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The Influence of Selection for Greasy Fleece
Weight on the Components of Fleece weight in
Romney Sheep

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Ai Hua LIU

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ABSTRACT

Variation in the clean fleece weight (W) of New Zealand Romney sheep was related to variation in its four components: smooth body surface area (S), mean number of fibres (follicles) per unit area of skin (N), mean fibre cross-sectional area(A) and mean fibre length (L). The influence of the combined components, wool weight per unit area, fibre volume and total number of fibres (follicles) was considered.

The contribution of the components to differences in fleece weight between the Massey fleece weight selected and control flocks was analysed using the "percentage deviation" technique. L was the most important contributor to fleece weight differences. The components of A and N were about equally important in contributing to between flock differences in fleece weight. By contrast, the contribution of S was relatively small.

Wool weight per unit area had far more influence on fleece weight than body surface area (about 84% : 16%). Also, fibre volume made a greater contribution to between flock differences than the total fibre number.

Attempts were also made to assess the relative importance of the components of fleece weight between ewes within each flock using either simple linear regression or multiple regression (standardized partial regression coefficients) techniques. Within both the selected

and control flocks, A and S appeared relatively more important than between flocks, whereas, the L appeared to be less important, but the L seemed more important within the selected flock than within the control flock in determining the phenotypic differences in fleece weight between sheep.

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TABLE OF CONTENTS

Abstract	I
Acknowledgements	III
List of Tables	VII
List of Figures	X
CHAPTER 1 INTRODUCTION	1
CHAPTER 2 REVIEW OF LITERATURE	3
2.1 Responses to selection for fleece weight	3
2.1.1 Selection for greasy fleece weight in New Zealand Romney sheep	3
(a) Direct response in greasy fleece weight	4
(b) Correlated responses	7
(c) Physiological changes	8
2.1.2 Selection for clean fleece weight in Merino sheep	10
(a) Direct response in clean fleece weight	14
(b) Correlated responses to selection for clean fleece weight	18
(c) Physiological and biochemical consequences of selection	19
2.2 The effects of selection for fleece weight on the components of fleece weight	20
2.2.1 Wool production per unit area of skin	22
(a) Mean fibre cross-sectional area (A)	22

(b) Mean fibre length (L)	23
(c) Mean number of fibres per unit area of skin (N)	25
2.2.2 Wool growing surface area	26
(a) Skin wrinkle (R)	26
(b) Smooth body surface area (S)	28
2.3 Selection on the components of clean fleece weight	28
2.3.1 Direct responses in the components	30
2.3.2 Correlated responses in clean fleece weight	32
 CHAPTER 3 MATERIALS AND METHODS	 35
3.1 Materials	35
3.1.1 Sheep and environment	35
3.1.2 Measurements	37
3.2 Statistical methods	40
3.2.1 Derivation of the components from measured characters	40
3.2.2 Techniques for assessing the influence of each component on fleece weight	42
(a) The percentage deviation technique	42
(b) Simple linear regression of the log of each component on log fleece weight	43
(c) Standardized partial regression of fleece weight on components (multiple regression)	44

CHAPTER 4 RESULTS	46
4.1 Prediction of fibre length	46
4.2 Fitted means for characteristics and components of fleece weight	48
4.3 Contribution of the components to differences in fleece weight between selected and control flocks	52
4.4 Contribution of the components to differences in fleece weight between ewes within each flock	55
4.4.1 Correlations between the components within each flock	55
4.4.2 Contribution of the components to differences in fleece weight within each flock	57
4.5 Comparison of between and within flock contributions of the components to differences in fleece weight	60
CHAPTER 5 DISCUSSION AND CONCLUSIONS	64
5.1 Methods of predicting fibre length	64
5.2 Techniques for estimating the relative influence of each component on fleece weight	65
5.3 Comparison of the importance of components	69
5.4 Conclusions	77
REFERENCES	79

LIST OF TABLES

Table 1. Summary of selection experiments for increased fleece weight in New Zealand Romney sheep	5
Table 2. Summary of selection experiments for increased clean fleece weight (CFW) in Australian Merino sheep	12
Table 3. Annual percentage rates of improvement in flocks selected for increased clean fleece weight	15
Table 4. Summary of lines selected on the components of clean wool weight	29
Table 5. Regression coefficients of direct responses in selection criterion, expressed as percentage deviations from control on time (year) for ewes in CSIRO single-trait selection lines	31
Table 6. Mean value of each characteristic and its standard error for 49 ewes in fleece weight selected (FW) and control (C) flocks	49

Table 7. (a) Mean values of clean fleece weight and its components for ewes in fleece weight selected (FW) and control (C) flocks. The values (mean \pm SE) were based on 16 ewes with fibre length measured	50
(b) Mean values of clean fleece weight and its components for ewes in fleece weight selected (FW) and control (C) flocks. The values (mean \pm SE) were based on 49 ewes with predicted fibre length	51
Table 8. (a) Contribution of the components to differences in fleece weight expressed as percentages of the control flock means. Values were based on 16 ewes with measurement of fibre length	53
(b) Contribution of the components to differences in fleece weight expressed as percentages of the values of the control flock. Values were based on 49 ewes with predicted fibre length	54
Table 9. Correlation of the components within fleece weight selected (a) and control (b) flocks	56

- Table 10. Contribution of components (in logarithms) to differences in W between ewes within each flock as assessed by the coefficients of determination (R^2) 58
- Table 11. Proportion of the sum of within flock variation in fleece weight accounted for by each component 58
- Table 12. Standardized partial regression coefficients of the log of each component on the log of clean fleece weight 59

LIST OF FIGURES

- Fig.1. The relationship between mean staple length and mean fibre length 47
- Fig.2. Proportion of between and within flock change in clean fleece weight accounted for by each component (between flock values expressed as percentage deviations; within flock values expressed as coefficient of determination R^2 from simple linear regression) 61
- Fig.3. Proportion of between and within flock change in clean fleece weight accounted for by each component (between flock values expressed as percentage deviations; within flock values expressed as the standardized partial regression coefficients) 62
- Fig. 4 Path diagram indicating the interrelations of components and clean fleece weight (W)
 (a) within the selected flock 68
 (b) within the control flock 68

CHAPTER 1.

INTRODUCTION

Fleece weight is an important criterion when selecting for improved wool production. Of the various wool characteristics which determine returns to the farmer, fleece weight is probably the most important. Since it has considerable economic importance, it is desirable to know the rate at which this trait can be altered by selection and to what degree other traits show correlated changes. To this end, a selection experiment was established at Massey University in 1956 using New Zealand Romney sheep. Responses to selection for greasy fleece weight in this flock have been reported by Blair (1981) and Blair *et al.* (1985).

The purpose of the present study was to examine the changes in the components that contribute to variation in fleece weight and to produce some estimates of the relative importance of the components in the response to selection for fleece weight in Romney sheep.

