

CONTRACT REVIEW

IMPROVING WOOL STRENGTH

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Low fibre strength is becoming widely recognised as a major problem for merino wools. The wool fibre is now weaker than many synthetics, and as the speed of manufacturing increases, price penalties for low staple strength (SS) are being imposed above the traditional limit of 25-30 N/ktex. Currently, a quarter of all Australian merino wool is penalised for low SS. Fibre strength must be improved if the wool industry is to maintain its position in the market. For these reasons, a program within the Cooperative Research Centre for Premium Quality Wool aims to improve SS by focussing a co-ordinated effort by the Western Australian (WA) Dept of Agriculture, CSIRO and The University of Western Australia, supported by the Australian Wool Research and Promotion Organisation and various industry and farmer groups.

Considering the magnitude of the problem, it is surprising that so little is known about its causes or prevention. Standardised measures of SS have come into general use only recently, so there are few published data about its relative importance in weaners, lambing ewes and wethers or about management procedures that may predispose towards it. Furthermore, the strength of a staple is a composite measure depending on the strength of the fibres that make it up and their uniformity. The relative contributions of the intrinsic strength of individual fibres, the effect of changes in fibre diameter, and the importance of shedding and shut-down of individual follicles to overall SS is still under debate.

Causative factors are also unclear. A break in the wool traditionally is associated with stress, but the role of stress in less severe forms of staple weakness is unknown. Quantitative data are absent and potential mechanisms are ill-defined. The heritability of SS has been estimated recently, but the genetic and phenotypic relationships with other fleece characteristics are still being established. Quantitative relationships between nutrition and wool growth have been established for many years, but low SS occurs in situations of poor and changing nutrition, which are much less defined. To reduce the cost of supplements, it may be more important to determine how to feed the wool follicle, rather than to feed the sheep. However, follicular characteristics associated with SS have yet to be described, and obtaining this knowledge is only the first step in developing economic and practical feeding regimes that improve SS.

This contract summarises our current knowledge. Given the importance of the area, the increasing use of the SS measurement and the current research interest, considerable developments can be expected over the next few years.

STAPLE STRENGTH AND EARLY STAGE PROCESSING

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Wool suffers from 2 important disadvantages relative to fibres it competes with - it is relatively coarse and weak. Cotton fibres are typically less than 15 μm in mean fibre diameter, and the tenacity (the force required to break a fibre rationalised to its cross sectional area) of individual fibres is on average greater than that of wool (Morton and Hearle 1975). Generally, the tenacity of synthetic fibres is even higher and they can be manufactured to any desired diameter. These facts, together with the long term trend by the apparel industry towards lighter weight garments, fewer fibres in the cross section of yarns, greater processing speeds, less labour on the processing floor, and less wastage, are placing pressure on wool growers to decrease mean fibre diameter and increase fibre strength of their product. Here-in lies a

conflict in the characteristics of the current Australian wool clip, since as outlined later in this contract (Baker *et al.*) there is a positive association between wool SS and mean fibre diameter.

Importance of wool staple strength

Wool SS is important because it affects the length of fibres in the wool top (Hauteur), the variation of Hauteur in the top, and the amount of short fibres lost during carding and combing. Both Hauteur and variation of Hauteur are widely held to affect the spinning performance of the top and the resultant yarn properties. Most contracts from spinners specify Hauteurs of 65-80 mm, and a coefficient of variation of Hauteur of 40-50%. In modern worsted drawing and spinning equipment, mean fibre lengths greater than about 80 mm will span the distance between input and delivery rollers on the spinning frame, which may result in fibre breakage and cause unevenness in the yarn due to slubs. Weak wools break more in processing and tend to give higher content of short fibres in the top. High short fibre contents increase the number of yarn breakages during spinning, particularly if the yarn is being spun near to the practical minimum limit for the average number of fibres in the yarn cross section (presently about 35 fibres). The romaine, (the percentage of waste or noil) removed in combing, will affect the profit margins of the mill, as noil is generally less than half the value of the wool top. The short fibre content of the top can also influence the number of neps (small balls of entangled fibres) that develop in the drawing and spinning processes. Short fibres can appear as faults in the resulting fabric, due to the "fly" or fibre build-up on machinery making its way into the yarn in the form of short, thick faults. Increased short fibre is also thought to increase problems in drafting (drawing out of fibres to make the yarn), due to reduced fibre control, and result in reduced yarn regularity.

