The estimation of fibre diameter profile characteristics using reduced profiling techniques

D.J. Brown[AB], B.J. Crook[A] and I.W. Purvis[C]

[A] Animal Science, University of New England, Armidale, NSW 2351

[B] Present address: Animal Genetics and Breeding Unit, University of New England, Armidale, NSW 2351

[C] CSIRO Division of Animal Production and CRC for Premium Quality Wool, Armidale, NSW 2350

Short title: Estimating fibre diameter profiles

Contact address:
Mr. D.J. Brown
Animal Genetics and Breeding Unit
University of New England
Armidale
NSW 2351
Phone : 02 6773 3791
Fax: 02 6773 3266
E-mail: dbrown2@metz.une.edu.au

Summary

Alternative snippet sampling methods for rapidly estimating fibre diameter profiles (FDPs) are investigated in this paper using sheep grazing in two environments. FDPs were measured using staples from 40 Merino ewes from Chiswick in a temperate environment (n=20) and Bakers Hill in a Mediterranean environment (n=20). These ewes were the progeny of two sires within each of two bloodlines grazed at the two environments. Technique 1 was a simple reduced profiling technique, which generated profiles based on a subset of the original snippets. The FDP characteristics of maximum fibre diameter (Max), minimum fibre diameter (Min), difference between the maximum and minimum fibre diameter (Diff), fibre diameter variation along the profile (AstCV), average fibre diameter of the FDP (Profmean) and position of the Max estimated by technique 1 were highly correlated with those calculated from the full profile ($r > 0.96$). The correlations for the positions of Min were high ($r > 0.83$) while the correlations for the rates of fibre diameter change between the Max and the Min were lower, ranging from 0.65 to 0.90. This technique did not allow for the shape of the FDP and as a result often calculated a rate of change that was not significantly related to the original FDP.

A profile prediction technique was evaluated which utilised cubic spline functions to generate predicted profiles based on reduced profiles. This technique utilised more FDP characteristics and allowed for the calculation of two rates of fibre diameter change for each FDP. The actually fibre diameter values of the predicted profiles were all not significantly different ($P>0.05$) and highly correlated ($r > 0.91$) with the original full profile at all levels of snippet inclusion. The measures of absolute fibre diameter and along-staple variation in fibre diameter within the FDP were accurately estimated ($r > 0.80$) using only 1 in 10 snippets (on average approximately 13% of original snippets). Using approximately 27% of the original snippets all FDP characteristics can be estimated with acceptable accuracy ($r > 0.80$). Environment, bloodline and sire had significant effects on most FDP characteristics. These differences did not adversely affect the accuracy of the reduced profiling procedure.

Keywords: Fibre diameter profiles, estimation, prediction, reduced profiling.

Introduction

Low staple strength can be a major fault in Australian grown wool, especially wools grown in the Mediterranean environment, and is costing the Australian wool industry millions of dollars each year (Greeff *et al.* 1995). Physiological and environmental changes throughout the wool growth period create variation in fibre diameter along wool fibres. The way in which fibre diameter changes over the period of wool growth is termed a fibre diameter profile (FDP). Several studies have shown that the characteristics of a FDP are related to the strength of a staple. Minimum and maximum fibre diameter in a FDP are positively correlated with staple strength while the range, rate of change and along staple variation of fibre diameter are all negatively correlated with staple strength (Bigham *et al.* 1983; Denney 1990; Hansford 1992; Hansford 1994; Hansford and Kennedy 1988; Hansford and Kennedy 1990; Peterson 1997; Adams and Briegel 1998; Brown *et al.* 1999). The characteristics of the FDP can be directly related to the characteristics of the fibre length distribution in the top (Hansford 1994). Hansford (1997) demonstrated that the prediction of Hauteur could be improved by utilising information derived from the FDP. It has also been shown that FDP characteristics explain additional variation in staple strength above that which can be predicted using mean fibre diameter, fibre diameter variation and staple length (Brown *et al.* 1999).

There is a need to develop a technique to commercially extract FDP characteristics (Hansford 1997; Oldham *et al.* 1998). The OFDA2000 has recently been developed, which is capable of measuring fibre diameter profiles in both clean and greasy wool staples (Brims *et al.* 1999). Preliminary result suggest that the FDPs are a good indication of the true FDP of the staple (Brims *et al.* 1999), however more detailed studies are required using a range of FDP characteristics grown in a range of conditions.

Grignet *et al.* (1983), Hunter *et al.* (1990) and Maher and Daly (1998) have investigated using staple tex and cross-sectional area profiles as an alternative to using FDPs. However these authors did not directly compare the staple tex profile to full fibre diameter profiles. Schlink *et al.* (1999) compared both staple tex and cross sectional area profiles directly to standard FDPs and concluded that these techniques provide suitable alternatives to the presently more time consuming and destructive test methods used to generate FDPs. However this study did not compare any FDP characteristics such of rates of fibre diameter or cross sectional area change along the profiles.

