CHAPTER 3

The estimation of fibre diameter profile characteristics using reduced profiling techniques

3.1 Introduction

Physiological and environmental stresses throughout the wool growth period create variation in fibre diameter along wool fibres. Under standardised environmental conditions differences exist between individual sheep in their fibre diameter responses and therefore in their fibre diameter profiles (FDPs). It has been suggested that these differences may indicate differences in sensitivity to environmental change. For example, variation in fibre diameter along the staple has been shown to differ between selection lines, sire groups and bloodlines (Jackson and Downes 1979; Denney 1990a; Hansford 1994; Adams *et al.* 1997; Adams and Briegel 1998; Adams *et al.* 1998), suggesting that some sheep and/or bloodlines may show genetic predisposition in their fibre diameter responses under a given environmental scenario. The only genetic study of FDP characteristics to date (Yamin *et al.* 1999) indicated that the FDP characteristics were low to moderately heritable. The rate of fibre diameter change estimated in this study was not heritable however only 10 snippets were used to measure the FDP. These authors did not report any genetic correlations between FDP characteristics and other wool quality characteristics. Extensive genetic studies are required to accurately estimate genetic relationships between FDP and wool quality traits and evaluate whether aspects of the FDP offer potential as selection criteria for improving staple strength. These studies will require large numbers of FDPs to be generated, which given present techniques, is not practical.

A technique to commercially measure FDP characteristics is warranted (Hansford 1997a; Oldham *et al.* 1998). The current standard technique for measuring FDPs involves segmenting the staple of wool into a series of 2mm snippets, with 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 parameters, 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 along-staple variation in fibre diameter. This technique is time consuming, difficult to automate and as a result is also expensive. Using the Sirolan Laserscan, it takes approximately 30 to 35 minutes to measure the fibre diameter of the 2mm snippets from an average staple (80mm), costing approximately $7.50 to $8.75 in labour alone. Alternatively a standard mid-side measurement of fibre diameter costs approximately $1-2, which would result in a $10 - 20 total cost for a 10 segment FDP. As a result fibre diameter profiling is presently only suited to small research applications. Researchers have to limit the number of FDPs and therefore sheep being examined due to the work required and cost per staple. Thus, it would be beneficial if research techniques could be modified to reduce the workload and costs involved, whilst still maintaining acceptable levels of accuracy. The consequence of reducing the work required per staple would be that more staples and therefore more sheep could be studied during a given time period.

It may be possible to estimate the characteristics of a fibre diameter profile without measuring all the original snippets from a staple. Cubic splines are mathematical functions that provide many benefits for modelling longitudinal data (Statistical Sciences 1995). These functions may be able to be applied to FDPs to reduce the number of snippets that need to be measured. There have been no investigations into the use of reduced FDPs. 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 1990a; Hansford 1997a; 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.

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 FDP characteristics such as rates of fibre diameter or cross sectional area change along the profiles.

The OFDA 2000 (Brims *et al.* 1999) recently developed by BSC Electronics in Western Australia is designed to rapidly measure FDPs in greasy staples. At present there have been no extensive studies of the accuracy of this equipment over a range of wools. These validation studies will also require that a large number of FDPs are generated and at present it is not known which technique is the most appropriate to use.

This chapter describes the development and evaluation of three reduced fibre diameter profiling techniques with the aim of estimating FDP characteristics without having to measure all the snippets from the original FDP. The hypotheses tested in this study are;

- Accurate estimates of profile characteristics can be generated using subsets of snippets from the full FDP.
- Variation between staples within a mid-side sample does not influence FDP characteristics.
- That the environment in which the FDP was grown does not influence the accuracy of the profiling procedure.

3.2 Materials and Methods

3.2.1 Wool samples

Two sets of wool samples were collected to evaluate the reduced profiling procedures.

Armidale samples

Two staples were randomly selected from the mid-side sample of 28, 3 year old, Merino ewes from the CSIRO Fine Wool Project (Purvis 1997a). These 28 sheep represented 4 sheep from each of 7 fine and superfine bloodlines and were maintained on pasture in a temperate environment at Armidale, NSW, latitude $30^0$31'S, longitude $151^0$40'E.

Armidale – Yalanbee samples

A wool staple was obtained from each of 20 Merino ewes maintained in a temperate environment at Armidale (mid-side samples collected from the CSIRO Chiswick Research Station, Armidale, NSW) and 20 ewes maintained in a Mediterranean environment at

Yalanbee (CSIRO Yalanbee Field Station, Bakers Hill, WA, latitude 31°46'S, longitude 116°27'E). 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 in each environment were born in different years, they were all sampled at 2 years of age. In addition the Armidale animals where maintained in 4 management groups. The animals in each management group grazed together and were managed as one mob for the duration of the year. The Armidale sheep were shorn in early August and the Yalanbee sheep were shorn in early October.

3.2.2 Fibre diameter profiling

Armidale samples

Greasy staples were 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 snippets were then washed in Perchloroethylene (distributed by ICI chemicals) and dried using the Sirolan Air Blast. The mean fibre diameter of each snippet was measured using 500 counts by the LASERSCAN (Sirolan Laserscan™ Technology) (Charlton 1995). The fibre diameter measurements were plotted against their relative position in millimetres along the staple to generate the FDP.

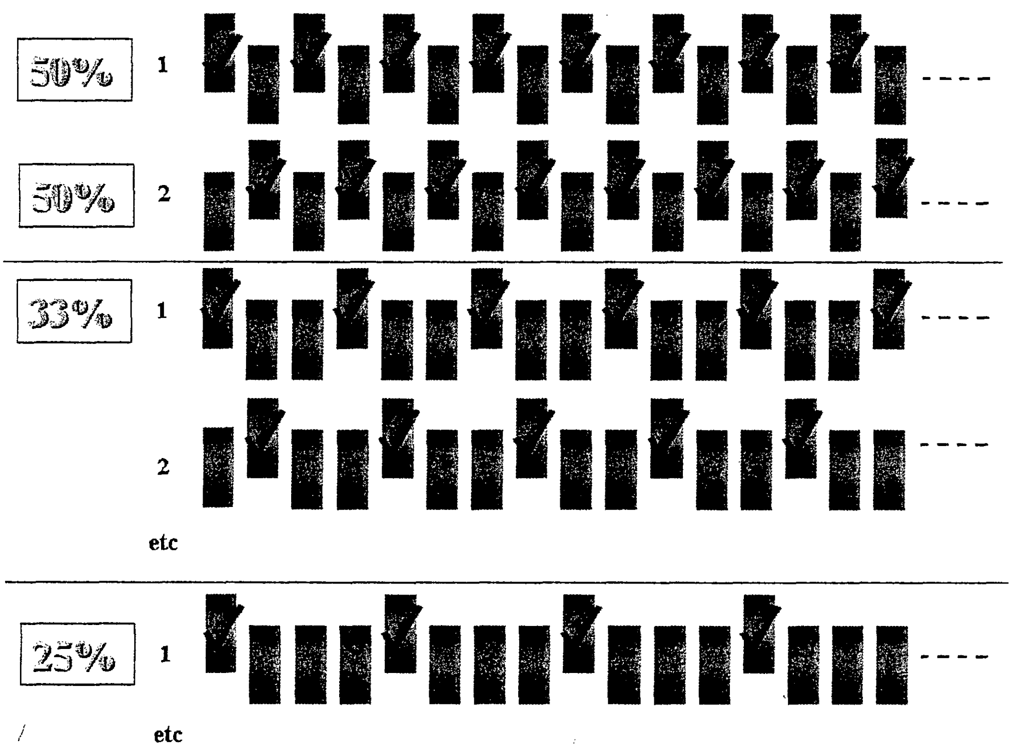
Armidale – Yalanbee samples

Greasy staples were randomly selected from each sheep, 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 as described for Armidale samples.

3.2.3 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 (Figure 3.1). Each of these levels of inclusion was repeated starting at the second snippet (for the 50, 33 and 25% inclusion) and the third snippet (for 33 and 25% inclusion) and the fourth snippet (for the 25% 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.

Figure 3.1 Illustration of snippet selection to generate the reduced FDPs



3.2.4 FDP characteristics

The same FDP characteristics were calculated for both sets of wool samples. 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 average fibre diameter for all the snippets in the FDP (Profmean);

- The position in millimetres of the minimum (Minpos) and the maximum (Maxpos) fibre diameter points, starting from the staple tip;
- The along staple variation in the mean fibre diameter of the snippets calculated as a the variance (AstVAR) and as coefficient of variation (AstCV);
- The rate of mean fibre diameter change (Regroc) between Max and Min, calculated by fitting a linear regression through all points;
- The rate of fibre diameter change between the Max and Min (2ptroc), calculated as (Max-Min)/(Maxpos-Minpos).

3.2.5 Profile prediction

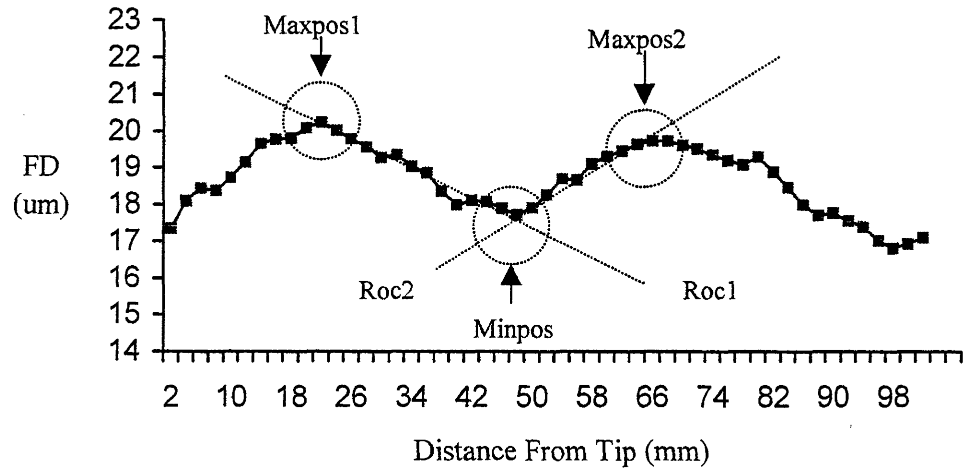
The original FDPs generated from the Armidale – Yalanbee samples were used to evaluate the profile prediction technique. Reduced profiles were generated in the same manner as described for the simple profile reduction technique, however more levels of inclusion were examined. There were 10 levels of inclusion from 1 in 1 (original full profile) down to 1 in 10 (ie. 1 snippet retained in every 10 original snippets). All the profiles included 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 reduced profile using the Spline function of S-PLUS (Statistical Sciences 1995). This function was then used to predict the full profile (predicted FDP).

The FDP characteristics Max, Min, Diff, Profmean, AstVAR and AstCV were calculated as above. Five additional characteristics were calculated to describe the predicted profiles more precisely. The following three points were identified in each FDP;

1. the position of the minimum fibre diameter (Mindiam) in approximately the middle of the profile (Minpos);
2. the maximum fibre diameter (Maxdiam1) between the Minpos and the tip of the profile (Maxpos1);
3. the maximum fibre diameter (Maxdiam2) between the Minpos and the base of the profiles (Maxpos2).

Figure 3.2 describes these points using a FDP from the Armidale environment as an example. 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 two methods described in the simple profile reduction technique (Regroc and 2ptroc).

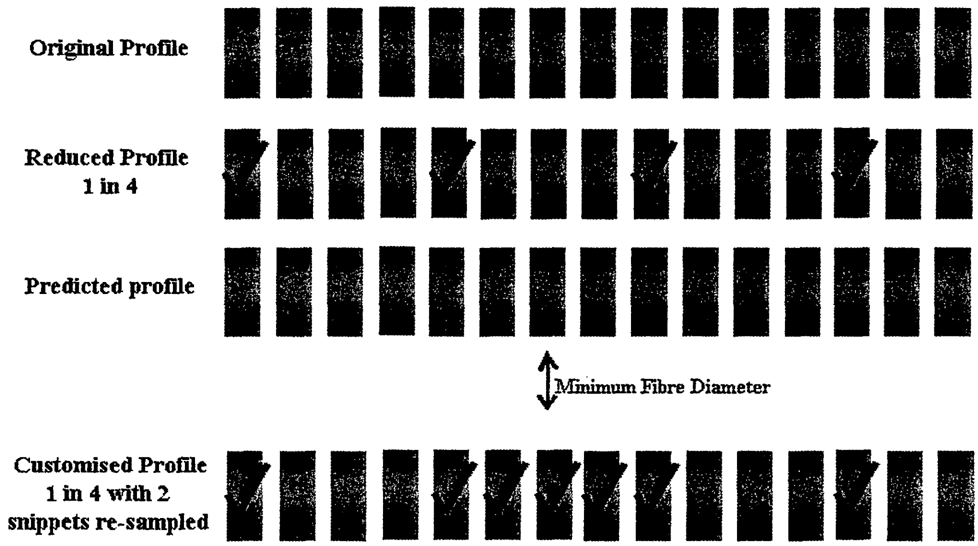
Figure 3.2 An example of an original full FDP from the temperate environment at Armidale, showing the additional traits calculated for the predicted and customised profiles



3.2.6 Customised profiles

The customised profile technique is an extension of the profile prediction technique and is designed to more accurately identify the Minpos, Maxpos1 and Maxpos2. The Minpos, Maxpos1 and Maxpos2 were estimated using the profile prediction technique. The original profile was then intensively re-sampled either side of these points (Figure 3.3). The sub-sampling was performed at 6 levels, which were 0, 1, 2, 3, 4 and 5 snippets re-sampled from each side of the Minpos, Maxpos1 and Maxpos2. The re-sampled points and the reduced profiles were combined to form a customised profile. The same FDP characteristics used for the profile prediction technique were then calculated from these customised profiles. The levels of initial and final inclusion were also recorded. The initial level of inclusion is the average percentage of snippets from the original profiles that were included in the reduced profile. The final level of inclusion is the average percentage of the original snippets included in the customised profiles.

Figure 3.3 Illustration of the snippet selection process used to generate the customised FDPs with selection of the snippets at the point of minimum fibre diameter with 2 snippets re-sampled as an example



3.2.7 Statistical analysis

Armidale

Least squares multivariate analysis of variance of the FDP characteristics was conducted using the General Linear Model procedure in SAS (1990). Bloodline, sheep within bloodline and staple within sheep were fitted in a mixed effect model. Least squares means were also calculated to compare means of the estimated FDP characteristics with those from the original FDP. Differences were considered to be significant at $P < 0.05$. The residual partial correlation coefficients were calculated to compare the FDP characteristics calculated using the original FDP to those estimated using the simple reduced profiling techniques.

The variance components in the model were estimated using the VARCOMP procedure of SAS (1990). Using these variance components the intra-class correlation coefficients (r1) were generated to estimate the repeatability of the measurements between snippet selection methods (eg 33-1 vs 33-2 vs 33-3) within each level of snippet inclusion, as follows:

$$r1 = \frac{\text{MS between classes} - \text{MS within classes}}{\text{MS between classes} + (n-1)\,\text{MS within classes}}$$

Armidale – Yalanbee samples

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 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 the 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 3.1. Residual correlation coefficients were calculated between the FDP characteristics calculated from the original FDPs and the FDP characteristics estimated using the reduced profiling techniques.

Table 3.1 The error terms used in the overall analysis to test the environment (Envt), bloodline (Bld), environment by bloodline interaction (Envt * Bld), Envt * Sire (Sire) and sire by environment interaction effects in the model

Source	Error term
Envt	MS Error + MS (Envt * Sire (Bld))
Bld	MS Error + MS (Sire (Bld))
Envt * Bld	MS Error + MS (Envt * Sire (Bld))
Sire (Bld)	MS Envt * Sire (Bld)
Envt * Sire (Bld)	MS Error

A second least squares analysis of variance was conducted treating each level of snippet inclusion as a separate treatment. This enabled the comparison of means between the original FDP and the estimated FDP characteristics from the predicted and customised FDPs at each level of snippet inclusion. The ranking of animals for each FDP characteristic was also examined at each level of snippet inclusion using Spearman's rank correlation (SAS 1990).