The greasy fleece weight consists of the weights of the clean fleece weight and various contaminants. The clean fleece weight (W) can be considered as the product of wool production per unit area of skin and wool-growing surface area (Turner, 1958). Wool production per unit area of skin can in turn be described as a function of follicle or fibre density (N), mean fibre cross-sectional area (A) and mean fibre length

(L), which is often derived from staple length. The wool-growing surface area is influenced by both the smooth body surface area (S), a function of body weight, and the degree of skin wrinkle or fold, which is probably unimportant for Romneys.

The relationship between fleece weight and its components for Romneys can be expressed as $W = S \cdot N \cdot A \cdot L \cdot K$, where K is a constant.

This equation shows that there are several possible pathways of increasing fleece weight by changing one or more of the components. It is therefore important to know which of the components are responsible for the increase in fleece weight that results from selection. The present study examined the relative influence of each component on fleece weight of two groups of Romneys, one selected for higher fleece weight and the other (control) selected at random.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Responses to selection for fleece weight.

Selection flocks based on increased fleece weight have been established in a number of breeds. Most of the selection experiments utilize Merino sheep and have been conducted in Australia. Work has also been carried out in New Zealand using Romney sheep.

Greasy and clean fleece weight have been used as selection criteria. The genetic and phenotypic correlations between these two traits are high (+0.7 to +0.9, Turner and Dunlop, 1974). Usually, for Romney or Romney-cross sheep, selection was based on greasy fleece weight, since it is the simplest measure of wool quantity. For Merino or Merino-cross sheep, selection was based on the clean fleece weight, because the amount of grease and suint is more variable between sheep.

2.1.1 Selection for greasy fleece weight in New Zealand Romney sheep

A number of selection flocks for increased greasy fleece weight using New Zealand Romney sheep have been established. A long-term experiment is being conducted at Massey University, Palmerston

North, New Zealand. Two selection flocks (an open-faced group and a fleece weight group), and a control flock, derived from the same base Romney flock, were established in 1956. Replacement ewes and rams for the face-cover group and fleece weight group were selected on the most open faces and the heaviest hogget fleece weights, respectively. Selection of replacements for the control flock was at random. Every effort was made to maintain similar conditions across the groups and the flocks were managed as nearly as possible to commercial conditions.

Several other selection flocks have been set up by Ministry of Agriculture and Fisheries (MAF). Most of the selection flock sheep were screened from industry flocks on hogget greasy fleece weight and then were compared with an unselected control flock drawn from the same base population. The selection experiments which are maintained by both the Massey University and MAF are summarized in Table 1.

(a) Direct response in greasy fleece weight

In all Romney flocks, selection was solely for increased greasy fleece weight and all have been effective. Blair *et al.* (1984; 1985) examined both the responses to selection for open face and the responses to selection for hogget greasy fleece weight in Experiment 1. The responses to selection were measured as a percentage of the cumulated selection differential. The flock average cumulated selection

Table 1. Summary of selection experiments for increased greasy fleece weight in New Zealand Romney sheep.

Experiment	Organisation	Flocks	Number of		Duration of experiments	References
			Rams	Ewes		
1	Massey University	High GFW ^a	4	80	1958-	Blair <i>et al.</i> (1985)
		Control	4	80	1958-	
2	MAF (Whatawhata)	High GFW	5	200	1967-	Johnson (1981)
		Control	20	200	1967-	
3	MAF (Woodlands)	High GFW	5	150	1973-	Clarke (1982)
		Control	5	150	1973-	
4	MAF (Invermay)	High GFW	10	200	1984-	Hawker <i>et al</i> (1988)
		Control	10	200	1984-	

a=Greasy fleece weight.

differential increased in a linear fashion in both sexes. The rate of accumulation was about 0.2 kg per year (Blair *et al.* 1985). Realized heritabilities of greasy fleece weight were 0.17 and 0.14 for yearling ewes and rams, respectively. There was no sign of any decline in the rate of response in later years.

Johnson (1981) reported an experiment on selection for production characters in Romney sheep under New Zealand hill country conditions (Experiment 2). Three flocks were established in 1967 at Whatawhata Hill Country Research Station, New Zealand, one Romney flock was selected for hogget body weight; another flock selected for hogget fleece weight and the third was a randomly bred control flock. Each flock comprises 200 mixed age ewes and the control flock is pen-mated to 20 rams and the selection flocks are single-sire mated to five rams. In this experiment, the response to direct selection for body weight was approximately 4.7 kg while that for fleece weight was approximately 0.5 kg over the season 1978/79. The realized heritabilities for body weight and fleece weight, as estimated from the regression of cumulative response on cumulative selection differential, were 0.23 and 0.19, respectively (Johnson, 1981).

Experiment 3 is another long-term selection study in Romney sheep. This study was closely integrated with breeding experiments at Tokanui and Templeton Research Stations, comprising five closed breeding flocks, each of 150 mixed-age ewes mated annually to five two-tooth rams. The lines were closed in 1973 and comprised a

randomly-selected control and four lines in which two-tooth replacements (ewes and rams) were selected on the lifetime average number of lambs born to their dams, 100-day body weight, hogget fleece weight or on a productivity index which included all three traits. Wool production in the fleece weight and productivity index lines were 6% superior to controls (Clarke, 1982).

In Experiment 4 (Hawker *et al*, 1988), a high fleece weight Romney ewe flock was established in 1984 at Invermay Agricultural Centre by selecting the top 0.6% on greasy fleece weight from 32,000 hoggets (average selection differential 40%). These ewes were mated with 10 rams in 1985 and 1986 (selection differentials 1.7 kg in 1985 and 2.0 kg in 1986). Relative to random progeny, the high fleece weight progeny born in 1985 and 1986 had 0.66 kg and 0.36 kg higher mean greasy fleece weight, respectively. Estimates of realized heritability were 0.45 and 0.22 for the 1985 and 1986 born hoggets, respectively. The high fleece weight hoggets had a significantly higher live weight than the control hoggets, also they had greater staple length, fibre diameter and staple strength with lower bulk and greater yellowness.

(b) Correlated responses

In all lines, selection for increased greasy fleece weight in Romneys resulted in correlated responses in wool characteristics and

other traits. Blair *et al.* (1985) reported that 24 years of selection for yearling greasy fleece weight in Romney sheep resulted in correlated responses in both yearling performances and lifetime average performances of mature females relative to control flock means. For yearling ewes, clean fleece weight, fibre diameter, staple length and yield increased, whilst correlated increases in mature females were observed for greasy and clean fleece weight, staple length and yield. In comparison with control flock means, the weaning weight and liveweight of the fleece weight flock increased, whereas quality number and crimp frequency decreased.