At present the standard research technique for measuring FDPs involves segmenting the staple of wool into a series of 2mm snippets, the fibre diameter being measured for each snippet (Hansford *et al.* 1985). Fibre diameter measurements are plotted against their position along the staple to produce the pattern of fibre diameter change throughout the wool growth period. A FDP can be described by calculating a number of characteristics, including maximum and minimum fibre diameter points, the difference between these points, rates of fibre diameter change between the points of maximum and minimum fibre diameter and the level of along staple variation in fibre diameter. This technique is time consuming, difficult to automate and as a result is also expensive. Thus, it would be beneficial if the technique could be modified to reduce the time and costs involved, whilst still maintaining acceptable levels of accuracy.

A common technique that has been utilised involves the segmentation of the staple into 10 snippets at equal distances along the staple (Jackson and Downes 1979; Denny 1990; Hansford 1997; Yamin *et al.* 1999). There have been no published studies on the relationship between the FDP characteristics estimated using this technique and those from the full original FDP.

The aim of this study was to establish whether accurate and precise estimates of profile characteristics could be estimated from subsets of the full profile data.

Materials and Methods

Wool Samples

Wool staples were obtained from 20 Merino ewes maintained in a temperate environment at Armidale (CSIRO Chiswick Research Station, Armidale NSW, latitude 30^{0}31’S, longitude 151^{0}40’E) and 20 Merino ewes maintained in a Mediterranean environment at Bakers Hill in Western Australia (CSIRO Yalanbee Field Station, Bakers Hill WA, latitude 31^{0}46’S, longitude 116^{0}27’E) (Purvis 1997). In both environments, there were two bloodlines of sheep (fine and medium). Within each bloodline the animals were progeny of two sires, the same sires being used in both environments to provide genetic linkage. There were 5 sheep per sire - bloodline - environment group. Although the animals were born in different years, they were sampled at 2 years of age. In addition the sheep maintained at Armidale where run in 4 different groups for management purposes. The animals within each management group grazed together and were managed as one mob for the duration of the year. The only differences between management groups were the paddocks that they grazed. The

Armidale sheep were shorn in early August and the Yalanbee sheep were shorn in early October.

Fibre diameter profiling

The greasy staples were held at both ends with surgical clamps and washed in Perchloroethylene (distributed by ICI chemicals) for 5 minutes with gentle agitation to maintain staple integrity. The staple was then left to dry overnight, wrapped in cling wrap and segmented using the CSIRO Wool Staple Segmenter, to yield a series of 2mm snippets for the entire length of the staple. The mean fibre diameter of each snippet was measured using 500 counts by the LASERSCAN (Sirolan Laserscan^{TM} Technology) (Charlton 1995). Fibre diameter measurements were plotted against their relative position in millimetres along the staple to generate the FDP.

The characteristics calculated to describe each FDP were;

The minimum (Min) and maximum (Max) fibre diameter in the profile and the difference between them (Diff);

The position in millimetres of the Min (Minpos) and the Max (Maxpos) fibre diameter points, relative to the staple tip;

The overall average of the fibre diameter measurements of the snippets over the entire FDP (Profmean);

The along staple variation in the mean fibre diameter of the snippets calculated as coefficient of variation (AstCV);

The rate of fibre diameter change (ROC) between Max and Min, calculated by fitting a linear regression through all points.

Simple profile reduction

A series of simple reduced profiles were constructed using approximately 50, 33 or 25% of the original snippets. Starting from the tip, snippets were sequentially selected from the original profile with the unselected snippets being eliminated. Each of these levels of inclusion was repeated starting at the second snippet (for the 1 in 2, 1 in 3 and 1in 4 levels of inclusion) and the third snippet (for 1 in 2 and 1 in 3 inclusions) and the fourth snippet (for the 1 in 4 inclusion). For example, to generate the 33% level of inclusion the first and then every third snippet thereafter was retained. This was then repeated starting at the second snippet and then the third. This procedure generated a set of nine reduced profiles for each animal. The corresponding millimetre measurements were always maintained for each of the snippets so that the snippets always corresponded to the same position within the original profile.

Profile prediction

Reduced profiles were generated in the same manner as described for the simple profile reduction technique, however more levels of inclusion were examined. There were 10 levels of inclusion from 1 in 1 (original full profile) down to 1 in 10 (ie. 1 snippet retained in every 10 original snippets). All these profiles include the first and last snippet from the original profile so that mean fibre diameter values were only interpolated and not extrapolated. A cubic spline function was fitted to each of these reduced profiles using the Spline function of S-PLUS (Statistical Sciences 1995). This function was then used to predict the full profile (predicted profiles).