3.3 Results

3.3.1 Simple profile reduction

The differences between the mean values of the FDP characteristics estimated from the simple reduced profiles and the mean values of the original profiles are shown in Table 3.2. The mean values for Profmean and Regroc estimated from all nine levels of inclusion were not significantly different from the original profile in both sets of wool samples. The means of Max and Minpos in Armidale-Yalanbee samples were also not significantly different over all levels of inclusion. The AstVAR, AstCV, 2ptroc and Minpos for Armidale samples and the Min, AstVAR, AstCV and 2ptroc in Armidale-Yalanbee samples were not significantly different for most levels of inclusion. The means of the Max, Min and Diff in Armidale samples and the Diff and Maxpos in Armidale-Yalanbee samples were significantly different for most levels of inclusion. The differences for most characteristics were consistently larger with lower levels of inclusion.

The correlations between the full profile and the reduced profiles for Profmean in Armidale samples and the Max, Min, AstVAR, Profmean and AstCV in Armidale-Yalanbee samples exceeded 0.95 at all the levels of inclusion (Table 3.3). In Armidale samples the correlations for Max, AstCV were greater than 0.75 while the correlations for the remaining characteristics were more variable and generally lower. In the Armidale-Yalanbee samples the correlations for Diff exceeded 0.86 at all the levels of inclusion. The correlations for Minpos ranged between 0.63 to 0.94 while the correlations for Maxpos ranged between 0.45 and 0.98. The rates of fibre diameter change were correlated at 0.19 to 0.90 for Regroc and 0.27 to 0.91 for 2ptroc. In both data sets the 2ptroc generally had greater agreement between methods than did the Regroc.

The results in Table 3.3 also indicate that the correlations obtained for the inclusion scenarios starting at the first snippet were greater than those obtained when starting at the 2nd, 3rd and 4th snippets.

Table 3.2 Differences between the mean values for the FDP characteristics estimated from the simple reduced profiles and the mean values as calculated from the full original profile

		FDP Characteristics.									
Level of Inclusion	**Starting Snippet**	**Max (µm)**	**Min (µm)**	**Diff (µm)**	**AstVAR (µm)**	**Profmean (µm)**	**AstCV (%)**	**Regroc (µm/mm)**	**2ptroc (µm/mm)**	**Maxpos (mm)**	**Minpos (mm)**
		Armidale (n=28)									
1 in 2	1	0.06	-0.09	**0.15**	-0.027	0.005	-0.073	-0.008	-0.002	0.16	1.61
	2	**0.08**	**-0.12**	**0.19**	-0.012	-0.005	-0.031	0.002	0.007	-0.10	-4.39
1 in 3	1	**0.12**	**-0.13**	**0.25**	**-0.067**	0.016	**-0.16**	-0.008	0.000	-0.87	1.7
	2	**0.10**	**-0.19**	**0.29**	-0.048	0.008	-0.129	0.001	0.01	0.23	-2.32
	3	**0.14**	**-0.28**	**0.42**	-0.001	-0.025	-0.001	0.011	**0.02**	0.36	**-10.90**
1 in 4	1	**0.17**	**-0.19**	**0.36**	**-0.083**	0.027	**-0.203**	-0.012	-0.001	-0.23	3.94
	2	**0.16**	**-0.25**	**0.41**	-0.049	0.019	**-0.16**	-0.001	0.008	-0.68	0.39
	3	**0.15**	**-0.32**	**0.47**	-0.048	-0.016	-0.135	0.008	**0.019**	0.29	**-9.74**
	4	**0.18**	**-0.32**	**0.49**	**-0.054**	-0.032	-0.088	0.011	**0.021**	-0.03	**-12.65**
		Armidale-Yalanbee (n=40)									
1 in 2	1	-0.00	0.05	-0.12	0.087	0.005	0.122	-0.002	-0.005	1.05	-2.30
	2	0.36	-0.02	-0.21	0.049	-0.014	0.030	-0.006	-0.010	**14.60**	2.60
1 in 3	1	-0.60	**0.35**	-0.28	-0.028	0.019	**0.258**	-0.006	-0.010	1.20	2.95
	2	0.28	0.05	**-0.36**	0.111	-0.010	0.138	-0.003	-0.011	**11.90**	-2.10
	3	-0.25	0.21	**-0.49**	0.032	-0.024	0.046	-0.018	**-0.021**	**23.75**	2.30
1 in 4	1	0.37	0.10	**-0.31**	**0.300**	0.019	**0.424**	-0.002	-0.009	0.60	0.50
	2	-0.31	0.22	**-0.54**	0.167	0.017	**0.248**	-0.004	-0.014	**15.75**	-1.15
	3	-0.39	**0.34**	**-0.54**	-0.070	-0.010	0.116	-0.019	**-0.024**	**22.30**	-0.20
	4	0.20	0.14	**-0.53**	0.073	-0.038	0.079	-0.015	**-0.022**	**20.60**	4.50

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

Using the FDP characteristics from the Armidale-Yalanbee samples the influence of environment on the simple reduced profiling procedure was examined. There were very small differences between environments in the correlations for the Max, Min, Diff and AstVAR. 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 rates of fibre diameter change also showed similar trends. In the Armidale environment the correlations were 0.63-0.89 and 0.77-0.89 for the Regroc and 2ptroc respectively, while the correlations in the Yalanbee environment were respectively 0.81 to 0.99.

The intra-class correlations between the FDP characteristics estimated for each starting snippet within each level of inclusion illustrated in Table 3.4 show similar trends to the previous results. The Max, Diff, AstVAR, Profmean and AstCV are moderately to highly correlated (r=0.30 to 0.85) within each level of inclusion. However, for the Maxpos, Minpos, 2ptroc and Regroc the intra-class correlations were generally low (r=0.01 to 0.40). The correlations generally decreased as the level of inclusion decreased.

Table 3.3 Residual correlation coefficients for the relationship between the FDP characteristics calculated from the full original FDP and those estimated from the reduced FDPs using simple profile reduction (n=40)

Level of Inclusion	Starting Snippet	Max	Min	Diff	AstVAR	Profmean	AstCV	Regroc	2ptroc	Maxpos	Minpos
		Armidale (n=28)									
1 in 2	**1**	0.94	0.94	0.95	0.96	0.99	0.96	0.51	0.69	0.87	0.80
	2	0.89	0.66	0.71	0.91	0.99	0.94	0.28	0.04	0.21	0.64
1 in 3	**1**	0.85	0.93	0.87	0.86	0.98	0.86	0.49	0.59	0.75	0.72
	2	0.86	0.53	0.56	0.77	0.98	0.78	0.31	0.17	0.77	0.52
	3	0.88	0.42	0.56	0.85	0.99	0.87	0.14	0.04	0.22	0.35
1 in 4	**1**	0.88	0.89	0.84	0.86	0.94	0.83	0.52	0.70	0.46	0.86
	2	0.85	0.51	0.61	0.76	0.94	0.82	0.14	0.11	0.19	0.38
	3	0.78	0.39	0.46	0.78	0.97	0.80	0.24	0.86	0.68	0.37
	4	0.86	0.43	0.51	0.55	0.96	0.75	0.37	0.02	0.43	0.51
		Armidale-Yalanbee (n=40)									
1 in 2	**1**	1.00	0.99	0.98	0.99	1.00	0.99	0.90	0.91	0.97	0.94
	2	0.98	0.99	0.94	0.99	1.00	0.99	0.84	0.87	0.66	0.90
1 in 3	**1**	0.99	0.98	0.96	0.99	1.00	0.99	0.73	0.83	0.98	0.90
	2	0.98	0.99	0.92	0.98	1.00	0.98	0.82	0.82	0.78	0.93
	3	0.96	0.98	0.87	0.97	1.00	0.98	0.72	0.74	0.50	0.84
1 in 4	**1**	0.99	0.98	0.96	0.97	1.00	0.97	0.65	0.80	0.97	0.83
	2	0.97	0.98	0.89	0.96	1.00	0.96	0.69	0.73	0.70	0.88
	3	0.97	0.97	0.89	0.97	1.00	0.97	0.82	0.73	0.45	0.88
	4	0.96	0.97	0.86	0.95	1.00	0.95	0.19	0.27	0.45	0.63

Table 3.4 The intra-class correlations between inclusion scenarios within each level of inclusion for the Armidale samples (n=28)

	Level of inclusion		
	1 in 2	**1 in 3**	**1 in 4**
Max	0.78	0.71	0.64
Min	0.47	0.25	0.25
Diff	0.54	0.32	0.30
AstVAR	0.66	0.30	0.32
Profmean	0.85	0.76	0.69
AstCV	0.81	0.74	0.62
Maxpos	0.19	0.27	0.14
Minpos	0.40	0.14	0.15
2ptroc	0.01	0.03	0.13
Regroc	0.04	0.08	0.12

Variation in FDP characteristics between staples

The raw fibre diameter measurements that make up the FDP were highly correlated (r=0.88, P<0.01) between staples. The mean values for all FDP characteristics were not significantly different (P>0.05) between staples (Table 3.5). Very high correlations (r > 0.90) were observed between staples for Max, Min, AstVAR, Profmean and AstCV. The correlations for Diff and Maxpos were high (r > 0.80) while the correlations for the Minpos, 2ptroc and Regroc were moderate (r=0.60 to 0.69).

Table 3.5 The least square means, standard errors (s.e.) and residual correlations between staples for each FDP characteristics from the Armidale samples (n=28)

	Max	Min	Diff	AstVAR	Profmean	AstCV	Maxpos	Minpos	2ptroc	Regroc
Staple 1	19.34	16.56	3.33	0.88	18.30	4.89	26.17	49.43	0.08	0.07
Staple 2	19.81	16.57	3.20	0.83	18.25	4.75	30.01	58.82	0.07	0.06
s.e.	0.42	0.06	0.07	0.02	0.04	0.06	1.57	4.68	0.01	0.01
Residual Correlations	0.94*	0.90*	0.80*	0.94*	0.96*	0.93*	0.82*	0.69*	0.61*	0.60*

* Correlation significant (P<0.05)

For Max, Min, Diff, Profmean and AstCV in the Armidale samples 81.2-95.7% of the total variation existed between bloodlines with, only a small proportion between sheep within bloodlines (5.0 -14.8%) and negligible variation (0.2 to 4%) between staples within sheep (Table 3.6). AstVAR, Maxpos, 2ptroc and Regroc showed a similar trend, though slightly more variation was exhibited between sheep and between staples. The variance components for Minpos did not show these trends with greater variation between sheep and little variation between bloodlines.

Table 3.6 The percentage of variation within each component of the model used from the Armidale samples

	Between Staples	Between sheep within bloodlines	Between bloodlines
Max	0.3	5.0	94.7
Min	1.0	11.0	88.0
Diff	4.0	14.8	81.2
AstVAR	2.3	40.3	57.5
Profmean	0.2	4.1	95.7
AstCV	0.8	5.3	93.9
Maxpos	6.8	34.8	58.4
Minpos	25.4	62.5	12.1
2ptroc	12.2	29.1	58.7
Regroc	10.3	30.3	59.4

3.3.2 Predicted profiles and customised profiles

The results for the predicted profiles and customised profiles are combined for ease of presentation. As the simple profile reduction technique indicated that including the first snippet produced more accurate results, the reduced profiles starting from the 2nd, 3rd and 4th snippets were not included for profile prediction and customised profile techniques.

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 3.7), with little difference between the two environments. Figure 3.4 demonstrates the close relationship between the predicted profiles and the original profiles for one of the FDPs produced in the Armidale environment.

Table 3.7 The residual correlations between the original full FDPs and the predicted FDPs at 10 levels of inclusion from the FDP prediction technique (n=40)

Level of Inclusion	Analysis: 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

Figure 3.4 An example of the fit between the predicted FDPs (at the 1 in 5 and 1in 10 levels of inclusion) and original full FDP for a sheep maintained in the Armidale environment

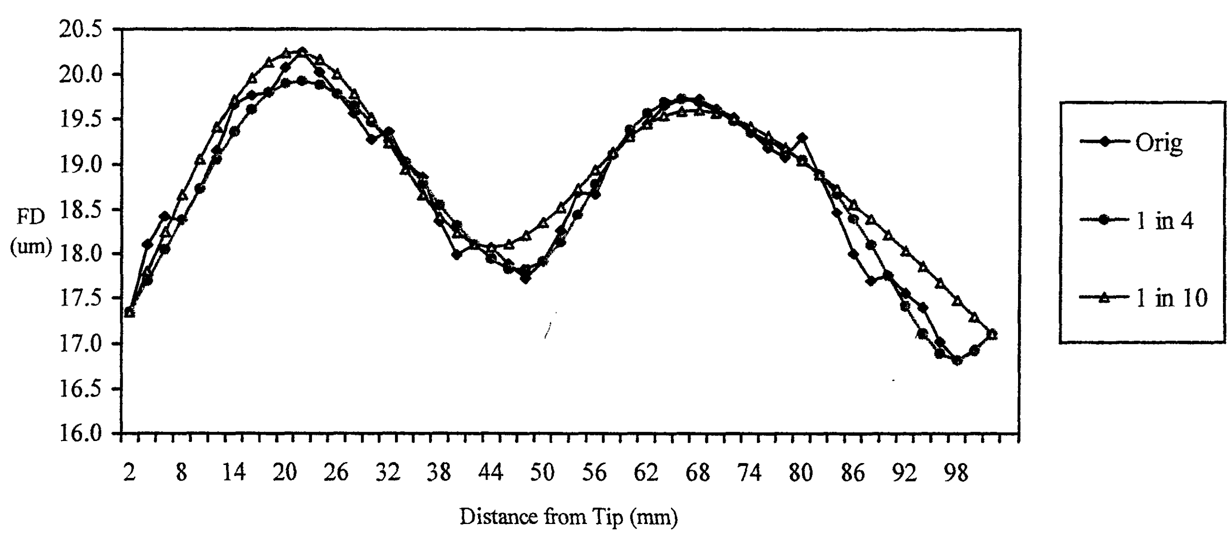


Table 3.8 The average level of final snippet inclusion as a percentage for each initial inclusion scenario from the FDP prediction and intensive re-sampling techniques

Snippets	Initial Level Of Inclusion								
Re-sampled	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
0	51.7	35.4	27.4	22.5	19.2	16.8	15.2	13.8	12.8
1	60.6	45.9	39.4	35.0	31.7	29.3	28.0	26.6	25.8
2	64.1	53.6	47.1	43.7	40.7	38.3	37.3	36.3	35.1
3	70.9	58.8	55.0	52.4	49.8	47.8	46.8	45.9	44.7
4	73.3	65.1	60.8	60.0	57.5	56.2	55.5	54.4	53.3
5	79.0	70.3	67.0	64.8	64.2	63.4	63.2	62.2	61.5

Table 3.8 illustrates the number of snippets included in the predicted profiles where there was no snippet re-sampling and the customised profile where snippets were re-sampled, all expressed as a percentage of the number of snippets in the original full FDP. The level of final snippet inclusion ranged between 12.8 and 79% of original snippets. Without any snippet re-sampling the average level of final snippet inclusion ranged between 12.8 and 51.7%.