Increasingly the Australian wool industry uses and provides a range of additional raw wool measurements to aid early stage processors in predicting Hauteur, coefficient of variation of Hauteur, and romaine. In developing these additional measurements, CSIRO, AWC and collaborating topmakers combined to validate the use of the measurements in processing prediction. The resulting trials provided data which the CSIRO developed into predictive equations which have become known as TEAM (Trials Evaluating Additional Measurement) formulae. While further refinement of prediction algorithms continues (Allen *et al.* 1990) the TEAM formulae provide a very clear illustration of the influence of the additionally measured parameters on processing performance. They are:

$$\text{Hauteur (mm)} = 0.52\text{SL} + 0.47\text{SS} + 0.95\text{D} - 0.19\text{M} - 0.45\text{VM} - 3.5$$

$$\text{Romaine (\%)} = -0.11\text{SL} - 0.14\text{SS} - 0.35\text{D} + 0.94\text{VM} + 27.7$$

$$\text{Coefficient of variation of Hauteur (\%)} = 0.12\text{SL} - 0.41\text{SS} - 0.35\text{D} + 0.20\text{M} + 49.3$$

(SL = staple length (mm), SS = staple strength (N/ktex), D = mean fibre diameter (μm), M = percentage of mid breaks (45 is used when M < 45%), VM = % vegetable matter)

The formulae show that an increase of 10 N/ktex in SS would result in an average increase in Hauteur of 5 mm, a decrease in romaine of about 1%, and a decrease in the coefficient of variation of Hauteur by about 4%. Staple length is also an important factor; a 10 mm increase in staple length will increase Hauteur by about 5 mm, and romaine and coefficient of variation of Hauteur will change by about 1% each. The importance of position of break can be seen in changing the percentage of mid breaks from 70% to 45%, again resulting in an increase of about 5 mm in Hauteur. There are clearly a number of options that wool growers can adopt to increase Hauteur. Changing the position of break by changing the time of shearing can achieve significant changes in Hauteur. Increasing SS will significantly increase Hauteur, even without the added benefits of a likely change in percentage of mid breaks.

Cost of low staple strength

Taking the top making and spinning performance together, it is easy to see why weak wools fetch lower prices at auction and are often seen mainly as blending wools. With the development of the ATLAS and Tuft Sampling machines, commercial objective testing of lots presale has been undertaken since 1985. Analysis by the AWC (R. Couchman pers. comm.) has shown that, relative to sound combing wool (> 30 N/ktex), the penalties received by lots at auction over the last three quarters of 1992/93 and the first quarter of 1993/94 were approximately 3.1% for part-tender wool (type W1 = 26-30 N/ktex), 7.5% for tender wool (W2 = 18-25 N/ktex) and 9.7% for rotten wool (V = < 18 N/ktex). This amounts to an estimated cost to the Australian wool industry of 16 c/kg clean for part tender wool, 38 c/kg clean for tender wool and 50 c/kg clean for rotten wool.

STAPLE STRENGTH, SEASONAL ENVIRONMENTS AND MANAGEMENT PRACTICES

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Twenty five percent of the Australian merino clip is produced in the south west of Western Australia. This region has a mediterranean climate and pastures here are dominated by annual species. It is characterised by marked seasonality in the quantity and quality of available pasture (Purser 1980), and this has a direct influence on wool production, on quality attributes of raw wool, and on the supply of wool to auction.