The FDP characteristics Max, Min, Diff, Profmean and AstCV were calculated as above. Five additional characteristics were calculated to describe the predicted FDPs more precisely as it was possible using the simple profile reduction technique that an inappropriate rate of change could be calculated (relevant to the full original profile). Three points were identified in each FDP at which the fibre diameter and millimetre measurements were recorded. Figure 1 describes these points using a FDP from the Armidale environment as an example. The points were;

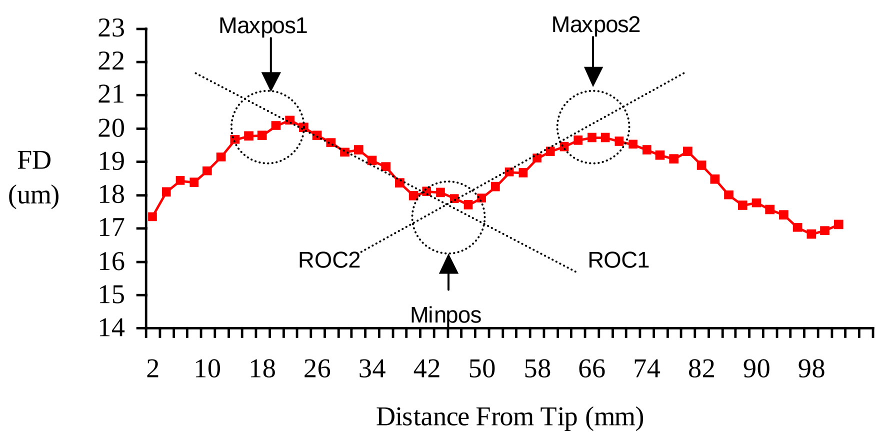
The position of the minimum fibre diameter (Mindiam) in approximately the middle of the profile (Minpos);

The maximum fibre diameter (Maxdiam1) between the Minpos and the tip of the profile (Maxpos1);

The maximum fibre diameter (Maxdiam2) between the Minpos and the base of the profiles (Maxpos2).

Using these three points two rates of fibre diameter change were calculated. The first rate of change (ROC1) was calculated between Maxpos1 and the Minpos and the second rate of change (ROC2) was calculated between the Minpos and maxpos2. These rates of change were calculated using the method described for the simple profile reduction technique.

Fig. 1. An example of an original full FDP from the Armidale environment



Statistical Analysis

Least squares analysis of variance of the FDP characteristics was conducted using the General Linear Model procedure in SAS (1990). As the 20 animals in the Armidale environment were also spread over 4 management groups, an overall analysis was conducted with the management group effect omitted to examine the influence of the environment, bloodline and sire. The data was then re-analysed within each environment with the management group effect included in the Armidale analysis. The management group effect was non-significant ($P > 0.05$) for all FDP characteristics and as a result only the overall analysis is reported. Environment, bloodline and their interaction were fitted as fixed effects. The sire (nested within bloodline) and environment by sire (within bloodline) interaction were fitted as random effects. The error terms used in the overall analysis to test each effect are shown in Table 1.

Table 1. The error terms used in the overall analysis to test the environment, bloodline, environment by bloodline interaction, sire and sire by environment interaction effects in the model

Source	Error term
Environment	MS Error + MS (Envt * Sire (Bld))
Bloodline	MS Error + MS (Sire (Bld))
Environment by Bloodline	MS Error + MS (Envt * Sire (Bld))
Sire within Bloodline	MS (Envt * Sire (Bld))
Environment by Sire within Bloodline	MS Error

Residual partial correlation coefficients were calculated between the FDP characteristics based on all the snippets (100%) and the FDP characteristics estimated using the reduced profiling techniques. The ranking of animals for each FDP characteristic was also examined at each level of snippet inclusion from the profile prediction technique using Spearman's rank correlation (SAS 1990).

Results

Simple profile reduction

The differences between the means of the FDP characteristics estimated from the simple reduced profiles and the means of the original profiles are shown in Table 2. The use of snippets other than the first as starting points for snippet selection reduced the predictive power of the reduced profiling procedures and were not subsequently considered in the analysis.

The mean values for the maximium fibre diameter, mean fibre diameter, positions of the maximum and minimum fibre diameter points and rates of fibre diameter change within the FDP estimated from all levels of inclusion were not significantly different from the original profile. The Min, Diff and AstCV were significantly different for the 1 in 2 and/or 1 in 3 levels of inclusion.

