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NJ mods in blue

JW mods in red

**Improvements in fleece weight and wool quality of Merino sheep selected visually for high fibre density and length.**

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**Abstract**

*A visual classing system for grading Merino sheep according to fibre density and length is evaluated. In a dam – progeny assessment, the classing types are shown to be strongly inherited. In 3 closed Merino flocks, the selection system led to increases of 0.101, 0.196 and 0.201 kilograms per year in clean fleece weight and corresponding decreases of 0.276, 0.258 and 0.199 microns per year for fibre diameter. (there is some mixup between 0.101 and 0.196 in the graph I need the data file to sort it out). The numbers of secondary follicles per follicle group is increased to levels not previously reported. Fibre length and uniformity, alignment and shape are improved along with softness, lustre and whiteness of the fleece.*

**Introduction**

It seems logical that selection of Merino sheep for high fibre density and length will produce high fleece weights of fine diameter wool. However, to avoid the high costs of direct measurement, an accurate method of visually classifying Merino sheep for density and length is required. It also seems logical that an increase in skin surface area will lead to increased wool production. However, the means of increasing skin surface area needs to be judiciously chosen to avoid skin wrinkles. There is also a need to minimize measurement costs. These objectives have been combined into an accurate method of visually classifying Merino sheep for density and length combined with a plain bodied, loose skin without wrinkles.

A method presented here was identified in pilot studies by one of us (JW) in 1987. The initial clue came from observing that the sheep needed to be plain bodied Merino sheep, and when shorn, produce a low bulk but dense fleece of high fleece weight. These sheep were also found to have measurably high fibre density and length and often, low fibre diameter. The fleeces consist of very long and closely packed fibre bundles\* and thin staples (Figure 1 left). The wool is very soft, lustrous and has high crimp amplitude (“deep” crimp) and low crimp frequency (“bold” crimp). This fleece structure is very different to that of most Merino sheep which have wrinkly skins, thick, stiff staples and closed backs (Figure 1 right). Also, the wool of these wrinkly sheep is not as long, soft, lustrous or deeply crimped as the high density and length animals.

(insert photo here)

**Figure 1. SRS ewe (right) and wrinkly ewe (left) from stud B in 1994. The sheep are 15 months old and carrying … months wool growth.**

*\* Footnote: a fibre bundle is the cluster of fibres produced by a follicle group (reference). It is only about 0.5 to 2 square millimetres in cross-sectional area*

The heritability of the classing grades was examined in a Merino stud flock where full pedigreed records were available. Changes in fleece weight, fibre diameter, follicle density, secondary follicle development, fibre length and wool quality were examined in three closed Merino stud flocks over 8 years.

**Materials and methods**

*Classing types*

Each sheep was classed into one of four types:

* plain bodied sheep with fleeces consisting of very long, and closely packed fibre bundles and thin staples. The wool is very soft, lustrous and has high crimp amplitude (“deep” crimp) and low crimp frequency (“bold” crimp). In long wool, the fleece parts along the backline. The skin is very loose. The sheep are referred to as “SRS®” and were expected to have high density and length (see Figure 1a).
* plain bodied sheep with fleeces consisting of long, thin staples. Fibre bundles are not present. The wool is soft and semi-lustrous. The crimp amplitude is not as pronounced as for SRS animals. The skin is loose. The sheep are referred to as “semi SRS” and were expected to rank next best for density and length.
* relatively plain bodied sheep with fleeces consisting of lightweight staples. The wool is non-lustrous and has low crimp amplitude. The sheep are referred to as “flat skin” and were expected to have low density. There are two subtypes: a soft and marginally loose skin with widely spaced fibre bundles and thin staples; and a thick and taut skin with flat, wide staples that are not soft.
* sheep with fleeces consisting of thick and stiff staples. The fleece is often excessively greasy, short in length and forms “closed “ backs. The skin is very thick and forms wrinkles to varying degrees over the body. No attempt was made to subdivide this class on degree of wrinkle . The sheep are referred to as “wrinkly” and are expected to have average to high density and low fibre length (see Figure 1b).

*Sheep*

In a Merino stud flock at Cooma, New South Wales, in 1996, 448 fully pedigreed lambs were classified at 6 months of age. The lambs were the progeny of dams previously classified into one of the 4 types. The sires were all classified as SRS rams. We refer to this flock as stud X.

Three closed Merino flocks of South Australian strong wool origin, located at Marnoo, Victoria, Australia, were used. The ewes and rams were classed at 14 months of age. All selection was done by visual classing. At most ewe classings, only the SRS and semi SRS types were kept, and the flat skin and wrinkly types culled. At ram classings, only the animals closest resembling the SRS type were kept. Young rams were retained each year as sires. There were approximately 1500 ewes in stud A, 1200 ewes in stud B and 600 ewe hoggets in stud C. Estimates of the proportions of ewes in each of the 4 classing types was made at the start and finish of the trials. Average fleece weights and fibre diameters were obtained from wool records at shearing.