A summary of the differences between mean values of the FDP characteristics from the original FDP and those estimated from the predicted FDP characteristics at all levels of inclusion and snippet re-sampling is given in Appendix 3.1. Mean values of the Max, Min, Minpos, Mindiam, Maxpos1, Maxdiam1, Maxpos2, Maxdiam2 and Profmean estimated from all levels of inclusion and snippet re-sampling were not significantly different (P>0.05) from the original FDP. The differences between the means for the measures of variation in fibre diameter along the profile and rates of fibre diameter change characteristics estimated from the profile prediction technique and the customised profiles were more variable. The majority (>87%) of the estimated means for Diff, Regroc1, Regroc2, 2ptroc1 and 2ptroc2 were not significantly different (P>0.05) for most levels of inclusion and re-sampling. The significant differences consistently occurred at the very low levels of final snippet inclusion (<20% final snippet inclusion). A greater percentage of the means for AstVAR and AstCV estimated from the predicted and customised profiles were significantly different to the means from the original profile (Table 3.9). The snippet re-sampling consistently reduced the differences between the means for all FDP characteristics. 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.

Table 3.9 The differences between the mean values of AstVAR and AstCV estimated from the predicted profiles (0 snippets re-sampled) and the customised FDPs to the means calculated from the original full FDPs. Ten initial levels of inclusion and 6 levels of intensive re-sampling are presented

	Snippets Re-sampled	Initial 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
AstVAR	0	0.171	0.314	0.433	**0.608**	**0.651**	**0.750**	**0.756**	**0.790**	**0.785**
(µm)	1	0.292	**0.517**	**0.671**	**0.762**	**0.815**	**0.783**	**0.802**	**0.761**	**0.780**
	2	0.315	**0.518**	**0.675**	**0.763**	**0.785**	**0.755**	**0.751**	**0.674**	**0.697**
	3	0.271	**0.484**	**0.546**	**0.658**	**0.680**	**0.646**	**0.645**	**0.584**	**0.606**
	4	0.209	0.369	0.436	**0.478**	**0.512**	**0.497**	**0.512**	**0.448**	**0.486**
	5	0.156	0.274	0.311	0.393	0.363	0.374	0.398	0.339	0.380
AstCV	0	0.256	0.482	0.714	0.650	**0.909**	**1.058**	**1.027**	**1.069**	**1.064**
(%)	1	0.208	**0.764**	**0.949**	**1.043**	**1.097**	**0.817**	**1.045**	**0.986**	**0.995**
	2	0.462	0.727	**0.911**	**1.006**	**0.802**	**0.981**	**0.947**	**0.843**	**0.853**
	3	0.353	0.424	0.685	**0.808**	**0.860**	**0.787**	**0.765**	0.686	**0.722**
	4	0.266	0.467	0.510	0.292	0.607	0.564	0.573	0.473	0.565
	5	-0.064	0.312	0.334	0.387	0.365	0.385	0.399	0.306	0.394

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

A summary of the correlations between the FDP characteristics from the original FDP and those estimated from the predicted FDP characteristics at all levels of inclusion and snippet re-sampling is given in Appendix 3.2. 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. Associated with this, the correlation coefficients increased, as the number of snippets re-sampled increased, demonstrating that for approximately the same levels of final inclusion, higher correlations were consistently observed for the scenarios with higher levels of initial inclusion and less snippet re-sampling.

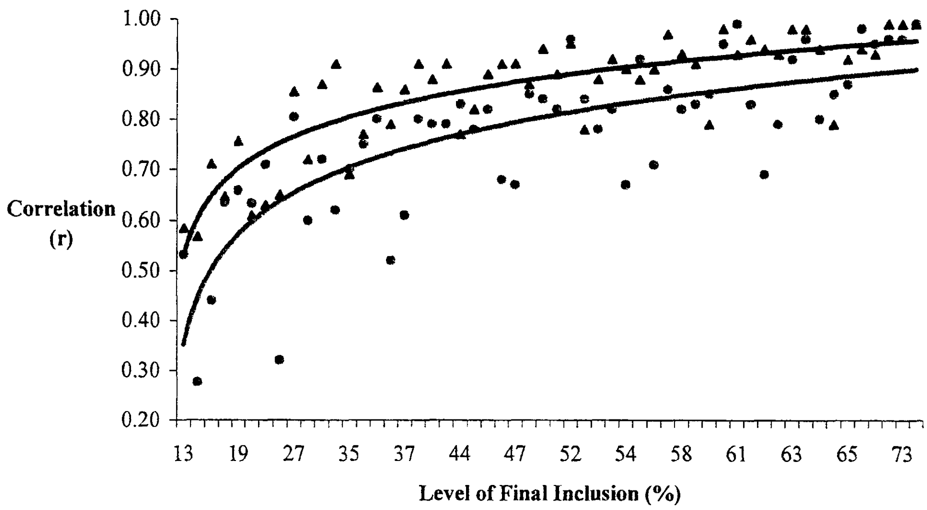
The Max, Min, Profmean, Mindiam, Maxdiam1 and Maxdiam2 estimated from the predicted profiles were very highly correlated with the original profile (r > 0.90) for all levels of inclusion and snippet re-sampling. Diff, AstVAR and AstCV from the predicted and customised profiles were also highly correlated with the values from the original profiles with the coefficients ranging between 0.80 - 0.99, 0.82 - 1.00 and 0.85 - 0.99 respectively. Examining the 1 in 7 inclusion scenario with no snippet re-sampling, which corresponds to the use of only 16.8% of the original snippets, correlations greater than 0.9 can be observed for the Max, Min, Diff, AstVAR, Profmean, Mindiam, Maxdiam1, Maxdiam2 and AstCV.

The correlation coefficients for the Minpos, Maxpos1 and Maxpos2 ranged between 0.61 - 1.00, 0.27 - 1.00 and 0.67 - 1.00 respectively over all the levels of inclusion. The correlations for the Minpos were more variable between inclusion scenarios and the trends were not completely consistent as the final level of inclusion was decreased. The re-sampling did not increase the correlation coefficients for the Minpos as much as it did for the other FDP characteristics. Re-sampling had a large influence on the correlations observed for Maxpos1.

The correlation coefficients for the Regroc1, Regroc2, 2ptroc1 and 2ptroc2 were variable, ranging between 0.28 - 0.99, 0.61 - 0.99, 0.25 - 0.99 and 0.56 - 0.99 respectively. The intensive re-sampling significantly increased the correlations for Roc1 and Roc2, using both the Reg and 2pt methods. The influence of increasing the level of final inclusion on the relationship between the original and estimated values for Regroc1 and Regroc2 is illustrated in Figure 3.5. Roc2 was consistently more highly correlated than Roc1. The two methods for calculating the rates of fibre diameter change, regression and two-point, were also shown to be very highly correlated, with an average correlation of 0.97 $\pm$ 0.0015 (s.e.) over all levels of inclusion.

The rank correlations showed similar trends to the residual correlations (Appendix 3.3). As would be expected 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, AstVAR, Profmean, AstCV, Mindiam, Maxdiam1, Maxdiam2, Maxpos1 and Maxpos2 ranged between 0.91 and 1.00. Minpos, Regroc1, Regroc2, 2ptroc1 and 2ptroc2 ranged between 0.58 and 1.00, 0.35 and 0.94, 0.64 and 0.96, 0.39 and 0.95 and 0.67 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, Regroc1, Regroc2, 2ptroc1 and 2ptroc2 become more variable.

Figure 3.5 The relationship between the level of final inclusion and the correlation between the original and estimated values for Regrocl (●) and Regroc2 (▲) from the predicted profiles. Correlations are from the predicted and customised profiles at 10 levels of initial snippet inclusion and 6 levels of intensive re-sampling



3.3.3 FDP characteristics between environments, bloodlines and sires

The effects of environment, bloodline, environment by bloodline interaction and sire on the FDPs all were highly significant ($P < 0.001$) for all levels of inclusion. These differences will be discussed in greater detail in Chapter 4. However these effects did not adversely affect the reduced profiling procedures. The significance of the effects included in the analysis of variance was also examined in all of the reduced and predicted profiles (data not shown). This indicated that reduced FDPs produced similar results from the analysis of variance as the original FDPs.

3.4 Discussion

The most acceptable technique and level of snippet sampling will depend on the intended use of the FDP characteristics generated. If actual estimates or group means were required for comparison it would be more appropriate to select a level of inclusion that produces high correlations and non-significant differences between mean values for the FDP characteristics of interest. If the FDP characteristics 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 depending on the level of correlation achieved. This would produce data that is highly correlated with the original FDPs but the mean values may be statistically different to the original FDP.

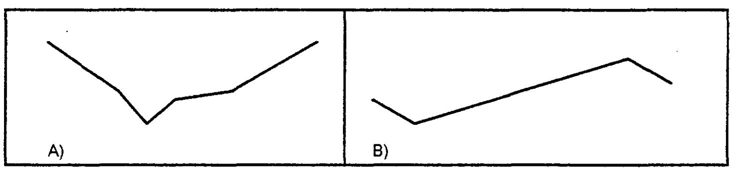
Accurate estimates of profile characteristics can be generated using subsets of snippets from the full original FDP. The residual correlations between the FDP characteristics from the simple reduced profiles with those from the original profiles were variable within each level of reduction depending on the snippet from which selection commenced. The intra-class correlations also indicated that the FDP characteristics from various simple reduced profiles within each level of inclusion were not highly related. These results indicate that the method of selection influences the accuracy achieved with the simple reduced profiles. Including the first snippet from the original FDP produced more accurate results than those profiles that did not include the first snippet.

The FDP characteristics from the simple reduced profiles were generally moderately to highly correlated with the FDP characteristics from the original profile. With few exceptions, the simple reduced profile produced group averages similar to those obtained using the original full profiles.

The rates of fibre diameter change from the simple reduced profiles were generally moderate to lowly correlated with those from the full original FDP. A rate of fibre diameter change is calculating by measuring the amount of fibre diameter change over the length of the change. As the actual values of the maximum and minimum fibre diameter were highly correlated, the inaccuracy in the estimation of the rates of fibre diameter change arose from differences in the distance between the position of, and therefore the distance between, the maximum and the minimum fibre diameter points. This finding led to a more detailed examination of the FDP characteristics. This indicated that the positions of the maximum and minimum from the simple reduced FDPs were in some instances in markedly different positions to those in the original FDPs. This problem arose when a profile had more than one distinct area of maximum or minimum fibre diameter. Although in the FDPs used in this study the correlations were moderate to high in some of the simple reduced FDPs the actual rates of fibre diameter change that were calculated were from different sides of the minimum compared to the original FDP (Figure 3.2). This also led to the estimation of rates of fibre diameter change in both the original and the reduced FDPs not being biologically relevant. For example in the reduced FDPs from the Armidale environment (Figure 3.2) the rates of fibre diameter change being calculated were between the maximum near the tip (at approximately 20mm) and the minimum near the base (100mm). This suggests that the simple profile reduction method may not be accurate.

Estimation of the positions of the maximum and minimum points of fibre diameter and the rates of fibre diameter change may be more accurate where the FDPs have different ranges in fibre diameter throughout the FDP or have different shapes. For example, if the FDP was a relatively uniform "V" shape (figure 3.6 a) it is highly likely that when the number of snippets used to estimate the FDP is reduced, the point of maximum will change sides of the minimum and therefore the correct, and in this case the greatest, rate of fibre diameter change may not be estimated. However if the FDP is shaped like figure 3.6 b, as snippets are reduced the Min and Max will be less likely to change sides.

Figure 3.6 Generalised shape of possible FDPs



These principles suggest that the shape of the fibre diameter profile will influence the accuracy of the simple profile reduction procedure. This was successfully overcome by the profile prediction technique. The predicted profiles are highly correlated with the original profiles at all levels of inclusion and therefore can be used to select the most appropriate FDP characteristics to calculate for those particular FDPs. This is important, as the shape of the FDP will influence the type and number of FDP characteristics that should be calculated.

The absolute fibre diameter values and measures of along-staple variation in fibre diameter estimated from the predicted FDPs were all very highly correlated with those calculated from the original profile. Except for the measures of overall variation in fibre diameter along the profile, the mean group values were generally not significantly different from the original FDP. 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 Diff, AstVAR and AstCV. If a higher level of accuracy is required the 1 in 7 inclusion scenario with no snippet re-sampling could be used. This level of inclusion corresponds to the use of only 16.8% of the original snippets and correlations greater than 0.9 for all the FDP characteristics except the positions of maximum and minimum and rates of fibre diameter change. This results in the technique explaining approximately 80% of the variation of these FDP characteristics between animals.

The correlations for the positions of the two maximum and one 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. The intensive re-sampling improved the accuracy of the estimates. However, at similar levels of final inclusion, higher correlations were achieved from more original sampling and no re-sampling. That is, higher correlations can 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. The snippet re-sampling also reduced the level of difference between the means of the estimated FDP characteristics and the FDP characteristics from the original FDP.

Considering all of the FDP characteristics, the most appropriate method producing the most consistent correlations at an acceptable level of accuracy was the 1 in 4 level of inclusion with no re-sampling. This method results in approximately 27% of the original snippets being used and correlations exceeding 0.80. Using this method the mean values of the estimated FDP characteristics were not significantly different from the mean values of the original FDP characteristics. This was deemed to be acceptable after considering two factors. Firstly, the variation between the staples in the FDP characteristics was considered. Although for all FDP characteristics the mean values were not significantly different between staples and most FDP characteristics were highly correlated between staples, some of the FDP characteristics were only moderately correlated between staples. This indicates that there is variation between staples within sheep for some of the FDP characteristics. Secondly, the major aim of measuring FDPs is to examine the differences between sheep in the shape of the FDPs. Considering this fact it may be more relevant to examine the similarities in the ranking's of the animals for each FDP characteristic. 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 for all FDP characteristics.

The absolute fibre diameter values and measures of along-staple variation in fibre diameter from the FDP are highly repeatable between staples within the mid-side sample. These results suggest that only one staple needs to be sampled from each sheep to give an accurate estimation of these FDP characteristics. Denney (1990a) also observed that the variation in fibre diameter along the staple (measured as along staple variance in fibre diameter) from the mid-side sample is representative of the variation in the whole fleece (9 sites covering should, mid-side and rump). Denney (1990a) and Jackson and Downes (1979) found that their FDP measurement technique for measuring along staple variance in fibre diameter was highly repeatable between duplicate (adjacent) staples sampled from the right mid-side of the same animal. However, the technique used by these authors only segmented the staple into 10 segments to generate the FDP. Hansford (1992) found similar patterns of fibre diameter change throughout the year (FDP) from eight sites covering the shoulder, mid-side, breech and withers of the sheep. However there were no statistical comparisons of FDP characteristics from these sites. There have been no studies investigating the variation in a range of FDP characteristics from a full FDP measured from staples randomly selected within a mid-side region.

The residual correlations for the positions of the maximum and minimum fibre diameter points and the rates of fibre diameter change were moderate. This suggests that more than one staple should be sampled if the estimates for the characteristics will be used to compare (rank) individual animals within a mob. Only one staple is required to be measured to estimate the mean value of these characteristics for a group.

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 1990a; Hansford 1997b). 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 would be accurate. However it may be possible that the reported rates of fibre diameter change are not 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 detailed in this chapter 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.

Although the use of staple tex and cross sectional area profiles have been investigated as alternatives to fibre diameter profiles (Grignet *et al.* 1983; Hunter *et al.* 1990; Maher and Daly 1998 and Schlink *et al.* 1999), there have been no comparisons of the characteristics of these profiles with the standard fibre diameter profile characteristics. These procedures may also benefit from the use of the cubic spline functions that accurately fit fibre diameter profiles.

There were significant differences in the FDP characteristics between environments, bloodlines and sire groups. These differences in FDP characteristics did not reduce the accuracy of the profile prediction procedure with the correlations being similar over both environments. This suggests that this technique can be used on FDPs of different shape without influencing accuracy. Furthermore the results demonstrated that the predicted FDPs also identified differences in the FDP characteristics between environments, bloodlines and sires.