Table 2. Differences between the mean of the FDP characteristics estimated from the simple reduced profiles and the mean of those calculated from the original full profile (100% of snippets)

	FDP Characteristics.							
Level of Inclusion	Max (µm)	Min (µm)	Diff (µm)	Profmean (µm)	AstCV (%)	ROC (µm/mm)	Maxpos (mm)	Minpos (mm)
1 in 2	-0.00	0.05	-0.12	0.005	0.122	-0.002	1.05	-2.30
1 in 3	-0.60	**0.35**	-0.28	0.019	**0.258**	-0.006	1.20	2.95
1 in 4	0.37	0.10	**-0.31**	0.019	**0.424**	-0.002	0.60	0.50

Means in bold type are significantly different from the mean of the original profile ($P<0.05$)

The correlations between the full profile and the reduced profiles for Max, Min, Diff, AstCV and Maxpos exceeded 0.95 at all the levels of inclusion (Table 3). The correlations for Minpos ranged between 0.83 and 0.94, while the correlations for the rates of fibre diameter change were between 0.65 to 0.90 for ROC. There were no differences between environments in the correlations for the Max, Min and Diff. However, the correlations for the positions of the Max and Min tended to be slightly higher in the Yalanbee environment (r = 1.00 and r = 0.84 - 0.98 respectively) than in the Armidale environment (r = 0.91 - 0.94 and r = 0.81 - 0.94 respectively). The correlations observed for the rate of fibre diameter change also showed similar trends. In the Armidale environment the correlations were 0.63 to 0.89 for the ROC, while the correlations in the Yalanbee environment were 0.81 to 0.99.

Table 3. Residual correlations between the FDP characteristics calculated from the original full profile (100% of snippets) and those estimated from the simple reduced profiles

Level of	FDP Characteristics.							
Inclusion	**Max**	**Min**	**Diff**	**Profmean**	**AstCV**	**ROC**	**Maxpos**	**Minpos**
1 in 2	1.00	0.99	0.98	1.00	0.99	0.90	0.97	0.94
1 in 3	0.99	0.98	0.96	1.00	0.99	0.73	0.98	0.90
1 in 4	0.99	0.98	0.96	1.00	0.97	0.65	0.97	0.83

Profile prediction

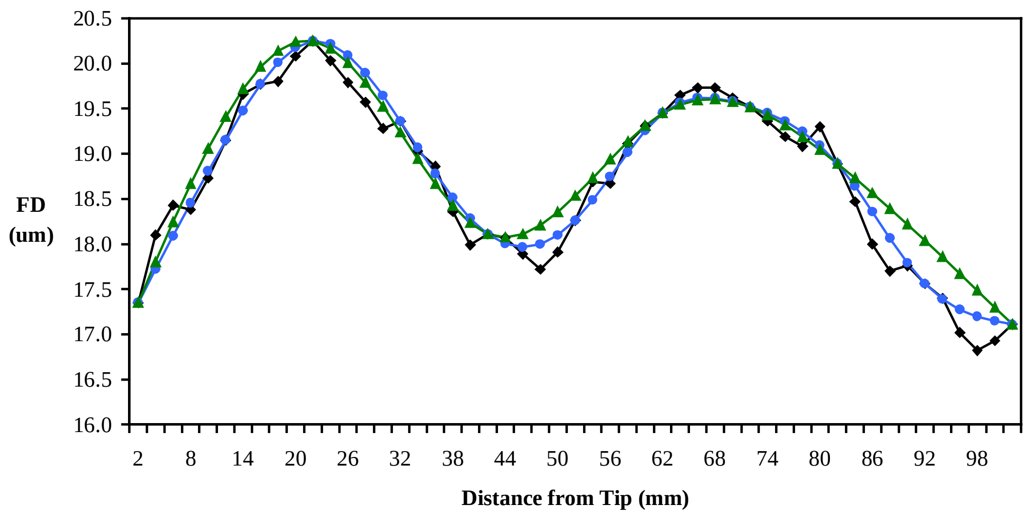
The actual fibre diameter values that made up the FDP were not significantly different to those of the original full profile at all levels of inclusion.

Table 4. The residual correlations between the original full FDPs and the predicted profiles at 10 levels of inclusion from the profile prediction technique

Level of		Analysis	
Inclusion	**Overall**	**Armidale**	**Yalanbee**
1 in 2	0.99	0.99	1.00
1 in 3	0.99	0.99	0.99
1 in 4	0.98	0.98	0.99
1 in 5	0.98	0.97	0.98
1 in 6	0.97	0.96	0.98
1 in 7	0.96	0.95	0.97
1 in 8	0.96	0.94	0.96
1 in 9	0.95	0.93	0.96
1 in 10	0.94	0.91	0.95

The correlations between the fibre diameter measurements for the predicted profiles and the original profiles at all levels of inclusion ranged from 0.91 to 1.00 (Table 4), with a tendency for slightly higher correlations in the Yalanbee environment compared to the Armidale environment. The effects of environment, bloodline, environment by bloodline interaction and sire on the FDPs were all highly significant (P = 0.0001) for all levels of inclusion. Figure 2 demonstrates the close relationship between the predicted profiles and the original profiles for one of the FDPs produced in the Armidale environment.