Correlated responses in wool characteristics were also observed in the MAF selection lines. Hawker *et al* (1988) stated that selection for high greasy fleece weight resulted in increased staple length, fibre diameter, staple strength and liveweight. It is concluded that the gains in high greasy fleece weight in Romney sheep are mainly contributed by fibre diameter and staple length.

(c) Physiological changes

In Romneys, physiological studies have centred on identification of physiological changes that may have accompanied the response in wool production.

Initial comparisons of dry matter digestibility between selection and control flocks have resulted in variable results, with one study

showing control animals to have superior digestibility, (62.8% v 60.1%) and the other studies showing no difference (McClelland *et al.* 1986). Thus, it appears that selection for increased fleece weight has not consistently changed the ability of animals to digest dietary nutrients. Thomson *et al.* (1989) found that there was no difference in digestibility between the lines when fed a meadow hay diet although fleece weight selected animals had a lower digestibility than control animals when fed lucerne chaff.

McClelland *et al.* (1987) examined the response in efficiency of wool production in the Romney flocks at Massey University. It was found that digestible dry matter intake per $\text{kg}^{0.75}$ did not differ between fleece weight selected and control rams. However, differences in wool growth and wool growth efficiency were significant throughout most of the trial period. McClelland *et al.* (1987) concluded that selection for higher fleece weight had produced animals capable of better utilization of nutrients for wool growth throughout the year.

Research has been initiated to examine concentrations of hormones and metabolites in the blood of selected and control animals. McCutcheon *et al.* (1987) and Clarke *et al.* (1989) have shown that the fleece weight selected animals have lower plasma concentrations of urea, creatinine and thyroxine than control animals. Differences in plasma urea concentration between the lines appear to reflect differences in the efficiency with which amino acids are used for wool growth and in kidney function. Similar results were also found by

Thomson *et al* (1989). The selected animals had approximately 1mM lower plasma urea concentration than control animals.

Matthew (1990) examined the differences between fleece weight selected and control lines in plasma urea, creatinine, tri-iodothyronine (T3) and thyroxine (T4) concentrations. It was found that significant differences were observed between the lines in plasma urea and creatinine concentrations with fleece weight rams maintaining consistently lower concentrations than control rams. No significant differences were found between the lines in either T3 or T4.

Studies have also been conducted to investigate wool sulphur concentrations and output for the two Romney lines. Antram *et al.* (1991) showed that high fleece weight animals had lower wool sulphur concentration than controls. Wool sulphur output was higher in the fleece weight selected line than in control. In another study (Sun *et al.* 1991), wool sulphur contents were examined at different positions over the body for the same lines. It was found that fleece weight selected animals had lower wool sulphur concentrations than controls at all the positions measured. These results suggest that selection for fleece weight has reduced wool sulphur contents over the entire body.

2.1.2 Selection for clean fleece weight in Merino sheep

Merino selection flocks were first established in Australia around 1950. Selection in many of the flocks was for increased or reduced

fleece weight, or for high or low values of other skin and wool characters. Also, a number of multi-trait selection flocks were formed, in which the main objective was to increase clean wool weight, but with the additional aims of maintaining wool quality and reducing such faults as excessive skin fold or wrinkle and face cover.

The selection flocks to be described are summarized in Table 2. These flocks were set up by the New South Wales Department of Agriculture (NSWDA) and the Commonwealth Scientific Industrial Research Organization (CSIRO). These experiments can be classified as either single-character selection lines, where selection was solely for increased clean fleece weight (Experiments 1 and 2) or multi-trait selection flocks in which selection was primarily for increased clean fleece weight but where other characters were taken into account (Experiments 3-5).

Pattie and Barlow (1974) described the selection flocks established at Trangie Agricultural Research Station in New South Wales, Australia. Two closed selection flocks were established in 1951, with each consisting of 100 ewes mated to five rams. One flock was selected for high clean fleece weight (Fleece-plus) and the other for low clean fleece weight (Fleece-minus). A randomly selected control flock (100 ewes mated to 10-25 rams) was used to measure the response to selection in the Fleece-plus and Fleece-minus flocks over approximately five generations (approximately 15 years). All three

Table 2. Summary of selection experiments for increased clean fleece weight (CFW) in Australian Merino sheep.

Experiment	Organisation	Flocks Rams	Number of Ewes		Period	Author(s)
1 ^a	NSWDA	High CFW	5	100	1951-	Pattie and Barlow (1974) McGuirk and Atkins (1976)
		Low CFW	5	100	1951-	
		Control	10-25	100	1951-	
2 ^a	CSIRO	High CFW	1	32-50	1954-1976	Turner <i>et al.</i> (1970)
		Low CFW	1	32-50	1954-1976	
		Control	5-10	200-250	1948-1976	
3 ^b	NSWDA	High CFW with limits on crimp frequency, skin wrinkle and face cover	6	200	1947-1972	Dun and Eastoe (1970)
		Control	10-25	100	1951-	
4 ^b	CSIRO	High CFW with limits on skin wrinkle and fibre diameter	5-15	200-600	1950-1978	Turner <i>et al.</i> (1968) Turner and Jackson (1978)
		Control	5-10	200-250	1948-1976	
5 ^b	CSIRO	High CFW with limits on skin wrinkle and either fibre diameter or crimp frequency	5-8	100-250	1950-1979	Turner <i>et al.</i> (1968)
control	5-10	200-250			1948-1976	Turner and Jackson (1978)

a: flocks selected on CFW only.

flocks were selected from a base population consisting of 1700 ewes and 150 rams, and were maintained in the same environment.

Turner *et al.* (1968; 1970) have reported results from the experiments with the CSIRO selection flocks. In 1947, breeding experiments with medium-wool Peppin Merinos began with the aim of estimating the heritability or genetic correlations of production characteristics and comparing two methods of sire selection (Turner *et al.* 1968). Two of the groups which began in 1947 were the S flock, in which sires were selected on their own performance and their half-sibs, and the MS flock, with selection on the sire's own performance alone. Again, a random control group was formed so that the responses to selection could be measured.

Turner *et al.* (1968) reported results from these two groups (S, MS) over two periods, 1950-1959 and 1961-1964. In the first period, both groups had been selected against high average fibre diameter and high degree of skin wrinkle. In the second period, mass selection was used for both sexes in both groups, with selection against high fibre diameter and degree of wrinkle in one group (S), and against crimp frequency and high degree of wrinkle in the other (MS).

In addition to these selection experiments, another Merino selection flock was set up in South Africa in 1969 (Heydenrych *et al.*, 1977). Five groups were established at the same time, two group of ewes and rams were selected on clean fleece mass at 18 months of age

with limits on fibre diameter and crimp frequency, another two group rams were selected for a wider S/P ratio at three months of age. Each of these groups contained 160 ewes and 5 rams. A control flock was also established consisting of 160 ewes and 16 rams. The response to selection for clean fleece mass was effective. After five years of selection, the clean wool production of the two fleece mass groups was 0.45 kg and 0.40 kg greater than the control groups. Also, the number of secondary follicles were increased in another two groups selected for a wider S/P ratio.