Wool is regarded as “tender” when the staple breaking strength is 26 N/ktex or less, and as part-tender when the staple breaking strength is between 26 and 30 N/ktex. Tender and part-tender wools have attracted heavy price penalties at auction in recent years and between 30 and 50% of wool from mature sheep (> 1.5 years old) and up to 70% of wool from weaner and hogget sheep (11.5 years old) is tender or part-tender (Baker *et al.* 1993; S.K. Baker, D.B. Purser, S.J. Foley and J.C. Wilson unpublished data).

The way that wool producers manage their flocks is determined largely by the seasonality of the environments in which wool is grown, and a range of factors was selected from a study by Barton *et al.* (1994) (Table 1) to reflect this. The relative contribution of each of these in explaining the variation in staple breaking strength and predicted combing performance (Hauteur) of Western Australian wools (Table 2) was determined by step-wise regression analysis using an additive model: $\mu + A + S + T + G + B + F$ (see Table 1) and expressed in rank order. Predicted processing performance (Hauteur) was estimated from quality characters of raw wool using the TEAM formula (Allen *et al.* 1990; see Harrowfield and Kelly, this contract). Average fibre diameter was included as a covariate in the analysis of staple breaking strength because of the strong association between fibre diameter and incidence of tender and part-tender wool (Baker *et al.* 1993). The relative importance of each of the factors changed from year to year (Table 2).

Table 1. Factors used to explain the variation in staple strength and predicted Hauteur.

Factor	Categories used
Average fibre diameter (μm) (μ)	continuous variable
Age of flock (A)	< 1.5 years, \geq 1.5 years, or unknown and mixed
Sex (S)	mature male (including wethers), mature female, or young, unknown and mixed
Time of shearing (T)	winter, spring, summer, autumn
Length of pasture growing season (months) (G)	3 to 8
Time of break of season (weeks) expressed relative to the average over 10 years (B)	-7 to +6
Number of false breaks in the season (F)	0, 1, 2

The timing of the opening rains at the beginning of the pasture growing season and average fibre diameter consistently ranked highly in explaining variation in staple breaking strength whereas age of the flock was most important in explaining variation in predicted Hauteur. Poor SS is more of a problem in fine wools than it is in broad wools and it is more of a problem in wools from weaner and hogget sheep than from mature sheep (Baker *et al.* 1993; S.K.Baker, D.B.Purser, S.J.Foley and J.C.Wilson unpublished data). Time of shearing also ranked highly in explaining variation in staple breaking strength and in predicted Hauteur, especially in years when there was no significant effect of timing of the opening rains. The influence of interactions between the factors is yet to be determined. These results suggest that the way that wool producers manage their flocks in response to the uncertainty of the break of the season contributes significantly to the variation in staple breaking strength.

Table 2. Factors ranked according to their importance in explaining variation in staple breaking strength or predicted Hauteur of Western Australian wools produced in the 1989/90, 1990/91 and 1991/92 wool-selling seasons. Rankings are only for factors which contribute significantly ($P < 0.05$).

	Staple strength			Predicted Hauteur		
	1989/90	1990/91	1991/92	1989/90	1990/91	1991/92
Average fibre diameter	3	1	1	not included		
Age of sheep	1	-	-	1	1	1
Sex of sheep	6	-	4	-	-	-
Time of shearing	5	2	3	-	3	2
Growing season	4	-	-	-	2	4
Break of the season	2	-	2	-	-	3
False breaks	-	-	-	-	-	5

ON-FARM PRACTICES AND TENDER WOOL

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Some information is available on factors which may influence the strength of wool fibres (Bigham *et al.* 1983; Reis 1992). However, the effects of many common farm management practices and environmental conditions on the SS of wool are far from certain and there are few options available to woolgrowers who wish to control the soundness of their wool clip.

Farmers often have anecdotal evidence that can provide valuable insights. To obtain some of this information, a preliminary questionnaire was circulated amongst some members of a consultancy group in the Kojonup-Boyup Brook area of south western Australia. Farmers were asked to rank in order what, in their opinion, they saw as the 3 most important causes of tender wool. Whilst by no means a random sample, the 47 responses, from 60 questionnaires, were investigated and summarised in Table 3 to give some insight into what some farmers perceive as the major causes of tender wool.