3.5 Conclusions

In all of the results generated from these experiments, the absolute fibre diameter measurements and along-staple measures of fibre diameter variation from the fibre diameter profiles demonstrated higher results than those of the positions of maximum and minimum fibre diameter and the rates of fibre diameter change. The correlations indicate that the entire staple does not need to be segmented and measured to give an accurate estimation of these FDP characteristics. The absolute fibre diameter measurements and along-staple measures of fibre diameter variation were highly repeatable between staples and therefore only one staple needs to be sampled per sheep to gain an accurate estimation of these characteristics.

The simple profile reduction technique did not accurately estimate the positions of the maximum and minimum fibre diameter points and the rates of fibre diameter change. It was concluded that the inaccuracies in the estimation of the rates of fibre diameter change arise from small differences in the distance between the points of maximum and minimum fibre diameter.

The profile prediction technique, through the use of cubic spline functions and specifically suited fibre diameter profile characteristics, produced accurate results. The best overall method evaluated utilised 27% of the original snippets and produced estimates for all FDP characteristics that were not significantly different to and highly correlated with those from the original FDP. The most appropriate level of snippet inclusion 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. The customised profile technique improved the correlations observed, however it is more efficient, in terms of final inclusion of snippets and accuracy of estimates, to use more original snippets and less re-sampling to generate the predicted FDPs.

The profile prediction technique makes it possible to measure larger numbers of FDPs without significant additional labour and cost whilst still maintaining acceptable accuracy. Utilising the profile prediction method and the 1 in 4 snippet inclusion level approximately four staples can be measured in the same time and cost in which 1 staple could be measured using the standard procedure. Furthermore the environment in which the FDP is grown does not influence the accuracy of the profiling procedure.

CHAPTER 4

Bloodline and sire differences in FDP characteristics over a number of environments

4.1 Introduction

Genetic differences between sheep may alter the way in which individual animals respond, in terms of fibre diameter, to their environment and therefore also the characteristics of their FDPs (Hansford 1994). Genetic differences may operate at the breed, bloodline, sire group and/or individual sheep levels. At present little is known about the genetic attributes of FDP characteristics.

Differences in the level of along staple variation in fibre diameter have been observed between individual sheep (Hansford 1994; Adams *et al.* 1996a; Adams *et al.* 1997), sire groups (Denney 1990a), selection lines (Jackson and Downes 1979; Adams *et al.* 1997) and bloodlines (Hansford 1994, Adams and Briegel 1998). The variation of fibre diameter along the staple has been used as an indicator of their susceptibility to environmental change or conditions. This suggests that some sheep may be genetically predisposed to produce a certain type of FDP. For example, sheep that are more susceptible to environmental changes will have greater variation in fibre diameter along their staples. It may be possible to select sheep with lower variation in fibre diameter along the FDP. However, at present no genetic parameters, such as heritability and genetic correlations have been estimated for the FDP characteristics. Therefore application of these selection theories awaits extensive genetic studies. The influence of bloodline and environment on a complete range of FDP characteristics, other than measures of overall along-staple variation in fibre diameter, such as rates of fibre diameter change has not been investigated as yet.

Two studies were conducted to examine the differences in FDP characteristics between bloodlines, sire groups and environments. The first study utilised data from experiment 2 in the proceeding chapter. The second study was conducted to generate a significantly larger data set from two environments, these being Condobolin, a different environment to those in the previous study and Armidale the same environment as in the previous study. This structure allows for comparison of multiple genotypes maintained in three different environments. These three environments will be described in more detail in the following section.

These studies aim to examine the influence on FDP characteristics of environment and the relative performance of bloodlines and sires linked across environments. The hypotheses for this study are;

1. Bloodlines of Merino sheep differ in their average FDP characteristics.
2. The differences in FDP characteristics between bloodlines are not influenced by environment.
3. Differences exist between sires within a bloodline in the average FDP characteristics of their progeny.
4. The differences in FDP characteristics between sire groups are not influenced by environment.

4.2 Materials and Methods

4.2.1 Experiment 1

The wool samples and fibre diameter profiling technique used for this experiment were described in section 3.3.2. Briefly, wool staples were selected from 40 Merino sheep from the CSIRO Fine Wool Project (Purvis 1997a). These sheep originated from two bloodlines (fine and medium) maintained in two environments (Armidale, NSW and Yalanbee, WA). The animals within each bloodline were the progeny of two sires. The greasy staples from these animals were washed, dried, wrapped in cling wrap and segmented to yield a series of 2mm snippets for the entire length of the staple. The fibre diameter was then measured in each of these snippets and the fibre diameter plotted against staple position to generate a full FDP for each sheep. The FDP characteristics of Max, Min, Diff, AstVAR, Profmean, AstCV, Mindiam, Maxdiam1, Maxdiam2, Minpos, Maxpos1, Maxpos2, Roc1 and Roc2 were calculated for each FDP as described in Chapter 3. The standard deviation and coefficient of variation of fibre diameter within each snippet was averaged over all snippets within each original FDP to give an estimate of between fibre variation in fibre diameter (AvSnipSD and AvSnipCV). Mid-side samples were measured by a commercial laboratory (Australian Wool Testing Authority, Sydney, NSW) using IWTO standards for the wool quality characteristics of mid-side mean fibre diameter (MFD), variation of fibre diameter within the mid-side sample expressed as the coefficient of variation (MFDCV), staple strength (SS) and staple length (SL). Least squares analysis of variance of the FDP and wool quality characteristics was conducted using the General Linear Model procedure in SAS (1990). Environment, bloodline and their interaction were fitted as fixed effects. The sire (nested within bloodline) and the environment by sire (within bloodline) interaction were fitted as random effects. Data were analysed both within and across environments.

4.2.2 Experiment 2

4.2.2.1 Wool Samples

Wool staples were obtained from 390 3-year-old Merino wethers from the CSIRO Fine Wool Project. These sheep were maintained at Armidale (111 mid-side samples collected from the Chiswick Research Station, Armidale, NSW) or at Condobolin NSW (279 from Condobolin Agricultural Research Station, Condobolin, NSW). In both environments, there were four bloodlines of sheep: 2 fine (F1 and F2) and 2 medium (M1 and M2). While bloodline M1 was the same bloodline as the medium bloodlines from experiment 1 the F1 and F2 bloodlines were different to the fine bloodline sampled in experiment 1. Samples were collected from animals born in 3 different years but all sampled at 33 months of age. All animals selected were progeny of a sire that had at least 2 progeny in both environments for that year. Different sire groups were used in each year. Therefore within each bloodline by year group the animals were progeny of the same sires in both environments. All wethers from the flock that met these criteria were sampled. The number of animals sampled in each environment, bloodline and year group is shown in Table 4.1.

Table 4.1 The number of animals sampled in each environment, bloodlines and year group from experiment 2

	Environment								
Year of	**Armidale**				**Condobolin**				
Sampling	**F1**	**F2**	**M1**	**M2**	**F1**	**F2**	**M1**	**M2**	**Total**
1996	8	10	6	11	13	38	17	33	**136**
1997	9	11	10	11	17	35	20	31	**144**
1998	11	9	5	10	25	21	6	23	**110**
Total	**28**	**30**	**21**	**32**	**55**	**94**	**43**	**87**	**390**

4.2.2.2 FDPs and FDP characteristics

A FDP was generated for each sheep using the 1 in 4 FDP prediction technique described in chapter 3. Briefly, a wool staple was randomly selected from the mid-side sample of each animal and was scoured (3x5 minutes in hexane and 1x5 minutes in hot water), dried overnight, wrapped in cling wrap and segmented in a series of 2mm snippets for the entire length of the staple. The total number of snippets in the original FDP was recorded. The first, last and every fourth snippet in-between were measured for fibre diameter using the Sirolan Laserscan. A cubic spline was fitted using S-Plus (Statistical Sciences 1995) which generated a predicted FDP for each animal the same length as the original FDP. The same FDP and wool quality characteristics were generated as described for experiment 1.

4.2.2.4 Statistical Analysis

Differences between groups in the FDP characteristics were analysed using least squares analysis of variance conducted using the General Linear Model procedure in SAS (1990). Year, environment (Envt), bloodline (Bld) and their interactions were fitted as fixed effects. Sire (nested within bloodline by year group) and Envt by sire (within bloodline by year) were fitted as random effects. The error terms used in the overall analysis to test each effect are shown in Table 4.2.

Table 4.2 The error terms used to test the effects in the model fitted in the analysis of variance from experiment 2

Source	Error term
Year	MS Error + MS (Sire(Bld * Year))
Envt	MS Error + MS (Envt * Sire(Bld * Year))
Envt * Year	MS Error + MS (Envt * Sire(Bld * Year))
Bld	MS Error + MS (Sire(Bld * Year))
Bld * Year	MS Error + MS (Sire(Bld * Year))
Envt * Bld	MS Error + MS (Envt * Sire (Bld * Year))
Envt * Bld * Year	MS Error + MS (Envt * Sire(Bld * Year))
Sire (Bld * Year)	MS (Envt * Sire (Bld * Year))
Envt * Sire (Bld * Year)	MS Error

4.2.3 Description of environments

Long-term average monthly rainfall and temperatures in these environments were obtained from the Australian Bureau of Meteorology. Figure 4.1 illustrates the long-term average rainfall in the Armidale, Yalanbee and Condobolin environments, while Figure 4.2 shows the annual variations in daily maximum and minimum temperature in each of these environments.

Figure 4.1 Long-term average monthly rainfall for the Armidale, Yalanbee and Condobolin environments (Australian Bureau of Meteorology)

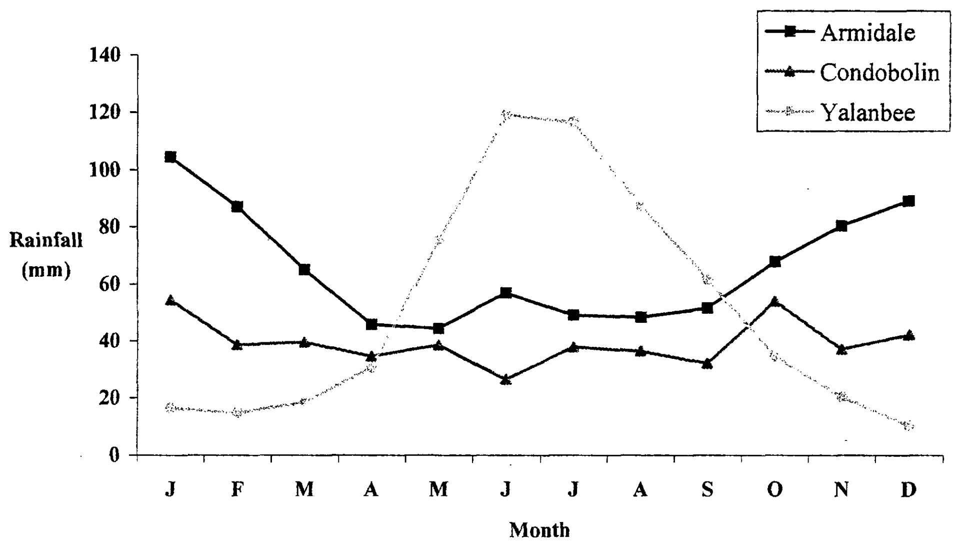
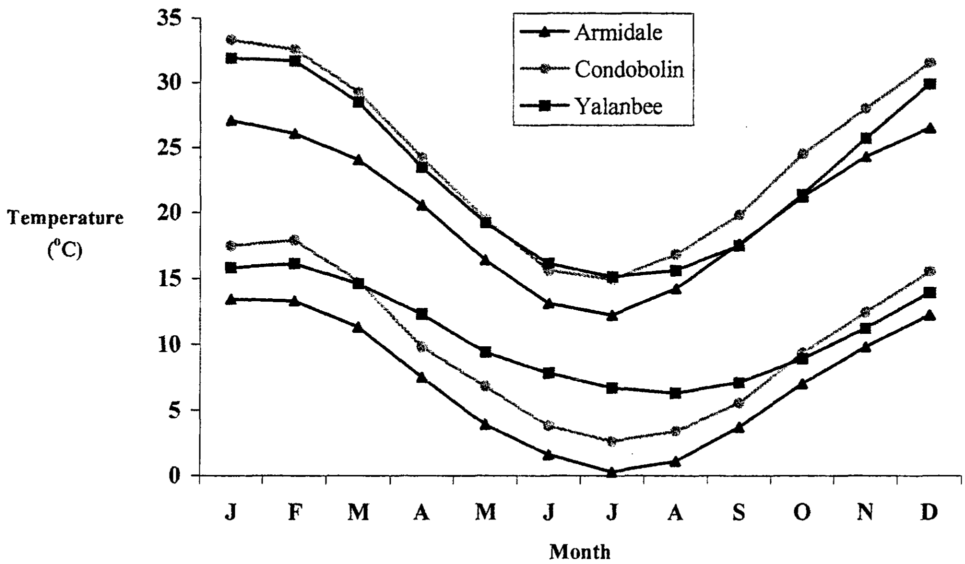


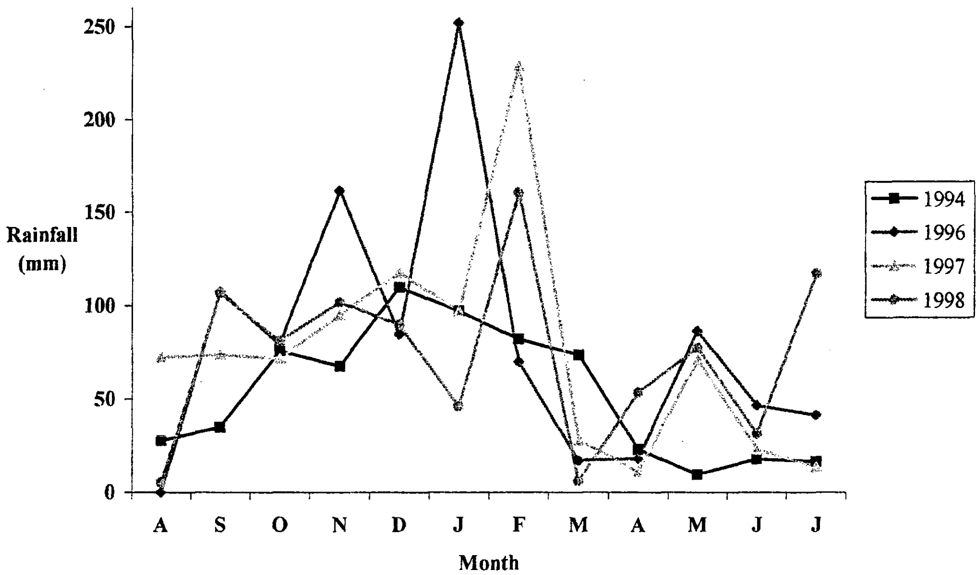
Figure 4.1 illustrates that the three environments all have different patterns of rainfall throughout the year. Armidale has a summer dominated rainfall pattern whereas in the Yalanbee environment the rain falls predominately in the winter months. Armidale has an average annual rainfall of 790mm while the average for Yalanbee is 605mm. Condobolin is a drier environment with an average annual rainfall of 472mm that generally occurs throughout the entire year. The average daily maximum and minimum temperatures of the three environments exhibit similar patterns throughout the year. The Armidale environment is consistently colder that the other two environments, with average annual maximum and minimum temperatures of 20.3 and 7.1 °C respectively. While the Condobolin has the hottest summer temperatures it has lower winter temperatures than the Yalanbee environment. The average annual maximum and minimum temperatures for Condobolin are 23.9 and 9.8 °C and 23.1 and 10.9 °C for Yalanbee.