Fig. 2. An example of the fit between the predicted profiles at two levels of inclusion (● 1 in 5 and ▲ 1 in 10) and the original full (◆) FDP for a sheep maintained in the Armidale environment



The level of snippet inclusion expressed as a percentage of snippets in the original full FDP ranged between 12.8 and 51.7% of original snippets.

The means of the Max, Min, Minpos, Mindiam, Maxpos1, Maxdiam1, Maxpos2, Maxdiam2 and Profmean estimated from all levels of inclusion were not significantly different (P>0.05) from the original profile. The estimated means for ROC1 and ROC2 at all levels of inclusion except the 1 in 10 were not significantly different (P>0.05) to those calculated form the original full FDP. The means of Diff and AstCV were significantly different from the mean of the original profile (Table 5) at all levels of inclusion below 1 in 5. Environment and bloodline did not significantly (P>0.05) influence the differences between the means from the reduced profiles and the means from the original FDP for all FDP characteristics.

Decreasing the level of initial snippet inclusion from 1 in 2 to 1 in 10 snippets consistently decreased the correlation between the FDP characteristics from the predicted and the original FDPs.

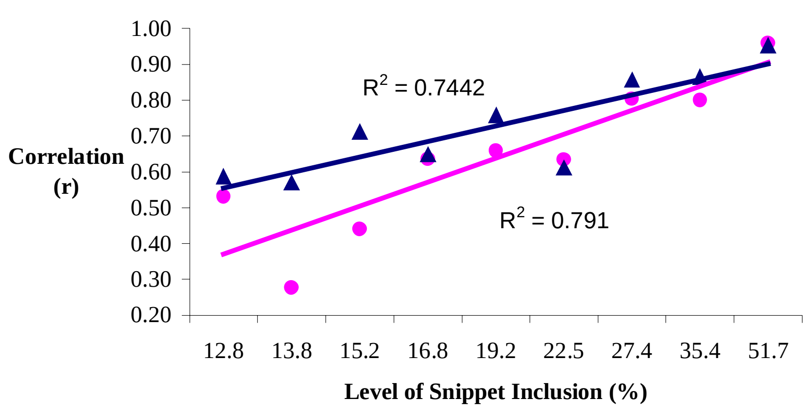
Table .5 The differences between the means of Diff, AstCV, ROC1 and ROC2 estimated from the predicted profiles from the profile prediction technique to the means calculated from the original full profiles

	Level Of Inclusion								
	1 in 2	**1 in 3**	**1 in 4**	**1 in 5**	**1 in 6**	**1 in 7**	**1 in 8**	**1 in 9**	**1 in 10**
Diff (µm)	-0.095	-0.206	-0.242	-0.264	**-0.412**	**-0.412**	**-0.501**	**-0.522**	**-0.656**
AstCV (%)	0.256	0.482	0.740	0.650	**0.909**	**1.058**	**1.027**	**1.069**	**1.064**
ROC1 (µm/mm)	-0.001	-0.011	-0.002	0.001	-0.002	-0.005	-0.012	-0.019	**-0.024**
ROC2 (µm/mm)	0.002	0.008	0.004	-0.004	-0.004	-0.006	-0.004	-0.014	**-0.027**

Means in bold type are significantly different from the mean of the original profile ($P<0.05$)

The Max, Min, Profmean, Mindiam, Maxdiam1 and Maxdiam2 estimated from the predicted profiles were very highly correlated with the original profile ($r > 0.90$) for all levels of inclusion. Diff and AstCV from the predicted and customised profiles were also highly correlated with the values from the original profiles with the coefficients ranging between 0.80 - 0.99 and 0.85 – 0.99 respectively. Examining the 1 in 7 inclusion which corresponds to the use of only 16.8% of the original snippets, correlations greater than 0.90 can be observed for the Max, Min, Diff, Profmean, Mindiam, Maxdiam1, Maxdiam2 and AstCV.

Fig. 3. The relationship between the level of snippet inclusion and the correlation between the original and estimated values for ROC1 ( ) and ROC2 ( ) from the predicted profiles



The correlation coefficients for the Minpos, Maxpos1 and Maxpos2 ranged between 0.62 – 0.99, 0.27 – 0.92 and 0.67 – 0.91 respectively. The correlation coefficients for the ROC1 and ROC2 were variable, ranging between 0.28 - 0.96 and 0.56 – 0.95 respectively. The influence of increasing the level of inclusion on the relationship between the original and estimated values for ROC1 and ROC2 is illustrated in Figure 3.