Table 3. Farmer opinions on the most important causes of tender wool

Response	1st choice	2nd choice	3rd choice
Lack of feed	6	3	1
Change in diet	6	4	1
Break of season	6	3	2
Summer rainfall	10	2	2
Sheep health - flystrike, worms	-	6	16
Other	10	16	14

Notably, all but 3 respondents included a "nutritional" cause. A point to consider would be the economics of any supplementary feeding treatments to improve SS. It is impossible to justify economically feeding for wool quality with current wool market conditions. However, it is still important to work on possible solutions in order that they can be considered when the economic climate changes. Summer rainfall was also of concern. Details such as the level of rainfall needed to affect wool quality and management options available to minimise this effect are not currently available. Also rainfall at the

“break of the season” results in a rapid change to green pasture and the influence of this dietary change needs further investigation.

The category “Other” included bloodline, pregnancy, feeding mismanagement, sudden environmental or weather changes, and acute changes or stresses. The role of “stressors”, such as yarding, marking, weaning and fasting on SS is unclear. There is little published work on this topic but separate pilot studies by P. Wynn, R. Rottenbury and A. Schlink (all personal communications) have suggested that stressors may reduce SS. It is generally thought that sheep must be under nutritional stress and losing liveweight before these other stressors will cause a break in the wool, but the magnitude of necessary weight loss and the importance of different stressors are far from certain.

Thus there is considerable scope to investigate the effects of various farm management practices on SS. It is important to identify those factors and events that are important and provide the grower with information as to how best control the SS of their clips within the practical and economic bounds of the farm.

FIBRES IN TENDER STAPLES

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Measurement of SS involves both a measurement of force required to break the staple and the linear density of the material broken. This measurement assumes that the linear density of the staple is constant throughout its length, so any factor which reduces fibre diameter (FD) along the staple will depress SS due to a reduction in the amount of material available to bear the load. Reductions in FD are produced by nutritional change, disease, pregnancy, lactation, season or any other factor which induces stress in sheep. Although minimum FD is a significant factor, it only accounts for 20-40% of the variation in SS (Hunter *et al.* 1983; Hansford and Kennedy 1990a). Indeed the latter paper showed a slightly closer association of SS with the rate of change in FD ($r^2=0.54$) than minimum FD ($r^2=0.41$), but no biological or physiological explanation has yet been developed.

The role of fibre shedding as a component of SS has only recently been highlighted (Schlink *et al.* 1992) although it has long been recognised as being involved in the formation of cotted wools (Lang 1945). Shed fibres appear to occur when there has been a drastic decline in FD below 8-12 μm (Lang 1945; A. Schlink and A. Dollin unpublished data). Shed fibres in merino sheep differ significantly from those of primitive sheep breeds (Chapman 1979) in that a club end is not formed and the shed fibre carries with it a portion of the inner root sheath. The incidence of shedding is highly correlated with SS below 30 N/ktex, while above 30 N/ktex it plays no role in SS (A. Schlink unpublished data).

Intrinsic strength of the fibres is the third component of SS, as FD change and shedding do not account for all of the variation in SS. Fibres of the same FD have varying breaking loads and do not always break at the point of minimum FD. Intrinsic strength is a reflection of the composition of the fibres in a staple, but no clear relationship has been established between protein composition and strength of wool fibres, despite many reports of differences in the proportions of the constituent proteins of wools of varying SS. There is a large potential for variation as 50 different proteins are present in the fibre (Powell *et al.* 1989) and their gene families are highly variable within and between breeds and individuals. Recent studies of high and low SS wools have shown significant differences in the protein bands on gel electrophoresis (P. Hynd unpublished data). A positive relationship has been found in Romney Marsh sheep between the percentage of orthocortical cells in the fibres and SS (Orwin *et al.* 1985) but not for merino wool staples (Hansford and Kennedy 1990b).