After 6 years of selection in stud A, skin and fleece samples were taken from a random sample of classed ewes, 20 months of age, to compare the fleece and follicle characteristics of the two main sheep types (SRS and semi SRS). Some of the measurements of these samples were reported by Brown (1995). One hundred and five ewes drawn at random from a larger mob in stud A were classed into SRS or semi SRS types. Fifteen animals of the wrinkly and flat skin types were excluded, leaving groups of 47 SRS and 43 semi SRS ewes respectively.

*Histology*

Midside skin samples were collected using a one centimetre circular trephine and fixed in 10% formol saline solution. Horizontal skin sections were prepared and measurements made as described by Maddocks and Jackson (1988) using the frozen section technique and measurement procedures of Nay (1973). The trio group of primary follicles along with the associated cluster of secondary follicles constitute the follicle group (Carter 1943). The secondary follicle to primary follicle ratio and the total follicle density were measured.

Additional fibre measurements were made on skin sections from the ewes in stud A. Fibre alignment was measured on 100 fibre cross sections per animal by determining the angle of the boundary between orthocortex and paracortex in relation to the horizontal plane. The proportion of cylindrical fibres (that is, fibres of near-circular cross section) was calculated from a visual estimate of each of 100 fibres after confirming that such a visual estimate agreed with measurements of major and minor axes. A fibre was regarded as cylindrical when the minor axis was more than 0.9 of the major axis.

*Fleece measurements*

Records of fleece weight, yield and fibre diameter were available for the total ewe flock in studs A and B and for the ewe hoggets in stud C. The corresponding numbers of ewes in each flock each year were known exactly.

Individual fleeces of the ewes from stud A in 1994 were weighed and yield, staple length and fibre diameter measured on midside samples. Wool samples were analysed for mean fibre diameter using the Optical Fibre Diameter Analyser (OFDA). The mean values for these measurements were reported by Brown (1996). Part of the midside samples were measured for fibre length and the ratio of fibre length to fleece length.

*Subjective wool assessments*

In blind tests on midside wool samples collected from the ewes in stud A in 1994, the animals were reclassified on visual appearance as SRS or semi SRS. This enabled a comparison of on-sheep assessment with on-wool-sample assessment, and also constitutes a study of repeatability of scoring.

Scores were then allocated to each sample for softness, lustre, whiteness and elasticity of the wool. Each characteristic was rated on a score of 1 to 4 (4 best).

*Flock surveys*

Between 1995 and 2000, twelve flock demonstrations were conducted at workshops across Australia comparing fleece weights, fibre diameter and fleece values of SRS Merino sheep and wrinkly (traditionally bred) Merino sheep.

In each demonstration, sheep of the same age, sex, shearing and management were used. The sheep had been selected visually by one of the authors (JW) as being either SRS grade or wrinkly grade.

At each workshop, the participants, numbering from 40 to 120 people per workshop, were told that the sheep comprised two classing grades of equal numbers of animals. The participants were then asked to choose half of the sheep, these being the animals they visually assessed as being high wool producers of fine diameter wool. Following this exercise, one of the authors (JW) chose half of the sheep he considered to be the right sheep. All of this was done as blind tests. The sheep were then shorn, the fleeces weighed, and the measured fibre diameters and wool yields made available to the wool valuer to estimate the value of each fleece.

**Results**

*Dam-progeny classing grades*

Table 1 lists the numbers of progeny of each classing type according to the classing type of the dam.

Table 1. Numbers of 6 months old progeny assigned to different classing grades of dams of known classing type.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Dam grades | Progeny grades | | | | Dam frequencies | Daughter frequencies |
| SRS | semi SRS | flat skin | wrinkly skin |
| SRS | 12 | 5 | 2 | 4 | 0.05 | 0.30 |
| semi SRS | 75 | 48 | 31 | 49 | 0.45 | 0.20 |
| flat skin | 36 | 27 | 35 | 66 | 0.37 | 0.18 |
| wrinkly skin | 13 | 10 | 12 | 23 | 0.13 | 0.32 |

Table 1 is a contingency table. A test of independence of the dam and daughter grades gave a Chi-squared value of 27.4 with 9 degrees of freedom. That is highly significant. The dam and daughter grades are correlated. This, in itself, is an indication of some degree of inheritance of the classer’s grades.