(a) Direct response in clean fleece weight:

In all flocks selected solely or principally for clean fleece weight, selection was effective in that average clean fleece weight in the selection lines were higher than those in the control populations. Average annual rates of improvement in these lines, expressed as percentage deviation from control line means, are shown in Table 3. These results suggest that progress was more rapid when selection was solely for increased clean fleece weight (Experiments 1 and 2) than in the multi-trait selection flocks 3-5. Results also showed that in multi-trait selection flocks, the S group made more genetic progress in clean wool weight than in the MS group.

Unfortunately, such analyses of the response in these experiments are inadequate if we wish to compare responses achieved with those expected. In all instances the selection flocks were established by

Table 3. Annual percentage rates of improvement in flocks selected for increased clean fleece weight

Experiment	Period of response	Estimated rate of improvement/year
1	1952-1981	1.18 ± 0.09
2	1954-1976	1.58 ± 0.20
3	1947-1967	1.02 ± 0.03
4	1951-1974	1.05 ± 0.09
5	1951-1974	0.85 ± 0.25

selecting the best males and females from amongst a large base population. This practice produced large selection differentials in the first generation. The analysis in which responses are related simply to years of selection will not account for such an effect. A more satisfactory procedure for examining responses to selection is to estimate the realized heritability for fleece weight, defined as the response obtained expressed relative to the cumulated selection differential. This enables a more direct comparison to be made between the responses achieved in different flocks and that expected from the heritability of fleece weight in the base population or control flock. It also enables the pattern of responses to be examined having removed variation attributable to fluctuations in selection differentials achieved in different years.

A second problem in assessing responses in these flocks is that genotype x environment interactions appear to have an important effect on clean fleece weight. This means that in comparing a selection flock with its control or its parallel flock selected for low clean fleece weight, the difference in performance between the flocks will depend on the environment in which they are compared. The magnitude of the difference is typically greater as the average level of production increases. Under paddock conditions, there was the wide variation in production performance between drops of hoggets. Therefore, it is to be expected that responses to selection would become more variable due to fluctuations in performance given by genotype x environment interactions. For example, the between-year coefficient of variation for

clean fleece weight in the control line of experiment 1 is 20% (Robards, 1979). An adequate analysis of selection response in these lines would need to accommodate such genotype x environment interactions (Turner and Jackson, 1978).

Responses to selection in all lines selected for high clean wool weight have been broadly in agreement with predictions. Realised heritabilities calculated for experiment 1 were 0.49, 0.50 and 0.30 after one, four and six generations, respectively (McGuirk, 1973), which agree well with the base population estimate of heritability of 0.47 found by Morley (1955).

Selection for low clean fleece weight produced faster downward responses than the upward responses from selection for high clean fleece weight in both experiments 1 and 2 (Pattie and Barlow 1974; Turner *et al* , 1970). Pattie and Barlow (1974) found response in selection for low clean fleece weight to be linear over the duration of experiment 1. Similarly, response to selection in Experiment 2 was initially symmetric, with regressions of percentage deviation from the control being +2.48% and +1.95% per year for rams and ewes in the high line and -1.51% and -3.64% per year for rams and ewes in the low line over the first five years of selection (Turner *et al* , 1970). However, over the next four years the corresponding figures were +0.63% and +0.28% difference from the control per year for the high line and -1.79% and -2.19% per year for the low line. For the total period of the experiment the figures for ewes were +1.52% and -3.08%

per year for the high and low lines, respectively. This asymmetrical response may be due to biological limits on the upward response to selection for high fleece weight, but not on the downward response to selection for low fleece weight.

(b) Correlated responses to selection for clean fleece weight

Characters which are correlated with fleece weight are of interest for a number of reasons. Because all breeds are to some extent dual-purpose, it is important to know if there are genetic correlations between fleece weight and characters such as reproductive performance and growth. Secondly, a genetic correlation with a fleece or skin character can throw some light on the mechanisms by which selection can bring about an increase in wool production and might also suggest useful indirect selection criteria in improvement programmes (McGuirk, 1983). Selection experiments in Merino flocks have shown that selection for increased clean fleece weight leads to increases in staple length and follicle density, with smaller changes in body weight, skin folds and fibre diameter and to an appreciable reduction in crimp frequency. Selection for increased fleece weight has also reduced the number of lambs born per ewe joined (McGuirk and Atkins, 1976). Barlow (1974) concluded that the gains in wool production per head were in components of wool production per unit area, principally in staple length, fibre diameter and fibre density and not in the components of the wool growing surface area of the sheep.

The correlated responses in components of fleece weight will be reviewed in the following sections.

(c) Physiological and biochemical consequences of selection

The most extensive investigation of physiological responses to selection have involved flocks selected for increased fleece weight. There have been a number of studies on the efficiency of conversion of feed to wool using animals sampled from selection and control flocks. Comparisons of animals from high and low fleece weight selection flocks, or from high fleece weight and control flock animals, provided direct evidence that the differences in wool production were due almost entirely to improved efficiency and not to increased intake (Williams, 1979, McGuirk, 1980). They found that 92% of the wool weight difference was accounted for by the differences in food efficiency and there was a negligible difference in voluntary food intake between the selected and control animals.

Selection for increased fleece weight does not appear to have altered feed digestibility or the proportion of dietary nitrogen reaching the abomasum (Piper and Dolling, 1969; Williams, 1979). Differences in production and efficiency would appear to be due to differences in the utilization of nutrients after absorption from the alimentary tract.

Studies to further examine differences in production and feed efficiency have focused on the availability and utilization of cystine

and on related changes in the sulphur content of wool. Wool is composed predominantly of keratin which has a high content of sulphur. The wool samples have been found to contain 2.7% to 4.2% of sulphur. Most of the sulphur is present as cystine, with smaller amounts of cysteine and methionine (Reis, 1979).

Selection for increased fleece weight has been shown to reduce the sulphur content of wool in Experiments 1 (Reis *et al.* 1967) and 5 (Piper and Dolling, 1966). The effect was not simply a dilution of the amount of sulphur in the wool, as selection for increased fleece weight increased total sulphur output. Also, plasma cystine levels were reduced by selection, probably leading to the lower concentration of sulphur in wool of sheep from high fleece weight selection flocks.

Both the rate of wool growth and its sulphur content are influenced by the availability of sulphur-containing amino acids. When supplements of cystine, methionine or casein are infused into the abomasum of sheep, both wool production and wool sulphur content are increased (Reis, 1979). The increase in sulphur content is due to an increased yield of high sulphur proteins.