Figure 4.2 Long-term monthly average daily maximum and minimum temperature for the Armidale, Yalanbee and Condobolin environments (Australian Bureau of Meteorology)



To compare years within the Armidale environment, the rainfall data from the years in which samples were collected are illustrated in Figure 4.3. This rainfall data corresponds to the 12-month period prior to the date of sampling. Figure 4.3 illustrates that the rainfall in 1994 of 636mm, which is the year in which the samples for experiment 1 were grown, was lower than the rainfall that fell in the years when the Armidale samples in experiment two were collected. Annual rainfall in 1996, 1997 and 1998 in this environment was 965, 902 and 876mm respectively.

Figure 4.3 Average monthly rainfall for the years in which samples were grown in the Armidale environment (University of New England Weather Station)



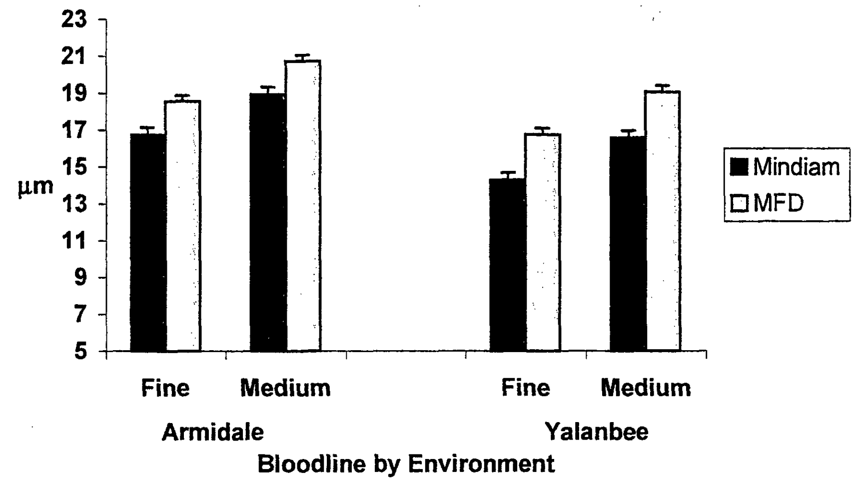
4.3 Results

Although the complete range of FDP characteristics were calculated only the Max, Mindiam, AstCV, Roc1, Roc2 and AvSnipCV are discussed as these characteristics adequately describe variation of fibre diameter in the FDP. The results from the analysis of variance for all characteristics are provided in Appendix 4.1 for experiment 1 and Appendix 4.3 for experiment 2. The means and standard errors for each characteristic within each environment-bloodline group are presented in Appendix 4.2 and 4.4 for experiments 1 and 2 respectively.

4.3.1 Experiment 1

The absolute fibre diameter values from the FDP and the mid-side sample were significantly lower, 1.6 to 1.8 μm for mean fibre diameter measured from the mid-side and 2.3 to 2.5 μm for the minimum fibre diameter in the FDP, in the Yalanbee environment compared to the same bloodlines in the Armidale environment (Figure 4.4). In each environment the fine bloodlines were lower for mid-side mean fibre diameter and the minimum fibre diameter in the FDP by 2.1 and 2.3 μm respectively.

Figure 4.4 Least squares means for Mindiam and MFD for the fine and medium bloodlines at Armidale and Yalanbee (experiment 1)



The along-staple and between fibre measures of variation in fibre diameter were not significantly (P>0.05) different between environments nor bloodlines. Mid-side variation in fibre diameter in the Yalanbee environment was 1.4 to 5.3 % higher than in the Armidale environment (Figure 4.5) and was also significantly higher in the medium bloodline (0.4 to 6.3 %) compared to the fine bloodline. While the difference in mid-side fibre diameter variation between bloodlines tended to be larger in the Yalanbee environment, the interaction between bloodline and environment was not significant (P>0.05).

Figure 4.5 Least squares means for AstCV, AvSnipCV and MFDCV for the fine and medium wool bloodlines at Armidale and Yalanbee (experiment 1)

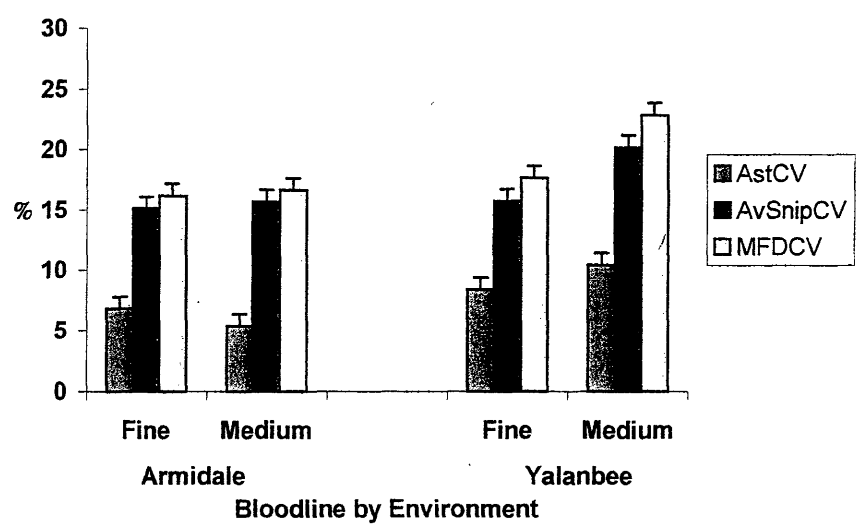
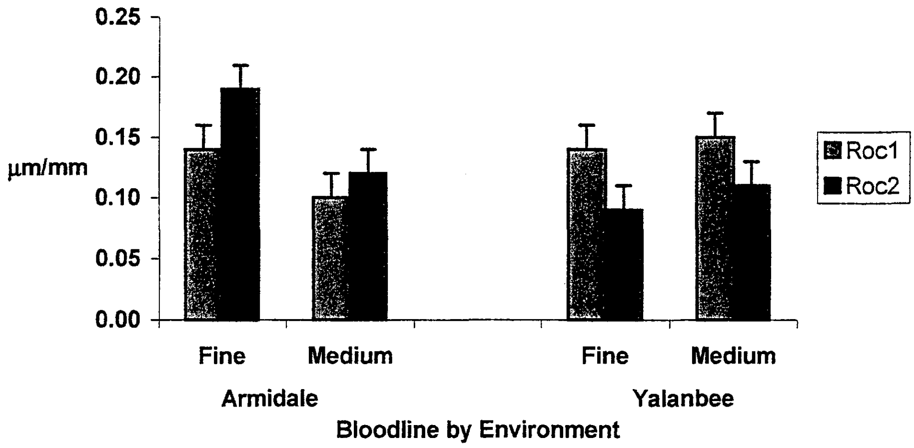
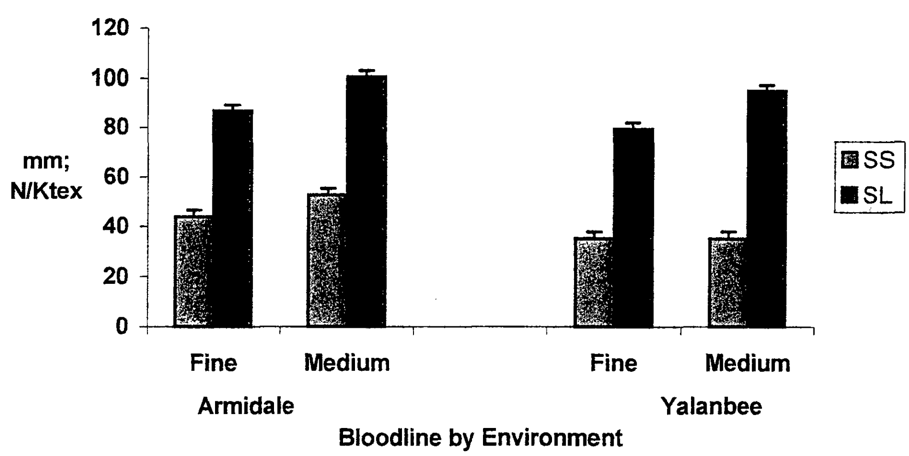


Figure 4.6 Least squares means for Roc1 and Roc2 for the fine and medium wool bloodlines at Armidale and Yalanbee (experiment 1)



There were no significant differences between environments nor bloodlines for the first rate of fibre diameter change (Roc1). Roc2 was significantly higher in the Armidale environment compared to the Yalanbee environment (Figure 4.6), with average bloodline values of 0.16 and 0.10 µm/mm respectively. The second rate of fibre diameter change (Roc2) was also significantly different between bloodlines ($P<0.05$), however these differences were dependent on environment ($P<0.05$). The fine bloodline was 0.07 µm/mm higher than the medium bloodline in the Armidale environment, but was 0.02 µm/mm lower than the medium bloodline in the Yalanbee environment.

Figure 4.7 Least squares means for SL and SS for the fine and medium wool bloodlines at Armidale and Yalanbee (experiment 1)



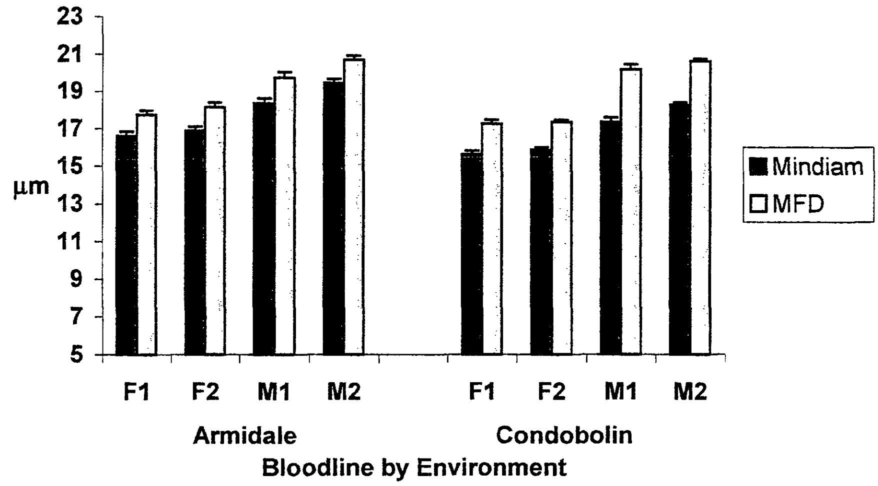
Wool grown in the Armidale environment had significantly higher staple strength compared to that grown in the Yalanbee environment (Figure 4.7). These environmental differences were 8.8 N/Ktex for the fine bloodline and 17.5 N/Ktex for the medium bloodline, with there being a significant bloodline by environment interaction for staple strength (P<0.05). Although not significant (P>0.05) the fine bloodline was 8.7 N/Ktex lower in staple strength compared to the medium bloodline in the Armidale environment whereas there was no difference between bloodlines in staple strength in the Yalanbee environment. Although staple length tended to be higher in the Armidale environment and in the medium bloodline, these difference were not significant (P>0.05).

The overall analysis indicated that staple strength was significantly influenced by differences in sire groups. The sire effect explained 23.3% of the overall variance in SS. The sire effect also approached significance for maximum fibre diameter in the FDP and the first rate pof fibre diameter change (Roc1) (P < 0.10) by explaining 3.1 and 3.5 % of the total variance respectively. There were significant interactions between sire groups and environment for variation in fibre diameter along and between-fibre and staple length. This was confirmed by the analysis within each environment with various FDP characteristics being significantly influenced by sires in each environment. Within the Armidale environment, sire significantly influenced the maximum fibre diameter in the FDP, mid-side mean fibre diameter and mid-side fibre diameter variation, explaining 19.5, 15.2 and 18.1% of the overall variance in these characteristics respectively. In this environment, the sire contribution accounted for 14.7 and 12.4% of the total variance respectively in along staple variation in fibre diameter and staple strength, though not significantly so (P<0.15). In the Yalanbee environment variation in fibre diameter along and between-fibre, staple length and staple strength were significantly different between sires. In this environment the sire effect accounted for 26.8, 24.6, 32.5 and 25.6% of the overall variation in these characteristics. Of the remaining characteristics the differences between sires accounted for less than 10% of the total variation in these characteristics in each environment.

4.3.2 Experiment 2

The absolute fibre diameter values from the FDP and the mid-side were significantly higher in the Armidale environment compared to those in the Condobolin environment (P<0.05). The least squares means for the minimum fibre diameter from the FDP and mid-side mean fibre diameter over environments were 17.8 and 19.1 μm respectively in the Armidale environment and 16.8 and 18.8 μm in the Condobolin environment. The least squares means for mean fibre diameter across bloodlines were 17.5, 17.7, 20.0 and 20.6 μm for the F1, F2, M1 and M2 respectively. While the least squares means for Mindiam and MFD between bloodlines showed very similar trends across environments (Figure 4.8), the differences between the bloodlines for Mindiam and MFD were dependent on environment ($P<0.05$). The difference between the finest and broadest bloodlines was 3.0 µm in the Armidale environment and 3.4 µm in the Condobolin environment.

Figure 4.8 Least squares means for Mindiam and MFD for the two fine (F1 and F2) and two medium (M1 and M2) at Armidale and Condobolin (experiment 2)



While along staple variation in fibre diameter and mid-side fibre diameter variation were significantly ($P<0.05$) higher in the Condobolin environment - 3.2 and 1.3% respectively - AvSnipCV was not significantly different between environments. Variation in fibre diameter along and between-fibre and mid-side variation in fibre diameter were also significantly different between bloodlines (Figure 4.9). The least squares means by bloodline were 6.3, 6.1, 7.3 and 7.5% for along staple variation in fibre diameter, 15.8, 15.1, 17.1 and 17.3% for variation in fibre diameter between fibres and 16.6, 16.4, 18.7 and 19.0% for mid-side variation in fibre diameter for the F1, F2, M1 and M2 bloodlines respectively. Only the differences between bloodlines for variation in fibre diameter along-fibres were significantly influenced by environment. The maximum differences between bloodlines for along-fibre variation in fibre diameter in the Armidale environment was 0.7% compared to 2.2% in the Condobolin environment.