We can consider the four grades to be a threshold trait, that is, we can assume that there is actually an underlying continuously distributed variate (perhaps something related to fibre

density and length), and that the three cutoff points between grades are each represented by a threshold value on the underlying scale. With this assumption, we can compute a polychoric correlation between dams and daughters on the underlying scale. A maximum likelihood estimate of this correlation was 0.255 with a standard error of 0.053. This correlation is doubled to obtain a heritability estimate of 0.51 with a standard error of 0.106.

We can obtain the position of the thresholds on the underlying scale, from tables of the normal distribution, using the dam and daughter frequencies given in Table 1. These are shown in Table 2.

Table 2. Estimates of the position of the thresholds between grades on the underlying scale in standard deviation units.

|  |  |  |  |
| --- | --- | --- | --- |
|  | SRS/semi SRS | semi SRS/flat | flat/wrinkly |
| Dams | * 1.63 s1 | 0.01 s1 | 1.35 s1 |
| Daughters | * 0.52 s2 | 0.02 s2 | 0.48 s2 |

We can arbitrarily choose to make the units on the underlying scale equal to the width of the semi grade (ie, the interval between the srs/semi and semi/flat thresholds). We call this a 'threshold unit'. We can then calculate that the standard deviation of dams on the underlying scale is s1 = 0.617 threshold units, and that the standard deviation of the daughters on the underlying scale is s2 = 1.85 threshold units. In other words, the daughter population is about 3 times as variable as the dam population. This is because the dam population was culled, prior to the experiment, whereas the daughter population is a complete unculled drop of lambs. There is some concern that the above heritability estimate may have been biased by the dam culling, because we used a dam-daughter correlation rather than a regression. It is not possible to do a polychoric regression. What we can do is code the classers grades as (srs=1, semi=2, flat=3, tight=4) and do a simple regression of daughter on dam. From this we get a regression coefficient of 0.34 with a standard error of 0.073. This implies a heritability of 0.68 with a standard error of 0.146. The correlation from this regression analysis was 0.21, not seriously different from the polychoric correlation above. We conclude that the heritability estimate from polychoric correlation is not seriously biased in the upward direction.

The complete picture of these data on the underlying scale is shown in Figure 2, which depicts the frequency distributions of the dam and daughter populations, and the spacing of the thresholds. Note that the thresholds are almost uniformly spaced on the underlying scale. This why coding the grades as an equal spaced series of integers was satisfactory in the previous paragraph. The daughter population is shown with its mean -0.296 threshold units to the left of the dam population mean which is set to zero. This represents response to selection of the sires. We can calculate that the phenotypic selection differential from choosing all SRS grade rams would have been -1.8 s1 units. We have to average this with zero for ewes giving -0.9 s1 units or -0.9 \* .61 = - 0.549 threshold units. With a heritability of 0.5 this leads to an expected genetic selection differential of 0.5 \* -0.549 = -0.275 threshold units in the daughters. This agrees well with the observed dam-daughter difference of -0.296. So the realised response agrees with that predicted from the heritability estimate. Not surprising as they are both based on the same observations.



Figure 2. Frequency distributions of the dam and daughter populations for the underlying continuous variable, which is divided into four grades by the thresholds shown in red, green and blue.

Note that the thresholds are spaced the same for the dam and daughter populations: this is because we are grading sheep for the same trait in both populations. The dam population has a considerably lower standard deviation than the daughter population, on the underlying scale. The daughter population has its mean shifted 0.3 threshold units to the left, this being the expected genetic shift due to selection of only grade "SRS" sires for mating to the dams. The three thresholds are close to equally spaced, indicating that the grading system achieves and approximately linear separation on the underlying scale.

*Repeatability of classing grades*

We only have repeat scoring data on the 'SRS' and 'semi-SRS' grades on a small subset of 67 animals. These were scored three times, once on the sheep (sheepscore), and twice from wool samples (woolscore1 and woolscore2). The numbers of sheep/samples scored in each category are shown in Table 3.

Table 3. Repeatability of classing grades: numbers of animals by grade.

Sheepscore Woolscore 1

semi SRS SRS

semi SRS 31 5

SRS 2 29

Sheepscore Woolscore 2

semi SRS SRS

semi SRS 30 5

SRS 3 29

Woolscore 1 Woolscore 2

semi SRS SRS

semi SRS 35 0

SRS 1 31

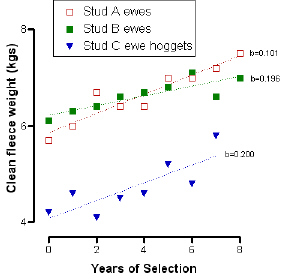
The correlations estimated by the polychoric correlation method for these three tables are

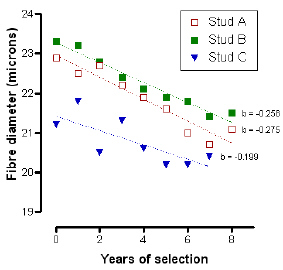
0.95 (se = 0.035) for sheepscore x woolscore 1, 0.93 ( se = 0.044) for sheepscore x woolscore 2, and 0.99 ( se not estimable) for woolscore 1 x woolscore 2.