Effects of nutrition on follicle function and staple strength

Nutrition plays a significant role in the regulation of wool follicle function, although these effects are buffered in the short term by body tissue reserves (Williams 1987). Although wool follicles are one of the most active tissues in the body in terms of cell turnover, few studies have been undertaken of the effects of nutrition on wool follicle dynamics and these have not been carried through to an examination

of the effects on SS. Hynd (1989) showed that nutrition significantly influenced fibre diameter, rate of fibre length growth, volume of the germinative region of the follicle bulb, rate of cell division and percentage of paracortical cells in the fibre. The cortical cell volume and follicle efficiency did not change with nutrition. Although these parameters are very responsive to nutritional fluctuations, there have been no reports relating these follicle changes to alterations in SS.

More recently P. Hynd (unpublished data) found that sheep selected on the basis of divergent fibre length growth and diameter and fed 2 nutritional regimes, differed widely in SS at the end of the experiment (11-41 N/ktex). At both low and high nutrition FD accounted for only 25% of the SS variation, the higher FD sheep having higher SS. Inclusion of the proportion of paracortical cells in the fibre removed significantly more variance (50%, $P < 0.002$). Change in FD with nutrition was positively related to SS, while fibre length was not. Further examination of these sheep in another experiment generated higher but more variable SS (38-67 N/ktex) revealing a high repeatability of SS between experiments ($r^2 = 0.44$), a significant relationship between the proportion of paracortical cells and SS ($r^2 = 0.25$) but no relationship between SS and FD. The results suggest that low SS is associated with the cortical cell type in Merinos in accord with the results of Orwin *et al.* (1985), but in contrast to Hansford and Kennedy (1990b).

Detailed studies are currently underway with the SS phenotypic and genetic selection lines from the WA Dept of Agriculture to determine the role of nutritional fluctuations on follicle function and fibre production. To date, the only raw wool measurement that consistently correlates with SS is the coefficient of variation in FD, supporting previous observations of Ritchie and Ralph (1990). The low SS phenotype have a higher fibre growth rate with poor nutrition, but this difference disappears with improved nutritional status, with no difference in FD. The challenge will be to determine the sources of these differences and to put into place low cost testing methods to rapidly identify sheep that will produce sound wool for a minimal cost input to the flocks.

GENETIC PREVENTION OF LOW STAPLE STRENGTH

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Staple strength is an important component in both the marketing and processing of raw wool and has long been viewed as a function of the prevailing environmental conditions. If SS could be incorporated into a breeding objective it would provide clear advantages to both ram breeders and their clients. Two recent WA studies have shown that SS is moderately to highly heritable. In the first of these, Howe *et al.* (1991) established 2 flocks, 1 run under "commercial", and the other under "stud" conditions. The treatments were designed to produce, on average, a 10 kg difference in both hogget and adult liveweight. About 2400 wool samples were tested from hoggets in 61 sire groups. Heritability estimates of SS (\pm sem) derived from this data set by restricted maximum likelihood techniques were 0.40 ± 0.15 and 0.31 ± 0.13 for the "stud" and "commercial" flocks (Y. Li and R.P. Lewer unpublished data). In the second study, data were collected from about 1100 male hoggets in the WA Dept of Agriculture (WADA) Base Flock Project over 2 years. The heritability estimate for SS was 0.51 ± 0.12 (R.P. Lewer unpublished data).

The magnitude of these heritability estimates is comparable with those of clean fleece weight and fibre diameter and as such, sufficiently high to justify the inclusion of SS within a breeding program. Wool buyers, processors and classers traditionally have relied on the hand held "flick test" to assess the strength of wool. Bell (1987) noted that it was difficult to break a staple in excess of 30 N/ktex. Rottenbury (1979) found that wool appraisers differed in both the force they applied to the staple and the thickness of the staple selected. Furthermore, wool classers rarely test more than 2 staples in a fleece, whereas a minimum of 6 staples is required to mechanically detect a difference of 2 N/ktex between midside samples (J. Stanton unpublished data). Clearly, neither wool nor sheep classers would be able to rank all animals in a mob with a sufficient degree of accuracy to provide a robust data set suitable for the calculation of a selection index. Automatic testing of length and strength (ATLAS) is available for additional measurement of both sale lots and individual fleeces. However, the cost of testing individual fleece staples is prohibitive to ram breeders (approximately \$10-13/sample).