Figure 4.9 Least squares means for AstCV, AvSnipCV and MFDCV for the two fine (F1 and F2) and two medium (M1 and M2) at Armidale and Condobolin (experiment 2)

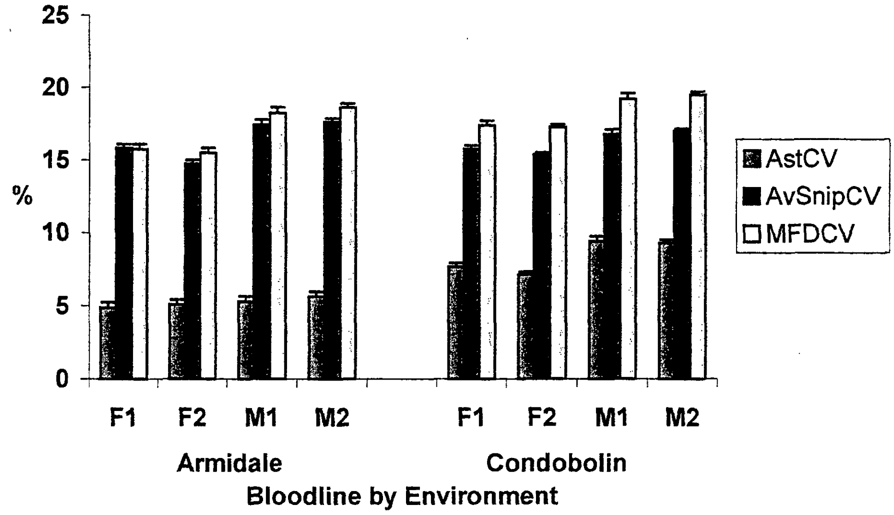
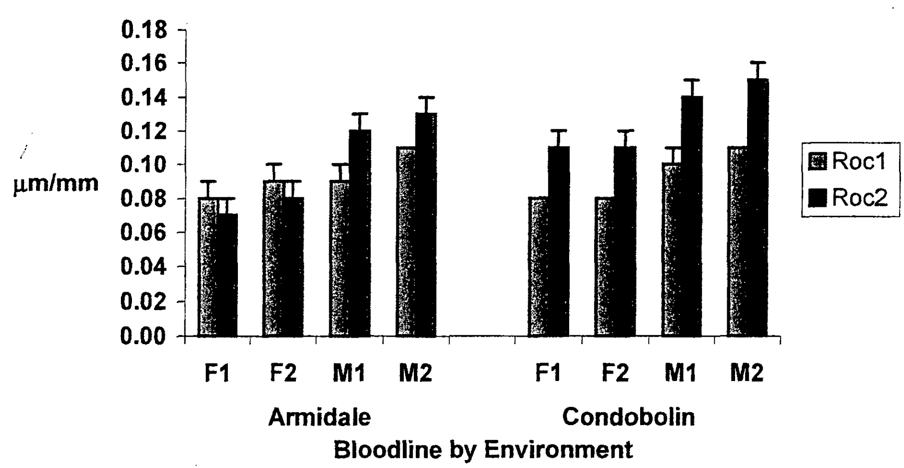


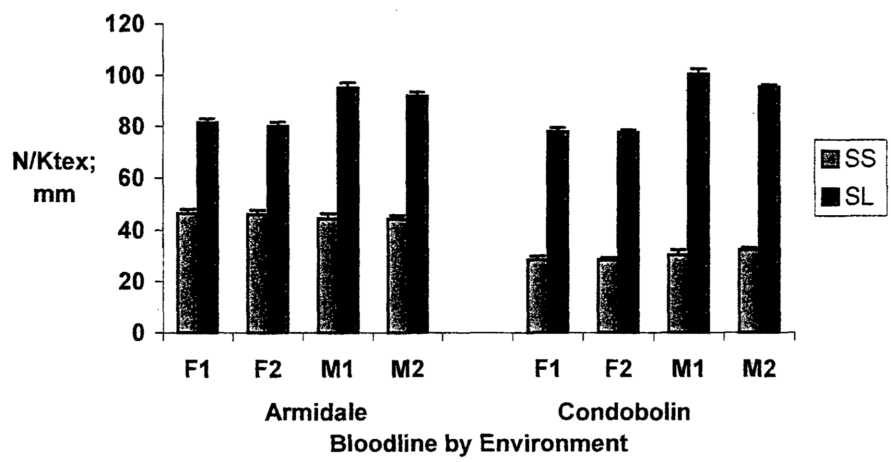
Figure 4.10 illustrates that while the least squares means for Roc1 were not significantly ($P>0.05$) different between environments, Roc2 was significantly higher (0.02 µm/mm) in the Condobolin environment ($P<0.05$). Both Roc1 and Roc2 were significantly influenced by bloodline ($P<0.05$). The bloodline least squares means for Roc1 were 0.08, 0.08, 0.09, 0.11 and for Roc2 were 0.09, 0.09, 0.13 and 0.14 for the F1, F2, M1 and M2 bloodlines respectively. The differences between bloodlines for both rates of fibre diameter change were not significantly ($P>0.05$) influenced by environment.

Figure 4.10 Least squares means Roc1 and Roc2 for the two fine (F1 and F2) and two medium (M1 and M2) at Armidale and Condobolin (experiment 2)



The least squares means for staple strength and staple length across bloodlines and environments are illustrated in Figure 4.11. Staple strength was 15.4 N/Ktex higher in the Armidale environment (P<0.05). However there were no significant differences between bloodlines within environment. Staple length was not significantly different between environments, although within environment the medium bloodlines had greater staple length than the fine bloodlines. The least squares means for staple length in each bloodline were 80.0, 78.8, 97.6 and 93.4 mm for the F1, F2, M1 and M2 bloodlines respectively.

Figure 4.11 Least squares means for SL and SS for the two fine (F1 and F2) and two medium (M1 and M2) at Armidale and Condobolin (experiment 2)



The characteristics of Max, Roc1 and SL were significantly (P < 0.05) different between sires. The sire effect accounted for 3.5, 19.1 and 6.8% of the total variation in these characteristics respectively. AstCV, in which the sire effect accounted for 7.0% of the variation, also approached significance at P < 0.10. Sire by environment interactions were observed for the Roc1 and SS at P < 0.05.

Year significantly influenced all FDP and wool quality characteristics (P < 0.05) (Appendix 4.3). There were also significant environment by year interactions (P<0.05) for all characteristics except Mindiam and AvSnipCV and there was an interaction between bloodline and year for AvSnipCV (P< 0.05). The three-way interaction between year, environment and bloodline was not significant for any characteristics.

4.4 Discussion

The first hypothesis for this study was accepted, this being that the FDP characteristics differ between bloodlines of Merino sheep. Differences were observed between bloodlines for many of the FDP characteristics in experiment 1 and all characteristics except staple strength in experiment 2. These results agree with those of Hansford (1994) and Adams and Briegel (1998) who observed differences in FDPs between bloodlines. Jackson and Downes (1979) also observed similar differences in along-staple variation in fibre diameter between lines selected for high and low fibre diameter. There were also significant interactions involving these bloodline differences and the environment. These interactions led to the rejection of the second hypothesis for this study, which stated that differences in FDP characteristics between bloodlines of sheep are not influenced by environment. These results indicate that while the FDP characteristics do differ between bloodlines, the magnitude of the expression of these differences is dependent upon the environment in which the sheep are maintained.

In both experiments the medium bloodlines generally differed to the fine bloodlines. In experiment 2, while the two fine bloodlines generally produced very similar FDP characteristics to each other, the two medium bloodlines generally differed from each other. These results indicate that not all bloodlines vary in FDP and wool quality characteristics. The differences observed appear to be related to the average fibre diameter of the bloodline. The bloodlines with the higher fibre diameter had greater variation along and between fibres, as well as higher rates of fibre diameter change within the FDP. Adams and Briegel (1998) and Peterson *et al.* (1998) also observed greater variation between fibres in bloodlines with greater mean fibre diameter.

Despite the distinct differences between bloodlines in mean fibre diameter and fibre diameter variation (both between and along fibre variation), significant differences in staple strength between bloodlines were only observed in the Armidale environment in experiment 1. Swan (1995) also found no significant trends or patterns in staple strength between 11 bloodlines studied, comprising superfine, fine and medium-fine bloodlines. It appears that there is greater genetic variation in staple strength between individual animals within bloodlines than between bloodlines (Swan 1995). It is possible that the higher average fibre diameter of the medium bloodlines, which is positively associated with staple strength, offset the reductions in staple strength that should have accompanied the increased fibre diameter variation of the medium bloodlines.

Peterson *et al.* (1998) observed that there was significantly greater variation in fibre diameter along fibres and lower staple strength in the broad wool sheep (20.1 micron) compared to the fine wool sheep (16.2 micron) examined. This trend was observed in the Yalanbee environment in experiment 1 but not in experiment 2. In experiment 2 the medium bloodlines had significantly greater along staple variation in fibre diameter compared to the fine bloodlines but no significant difference in staple strength were observed. In contrast, Adams and Briegel (1998) observed that there was greater along-staple variation of fibre diameter in a fine group (16.7 micron) compared to a broad group of sheep (20.0 micron). This result agrees with the results observed in the Armidale environment in experiment 1. When viewed overall, these results further demonstrate that differences between bloodlines in their FDP characteristics are dependent of the specific genotype and environment examined.

The hypothesis was also accepted that, differences exist between sires within a bloodline in the average of some FDP characteristics of their progeny. The absolute fibre diameter values, along-staple variation, between fibre variation and rates of fibre diameter change in the FDP were shown to differ significantly between sire groups. These differences were dependent on the environment in which the sire groups were maintained and as a result the hypothesis that the environment does not influence the differences in FDP characteristics between sire groups was rejected. Denney (1990a) also observed significant differences between sire groups in along staple variation in fibre diameter. These results suggest that it may be possible to select sires to reduce the variation of fibre diameter along fibres, but the benefits may not be apparent over all environments.

The FDP and wool quality characteristics varied between environments and years. Due to the marked difference in climate and pasture growth conditions between the environments and across years these differences in the FDP characteristics are expected. While the differences between the Armidale and Condobolin environments in experiment 2 varied between years, this did not influence the differences observed between bloodlines nor the bloodline by environment interactions observed.

The FDP characteristics from the two Armidale environments were different between experiments. While the mean fibre diameter in the FDPs over all bloodlines in the Armidale environments were less than one micron different between experiments, the FDPs from experiment one had 0.8 microns, 0.03 μm/mm and 0.06 μm/mm higher values for along staple variation in fibre diameter and rate of fibre diameter change 1 and 2 respectively. These differences are suprising given the obviously lower and less variable level of rainfall received during the period of wool growth from experiment 1 (Figure 4.3). Examining Figure 4.3 would tend to suggest that the variation in fibre diameter throughout the year in 1994 would have been lower than that from the remaining years (experiment2). Closer examination of this graph illustrates that approximately average rainfall was recorded during spring and summer however below average rainfall was recorded in winter. It is likely that this rainfall pattern combined with seasonal variations in temperature (Figure 4.2) would have in fact resulted in greater variation in fibre diameter along the staple and especially greater rates of fibre diameter change between the maximum and minimum fibre diameter points.

Higher staple strength was observed in the Armidale environment in both experiments. These differences are likely to be the direct result of the higher minimum fibre diameter, lower variation in fibre diameter along fibres and lower rates of fibre diameter change observed in the Armidale environment. Both experiments demonstrated that the differences between bloodlines were exaggerated in the Yalanbee and Condobolin environments compared to the Armidale environment. This may suggest that the opportunity for exploiting bloodline differences may be greater where the seasonal variation in wool growth is greater.

Schlink *et al.* (1998b) observed a significant interaction between staple strength group and diet for coefficient of variation of fibre diameter leading them to conclude that selection across flocks for staple strength on the basis of coefficient of variation of fibre diameter is likely to be misleading. Furthermore, Woods *et al.* (1995) observed significant seasonal variation in the coefficient of variation of fibre diameter. These observations suggest that the relationship between staple strength and coefficient of variation of fibre diameter may vary between flocks and with environmental conditions. In the current study coefficient of variation of mid-side fibre diameter was influenced by environment, bloodline, year and the associated interactions, which supports these previous findings. This again indicates that coefficient of variation of fibre diameter is influenced by environmental conditions and genotype. This also possibly supports the observation by Lang (1945) and Hynd (1992) that as wool production changes the relative change in fibre diameter of the coarser fibres is greater than that of the finer fibres.

4.5 Conclusions

Differences were observed between years, environments, bloodlines and sire groups in the FDP and wool quality characteristics, suggesting that it may be possible to utilise these differences to select animals that have more desirable FDP characteristics. However the genotypes in this study responded differently in each environment. The application of such a selection program requires detailed genetic studies to evaluate the genetic characteristics of FDPs and their genetic relationship to the other important wool quality characteristics. These results have indicated that it would be worthwhile to conduct a large study to establish the genetic parameters for FDP characteristics.

CHAPTER 5

The relationship between the FDP characteristics and staple strength across bloodlines and environments

5.1 Introduction

The main aim of measuring FDPs is to identify sheep with low levels of variation in fibre diameter along the staple and to breed animals with improved staple strength. Although there have been some investigations of the phenotypic relationships between FDP and wool quality characteristics, at present it is not known if FDP characteristics can improve staple strength over and above that which can be obtained using standard measurements of mean fibre diameter, fibre diameter variation and staple length. Furthermore it is not known how these relationships vary across genotypes and environments.

Thompson and Hynd (1998) imposed nutritional treatments to generate large variations in fibre diameter along-fibres which was not reflected in the total variation of fibre diameter in the fleece mid-side samples. This led the authors to conclude that measurement of variation of fibre diameter within mid-side samples largely reflects between-fibre variation in diameter and may mask considerable nutritionally induced variation in fibre diameter along-fibres. In support of these results Adams and Briegel (1998) found that the standard deviation of fibre diameter from the mid-side sample was highly correlated ($r= 0.67$ to 0.82) with variation in fibre diameter between-fibres but poorly correlated ($r= -0.12$ to 0.34) with variation of fibre diameter along-fibres in three strains of grazing Merino wethers. As a result of these findings, and the fact that FDP characteristics are a measure of fibre diameter variation along-fibres, it is anticipated that FDP characteristics will explain more of the variation in staple strength above that achieved using mid-side mean fibre diameter, fibre diameter variation and staple length. This may be especially important when along-fibre diameter variation is large.

Previous research has demonstrated that the coefficient of variation in mean fibre diameter is strongly and negatively related to staple strength, both phenotypically and genetically

(Hansford and Kennedy 1990a; Ritchie and Ralph 1990; Lewer and Li 1994; Greeff *et al.* 1995; Swan 1995). While mid-side measurements of mean fibre diameter are generally positively phenotypically and genetically correlated with staple strength (Table 2.1) the correlation between staple length and staple strength is more variable. Mid-side mean fibre diameter, fibre diameter variation and staple length are routinely and relatively cheaply measured and can be used with a range of other characteristics, such as fibre length variation and fibre shedding rates, to predict staple strength (de Jong *et al.* 1985; Thompson *et al.* 1995a; Thompson *et al.* 1995b; Peterson 1997a). At present it is relatively expensive ($8 to $10) to measure staple strength directly and if FDP characteristics are able to be cheaply measured they may be able to used to examine staple strength. At present estimates of FDP characteristics are more labour intensive to generate and are not commonly measured. It is not known whether FDP characteristics will explain a greater proportion of the variation in staple strength between sheep above that which can be explained by the more easily measured mid-side mean fibre diameter, fibre diameter variation and staple length.

Phenotypic relationships between FDPs and wool quality have been considered by previous researchers, indicating that the characteristics of the FDP are primarily associated with staple strength (Bigham *et al.* 1983; Hansford and Kennedy 1988; Denney 1990a; Hansford and Kennedy 1990a; Hansford 1992; Peterson 1997a; Adams *et al.* 1998; Thompson and Hynd 1998) (Table 2.1). These differences in the FDP characteristics can also be directly related to the characteristics of the fibre length distribution in the top (Hauteur) (Hansford 1994), such that prediction of hauteur could be improved by utilising information from the FDP (Hansford 1997a).

The correlation estimates presented previously in Table 2.1 suggest that the relative association between FDP and wool quality characteristics with staple strength may depend on environment and genotype. Low staple strength is a major fault in Australian wool, especially wool grown in the Mediterranean environment (Baker *et al.* 1994) where the marked seasonal pattern of wool growth throughout the year results in greater fibre diameter variation along the fibres/staples (Robards 1979). The results from Chapter 4 also demonstrated that differences exist between environments, bloodlines and sire groups in some FDP and wool quality characteristics. Adams and Briegel (1998) compared the relationship between a number of sources of fibre diameter variation and staple strength over three strains of grazing Merino wethers in a Mediterranean environment. The relative importance of the characteristics in determining staple strength varied between strains, with mean fibre diameter, variation along-fibres and variation between-fibres being the most important for the fine, medium and broad strains respectively. Through the use of FDPs the influence of variation in fibre diameter along and between-fibres on staple strength can be directly examined. To date there has been no direct comparison of how FDP characteristics relate to staple strength in genetically related sheep over a range of wool growing environments.

The studies that are reported in this chapter examine the relationship between the FDP and a number of wool quality characteristics with staple strength over three environments and genotypes. The two hypotheses for this study are;

1) That the FDP characteristics are significantly correlated and explain additional variation in staple strength above that explained by the wool quality characteristics of mean fibre diameter, variation in fibre diameter and staple length
2) That environment and genotype influence the relationships between FDP and wool quality characteristics with staple strength.