As a repeatability estimate, these correlations are not entirely satisfactory, because they only cover the top 2 grades.

*Correlated responses in fleece weight and fibre diameter in studs using the SRS selection system*

Annual measurements of clean fleece weight and mean fibre diameter for the stud flocks A, B and C are shown in Figures 3a and 3b respectively. The responses are from in-stud selection of rams and ewes, there being no introduction of sheep from outside sources. The data used for studs A and B are for the total ewe flock while the data for stud C are for ewe hoggets.





**Figure 3a and 3b.** The clean fleece weight and fibre diameter responses to selection using the SRS classing system in studs A, B and C.

There is a problem in Fig 3a. Stud A has a slope of b=0.101 but is shown as a steeper slope than Stud B which has b=0.196? Have these two been labelled wrongly?

Yes, the slopes for studs A and B are the wrong way around. I will send you the raw data so that you can check the regressions.

At stud A, the 1983-87 flock average for ewes was 7.5 kilograms greasy fleece weight and 22.2 microns fibre diameter. For 1990-94, the average was 8.6 kilograms and 21.1 microns and for 1994 alone, 9.1 kilograms and 20.7 microns. After 13 years of selection, the ewes averaged 8.8 kilograms greasy fleece weight and 18.2 microns for fibre diameter.

At stud B in 1987, the flock average for ewes was 7.8 kilograms for greasy fleece weight and 23.5 microns for fibre diameter. By 1994 the values were 9.5 kilograms and 21.3 microns. After 13 years of selection, the ewes averaged 8.8 kilograms for greasy fleece weight and 18.8 microns for fibre diameter.

At stud C in 1988, the flock average for the ewe hoggets was 4.1 kilograms clean fleece weight and 21.4 microns for fibre diameter. By 1994 the values were 5.5 kilograms clean fleece weight and 20.4 microns for fibre diameter. After 13 years of selection, the ewe hoggets averaged 6.1 kilograms greasy fleece weight and 17.2 microns for fibre diameter.

Previous 3 paragraphs:

It is confusing to present CWW in the Figure then talk about GFW in the text. Either include a GFW Figure too, or talk only CWW in text.

I will send corrections.

Because there were no randomly mated control flocks included in these trials, it cannot be assumed that all of the changes in fleece weight and fibre diameter in Figure 3 are genetic. It may have been due to improved nutrition. However, this seems unlikely as fibre diameter would be expected to increase, not decrease, if better nutrition was the cause.

The proportions of ewes in the four classing types of each flock at the start and finish of the in-stud selection trials are listed in Table 3. These give us an estimate of the direct response to selection in the studs A, B, and C.

Table 3. Estimates of the percentages of ewes of the four different classing types in each flock at the start and finish of the 8 year trials.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Flock | Timing of assessment | SRS (%) | Semi SRS (%) | Flat skin and wrinkly skins (%) |
| Stud A | 1988 | 20 | 40 | 40 |
| 1994 | 50 | 40 | 10 |
| Stud B | 1988 | 10 | 30 | 60 |
| 1994 | 50 | 40 | 10 |
| Stud C | 1988 | 0 | 30 | 70 |
| 1994 | 40 | 40 | 20 |

Only 10 to 20 % of the ewes in studs A and B, and none of the ewe hoggets in stud C were estimated to be SRS types at the start of the trials. At the finish of the trials, the estimates had risen to 50%, 50% and 40 % respectively. In all flocks, the estimates of semi SRS types were high (30 to 40%) at the start and finish.

These changes in proportions correspond to shifts in the mean on the underlying scale of -0.84 s for Stud A, -1.28 s for Stud B, and -1.36 s for Stud C. If these are cumulated genetic selection differentials over the four years, and if the heritability is 0.5, they correspond to phenotypic selection differentials of -.42 s, -.64 s, and -.68 s per year. To get those phenotypic selection differentials one would have had to have selected proportions of 0.34, 0.26, and 0.24 respectively, averaged over rams and ewes. This is entirely feasible. For example selecting 1% of rams and 65% of ewes leads to an average proportion of 0.34. So the direct response in classing grades seen here is compatible with the heritability estimate.