The rank correlations showed similar trends to the residual correlations. The FDP characteristics that are more highly correlated have rankings that are also more highly correlated. Over all levels of inclusion the correlations for Max, Min, Diff, Profmean, AstCV, Mindiam, Maxdiam1, Maxdiam2, Maxpos1 and Maxpos2 ranged between 0.91 and 1.00. Minpos, ROC1 and ROC2 ranged between 0.58 and 1.00, 0.35 and 0.94 and 0.64 and 0.96 respectively. At the 1 in 4 level of inclusion the rank correlations were all > 0.88. At this level of inclusion, the technique explains 77% of the variation in the rankings of the animals. At levels of profile inclusion lower than 1 in 4 the correlations of the ranks for Minpos, ROC1 and ROC2 become more variable.

Difference in the FDP characteristics between environments, bloodlines and sires

Environment significantly ($P < 0.05$) influenced Diff, Profmean, AstCV, Mindiam, Maxpos1, Maxpos2 and ROC1. The FDP characteristics of Max, Min, Profmean, Mindiam, Maxdiam1 and Maxdiam2 were significantly different between bloodlines. Sire also influenced the positions of the Mindiam, Maxdiam1 and Maxdiam2 and the along staple variation of fibre diameter (AstCV). These differences in the FDP characteristics between environments, bloodlines and sires did not adversely affect the reduced profiling procedures. The significance of these effects was also examined in all the reduced profiles (data not shown). This indicated that reduced FDPs produced similar results from the analysis of variance as the original full FDPs.

Discussion

The absolute fibre diameter values and measure of along-staple variation in fibre diameter from the predicted FDPs were all very closely related to those calculated from the full original profile at all levels of inclusion. Accurate estimates ($r > 0.80$) of all of these characteristics can be achieved using only 1 in 10 (13%) of the original snippets.

While these estimates are highly correlated the results indicated that small differences between the means were significant ($P<0.05$) for the range in fibre diameter and along-staple variation in fibre diameter. If a higher level of accuracy is required the 1 in 7 inclusion scenario can be used. This level of inclusion corresponds to the use of only 16.8% of the original snippets and correlations greater than 0.90 for all the fibre diameter profile characteristics that indicate absolute measures of fibre diameter and along-staple variation in fibre diameter. This results in the technique explaining approximately 80% of the variation of these FDP characteristics between animals.

The correlations for the positions of the maximum and minimum fibre diameter points and rates of fibre diameter change ranged from low at the low levels of snippet inclusion to very high at the higher levels of inclusion. There was an approximately linear relationship between the level of snippet inclusion and the strength of the correlation for the rates of fibre diameter change between the predicted profiles and the full original profile.

Considering all of the FDP characteristics the most appropriate method that produced the most consistent correlations at an acceptable level of accuracy was the 1 in 4 level of inclusion. This results in approximately 27% of the original snippets being used and correlations of greater than 0.80. The means of the estimated FDP characteristics were not significantly different from the means of the original FDP characteristics. This was deemed to be acceptable after considering two factors. Firstly, previous research by the authors (unpublished data) examining FDPs from two staples randomly selected from mid-side samples indicated variation between these staples in the position of the minimum and rates of fibre diameter change. Although for all FDP characteristics the mean values were not significantly different between staples the Minpos and ROC were only moderately correlated ($r=0.55$ to 0.69). The absolute fibre diameter values and along-staple variation in fibre diameter were highly correlated between staples ($r > 0.80$). The rate of fibre diameter change was only correlated at $r=0.30$. The raw FDPs were correlated at $r = 0.88$. This indicates that there is variation between staples within sheep and the precise value of the FDP characteristics may not be so important. Secondly, the major aim of measuring FDPs is to examine the differences between sheep in the shape of the profiles. Considering this fact it may be more relevant to examine the similarities in the ranking's of the animals for each FDP characteristic between each inclusion scenario. The rank correlations demonstrated that ranking's of the animals at the 1 in 4 scenario are very similar (r>0.80) to the ranking's of the animals using the original profile.

The most acceptable scenario will depend on the intended use of the data generated. If actual figures were required for comparison it would be more appropriate to select a level of inclusion that produces high correlations and non-significant differences between means for the FDP characteristics of interest. If the FDP characterises are required to rank animals, ie to identify the animals with the lowest level of along staple variation in fibre diameter, a lower level of inclusion may be able to be used. This would produce data that is highly correlated with the original FDPs but the mean values may not be statistically similar to the original FDP.

While the majority of FDP characteristics generated from the simple reduced profiles were moderately to highly correlated with, and generally not significantly different from, the FDP characteristics of the full original profile the position of the minimum and rates of fibre diameter change were not highly correlated at lower levels of snippet inclusion.