2.2 The effects of selection for fleece weight on the components of fleece weight.

Studies on the relationships between fleece weight and its components have been reported by Schinckel (1956, 1957), Turner

(1956, 1958), Young and Chapman (1958), Dun (1958) and Turner *et al.* (1970) for various strains of Merino sheep, by Henderson and Hayman (1960) for New Zealand Romney sheep and by Doney (1963) for Scottish Blackface sheep. One reason for interest in these relationships is that a number of the components (notably average fibre diameter, body weight or size and staple length) are of direct economic importance in their own right. The animal's potential for wool growth can also be assessed from attributes of its components.

The components of clean fleece weight were defined by Turner (1958). The clean wool production per head (W) can be expressed as the product of:

*Wool production per unit area of skin

*Wool-growing surface area

The wool production per unit area is the product of:

*Mean fibre cross-sectional area (A)

*Mean fibre length (L)

*Mean number of fibres per unit area of skin (N)

Similarly, the wool growing surface area can be described as:

*Smooth body surface area (S)

*Wrinkle score (R).

The relationship between clean fleece weight and its components can be written as :

$$W = S. R. N. A. L. K.$$

where K is a constant.

2.2.1 Wool production per unit area of skin

(a) Mean fibre cross-sectional area (A)

The mean fibre cross-sectional area can be defined as:

$$A = \pi [D^2 + V(D)]/4$$

where D = average fibre diameter and

V(D) = between-fibre variance for diameter.

Turner (1958) stated that when the between-fibre coefficient of variation for diameter was 20% or less, as would usually occur for medium-or fine-wool Merinos, the error introduced by omitting V(D) would be 4% or less and could be neglected. Most studies where calculations of average fibre cross-sectional area has been made have followed this assumption (Davis and McGuirk, 1987). However, for other breeds, the between-fibre coefficient of variation for diameter may exceed 20%, in this case, the error introduced by neglecting V(D) should be considered.

The change in mean fibre cross-sectional area (a function of average fibre diameter) following selection on clean fleece weight in Australian Merinos was generally variable or small. Barlow (1974) showed that correlated responses in fibre cross-sectional area to selection for high and low clean fleece weight in the Peppin Merinos were +0.3 and +0.04 for the high and low line respectively expressed as regressions of correlated response on response in clean fleece

weight. Turner *et al* (1970) stated that in all high wool weight lines, there was a small decrease in fibre cross-sectional area.

In both the CSIRO selection lines with restrictions on fibre diameter, the restriction was successful in holding fibre diameter while fleece weight increased (Turner *et al.* 1968, Turner and Jackson 1978). This agreed well with the expectation based on the genetic correlation as average fibre diameter has a low or negligible correlation with clean fleece weight in Merinos (Brown and Turner, 1968).

In New Zealand Romney sheep, with no restriction, fibre diameter is one of the characters which contributed to the increases in wool production. Blair (1981) indicated that fibre diameter increased by about 1.5 microns during 21 years evaluation. He also noted that an increase in mean fibre diameter of this magnitude is unlikely to affect the value of Romney wool in New Zealand. Blair *et al.* (1985) reported that mean fibre diameter showed a moderate positive correlated response in both yearling sexes.

(b) Mean fibre length (L)

Mean fibre length is one of the most important components which contributes to the gains in wool production. With raw wool, length evaluation is usually based on staple length, and a constant relationship (h) between average fibre length (L) and average staple

length (l) is assumed, so that $L=lh$. In raw wool, the mean fibre length is usually somewhat greater than the staple length, this being due to the fact that the individual fibres are straightened before measurement while they are crimped in the staple. In general, the fibre length/staple length ratio is higher for wool with greater crimp frequency.

The results of selection for clean fleece weight in Australian Merinos have shown that there was a significant correlated increase in staple length. Selection for high clean fleece weight in the CSIRO flocks resulted in increases in staple length of +0.52 expressed as regression of percentage correlated responses on clean fleece weight (Turner *et al.*, 1970). Brown and Turner (1968) indicated that the staple length has a moderate positive genetic correlation (between +0.4 and +0.6) with clean wool weight. Also, staple length was highly heritable, with a heritability of 0.48 (Gregory, 1982).

Similarly, selection for increased greasy fleece weight in New Zealand Romneys has also shown that there was a significant correlated increase in staple length. Blair *et al.* (1985) showed that the correlated response was about 0.5% per year and actual change in yearling staple length was 15mm in both sexes.

(c) Mean number of fibres per unit area of skin (N)

Mean number of fibres per unit area (N) can be assumed to equal to the number of follicles per unit area and thus can be partitioned as:

$$N = n_p + n_s$$

where n_p = number of primary follicles per unit area and

n_s = number of secondary follicles per unit area.

The mean number of fibres per unit area is usually considered as one of the most important contributors to wool production per unit area when selecting for high wool weight with restriction on fibre diameter. Turner *et al* (1968) described the effects of selecting for clean wool weight with a ceiling on diameter and showed that the number of fibres per unit area increased with increases in fleece weight. Dun (1958) and Barlow (1974) reported the same observation. In the selection flocks at Trangie, it was also found that N was one of the most important components contributing to the differences between the Fleece-plus and Fleece-minus flocks, accounting for 47% of the difference.

Further work by Jackson *et al.* (1975), examined four follicle characteristics - follicle depth, follicle curvature, number of follicles per unit area of skin and ratio of secondary to primary follicles for the CSIRO selection Peppin Merino flocks described by Turner *et al.* (1968). The results have shown that, with respect to skin characters, selection for clean wool weight resulted in increased follicle number per unit

area, secondary to primary follicle ratio and follicle depth and a decrease in follicle curvature. They also found that selection against the degree of skin wrinkle would have little effect on follicle depth and number of follicles per unit area and a lowering of follicle curvature and the ratio of secondary to primary follicles. Selection against fibre diameter would lower follicle depth and follicle curvature and raise number of follicles per unit area and the follicle ratio. Jackson *et al* (1975) concluded that these four follicle characteristics were highly heritable and sufficiently correlated with wool characteristics to be of interest to both the wool biologist and the sheep breeder.

2.2.2. Wool growing surface area

(a) Skin wrinkle (R)

The degree of skin wrinkle is associated with the wool growing surface area of the sheep, especially in Merinos. Generally, the more skin folds in the sheep, the greater is the surface area for wool production. This component is more important in Merino breeds in relating to changes in clean wool weight than other breeds, such as the Romney.

The changes in wrinkle score following selection for high and low clean fleece weight were variable in sign. Turner *et al* (1970) have shown that there was a marked downward trend in wrinkle score in

both high and low clean wool weight lines. However, Barlow (1974) stated that a small but significantly positive association was apparent between clean wool weight and wrinkle score in Fleece-plus and Fleece-minus flocks of Peppin Merinos. This decreased in magnitude following the initial response to selection in the Fleece-plus flock, but increased in the Fleece-minus flock.