*Phenotypic selection differentials*

The classing technique described here is a multi-trait procedure. There is some interest in seeing how much phenotypic selection differential was being placed on the various skin and fleece traits. Two sets of data were available, one of skin-traits on visually selected sires and the other of a comprehensive set of wool and skin traits on ewes classed as 'srs' and 'semi-srs'.

Skin traits of selected rams: Follicle and fibre measurements were made on visually selected sires, mostly 15 months of age, on several occasions over the 8 year period of selection in studs A and B. Table 4 lists the mean values and standard errors.

Table 4. Follicle and fibre measurements (mean + - standard errors) of visually selected rams used in the breeding programs of studs A and B.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Measurement | Stud A | | Stud B | | |
| 1988  n = 7 | 1995  n = 12 | 1988  n = 18 | 1991  n = 4 | 1994-95  n = 4 |
| S/P ratio | 35.7 (2.5) a | 48.8 (1.1) b | 31.1 (1.1) a | 41.4 (1.4) b | 44.2 (4.2) b |
| follicle density  (per mm2) | 98.6 (13.2) a | 96.7 (7.1) a | 77.3 (4.0) a | 71.2 (7.2) a | 70.1 (8.8) a |
| primary fibre diameter (mean) | 20.8 (0.92) a | 18.9 (0.49) a | 23.6 (0.61) a | 19.5 (1.12) b | 19.5 (0.65) b |
| primary fibre diameter (standard deviation) | 3.17 (0.26) a | 2.73 (0.17) a | 3.33 (0.15) a | 2.25 (0.22) b | 2.25 (0.26) b |
| secondary fibre diameter (mean) | 21.8 (0.48) a | 20.5 (0.32) b | 23.8 (0.36) a | 20.9 (0.71) b | 21.7 (0.86) b |
| secondary fibre diameter (standard deviation) | 2.37 (0.25) a | 2.44 (0.14) a | 3.26 (0.16) a | 2.95 (0.34) a | 3.20 (0.43) a |

Footnote: within each flock, mean values with different superscripts are significantly different at P < 0.001.

For the rams bred and kept as sires, the S/P ratios increased whilst primary fibre diameter and secondary fibre diameter decreased during the course of the trials, follicle densities remained unchanged at the high starting levels.

Comparison of the fleece, follicle and fibre characteristics of ewes (stud A): The classing of wool samples into SRS and semi SRS grades was highly repeatable. Sixty four of the 70 samples were reclassified correctly.

The measurements and scores for these ewes are listed in Table 5.

**Table 5. Follicle, fibre and fleece characteristics of SRS and semi SRS ewes (stud A)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Characteristic | SRS | | semi SRS | | P value |
| mean | sem | mean | sem |  |
| clean fleece weight (kgs) \* | 6.61 | 0.11 | 5.72 | 0.13 | <0.0001 |
| yield (%) | 72.7 | 0.62 | 72.6 | 0.74 | Ns |
| fibre diameter of fleece  (mean) | 20.4 | 0.21 | 21.8 | 0.23 | <0.0001 |
| follicle density  (per mm2) | 92.6 | 3.79 | 78.6 | 2.80 | <0.005 |
| secondary follicle to primary follicle ratio (S/P ratio) | 38.8 | 0.70 | 27.2 | 0.51 | <0.0001 |
| follicle group area (mm2) | 0.973 | 0.038 | 0.826 | 0.031 | <0.005 |
| primary fibre diameter (mean) | 19.0 | 0.42 | 21.6 | 0.40 | < 0.0001 |
| primary fibre diameter (standard deviation) | 2.57 | 0.08 | 2.79 | 0.12 | ns |
| secondary fibre diameter (mean) | 18.0 | 0.27 | 19.1 | 0.29 | <0.0001 |
| secondary fibre diameter (standard deviation) | 2.76 | 0.12 | 3.10 | 0.11 | < 0.05 |
| laneway diameter (microns) | 135 | 5.26 | 81.4 | 4.25 | <0.001 |
| fibre alignment (%) | 71.2 | 1.90 | 54.8 | 0.66 | <0.0001 |
| cylindrical fibres (%) | 88.0 | 0.99 | 69 | 1.83 | <0.0001 |
| fibre length (mean in mms) | 90.4 | 1.50 | 81.13 | 1.59 | <0.0001 |
| fibre length (standard deviation) | 9.07 | 0.43 | 13.11 | 0.84 | <0.0001 |
| fibre length to fleece length ratio | 1.28 | 0.01 | 1.18 | 0.01 | <0.0001 |
| softness | 3.1 | 0.14 | 2.2 | 0.13 | <0.0001 |
| lustre | 2.8 | 0.12 | 2 | 0.09 | <0.0001 |
| elasticity | 3.8 | 0.19 | 2.6 | 0.23 | <0.001 |
| whiteness | 2.8 | 0.13 | 1.8 | 0.10 | <0.0001 |

*\* footnote: clean fleece weights were obtained for 12 months wool growth. All other fibre and fleece measurements and fleece scores were obtained from midside wool samples collected 5 months earlier (7 months wool growth)*

All but three of the mean values of the 15 traits were significantly better in the SRS ewes than in the semi SRS ewes. The exceptions were wool yield, DpSD and follicle group area.