The fact that the rates of fibre diameter change and the position of the minimum and maximum fibre diameter points were variable may be related to the shape of the FDPs. In the Armidale environment the FDPs where generally "M shaped" (Figure 2), with the fibre diameter at the left hand point of maximum fibre diameter (closest to the tip) generally being greater than the point of maximum fibre diameter closest to the base. There were three areas of minimum in these profiles corresponding to the tip, base and middle of the profile. The FDPs from the Yalanbee animals were generally "V shaped" with the peaks in fibre diameter on either side of the profile. Detailed examinations of the FDP characteristics estimated from the simple reduced profiles demonstrated that in some instances the reduced profiles were estimating positions of maximum and minimum fibre diameter that were in markedly different positions within the reduced FDPs relative to the full original FDPs. The aim of calculating the rate of change between the maximum and minimum fibre diameter points is to identify the major slope in the profile, which has been shown to be associated with staple strength (Hansford and Kennedy 1988; Hansford and Kennedy 1990; Peterson 1997; Brown *et al.* 1999). For example, it is anticipated that in the FDPs grown in both environments the rates of change of greatest importance are likely to be the two rates of change either side of the minimum. The reduced profiles were in some situations selecting a position of maximum fibre diameter on the left-hand side of the profile (at approximately 24mm in Figure 2) and selecting positions of minimum fibre diameter at the base of the FDP (at approximately 98mm in Figure 2). This resulted in the calculation of rates of fibre diameter change that were not biologically appropriate and not always relevant to the original profile. Although the moderate to high correlations and the non-significant differences between means suggest that accurate estimations were achieved they actually may not be appropriate since they were in some instances not related to the rate of change that is of interest. In the FDP profiles used in this experiment the two rates of fibre diameter change either side of the minimum were of very similar magnitude. Therefore irrespective of which actual rate of fibre diameter was selected the results would be similar. In other wools in which the shape of the FDP and therefore the rates of fibre diameter change either side of the minimum were markedly different the procedure may produce inaccurate results.

The very high correlations between the original and the predicted profiles ($r > 0.91$ for all levels of inclusion) generated by the profile prediction technique indicate that the predicted profiles are a very good indication of the shape of the original FDPs (Figure 2). Since the predicted profiles describe the shape of the FDP well, they can then be examined and used to identify the most appropriate FDP characteristics to calculate.

A third technique was also evaluated (unpublished data) which involved positional re-sampling of the original profile at the positions of the maximum and minimum fibre diameter as estimated from the profile prediction technique. These points were then included in the reduced profile to form a customised profile. This technique was designed to improve the estimation of the positions of the maximum and minimum fibre diameter and therefore the rates of fibre diameter change. However, while the positional re-sampling improved the accuracy of the estimates, higher correlations could be achieved at a lower level of final snippet inclusion by using more original snippets to predict FDPs rather than lowering initial inclusion and increasing the level of re-sampling.

These results have implications for previous research as well as future studies. Yamin *et al.* (1999) reported genetic parameters for a range of fibre diameter characteristics using the 10-segment snippet method (Jackson and Downes 1979; Denny 1990; Hansford 1997). The results from the predicted profile indicate that these estimates for the absolute fibre diameter values and the measures of along-staple variation in fibre diameter from the FDPs should be accurate. However it may be possible that the reported rates of fibre diameter change may not be accurate representations of the full original FDP.

At this point in time there are no published validation studies for the OFDA 2000 which has been developed to measure FDPs in greasy staples. The results from the studies have implications for these future validation studies required for the OFDA 2000. The profile prediction procedure could be utilised to generate full fibre diameter profiles to compare to the fibre diameter profiles measured using the OFDA 2000. The level of inclusion used will depend on the characteristics measured and the intended use of the estimates.

There were significant differences in the FDP characteristics between environments, bloodlines and sires. These differences did not reduce the accuracy of the procedure once suitable FDP characteristics are estimated. This suggests that the profile prediction technique can be used on FDPs of difference shape without influencing its accuracy.

Conclusions

This study has demonstrated that accurate estimations of FDP characteristics can be made without using the full original profile. The best overall method evaluated utilised 27% of the original snippets and produced estimates for all FDP characteristics that were not significantly different and highly correlated with those from the original FDP. The most appropriate profiling procedure to use will depend on the intended use of the data, the shape of the FDP, the characteristics that will be calculated from the FDPs and the number of animals that are to be measured.

These techniques make it possible to measure larger numbers of FDPs without significantly additional labour. It may also be possible to utilise the profile prediction technique to estimate genetic parameters for FDP characteristics and further examine their relationship with staple strength.

Acknowledgements

The authors would like to thank the CSIRO Division of Animal Production at Armidale for gratefully making the wool samples, equipment for profiling and technical advise available for this research. The authors would also like to gratefully acknowledge Dr. Bob Murison for his assistance provided with data analysis and profile prediction. D.B. was in receipt of an Australian government scholarship and was also partly funded by the Cooperative Research Centre for Premium Quality Wool.