5.2 Materials and Methods

This study utilised the FDP characteristics derived from two experiments, as described in Chapter 4. Least squares analysis of variance of the FDP and wool quality characteristics was conducted using the General Linear Model procedure of SAS (1990). Residual correlations were utilised to examine the pair-wise relationships between the FDP and wool quality characteristics with staple strength. Stepwise multiple regression analysis was then performed to identify which variables in combination significantly explain the most variation in staple strength. This analysis has the major benefit of accounting for all the correlations between the FDP and wool quality characteristics as well as the relationship of each with staple strength. The stepwise multiple regression approach commenced with no variables in the model and sequentially added the most highly correlated variables. Variables entered the model when the F statistic for each variable was significant at $P<0.15$. After each variable was added the stepwise method looked at all variables already included in the model and removed any variable that did not produce a F statistic significant at the $P<0.15$ level. Both the residual correlations and stepwise multiple regression analyses were performed over all data and over data within each bloodline and environment.

5.3 Results

5.3.1 Experiment 1

Table 5.1 illustrates that the FDP characteristics are correlated with staple strength. A complete list of all FDP characteristics is tabulated in Appendix 5.1. The absolute fibre diameter values within the FDP were moderately to highly and positively correlated with staple strength (r= 0.26 to 0.67 for maximum fibre diameter and 0.54 to 0.82 for minimum fibre diameter respectively over the five analyses). Variation in fibre diameter along and between-fibres and the rates of fibre diameter change were negatively correlated with staple strength, with the correlations ranging between -0.17 and -0.42 for along-fibre variation in fibre diameter, -0.01 and -0.41 for Roc2 and -0.03 and -0.47 for between-fibre variation in fibre diameter. Roc1 was correlated at r= -0.63 in the Armidale environment and r= -0.21 in the Yalanbee environment. The correlations for the remaining FDP characteristics were generally only slightly stronger in the Armidale environment.

Table 5.1 The residual correlations between the FDP and wool quality characteristics with staple strength over all the data (n= 40), within each environment (n= 20) and within each bloodline (n= 20) in experiment 1

	Overall	Environments		Bloodlines	
		Armidale	Yalanbee	Fine	Medium
Max	0.26	0.67*	0.29	0.46*	0.37
Mindiam	0.60*	0.82*	0.54*	0.54*	0.71*
AstCV	-0.39*	-0.33	-0.34	-0.17	-0.42
Roc1	-0.38*	-0.63*	-0.21	-0.36	-0.19
Roc2	-0.34*	-0.30	-0.26	-0.01	-0.41
AvSnipCV	-0.45*	-0.26	-0.37	-0.03	-0.47*
MFD	0.33*	0.67*	0.40	0.50*	0.45
MFDCV	-0.61*	-0.44	-0.56*	-0.20	-0.72*
SL	0.01	0.58*	-0.39	0.06	-0.27

* Correlation coefficient significant (P<0.05)

The correlations between the FDP and wool quality characteristics with staple strength were generally similar between bloodlines with the exception of between-fibre variation in fibre diameter and mid-side variation in fibre diameter. These two characteristics while not highly correlated with staple strength in the Fine bloodline (r= -0.03 and -0.20 respectively) were moderate to highly correlated with staple strength in the Medium bloodline (r= -0.47 and -0.72 respectively).

The wool quality traits were also correlated with staple strength. Mean fibre diameter was positively correlated with staple strength (r= 0.33 to 0.67). Variation in fibre diameter (MFDCV) was negatively correlated with staple strength with the correlations ranging between r= -0.20 and -0.61. The correlation between staple length and staple strength varied between environments and bloodlines. Staple length was positively correlated (r= 0.58) in the Armidale environment but negatively correlated in the Yalanbee environment and medium bloodline (r= -0.39 and -0.27).

Table 5.2 The proportion of variation in staple strength (SS) explained by the wool quality, FDP and both wool quality and FDP characteristics in the stepwise multiple regression analysis over all data in experiment 1

Wool Quality Characteristics		FDP characteristics		FDP and Wool quality characteristics	
Characteristics	**% of variation in SS explained**	**Characteristics**	**% of variation in SS explained**	**Characteristics**	**% of variation in SS explained**
Overall					
MFDCV	33.3	Mindiam	42.1	Mindiam	42.1
MFD	25.6	AvSnipCV	20.8	AvSnipCV	20.8
SL	5.0			SL	9.7
Total	**63.9**	**Total**	**62.9**	**Total**	**72.6**
Armidale					
MFDCV	37.0	Mindiam	58.5	Mindiam	58.5
MFD	35.5	AvSnipCV	19.7	MFDCV	22.3
				Roc2	3.9
Total	**72.5**	**Total**	**78.2**	**Total**	**84.7**
Yalanbee					
SL	24.1	-	-	SL	24.1
MFD	29.4			MFD	29.4
				AvSnipCV	6.9
Total	**53.5**	**Total**	**0**	**Total**	**60.4**
Fine					
MFD	38.7	Mindiam	34.4	MFD	38.7
MFDCV	8.8	AvSnipCV	13.0	AvSnipCV	11.5
SL	13.0			SL	8.6
				Mindiam	6.5
Total	**60.5**	**Total**	**47.4**	**Total**	**65.3**
Medium					
MFDCV	75.8	Mindiam	63.7	MFDCV	75.8
		AvSnipCV	15.6	Roc2	6.7
		Max	4.1	Mindiam	3.6
				SL	2.8
				Max	3.4
Total	**75.8**	**Total**	**83.4**	**Total**	**92.3**

Mid-side mean fibre diameter variation was not significantly correlated with along-staple variation in fibre diameter in the Armidale environment (r= 0.09) nor in the Yalanbee environment (r= 0.40). AvSnipCV was significantly and positively correlated with mid-side mean fibre diameter variation (r= 0.67 and 0.69 respectively) in both environments. AvSnipCV was not significantly correlated with along-staple variation in fibre diameter in both environments (r= -0.25 and -0.05). Along-staple variation in fibre diameter was moderately and negatively correlated with mid-side mean fibre diameter, r= -0.62 to -0.04 in the Armidale and Yalanbee environments respectively.

The step-wise multiple regression in the overall analysis indicated that the wool quality characteristics of mid-side mean fibre diameter variation, mid-side mean fibre diameter and staple length explained around 64% of the variation in staple strength (Table 5.2) while the FDP characteristics of minimum fibre diameter and between-fibre variation in fibre diameter explained 63%. In combination the FDP and wool quality characteristics explained approximately 73% of the variation in staple strength. The other characteristics did not account significantly for variation in staple strength. In the Armidale environment Mindiam, mid-side mean fibre diameter variation and Roc2 explained 85% of the variation in staple strength. In the Yalanbee environment staple length, mid-side mean fibre diameter and between-fibre variation in fibre diameter explained 60% of the variation in staple strength. The other characteristics, including along-staple variation in fibre diameter, did not significantly improve the explanation of staple strength.

The FDP characteristics explained greater variation in staple strength compared to the wool quality characteristics in only the Armidale and medium bloodline analyses (5.7 and 7.6% respectively). The combination of the FDP and wool quality characteristics explained 4.8 to 16.5% greater variation in staple strength than could be explained by the wool quality characteristics alone over all analyses. The importance of the various measures of absolute fibre diameter, fibre diameter variation, rates of fibre diameter change and staple length in explaining variation in staple strength was dependant on which characteristics were available for analysis. The overall analysis of the wool quality characteristics indicated that fibre diameter variation explained approximately 10% more variation in staple strength than fibre diameter. However analysis of the FDP characteristics alone indicated that minimum fibre diameter was twice as important (20.8 to 42.1%) in explaining staple strength as fibre diameter variation.

The Armidale analysis also demonstrated that the priority of the measures of absolute fibre diameter relative to that of fibre diameter variation in explaining staple strength altered between the analysis of the mid-side and the FDP characteristics. The mid-side measurements suggested that absolute fibre diameter and fibre diameter variation explained approximately equal quantities of the variation in staple strength (approximately 36 and 37% respectively). However the FDP characteristics demonstrated that minimum fibre diameter was approximately three times more important than that of fibre diameter variation (59 and 20% respectively). In the Yalanbee environment the FDP characteristics alone provided no significant explanation of variation in staple strength.

The stepwise multiple regression also indicated that for the fine wool bloodline mid-side variation in fibre diameter, variation between fibres in diameter, staple length and minimum fibre diameter explained 65.3% of the variation in staple strength. In the medium bloodline mid-side mean fibre diameter variation, the second rate of fibre diameter change, minimum fibre diameter, staple length and maximum fibre diameter explained 92.3% of the variation in staple strength. The remaining characteristics did not significantly explain any additional variation in staple strength.

The stepwise multiple regression analysis within bloodlines also demonstrated the different interpretation provided by the FDP characteristics compared to that gained from the mid-side measurements. For example, for the medium wool bloodline the mid-side measurements indicated that fibre diameter variation explained approximately 76% of the variation in staple strength while the FDP characteristics suggested that minimum fibre diameter was vastly more important explaining approximately 64% of the variation in staple strength.

5.3.2 Experiment 2

The residual correlations of the FDP and wool quality characteristics with staple strength over each analysis are shown in Table 5.3. A complete list of the residual correlations for all FDP characteristics is tabulated in Appendix 5.2. The characteristics of minimum fibre diameter ($r= 0.25$ to 0.49) and mid-side mean fibre diameter ($r= 0.09$ to 0.35) were lowly to moderately and positively correlated with staple strength across all analyses.

Table 5.3 The residual correlations between the FDP and wool quality characteristics with staple strength over all the data (n= 380), environment (n= 110 and 270) and within each bloodline (n= 83, 62, 116 and 119) in experiment 2

	Overall	Environment		Bloodline			
		Armidale	Condobolin	F1	F2	M1	M2
Max	0.16*	0.08	0.18*	0.16	0.12	0.12	0.21*
Mindiam	0.44*	0.25*	0.49*	0.42*	0.41*	0.41*	0.49*
AstCV	-0.41*	-0.32*	-0.44*	-0.33*	-0.42*	-0.50*	-0.40*
Roc1	-0.29*	-0.20	-0.32*	-0.38*	-0.31*	-0.38*	-0.19*
Roc2	-0.02	-0.03	-0.03	-0.03	-0.15	-0.08	-0.03
AvSnipCV	-0.36*	-0.27*	-0.39*	-0.39*	-0.28*	-0.35*	-0.41*
MFD	0.27*	0.25*	0.28*	0.33*	0.09	0.31*	0.35*
MFDCV	-0.41*	-0.25*	-0.45*	-0.33*	-0.39*	-0.51*	-0.39*
SL	0.06	0.06	0.06	0.32*	0.12	0.02	-0.07

* Correlation coefficient significant (P<0.05)

The characteristics of along-staple variation in fibre diameter (r= -0.32 to -0.50), Roc1 (r= -0.16 to -0.38), between-fibre variation in fibre diameter (r= -0.25 to -0.48) and mid-side variation in fibre diameter (r= -0.25 to -0.51) were moderately to highly and negatively correlated with staple strength. The remaining characteristics were not highly correlated with staple strength. The correlation coefficients were generally similar between environments and bloodlines. However, most characteristics were consistently more highly correlated in the Condobolin environment compared to the Armidale environment.

Table 5.4 The proportion of variation in staple strength (SS) explained by the wool quality, FDP and both wool quality and FDP characteristics in the stepwise multiple regression analysis over all data in experiment 2

Wool Quality Characteristics		FDP characteristics		FDP and Wool quality characteristics	
Characteristics	% of variation in SS explained	Characteristics	% of variation in SS explained	Characteristics	% of variation in SS explained
MFD	19.1	Mindiam	27.3	Mindiam	27.3
MFDCV	13.3	AstCV	16.7	AstCV	16.7
		AvSnipCV	2.2	MFDCV	2.7
		Roc1	0.4	Max	0.3
		Max	0.7	SL	0.4
				Roc1	0.7
				AvSnipCV	0.5
Total	**32.4**	**Total**	**47.3**	**Total**	**48.6**

Table 5.4 illustrates that in the overall analysis the wool quality characteristics explained 32.4% (P<0.001) and the FDP characteristics 47.3% (P<0.001) of the variation in staple strength. When combined the FDP and wool quality characteristics explained 48.6% (P<0.001) of this variation. The mid-side and FDP characteristics provided a similar interpretation as to the priority of absolute fibre diameter relative to fibre diameter variation in explaining variation in staple strength.

The characteristics that significantly explained additional variation in staple strength varied between environments (Table 5.5). The FDP characteristics explained 4.7 to 28.9% more variation in staple strength than the wool quality characteristics in all analyses. In the Overall and fine bloodline analyses, combining the wool quality and FDP characteristics explained additional variation in staple strength (1.3, 2.6 and 4.4% respectively) than the mid-side mean fibre diameter, fibre diameter variation and staple length characteristics alone.

Table 5.5 The proportion of variation in staple strength (SS) explained by the wool quality, FDP and both wool quality and FDP characteristics in the stepwise multiple regression analysis within each environment in experiment 2

Wool Quality Characteristics		FDP characteristics		FDP and Wool quality characteristics	
Characteristics	% of variation in SS explained	Characteristics	% of variation in SS explained	Characteristics	% of variation in SS explained
Armidale					
MFD	12.2	AstCV	12.8	AstCV	12.8
MFDCV	6.0	Mindiam	8.7	Mindiam	8.7
		AvSnipCV	6.4	MFDCV	6.4
Total	**18.2**	**Total**	**27.9**	**Total**	**27.9**
Condobolin					
MFDCV	16.8	Mindiam	31.1	Mindiam	31.1
MFD	14.1	AvSnipCV	10.2	AvSnipCV	10.2
SL	0.6	Roc1	2.8	Roc1	2.8
Total	**31.5**	**Total**	**44.1**	**Total**	**44.1**

In both environments the interpretation as to the importance of the measurements of absolute fibre diameter values relative to measures of fibre diameter variation in predicting staple strength varied between the models including only the mid-side measurements compared to those that included only the FDP characteristics. Utilising only the mid-side measurements suggested that mean fibre diameter was most important in explaining staple strength in the Armidale environment however fibre diameter variation was of greatest importance in the

Condobolin environment. The reverse was observed when only the FDP characteristics were analysed.

Table 5.6 The proportion of variation in staple strength (SS) explained by the wool quality, FDP and both wool quality and FDP characteristics in the stepwise multiple regression analysis within each bloodline in experiment 2

Wool Quality Characteristics		FDP characteristics		FDP and Wool quality characteristics	
Characteristics	% of variation in SS explained	Characteristics	% of variation in SS explained	Characteristics	% of variation in SS explained
F1					
MFDCV	30.4	AstCV	34.8	AstCV	34.8
MFD	13.6	Max	7.3	MFD	10.9
SL	3.0	AvSnipCV	6.5	SL	6.6
		Roc1	1.8	MFDCV	2.2
		Mindiam	1.5		
Total	**47.0**	**Total**	**51.9**	**Total**	**54.5**
F2					
MFDCV	30.3	AstCV	32.6	AstCV	32.6
MFD	6.3	Mindiam	6.5	Mindiam	6.5
		AvSnipCV	4.5	MFDCV	6.8
		Roc1	3.8	Max	1.7
		Max	2.4	Roc1	3.3
				AvSnipCV	2.1
				MFD	1.2
Total	**36.6**	**Total**	**49.8**	**Total**	**54.2**
M1					
MFDCV	27.4	AstCV	36.2	AstCV	36.2
MFD	3.3	Mindiam	7.2	Mindiam	7.2
		Roc1	3.3	Roc1	3.3
Total	**30.7**	**Total**	**46.7**	**Total**	**46.7**
M2					
MFDCV	16.1	Mindiam	45.8	Mindiam	45.8
MFD	9.6	Max	6.1	Max	6.1
		AvSnipCV	1.6	AvSnipCV	1.6
		Roc1	1.1	SL	1.1
Total	**25.7**	**Total**	**54.6**	**Total**	**54.6**

The characteristics that explained a significant proportion of variation in staple strength for the animals within each bloodline are illustrated in Table 5.6. The FDP characteristics explained greater variation in staple strength than the wool characteristics in all four bloodlines (4.7, 13.2, 16.1 and 28.9% for bloodlines F1, F2, M1 and M2 respectively). Combining the FDP with the wool quality characteristics further increased the proportion of variation in staple strength explained for bloodlines F1 and F2 (2.6 and 4.4% respectively) however no increase in the proportion of variation in staple strength explained was observed in bloodlines M1 and M2.