SRS ewes produced 15 % more clean wool of 1.4 microns finer diameter than the semi SRS ewes. Density and secondary follicle to primary follicle ratio were higher. The follicles were arranged in smaller follicle groups separated by wider laneways than measured in the semi SRS ewes. The primary fibres were 2.7 microns finer and the secondary fibres 1.0 microns finer. The fibres of SRS ewes were better aligned, more uniform in diameter and length, more cylindrical in shape and proportionally longer than the fleece length. The wool of the SRS ewes was softer, more lustrous, more elastic and whiter.

It is quite clear that the SRS classing system leads to a phenotypic selection differential for a large number of traits. Means for classing grades can be converted to a phenotypic selection differential for any trait, if we know the proportion or number of sheep of each grade selected.

*Flock surveys*

Results of the 12 demonstration trials comparing the fleece weights, fibre diameter and fleece values of SRS Merino sheep and traditionally selected (wrinkly) Merino sheep are shown in Table 6.

**Table 6. Comparisons of fleece weight, fibre diameter and fleece value differences between smooth bodied SRS Merino sheep and wrinkly Merino sheep.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| SRS Merino sheep | | | Wrinkly Merino sheep | | | Sheep | Trial |
| GFW (kgs) | FD | Fleece value | GFW  (kgs) | FD  (um) | Fleece value |
| 3.5 | 16.7 | $50.87 | 3.4 | 17.5 | $41.17 | Ewes,12 months, unshorn, 35 per group | 1997  Walcha, NSW |
| 9.3 | 19.6 | $54.50 | 8.8 | 22.3 | $34.58 | Wethers, 2 years, 13 months wool, 40 per group | 1998  Bullaring, WA |
| 3.8 | 16.7 | $41.86 | 4.1 | 20.3 | $18.61 | Ewes, 15 months, 8 months wool | 1998  Esperance WA |
| 5.1 | 18.6 | $38.92 | 5.6 | 21 | $28.16 | Ewes, 15 months, 12 months wool, 8 per group | 1998  Coleraine, Vic |
| 3.2 | 15.8 | $90.40 | 3.2 | 17.6 | $31.35 | Ewes, 12 months, unshorn, 4 per group | 1999  Walcha, NSW |
| 6.9 | 17.2 | $90.43 | 6.9 | 18.7 | $41.75 | Ewes, 14 months, 8.5 months wool, 9 per group | 1999  Cooma, NSW |
| 6.6 | 18.5 | $50.33 | 6.2 | 21.7 | $21.50 | Ewes, 2 years, 11 months wool, 6 per group | 1999  Yeoval, NSW |
| 6.0 | 17.8 | $96 | 5.8 | 20.5 | $33.40 | Ewes, 14 months, 8 months wool, 5 per group | 2000  Cooma, NSW |
| 9.1 | 19.4 | $66.98 | 8.3 | 22.5 | $25.89 | Ewes, 12 months, unshorn, 3 per group | 2000  Karoonda, SA |
| 3.3 | 16.5 | $94 | 3.0 | 20.5 | $17.00 | Wethers, 15 months, 9 months wool, 6 per group | 2000  Blackall, Qld |
| 4.7 | 16.9 | $95.37 | 3.7 | 19.4 | $32.12 | Ewes, 13 months, 9 months wool, 5 per group | 2000  Badgingarra, WA |
| 5.4 | 16.5 | no data | 5.3 | 17.7 | no data | Ewes, 19 months, 10 months wool, 8 per group | 2000  Mungindi, NSW |

SRS Merino sheep grossed $67 per fleece compared with $29 per fleece for tradionally selected (wrinkly) sheep. The SRS sheep produced, on average, 10 % more wool that was 2.5 microns finer.

In the 1999 and 2000 trials at Cooma, New South Wales, the SRS Merino ewes produced an average of 0.1 kilogram more wool (for 8 to 8.5 months wool growth) than the wrinkly ewes. The SRS ewes had higher wool yield (76.2 % versus 68.6 % in 1999 and 74.2 % versus 70.2 % in 2000), were 2.7 microns finer, and grew longer fleeces (96 mm versus 76 mm in 1999, and 125 mm versus 101 mm in 2000). Also, the SRS ewes had a lower standard deviation of fibre diameter (2.9 versus 4.0 in 1999 and 2.8 versus 4.2 in 2000) and higher comfort factors (99.7 % versus 98.8 % in 1999, and 99.5 % versus 97.1 % in 2000).