Most experiments conducted with the Australian Merino based on selection for increased clean wool weight, have had a ceiling on skin wrinkle. In the study by Turner *et al* (1968), selection for high clean fleece weight with restrictions on fibre diameter and skin wrinkle was associated with negligible changes in either of these components indicating that the ceilings were successful. Turner and Jackson (1978) stated that the genetic correlations of wrinkle score with crimp frequency and fibre diameter were both positive (0.2-0.3 and 0.2 respectively). Restraint against increasing fibre diameter would reinforce selection against increasing wrinkle score, whereas selection to keep crimp frequency from falling would tend to raise wrinkle score. Therefore, if both fibre diameter and high crimp frequency are selected against, the degree of skin wrinkle will also be kept at a minimum.

In Romneys, the wrinkling factor is probably unimportant in contributing to the wool growing surface area and fleece weight.

(b) Smooth body surface area (S)

The smooth body surface area is directly related to liveweight. In practice, this component is difficult to measure, so that the smooth body surface area is usually derived from liveweight.

Selection experiments in Australian Merino sheep have shown that when selection was for clean wool weight, there was little change in liveweight. Barlow (1974) indicated that selection for increased fleece weight has not led to an increase in liveweights. This agreed well with expectation based on a low positive genetic correlation (about +0.16) between clean wool weight and liveweight (Barlow, 1974).

Selection for high greasy fleece weight in Romneys resulted in correlated responses in liveweight (Johnson, 1981; Blair *et al*, 1985).

2.3 Selection on the components of clean fleece weight

A number of selection flocks were established by both the CSIRO and the NSWDA at the same time as the clean wool weight selection lines with the aim of improving clean fleece weight through selection on a component. Most of them utilised divergent selection in which selection was for increased and decreased expression of the components of fleece weight and were used to compare with control flocks. These selection lines are summarized in Table 4.

Table 4. Summary of lines selected on the components of clean wool weight.

Selection experiments	Organisation	Flocks	Number of		Period	Author(s)
			Rams	Ewes		
1	NSWDA ^a	High Wr	5	100	1951-1975	Dun (1964)
		Low Wr	5	100	1951-1975	
		Control	10-25	100	1951-	
2	NSWDA	High Ww	5	100	1951-1983	Pattie (1965)
		Low Ww	5	100	1951-1983	
		Control	10-25	100	1951-	
3	CSIRO ^b	High B	1-2	28-51	1947-1973	Turner <i>et al.</i> (1970)
		Low B	1-2	33-50	1950-1973	
		Control	5-10	200-250	1948-1976	
4	CSIRO	High N	1-2	29-50	1950-1976	Turner <i>et al.</i> (1970)
		Low N	1-2	32-50	1950-1976	
		Control	5-10	200-250	1948-1976	
5	CSIRO	High L	1-2	33-50	1950-1976	Turner <i>et al.</i> (1970)
		Low L	1-2	26-50	1950-1976	
		Control	5-10	200-250	1948-1976	
6	CSIRO	High D	1	29-51	1954-1976	Turner <i>et al.</i> (1970)
		Low D	1	28-50	1954-1976	
		Control	5-10	200-250	1948-1976	
7	CSIRO	High W	1	31-48	1954-1971	Turner <i>et al.</i> (1970)
		Low W	1	29-51	1954-1971	
		Control	5-10	200-250	1948-1976	
8	CSIRO	High Y	1	30-50	1954-1976	Turner <i>et al.</i> (1970)
		Low Y	1	28-50	1954-1968	
		Control	5-10	100-250	1948-1976	
9	CSIRO	High Np	4-5	75-100	1956-1973	Rendel and Nay (1978)
		Low Np	4-5	75-100	1956-1973	
		Control	4-5	75-100	1956-1973	
10	CSIRO	High S/P ratio	4-5	75-100	1956-1973	Rendel and Nay (1978)
		Low S/P ratio	4-5	75-100	1956-1973	
		Control	4-5	75-100	1956-1973	

a: NSWDA=New South Wales Department of Agriculture-lines kept at Trangie Agricultural Research Centre, NSW.

b: CSIRO=Commonwealth Scientific and Industrial Research Organization-lines kept at Gilruth Plains, Cunnamulla Qld (1947-1965) and thereafter at 'Arding' or 'Longford' Armidale NSW.

Symbols: Wr=wrinkle score; Ww=weaning weight; B=body weight; N=number of fibre per unit area; L=staple length; D=average fibre diameter; W=clean wool weight per unit area; Y=clean scoured yield; Np=primary follicle density; S/P ratio=the ratio of secondary to primary follicles.

In the NSWDA selection lines, liveweight and wrinkle score (wool-growing surface area), were the selection criteria, both being measured at weaning. The CSIRO lines included lines selected for high and low values of wool production per unit area, as well as its components, fibre number per unit area, staple length and average fibre diameter. Also, the selection lines were established for liveweight, clean scoured yield and the skin characters of primary follicle density and secondary to primary follicle ratio. All traits were measured on both ewe and ram hoggets and selection was on these measurements.

2.3.1 Direct responses in the components

In the NSWDA selection lines, selection for wrinkle score and weaning weight were successful with realised heritabilities after six generations of selection of 0.33 and 0.53 in experiment 1 and 0.21 and 0.19 in experiment 2 for the high and low lines respectively (McGuirk, 1973). Except for the high line of experiment 1, these estimates agreed well with base population heritability estimates of 0.5 (Morley, 1955) and 0.19 (Pattie, 1965) for wrinkle score and weaning weight respectively.

In the CSIRO selection lines, realised heritabilities were not estimated but regression coefficients of percentage deviation from control revealed that selection was generally successful (see Table 5). Sometimes, the response appeared to be asymmetric. For fibre diameter and staple length, selection for low values of these

Table 5. Regression coefficients (b) \pm standard error (se) of direct responses in the selection criterion expressed as percentage deviations from control on time (years) for ewes in CSIRO single-trait selection lines (Turner *et al.*, 1970).

Selection criterion	High line		Low line	
	b	se	b	se
Clean wool weight	+1.52	0.29	-3.08	0.24
Clean wool weight/area	+2.37	0.88	-3.78	0.60
Number of fibres/area	+3.19	0.34	-1.87	0.18
Clean scoured yield	+1.11	0.11	-1.67	0.21
Liveweight	+1.47	0.11	-1.58	0.12
Staple length	+0.75	0.12	-1.67	0.13
Average fibre diameter	+1.04	0.19	-1.45	0.15

components was more effective than for high values while for wrinkle score and percentage yield, selection response for the high value was greater than for the low value (Turner *et al.* 1970). With selection for liveweight and clean wool weight per unit area, the response was about equal in the high and low lines.