As SS is both difficult and expensive to measure, there is considerable interest in finding a correlated

trait for use as a selection criterion. Hansford and Kennedy (1988) reported an association between the rate of change of FD and SS. Similarly, Ritchie and Ralph (1990) found a relationship with the total variation in FD, expressed as the coefficient of variation (CV) of FD, and SS. These results support one another and provide a logical starting point in the search for a genetically correlated trait. Li and Lewer (unpublished data) have computed genetic correlations (\pm sem) for the "stud" and "commercial" flocks of Howe *et al.* (1991) between SS and the CV of FD (-0.66 ± 0.15 and -0.82 ± 0.12), clean fleece weight (0.10 ± 0.29 and 0.03 ± 0.30) and average FD (0.45 ± 0.20 and -0.07 ± 0.28). Lewer (unpublished data) has also found medium to high genetic correlations between SS and the CV of FD (-0.62 ± 0.27), clean fleece weight (0.42 ± 0.20) and average fibre diameter (0.37 ± 0.17) in the WADA Base Flock Project.

These data suggest that the incorporation of SS within the breeding objective should not adversely affect production of the other economically important traits in sheep bred in a commercial environment. The data also suggest a possible genotype by environment interaction. However at the time of writing, no data are available to estimate the level of this interaction. A genotype by environment interaction may have significant ramifications on the way that ram breeders operate, particularly those breeding animals under the conditions that do not mirror the commercial operation. Coefficient of variation of FD and the mean FD are relatively cheap and easy to measure and could be used as selection criteria. Coefficient of variation of FD in particular shows promise as an indirect selection criterion, but all could be combined in a selection index approach.

A clear limitation to these data is the lack of estimates of both genetic and phenotypic correlations between hogget and lifetime SS performance. Similarly, there are no estimates available for the correlation between hogget FD variability and SS in adults. Despite these current gaps in knowledge, given that the estimates of heritability are moderate, it may be expected that estimates of repeatability will in fact be moderate to high.

The development of estimates for the heritability of SS has further benefits. Intensive selection of commercially bred ewe and ram hoggets for SS has recently commenced at Katanning, which will develop lines of sheep with widely diverging SS. This research tool will be an invaluable aid in further investigating both the genetic and biological factors that, under different management conditions, control SS.

PREVENTION OF LOW STAPLE STRENGTH BY NUTRITIONAL MEANS

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It is not possible to accurately predict the growth rates of annual pastures, the amount that will be available to sheep during the pasture growing season, or the rates of decline in amount and quality of these pastures through maturity and senescence until death. These changes in nutrient availability affect wool growth rate and variability in fibre diameter along the staple. Their implications for SS vary for sheep shorn in spring or late summer-autumn, for different classes of dry stock (young growing vs adult, thin vs fat animals) and for ewes lambing in autumn or late winter-spring.

Given these complexities, how can nutrition of grazing sheep be manipulated or managed to produce sound wool and what research is appropriate? While an increasing number of reports are appearing on effects of nutrition on SS, few have involved comprehensive studies of the prevailing feed conditions and the nutrient intake and utilisation by grazing stock. The principles of effects of specific nutrients and of nutrient changes on follicle function and SS will continue to be investigated under pen feeding conditions. However, we must keep in mind that the eventual goals are management practices which will cost effectively improve SS on farms.