In the 2000 trial at Badgingarra, Western Australia, the SRS ewes again produced one kilogram more wool than the wrinkly ewes, and the wool was 2.5 microns finer in diameter. The diameter variation along the length of the fibres was much lower in the SRS ewes than in the wrinkly ewes (means of 1.0 um and 5.2 micron respectively).

In the 2002 trial at Mungindi, New South Wales, the mean fibre length of the semi SRS ewes was higher than for the wrinkly ewes (0.55 mm versus 0.47 mm).

In all demonstration trials, almost all workshop participants chose the wrinkly sheep groups of sheep as their preferred selection for high fleece weight, low fibre diameter and high yield (least perceived dust penetration) . One of the authors (JW) always chose the sheep of the SRS grade.

**Discussion**

The dam-progeny study of classing types indicates that the classing method separates sheep into 4 grades which can be mapped onto an underlying continuous scale. Variation on the underlying scale is highly heritable, as evidenced by a polychoric correlation estimate of heritability of 0.5, and by shifts in the proportions of sheep in each grade under selection.

There is some element of surprise, that a subjective grading would have such a high heritability. Most subjectively graded attributes in sheep have heritabilities of 0.3 or less. The explanation has to be that this is a multi-trait grading. It is analagous to the mean of a number of measurements and therefore exhibits the phenomenon of attenuation of errors. Errors which are random for each trait tend to cancel each other out when several traits are combined.

A single measured trait, such as clean fleece weight or fibre diameter, has a repeatability of 0.5 to 0.7 (Turner and Young 1969). This means that at least 30% (and maybe 50%) of the observed or phenotypic variance is measurement error. SRS classing grades have a repeatability of 0.9. This means that SRS classing grades have only 10% of the phenotypic variance as measurement error. This explains the higher heritability.

We need to compare the correlated responses in clean fleece weight and fibre diameter in Figure 3, with those that might be achieved by direct selection for measured clean fleece weight or fibre diameter.

To do this we need to imagine a flock with one age group of rams (2 years old) and five age groups of ewes (ages 2, 3, 4, 5 and 6 years). For every 100 ewes there will be approximately 20 per age group, so we need 20 ewe replacements each year, to be chosen from say 50 ewe lambs, a selected proportion of 0.40 giving a selection differential of 0.9 standard deviations. We also require 2 ram replacements per 100 ewes mated, and these are to be chosen from about 50 ram lambs, giving a selected proportion of 0.04 or a selection differential of 2.0 standard deviations. The average selection differential of rams and ewes then would be (2.0 + 0.9)/2 = 1.45 standard deviations.

If this were single trait selection for clean fleece weight the response per generation would be selection differential x heritability x standard deviation = 1.45 x 0.4 x 0.9 = 0.522 kilograms per generation. The generation interval for this imaginary flock would be 2 years for rams and 4 years for ewes, an average of 3 years. So the predicted (as distinct from the realized response) in clean wool weight per year is 0.522/3 = 0.17 kilograms per year. This is remarkably similar to the annual rates of change shown in Figure 3a (0.101, 0.196, 0.200). This is not a precise comparison. There is no guarantee that the flock structures in studs A, B, and C is the same as we assumed in our imagined flock. Also the responses in studs A and B are measured on the whole ewe flock and should be 'damped' compared to what they would have been if only successive drops of hogget ewes had been measured, as in Stud A.

The same calculation for fibre diameter leads to a predicted (again, not realized) response for our imagined flock of -1.74 micron per generation or -0.58 micron per year. This is larger than the annual rates of change shown in Figure 3b (-0.258, -0.275, -0.199). The SRS classing procedure clearly does not put as much negative selection differential on fibre diameter as would be achieved by single trait direct selection.

In practice one would be unlikely to use single trait selection for either clean fleece weight or fibre diameter. Often, it is recommended that some index combining the two be used, with the aim of achieving zero or negative genetic change in fibre diameter combined with maximum possible genetic increase in clean wool weight. There are a whole array of options here, including use of information from relatives as well as phenotypic observations to increase accuracy of selection. However, this approach of index selection is rejected by the authors since it does not lead to the major improvements in wool quality reported in this paper, and which are fundamentally important for improving processing and textile performance of Merino wool.