Responses in two sets of CSIRO skin selection experiments were examined by Rendel and Nay (1978). Selection for high primary follicle density or high secondary to primary follicle ratio (S/P) was effective. Averaged over the last three lambings in this experiment, the divergence between the lines, expressed as a percentage of the low line mean, was about 72.6% and 96.0% (Rendel and Nay, 1978).

2.3.2 Correlated responses in clean fleece weight

The correlated responses in clean wool weight following selection on weaning weight and skin folds score were small (McGuirk, 1973). In the CSIRO selection lines, selection for increased clean scoured yield and staple length resulted in little increase in clean wool weight, being 0.38 and 0.04, respectively, expressed as percentage deviations from the control (cited by Davis and McGuirk; 1987). Unexpectedly, there were significant decreases in clean fleece weight in lines selected for high values of clean wool weight per unit area, number of fibres per unit area, liveweight and average fibre diameter. However, selection for low values of all these components reduced fleece weight, in

agreement with what was expected according to the genetic correlations.

Rendel and Nay (1978) described responses to selection for increased and reduced primary follicle density and S/P ratio and claimed that selection for increased primary follicle density or S/P ratio did not increase fleece weight. Averaged over the last three lambings, fleece weights were lower in these flocks than in their matched flocks selected for low values of these skin traits. The low S/P ratio line grew 0.12 kg more wool in males and 0.05 kg more in females. The low primary follicle density line grew heavier fleeces than the high lines by about 0.27 kg in males and 0.17 kg in females. These results disagree with the positive correlated responses in clean wool weight expected from base population genetic parameters (Jackson *et al.* 1975). Similarly, single-character selection for increased follicle depth and increased total follicle number did not increase fleece weights.

Selection on the components of clean wool weight in Australian Merinos was ineffective in increasing fleece weights. Davis and McGuirk (1987) concluded that none of these component traits appeared promising as a possible indirect selection criterion to increase wool production. Davis and McGuirk (1987) also suggested that, especially for the components of wool production per unit area, there were compensatory changes in components other than the selection criterion, such that clean wool weight does not change.

Selection for high wool weight per unit area increased the number of follicles per unit area, but there was a decrease in average fibre diameter. Such a response would be predicted from the genetic correlation between the two traits which is high and negative. Another reason is that the flocks selected for the components of fleece weight were small and unreplicated so that responses would have been affected by random genetic drift and inbreeding.

CHAPTER 3.

MATERIALS AND METHODS

3.1. Materials

3.1.1. Sheep and environment

Sheep and management: The sheep used in this study came from the Massey University fleece weight selected flock and control flock. Details of these two flocks have been described by Blair *et al.* (1984).

In 1956, two flocks, each of 80 mixed-age ewes (1.5 to 4.5 years-old) were established by random allocation from a larger flock established earlier as being a widely representative sample of New Zealand Romneys. Replacement breeding animals in one flock were selected for high greasy fleece weight (FW line). Replacements in a control (C line) flock were chosen at random. Each year, 4 new rams were used in each flock, the flocks having been closed in 1958. These rams were used only for one mating period at about 1.5 years of age. Breeding ewes were culled for age at 5.5 years.

The ewes from both flocks were run together, except at mating. The flocks were managed as nearly as possible to commercial conditions. Breeding ewes were shorn once a year in November/December, at which time the greasy fleece weight and

liveweight after shearing were recorded. A mid-side sample of wool was collected for the evaluation of several wool characteristics.

In March each year the ewes within each flock were randomised within age group, into 4 mating groups, each group being paddocked with one ram during the mating season (mid-March to late-April). Lambing took place during August and September. The new-born lambs were weighed, tagged and sexed. The date of birth, birth rank, ear tag number and dam number were also recorded. The lambs were weaned and weighed in December. At this time, a proportion of ram lambs were randomly culled. After weaning all lambs were shorn in December. This practice ensured a constant period of wool growth for all animals between lamb and hogget shearing.

Ram and ewe hoggets were grazed separately, but within sex all hoggets were run together. Hoggets were shorn at the beginning of October. Individual greasy fleece weight, including bellies and pieces, were recorded. A mid-side sample of wool was also collected. After shearing, hogget live weights were recorded. Replacement ewes and rams for the following mating season were chosen soon after hogget shearing.

Environment: The sheep were run on the Sheep and Beef cattle Research Unit of Massey University. In this area, the altitude is about 60-90 m. The mean annual rainfall is about 1000-1200mm and mean temperature ranged from 11.6°C to 20.6°C. The sheep were grazed in

paddocks at an average stocking rate of 12-15/ha. The pasture species are predominantly perennial ryegrass and white clover.

3.1.2 Measurements

The measurements used in this thesis were made only on ewe hoggets born in August-September 1988. In October 1989, the ewe hoggets were shorn, the fleeces were weighed and a wool sample was removed. Prior to shearing, this sample had been marked lightly with coloured chalk (raddle). The samples were placed in a plastic bag and transported to the laboratory. A few days later, skin samples were taken. The characteristics measured were: greasy fleece weight (GFW), clean fleece weight (W), clean scoured yield (Y), quality number (QN), total crimp number (TCN), staple length (SL), fibre length (FL), mean fibre diameter (FD), bodyweight (B), number of primary and secondary follicles per unit area of skin and the ratio of secondary to primary follicles (S/P).

Greasy fleece weight (kg): Yearling greasy fleece weights were recorded when the animals were shorn at the age of 13-14 months. Belly-wool and pieces were included in the greasy fleece weight.

Yield (%) : The measurement of clean scoured yield consisted of:

(1) Obtaining a greasy weight (Wg): greasy mid-side samples were weighed after being conditioned at 20°C and 68% relative humidity for 2 days.

(2) Removing the contaminants by detergent scouring the samples.

(3) Obtaining the weight of clean wool (W_c): after scouring, the samples were again conditioned as in step (1) before the weight of clean wool was measured.

(4) Calculating yield (%): $Y = 100 W_c/W_g$

Clean fleece weight was calculated as: $W = GFW \times Y/100$.

Staple length : Staple length measurement was made by placing a staple on a flat surface with a ruler on top. Care was taken not to stretch the staple.

Fibre length : Fibre length was measured on samples from 16 sheep (8 from each flock) by using a strip of accurately marked metric graph paper, carbon paper and forceps. The graph paper was firstly placed down the strip and was covered with carbon paper. Then, a small staple of wool was placed so that the butt end slightly overlapped one end of the graph paper and the staple was parallel with the strip. A weight, sufficient to straighten the fibres as they were drawn from beneath it, was then placed on top of the staple precisely at the end of the graph paper. Finally, forceps were used to draw the fibres from beneath the weight. When the fibre came free of the weight, the point of the forceps was forced down onto the carbon paper. The marks thus created on the graph paper formed a frequency distribution from which the mean fibre length was calculated.

Total crimp number and crimp frequency : The total number of crimps along a staple of greasy wool from the mid-side sample were counted. Crimp frequency, in crimps per 25 mm, was derived from the staple length and total crimp number.