Summer-autumn

For spring shorn sheep to produce sound wool, it may be necessary to provide additional energy and protein supplements from clover-wilting (Thompson and Curtis 1990; A.J.M. Ritchie unpublished data). Several studies have shown that supplementation of young sheep can increase SS (Rowe *et al.* 1989; Gardner *et al.* 1993) and may alter the position of break (Rowe *et al.* 1989). Linear relationships have been found between negative liveweight change (LWC) in the period prior to the point of break (POB) in the staple, and SS within, and across, a number of supplementary feeding experiments with young

sheep (P.T. Doyle unpublished data). The relationship across experiments for weaners which had been shorn as lambs was:

$$SS = 29.0(\pm 2.45) + 0.14(\pm 0.018) \text{ LWC} \quad (r^2 = 0.86, n = 21, P < 0.01).$$

However, the intercept and slope of the relationship varied between experiments at different locations and the reasons for this require clarification. Taken across 20 field experiments, a slow rate of body weight gain throughout the summer and autumn was necessary if SS of hogget wool was to be greater than 30 N/ktex. Other factors may contribute to low SS even when these nutritional conditions are fulfilled, such as variability in supplement intake among the flock, and hormonal or environmental stresses which affect the continuity of wool growth (Peter *et al.* 1993). Currently, the most practical option for producing sound wool and staples without several weak points, is to ensure the nutrient intake of spring shorn sheep is at a level which avoids tissue catabolism. There may be other options that promote wool growth independently of liveweight change, but they need to be identified and may become practical after appropriate strategic research.

The feeding requirements and liveweight pattern needed to ensure sound wool for summer-autumn shorn animals, where the POB is nearer the tip, may be quite different to that outlined for spring shorn sheep. In this situation it may not be necessary to avoid weight loss until some time after shearing.

Lambing ewes suffer penalties in wool production and SS compared to dry sheep (Masters *et al.* 1993), and this is compounded where there are limitations in the availability and quality of paddock feed. Supplementation of autumn lambing ewes in mid and late pregnancy to maintain a high condition score increases wool production and SS, however maintaining a constant conceptus-free liveweight during late pregnancy will not ensure $SS > 30$ N/ktex (Kelly *et al.* 1992). As an alternative, it may be possible to provide specific supplements in critical amounts at strategic times during late pregnancy (Masters *et al.* 1993), although the practicality of delivering such supplements to individual sheep under extensive grazing will prove difficult.

Winter-spring

Mata *et al.* (1990) reported that reducing the protein content of a maintenance ration resulted in higher SS (49 vs 35 N/ktex) than increasing the protein level in such a ration. Thus not only the total nutrient supply and the balance of nutrients, but also the direction of change in nutrient supply may markedly affect SS. Around the break of season, nutrient supply and the balance of nutrients available to the tissues change rapidly and would be difficult to control in grazing animals. In a grazing experiment where sheep were supplemented at different levels of digestible energy from grain in summer and autumn and managed to grow at different rates in winter and spring there were significant effects of nutrition on SS under dry conditions, but not on green feed (Doyle 1993). However, it was extremely difficult to manage the rate of liveweight increase during the first 4 weeks of green pasture availability. As SS is determined in part by the rate of change in diameter around the POB, nutritional management at this time is critical in the production of sound wool. There is a need for more comprehensive basic and applied investigations of the effects of plane of nutrition and alterations in feed quality and availability on the regulatory mechanisms involved in partitioning of nutrients between wool and other functions over short periods where marked changes are occurring. However, the consequences of these short term events will need to be considered in relation to management and sheep performance through the entire period of fleece production.

Thompson *et al.* (1994) found no effect of nutritional management in spring on SS in adult sheep despite a reduction in FD variation along the staple. The events which determined the point of minimum FD and the POB were outside the experimental period. However, where strip grazing was used to control intake of dry sheep, variation in FD along the staple was reduced and SS increased (Doyle and Thompson 1993). In this experiment, the nutritional treatments were commenced around the POB, but the sheep had been losing weight through autumn and SS was generally low.

The FD profile for spring lambing ewes is more uniform and SS higher than for autumn lambing sheep (Foot and Vizard, 1993). For ewes lambing on green feed, the amount on offer and pasture growth rates will be the primary determinants of nutrient intake. The minimum amount of green pasture on offer that is needed to achieve maintenance of wool growth rate and hence SS through late pregnancy, parturition and lactation is not well defined.

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