The most that can be said from this somewhat imprecise comparison is that the observed annual rates of change in clean wool weight and fibre diameter in Figure 3 are within the bounds of feasibility for a conventionally structured, self-replacing sheep flock. We are not dealing with a 'magic' huge response, such as might be observed if a major gene had been allowed to segregate; nor are we dealing with a very much reduced correlated response to selection, such as might be observed if the heritability of SRS classing grade were low, or if its genetic correlations with clean wool weight and fibre diameter were low.

SRS classing leads to similar genetic improvements in clean wool weight and fibre diameter when compared to selection predicted on measured clean wool weight and/or fibre diameter. However, the SRS sheep and fleeces are far more advanced for wool quality and the fibre properties responsible.

This difference in wool quality stems from a unique follicle patterning of SRS sheep where orderly and well-spaced rows (wide laneways) of small follicle groups, characterized by extensive formation of secondary branching (derived) follicles, has occurred and is coupled with major improvements in fibre length and uniformity (insert our staple formation reference here). The same trend is evident in the skins of the Stud A ewes. Whilst the follicle group area of the SRS ewes is 17 % larger than that of the semi SRS ewes (means of 0.973 mm2 versus 0.8266 mm2), the respective S/P ratios indicate that there are 42 % more secondary wool follicles in the follicle groups of the SRS ewes. Since initiation sites for secondary original follicles are more or less constant between Merino sheep (Moore et al reference here), the closer packing of follicles within the follicle group of SRS ewes may be due to faster and more extensive development of the secondary branching follicles.

SRS classing of sheep puts a large selection pressure on the following:

* loose, thin skins and avoiding skin wrinkle
* development of secondary branching follicles (S/P ratio)
* fibre length growth rate and some associated fibre properties (softness, lustre, circularity and elasticity)

Exactly how these three aspects are impacted on by SRS classing grades is not fully understood. We have the following insights:

* the link to wrinkle and macro skin development is fairly obvious. The SRS grade definitions given here emphasize wrinkle, skin thickness, and skin looseness. It is the combinations that matter, not any one characteristic. Loose skin is clearly a path to increasing the skin surface area, without increasing body size, and without the undesirable attribute of skin wrinkle. Thin skin is a path to development of small follicles which grow long, fine fibres.
* the impact on follicle development is probably controlled by the size of primary follicles. The pre-papilla cell theory of Moore et al (1989) holds that if few pre-papilla cells are used to initiate primary follicles, then there will be more pre-papilla cells available later to form secondary branching follicles. The measurements of primary fibre diameter and secondary follicle to primary follicle ratio on graded rams and ewes indicate that this is happening.
* the impact on follicle function (fibre length growth rate and the properties softness, lustre, elasticity and fibre circularity) is less well understood. It may be that highly branched compound follicles grow a different type of fibre. It may be that there is some other link not involving follicle development such as thin skin being directly associated with follicle function.

We can summarize the ways in which the mechanisms discussed above lead to correlated responses in clean wool weight and fibre diameter, to selection on SRS grades, as follows.

The correlated increases in clean wool weight come from increases in

* density
* fibre length
* loose skin ( increased skin area)

The correlated decreases in fibre diameter come from

* increased density
* increased L/D ratio
* thin skin (smaller follicles)

As noted above, some of the mechanisms behind these pathways to correlated change are understood better than others.

Some of the follicle characteristics observed in rams and ewes of the SRS grade were outside of the bounds of previous observations. The SRS rams and ewes in the 3 closed flocks had levels of secondary follicle development and follicle density much higher than found in Merino stud flocks surveyed by Carter and Clarke (1956). Fibre length of the SRS ewes, measured in 1994 at a mean value of 0.43 millimetres per day in this study, was also high. In 2017, the mean fibre length of SRS Merino sheep lies between 0.60 to 0.70 miilimetres per day (staple formation reference here).

We need to make due allowance for our observations here being on selected sheep, so they would be expected to be extreme. It is still quite surprising how extreme some SRS selected animals have become. It does suggest that there is potential for further improvement of Merino sheep in these directions. Extreme animals for one trait are interesting but not economically important. It is the extreme combinations of several traits that are of merit.

The combination of high density due to extensive secondary follicle branching and high fibre length and high fibre length to fleece length ratio appears to underpin the rapid increases in clean fleece weight and decreases in fibre diameter. These follicle and fibre traits in combination, also appear to be reliably identified by the SRS classing method.

The fact that in 12 demonstration trials (Table 6), one of the authors (JW) correctly chose visually every sheep classed as SRS grade, and these sheep were clearly shown on measured performance subsequently to be the high wool producers of fine diameter wool, is very important. The fact that most other people participating in these demonstration trials, who were mostly Merino breeders, chose the wrinkly type in preference to the SRS type as being the high wool producers of fine diameter, should be of great concern to the Australian Merino industry.

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