation between December and March will ensure the presence of the maximum number of cashmere fibres in the fleece at the end of the anagen phase of the growth cycle. Brush end formation in cashmere fibres in January–February may be a vestige of a biannual fleece growth cycle, although there is no evidence of this phenomenon in the hair growth cycle. This secondary period of regression is similar to the subsidiary peak of secondary follicle inactivity in female deer reported by Ryder (1977). In goats and deer this occurs shortly after the summer solstice, while the primary cycle of follicle regression occurs between the winter and summer solstices.

Measurements conducted on the 29 breeding does at pasture confirm the data collected from the experimental does in NL. The maximum mean length of cashmere, its time of occurrence and fleece composition as illustrated by CHR at shearing, are similar. There was little difference between the maximum linear growth rate of cashmere in grazing and housed does; however, cashmere growth rate in the former group tended to be higher.

It can be concluded from this work that cashmere production may be maximized by exploiting the basic circannual rhythms of growth. Fleeces should be harvested during the anagen phase of the growth cycle (January to July). Production will be optimized by shearing around the winter solstice in June–July; however, environmental hazards need to be considered. Because of changes in fleece composition, shearing later than July is detrimental, since many cashmere fibres have been lost from the fleece at this stage. Maximum linear growth occurs around a time of minimum fibre diameter, which means that fleece value is likely to be maximized since fineness is a critical determinant of quality. Continuous light treatment will increase the number of growth cycles completed during exposure for 2 years. This will obviously increase production; however, the benefit does not persist beyond 2 years.

Acknowledgments

References

Burns, R. H., von Bergen, W., and Young, S. S. (1962). Cashmere and the undercoat of domestic and wild animals. *J. Text. Inst.* **53**, 45–68.

Chapman, R. E. (1960). Measurement of wool samples. Tech. Pap. Anim. Res. Lab., CSIRO Aust., No. 3, Appendix III, pp 97–108.

Downes, A. M., Clarke, W. H., and Dagg, T. C. (1967). *Atomic Energy (Sydney)* **10**, 2–7.

Ebling, F. J., and Hale, P. A. (1970). The control of the mammalian moult. *Mem. Soc. Endocrinol.* **18**, 215–37.

Epstein, H. (1969). 'Domestic Animals of China.' (Commonwealth Agricultural Bureau: Farnham Royal, Bucks.)

Holst, P. J., Clarke, W. H., and Maddocks, I. G. (1982). Skin and fleece characteristics of two groups of feral goats. *Aust. J. Exp. Agric. Anim. Husb.* **22**, 173–6.

McDonald, B. J. (1985). The cashmere growth cycle. First Int. Cashmere Seminar, Aust. Nat. Univ. Canberra, pp 126–31. (Australian Cashmere Goat Society: Melbourne.)

Ryder, M. L. (1966). Coat structure and seasonal shedding in goats. *Anim. Prod.* **8**, 289–302.

Ryder, M. L. (1977). Seasonal coat changes in grazing Red deer (*Cervus elaphus*). *J. Zool., Lond.* **181**, 137–43.

Ryder, M. L., and Stephenson, S. K. (1968). 'Wool Growth.' (Academic Press: London.)

Smith, I. D., Clarke, W. H., and Turner, H. N. (1973). The potential of feral goats in Australia for cashmere production. *J. Aust. Inst. Agric. Sci.* **39**, 128–31.