The analysis of the FDP characteristics for the M2 bloodline again provided an alternative interpretation of how fibre diameter and fibre diameter variation combine to explain variation in staple strength. While the mid-side measurements suggested that fibre diameter variation was of greatest importance, the FDP characteristics demonstrated that minimum fibre diameter was the most influential characteristic. For the remaining bloodlines the mid-side and FDP measurements resulted in a similar interpretation of the influence of fibre diameter and fibre diameter variation on staple strength.

Mid-side fibre diameter variation was moderately correlated with along-staple variation in fibre diameter in the Armidale environment ($r = 0.28$ $P<0.05$) and highly correlated in the Condobolin environment ($r = 0.61$ $P<0.001$). Between-fibre variation in fibre diameter was significantly positively correlated with mid-side fibre diameter variation ($r = 0.45$ to 0.72, $P<0.001$) over all analyses while between-fibre variation in fibre diameter was not highly correlated with along-staple variation in fibre diameter over all analyses ($r = 0.10$ to 0.34). While both rates of fibre diameter change and variation in fibre diameter between fibres were positively correlated with mid-side mean fibre diameter ($r = 0.50$ to 0.73, $r = 0.03$ to 0.70 and $r = 0.07$ to 0.26 respectively), along-staple variation in fibre diameter was not significantly correlated with mid-side mean fibre diameter ($r = -0.04$ to 0.23) over all analyses.

5.4 Discussion

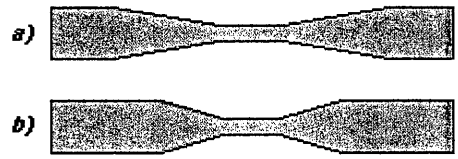
The results from these experiments lead to the accepting of the two hypotheses for this study. That is, the FDP characteristics were significantly correlated with staple strength and significantly explained additional variation in staple strength above that explained by the mid-side wool characteristics of mean fibre diameter, fibre diameter variation and staple length. The relationship between the FDP characteristics and staple strength also varied between environments and genotypes.

Despite differences in genotype, sex, physiological status and nutritional conditions, strong relationships ($r = 0.70$ to 0.85) have been observed between staple strength and minimum fibre diameter (Bigham *et al.* 1983; Fitzgerald *et al.* 1984; Orwin *et al.* 1988; Hansford and Kennedy 1990a; Bray *et al.* 1993; Peterson 1997a; Adams *et al.* 1998; Adams and Briegel

1998; Peterson *et al.* 1998; Thompson and Hynd 1998). Under field and grazing conditions the relationship between the minimum fibre diameter and staple strength can also be weak, where it is likely that other factors such as fibre shedding may have more of an influence on staple strength (Thompson and Hynd 1998). It is most likely that the minimum fibre diameter influences the amount of material present to bear the load at the most vulnerable point within the staple. Based on these results it can be assumed that sheep with greater minimum fibre diameter in the FDP will have greater staple strength. This relationship holds true over different breeds, environments and nutritional conditions. Despite these consistent relationships between minimum fibre diameter and staple strength the results in Chapter 4 demonstrated that while there were significant variations between bloodlines in minimum fibre diameter, differences in staple strength were not apparent when bloodlines are compared.

The rates of fibre diameter change were negatively correlated with staple strength ranging between -0.01 and -0.63. Negative correlations of -0.42 to -0.77 were also observed by Hansford and Kennedy (1988), -0.64 by Peterson (1997a) and -0.67 by Thompson and Hynd (1998). These results support the theory that staples that have faster changes in fibre diameter have lower staple strengths. However while always negatively correlated the importance of each particular rate of fibre diameter change depends on the specific genotype and environmental situation. The stepwise multiple regression supported these differences with a rate of fibre diameter change not explaining additional variation in staple strength in some analyses. These differences most likely arise due to differences in the shape of the FDP associated within each genotype and environment. It is anticipated that the rate of fibre diameter change influences staple strength by influencing the amount of material present in the staple (average linear density) (Thompson and Hynd 1998). If two staples are compared with similar minimum and maximum fibre diameters the staple that has a slower rate of fibre diameter change (Figure 5.1a) will have a lower average tex value compared to the staple that has a greater rate of fibre diameter change (Figure 5.1b). As force is corrected by linear density, the staple with the greater rate of fibre diameter change will have increased linear density and a lower value of staple strength.

Figure 5.1 Representation of how rates of fibre diameter changes may influence staple strength



The overall measure of along-staple variation in fibre diameter was consistently negatively correlated with staple strength. This supports the previous research of Denney (1990a), Peterson (1997a), Adams and Briegel (1998), Adams *et al.* (1998), Peterson *et al.* (1998) and Thompson and Hynd (1998) as summarised in Table 2.1, with correlations ranging between r= -0.21 and -0.84. While these characteristics were correlated with staple strength the multiple regression analysis indicated that in the wools studied in experiment 1 they did not improve the explanation of staple strength. In experiment 2 along-staple variation in fibre diameter significantly improved the explanation of staple strength in all analyses except in Condobolin and one of the medium bloodlines (M2). Peterson (1997a) also demonstrated that the along-staple variation in fibre diameter explained a significant proportion of the variation in staple strength. The results again indicate that the relationship between the FDP and wool quality characteristics with staple strength varies between genotypes of sheep and environmental conditions in which they are grazing.

AvSnipCV was calculated to estimate the amount of variation in fibre diameter between-fibres. This characteristic has not been commonly calculated from FDPs. Thompson and Hynd (1998) and Adams and Briegel (1998) introduced the use of this characteristic to estimate variation in fibre diameter between-fibres. Within a 2mm snippet it is assumed that there is only small variation in fibre diameter along-fibres. The results demonstrate in all analyses that greater variation between-fibres resulted in lower staple strength. The strength of this association also varied between environments and bloodlines. Furthermore the stepwise multiple regression equations indicated that in all the analyses except one of the medium bloodlines (M1), variation in fibre diameter between-fibres assisted in explaining additional variation in staple strength. The accuracy of this measure may be questioned as there can be large variation in fibre diameter over very short periods of time (Schlink *et al.* 1996b). These authors found that over a two-day period of fibre growth, the fibre diameter can vary by as much as 8 μm. Assuming that AvSnipCV provides a relatively accurate measure of between-fibre variation it can be postulated that staple strength is influenced by two mechanisms. The first is that considering the strong relationship between fibre diameter and length (Hynd

1994a) it would be anticipated that increased variation in fibre diameter leads to increased fibre length variation. Greater variation in fibre length has been shown to reduce staple strength by reducing the number of fibres within each staple that come into tension at the point of peak force (reviewed in section 2.4.4). The second mechanism may be that there is an increased proportion of broader fibres, which are more susceptible to variation along-fibres and more finer fibres which are weaker and more susceptible to fibre shedding (as discussed in sections 2.5.2 and 2.4.3).

The wool quality characteristics were also correlated with staple strength. Mean fibre diameter was positively correlated in both experiments (r= 0.09 to 0.67) and mid-side variation in fibre diameter was consistently negatively correlated (r= -0.20 to -0.72) with staple strength. These results are also in agreeance with those previously reported (Table 2.1). The relationships between staple length and staple strength were highly variable across environments and bloodlines, ranging between -0.39 and 0.58. The published correlations illustrated in Table 2.1 are similarly variable ranging from -0.16 to 0.80. These results indicate that the relationship between staple length and staple strength is also very dependent on environment and genotype.

The multiple regression analysis in both experiments indicated that the FDP characteristics improved the explanation of staple strength across different environments and bloodlines above that explained by the more easily measured wool quality characteristics of mid-side mean fibre diameter, fibre diameter variation and staple length. These results indicate that it is beneficial, in terms of examining staple strength, to measure the FDP characteristics. However, it must be remembered that each regression analysis ignored certain fixed effects due to constraints in the available models. For example the analysis across environments did not include the effects of bloodline, year or sire, Chapter 4 demonstrated that these effects influenced many of the FDP characteristics and staple strength.

The results in both experiments have demonstrated that the relationships between the FDP and wool quality characteristics with staple strength were different between bloodlines. The FDP characteristics that were significantly correlated with staple strength were not the same between the fine and medium bloodlines. The multiple regression also confirmed these differences in relationships between the bloodlines. The reason for these results remains unknown, however it is possible that they are related to the differences in the FDP and wool quality characteristics between bloodlines (Chapter 4).

Thompson and Hynd (1998) and Adams and Briegel (1998) suggested that the mid-side measures of fibre diameter variation masked along-fibre variation in fibre diameter and was more related to variation between-fibres. The results observed in experiment 1 support these theories. Mid-side fibre diameter variation was significantly correlated with variation in fibre diameter between-fibres but not significantly correlated with AstCV, the measure of along-fibre variation in fibre diameter. These trends were not as obvious in experiment 2 with mid-side fibre diameter variation being moderately to highly correlated with along-staple and between-fibre variation. However between-fibre variation in diameter was not highly related to along-fibre variation in fibre diameter.

The stepwise multiple regression analysis indicated that the priority of absolute fibre diameter compared to fibre diameter variation in determining staple strength was dependant on the type of characteristics utilised. Using an example from the overall multiple regression analysis in experiment 1 to illustrate, fibre diameter variation was of greater importance in explaining variation in staple strength compared to the mid-side measure of absolute fibre diameter. However the analyses which included the FDP characteristics indicated that the measure of minimum fibre diameter was twice as important as fibre diameter variation. These results indicate that the inclusion of FDP characteristics not only result in a greater explanation of the variation in staple strength they also lead to a different interpretation of how absolute fibre diameter and fiber diameter variation combine to influence staple strength. Therefore in some situations mid-side measurements of fibre diameter and fibre diameter variation cannot be used as an indication of how fibre diameter and fibre diameter variation within a FDP related to variation in staple strength. The fact that the absolute fibre diameter measurements change in their compared importance in predicting staple strength relative to the sources of fibre diameter variation is likely to be a result of their method of measurement. While mid-side mean fibre diameter includes fibre diameter measurements from the entire length of the staples, the absolute fibre diameter measurements from the FDP originate from specific points along the staple which have biological implications for staple strength.

It would be anticipated that the FDP characteristics would provide the most benefits in explaining staple strength where there is significant along-fibre variation in fibre diameter that is not always reflected in the mid-side coefficient of variation of fibre diameter measurements. This was not observed in experiment 1, while there was significantly more variation in fibre diameter along the staple (Chapter 4) in the Yalanbee environment compared to the Armidale environment the only FDP characteristic in the Yalanbee environment which significantly explained additional variation in staple strength was the measure of variation in fibre diameter between-fibres. In the Armidale environment measurements of along-fibre variations in fibre diameter improved the explanation of staple strength. In the Condoblin environment, which had significantly greater variation along the FDP, the FDP characteristics explained 16% more variation in staple strength however minimum fibre diameter was the major factor. These trends were not influenced by differences in the level of variation in fibre diameter between-fibres. However, in the environments and bloodlines where there were greater amounts of fibre diameter variation throughout the year, minimum fibre diameter appeared to have greater importance as a predictor of staple strength. The results again illustrate that there is a complex interaction between environment and genotype and the way that mean fibre diameter, minimum fibre diameter and variation in fibre diameter along and between-fibres can be used in combination to predict staple strength.

The correlations observed in the Armidale environment in experiment 2, although differing in magnitude, were relatively similar to those observed in the Armidale environment in experiment 1. Although approximately 60% less variation in staple strength was explained in experiment 2, the only difference in the characteristics selected by the multiple regression was the inclusion of AstCV in the FDP characteristics in experiment 2. These discrepancies may have resulted from two main factors. Firstly, there was a large difference in the number of animals measured in experiment 1 compared to experiment 2 (40 versus 390). This large difference in the number of animals studied is likely to have a significant influence on the strength of relationships observed. Secondly there were differences in some of the characteristics of the FDPs between the two experiments (Chapter 4). These differences are likely to be a result of the differences in age, sex and bloodlines between the animals used in the Armidale environment from the two different experiments. The meteorological data presented in Chapter 4 also demonstrated that the rainfall pattern received in experiment 1 was visibly different to that which fell when the samples from experiment 2 were grown. As also discussed in Chapter 4, experiment one tended to have greater variation in fibre diameter along the staple, however the FDP characteristics explained greater proportions of the variation between animals in staple strength. This again suggests that the along-staple variation in fibre diameter provides more benefit in predicting staple strength when variation along the FDP is lower. When variation in fibre diameter along the FDP increase it appears that minimum fibre diameter increases in importance as a predictor of staple strength. The reasons for these results are unclear and are an important area for future research.

A number of previous studies have suggested that sheep that have greater mean fibre diameter have greater changes in fibre diameter throughout the wool growth period (Jackson and Downes 1979; Quinilivan 1990; Thompson 1993; Bow and Hansford 1994; Earl *et al.* 1994). The positive correlations observed between the mean fibre diameter and the rates of fibre diameter change in experiment 2 agree with this previous research. However in both experiments along-staple variation in fibre diameter was not positively correlated with the mean fibre diameter of the FDP. It would still remain that coefficient of variation in fibre diameter along the staple is a better measure of along-staple variation in fibre diameter than variance of standard deviation alone as it is corrected for differences between sheep in mean fibre diameter of the profile. These relationships will be investigated in more detail in the Chapter 6.

5.5 Conclusions

These studies have confirmed that the FDP and wool quality characteristics are correlated with changes in staple strength in wools grown by different genotypes maintained in a number of different environments. Although the magnitudes of the correlations vary between environments and genotypes the direction of the association is generally similar. The results also demonstrated that the FDP characteristics improve the explanation of staple strength above that which can be achieved by utilising the easily measured wool quality characteristics alone. The characteristics that provide the best explanation of staple strength also varied between bloodlines and environments. However four traits which all can be measured from the FDP stood out as the major variable explaining variation is staple strength these being minimum fibre diameter, along-staple variation in fibre diameter, between-fibre variation in fibre diameter and mean fibre diameter. However the level of their importance varied between analyses. The use of fibre diameter profile characteristics also provides for an alternative interpretation of how the absolute fibre diameter and fibre diameter variation combine to explain staple strength compared to the use of mid-side measurements alone.

Based on these results the measurement of FDPs is beneficial in terms of explaining staple strength. This highlights the benefits that can be gained from measuring FDPs. However the physiological or biological causes of the differences between sheep in FDP characteristics remain unknown. More research is required to quantify the effect of variation in fibre diameter and length between and along fibres on staple strength and why these relationships vary between environments and genotypes. With more extensive studies FDP characteristics offer new opportunities in selection programs to improve staple strength.

The relationships between the FDP and mid-side characteristics vary between each environment and genotype combination. The differences observed between bloodlines and sires for some of the FDP and mid-side characteristics were also significantly influenced by the environment (Chapter 4). These results are very important when considering the potential use of FDP characteristics in selection programs. It appears that the differences between genotypes in these characteristics and their relationship with staple strength will depend on the environment in which they are maintained.

All the research conducted to date has been at the phenotypic level. Given the nature of FDPs it is highly likely that the relationships between the FDP and mid-side characteristics and staple strength are influence by environmental factors. The relationship between mid-side fibre diameter variation and staple strength is variable between environments and genotypes at the phenotypic level, however the strong negative relationship appears to be consistent at the genetic level. A detailed genetic analysis of these relationships is required with a number of genotypes and environments so as to ascertain the genetic relationship between the FDP characteristics and all wool quality characteristics.