Bibliography

Adams, N.R. and Briegel, J.R. (1998). Liveweight and wool growth responses to a Mediterranean environment in three strains of merino sheep. *The Australian Journal of Agricultural Research* **49,** 1187-1193.

Bigham, M.L., Sumner, R.M.W., Hawker, H. and Fitzgerald, J.M. (1983). Fleece tenderness - A review. *Proceedings of the New Zealand Society of Animal Production* **43,** 73-78.

Brown, D.J., Crook, B.J. and Purvis, I.W. (1999). Genotype and environmental differences in fibre diameter profile characteristics and their relationship with staple strength in Merino sheep. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* **13,** 274-277.

Brims, M.A., Peterson, A.D. and Gherardi, S.G. (1999). Introducing the OFDA2000 - For rapid measurement of diameter profile on greasy wool staples. In “International Wool Textile Organisation Meeting”, Report No. RWG 04, South Africa.

Charlton, D. (1995). Sirolan-Laserscan – A review of its development, performance and application *Wool Technology and Sheep Breeding* **43(3),** 212-228.

Denney, G.D. (1990). Phenotypic variance of fibre diameter along wool staples and its relationship with other raw wool characters. *The Australian Journal of Agricultural Research* **30,** 463-467.

Greeff, J.C., Lewer, R.P., Ponzoni, R.W. and Purvis, I. (1995). Staple strength: Progress towards elucidating its place in Merino breeding. *Procedding of the Australian Association of Animal Breeding and Genetics* **11,** 595-601.

Grignet, J., Delfosse, P., Godard, P., Lenoir, J., Ainsworth, W. D., and Russel (1983). Use of a modified sensor to evaluate the length and variation in linear mass (cross-section) of raw wool staples. *In* “International Wool Textile Organisation”, pp. Report No. 14., Copenhagen.

Hansford, K.A. (1992). Fibre diameter distribution: Implications for wool production. *Wool Technology and Sheep Breeding* **40(1),** 2-9.

Hansford, K.A. (1994). Fleece specifications and processing prediction. In "Woolspec

94", Proceedings of a seminar on specification of Australian wool and its implications for marketing and processing., Sydney, Nov. 1994 R.A. Rottenbury, K.A. Hansford, and J.P. Scanlan., CSIRO Division of wool technology.

Hansford, K.A. (1997). A study of the specification and top-making performance of Western Australian fleeces and sale lots. *In* “International Wool Textile Organisation”, Report No. 15., Nice.

Hansford, K.A., Emery, G.B. and Teasdale, D.C. (1985). A method to measure the diameter profile of wool staples. *Wool Technology and Sheep Breeding*. **40(1)**, 25-27.

Hansford, K.A. and Kennedy, J.P. (1988). Relationship between the rate of change in fibre diameter and staple strength. *Proceedings of the Australian Society of Animal Production* **17,** 415.

Hansford, K.A. and Kennedy, J.P. (1990). The relationship between variation in fibre diameter along staples and staple strength. In "Proceedings of the 8th International Wool Textile Research Conference.", Christchurch, N.Z., Feb. 1990. **1,** 590.

Hunter, L., van Wyk, J. B., de Wet, P. J., Grobbelaar, P. D., Pretorius, P. S., Morris, J. de V., and Leeuwner, W. (1990). The effects of nutritional and lambing stress on wool fibre and processing characteristics. *In* “Proceedings of the 8th International Wool Textile Research Conference” (H. Crawshaw, ed.), Vol. 2, pp. 145-56. WRONZ, Christchurch.

Maher, A. P., and Daly, J. S. (1998). The derivation of the cross-sectional area along wool fibre from OFDA diameter measurements. *Journal Textile Institute* **89**, 133-141.

Oldham, C.M., Couchman, R.C., and Robinson, G.A. (1998). Report on an investigation into effects of season of shearing and selling centre on processing performance to top. *In* “International Wool Textile Organisation”, Report No. 6., Dresden.

Peterson, A.D. (1997). The components of staple strength. Post-Graduate Masters Thesis, The University of Western Australia.

Purvis, I.P. (1997). Breeding for improved productivity and wool quality in fine wool Merinos. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* **12,** 697-700.

SAS (1990). SAS/STAT User's Guide. Version 6, Fourth edition, Cary, N.C. : SAS

Institute.
Schlink, A. C., Clark, S. K., and Murray, A. M. (1999). Using staple tex profiles as an alternative to fibre diameter. *Wool Technology and Sheep Breeding.* **47(2)**, 118-127.
Statistical Sciences (1995). S-PLUS Reference Manual, Version 3.3 for Windows, StatSci, A Divsion of MathSoft Inc.: Seattle.