Quality number : Quality number was a visual appraisal evaluation of the fineness of the wool. It was based mainly on staple crimp frequency, handle and lustre (Wickham, 1971).

Mean fibre diameter : Mean fibre diameter was measured by the air flow technique (Ross, 1958). The procedure was to card a small sample of clean scoured wool, weigh out 2.5g, place this in the chamber, start the pump, adjust the pressure using a valve and then read the diameter directly off the calibration attached to the flowmeter. The sample was removed from the chamber, teased out and then reweighed and retested. This was repeated for another sample and then the mean fibre diameter was calculated.

Follicle population determination : Wool follicle populations were determined by histological examination of a skin biopsy sample (Maddocks and Jackson, 1988). Two samples of skin were removed from the right mid-side of each animal by means of a 1 cm diameter trephine under local anaesthetic. The samples were fixed in Bouin's fluid for 24 hours before being transferred to 70% alcohol for dehydration. After histological processing and wax embedding, 5-8 μm thick cross-sections were cut from the sebaceous gland level. These

sections were stained with Haematoxylin, Eosin and Picric acid. Primary (P) and secondary (S) follicle counts were made on ten 1 mm² microscope fields per sample. These counts were then used to calculate the ratio of secondary to primary follicles (S/P).

A correction factor to adjust for shrinkage of samples after removal from the skin was calculated as follows (Maddocks and Jackson 1988):

$$\text{Correction factor} = \text{Area of specimen} / \text{area of trephine}$$

where the area of specimen was determined by measuring the skin sections. The correction factor was 0.75 in the present study.

3.2. Statistical methods

3.2.1. Derivation of the components from measured characters

For Romney sheep, the clean fleece weight (W) can be considered as derived from four components—mean number of fibres per unit area of skin (N); mean fibre cross-sectional area (A); mean fibre length (L) and smooth body surface area (S), so that:

$$W = S.N.A.L.K$$

where K is a constant. If we assume a constant specific gravity of wool (P) and a constant relationship (h) between average fibre length and average staple length, such that $K = Ph$.

These components are difficult to measure and some must be derived from other observed characters.

The smooth body surface area (S) was derived from bodyweight (B) using the following equation

$$S = 0.0909 B^{0.67} \text{ (Lines and Peirce 1931).}$$

The number of fibres per unit area (N) was assumed equal to the number of follicles per unit area which were identified in skin sections: $N = n_p + n_s$.

Mean fibre cross-sectional area (A) is most accurately estimated from fibre diameter as:

$$A = \pi [D^2 + V(D)]/4$$

where D = mean fibre diameter and V(D) = variance in fibre diameter. However, Turner (1958) ignored V(D), suggesting that such an approach would lead to a 4% error or less. Thus, in the present analysis the formula used was:

$$A = \pi D^2/4$$

Mean fibre length was measured only for 16 samples in this study. The others were estimated from measured staple length, by using either the regression coefficients of the fibre length on staple length or the ratio of fibre length to staple length.

3.2.2. Techniques for assessing the influence of each component on fleece weight

In this study, various techniques have been used for estimating the relative influence of each component on clean fleece weight.

(a) The percentage deviation technique

The percentage deviation technique described by Turner (1951; 1958) was used for assessing the influence of each component on fleece weight. This is a rapid method of apportioning differences in fleece weight to differences in the components when only two groups of data are being compared.

If a difference in clean fleece weight (W) was written as ∂W , the corresponding difference in a component C_i as ∂C_i and continued multiplication as Π ,

$$\text{then } W = K' \Pi C_i$$

$$\text{and } W + \partial W = K' \Pi (C_i + \partial C_i)$$

$$\text{whence } 1 + \frac{\partial W}{W} = 1 + \sum \frac{\partial C_i}{C_i} + \sum_{i \neq j} \frac{\partial C_i \partial C_j}{C_i C_j} + \text{higher order terms.}$$

In general, terms of second order or higher can be neglected, so

$$\text{that: } \frac{\partial W}{W} = \sum \frac{\partial C_i}{C_i}$$

It is convenient to express these proportions as percentages,

putting $\frac{\partial W}{W} \cdot 100 = W_p$ and $\frac{\partial C_i}{C_i} \cdot 100 = C_{ip}$.

Then the simple statement can be made that

$$W_p = \sum C_{ip}$$

or, a percentage difference in clean fleece weight is approximately equal to the sum of the corresponding percentage differences in the components.

This technique was used to make a direct comparison between the two lines of sheep in the present analysis. In this case, the mean values of the observations for control flock were taken as the base, the corresponding mean values in the selected flock being expressed as a percentage deviation from the base.

- (b) Simple linear regression of the log of each component on log fleece weight

This method is based on the assumptions that the components of fleece weight are independent. A change in one would produce a proportional change in fleece weight and the overall relationship between fleece weight and its components is linear after log transformation. The coefficient of determination (R^2) for any component was used for assessing the proportionate reduction of total

variation in fleece weight (Y) associated with each component (X). The R^2 can take values between 0 and 1. The larger the R^2 , the greater is the degree of association between fleece weight (Y) and the component (X). The model used can be written as follows:

$$\hat{Y} = a + bX$$

where \hat{Y} is an estimate of the log of clean fleece weight; a is the constant; b is the regression coefficient; X is the log of a component.

(c) Standardized partial regression of fleece weight on components (multiple regression)

Standardized partial regression coefficients are those in equations where all variables have been standardized, that is, measured from their means in units of standard deviations. These coefficients can be used to compare between regression coefficients based on independent variables which are different in units. Standardized partial regression coefficients were denoted by b_1' b_k' . The standardized regression equation is:

$$\frac{\hat{y} - \bar{y}}{s_y} = b_1' \frac{x_1 - \bar{x}_1}{s_1} + \dots + b_k' \frac{x_k - \bar{x}_k}{s_k}$$

$$\text{or } \hat{Y} = b_1'x_1' + \dots + b_k'x_k'$$

The equation for computing standardized partial regression coefficients is:

$$b_i' = b_i \frac{s_{xi}}{s_y}$$

where b_i' is the standardized partial regression coefficient; s_{x_i} is the standard deviation of a component; s_y is the standard deviation of clean fleece weight. For the present calculation, the data were log transformed before computation.

All statistical analyses were performed using either the statistical package 'REG' (Gilmour, 1985) or the Minitab computer package (Cruze and Weldon, 1989).

CHAPTER 4

RESULTS

4.1. Prediction of fibre length.

Fibre length is an important component of fleece weight, but its measurement is complicated, whereas, the measurement of staple length is simpler and faster. The mean fibre length can be derived from staple length. Fig. 1 shows the relationship between mean staple length and mean fibre length in scoured wool. The correlation coefficient is 0.75 ($P < 0.001$) and regression coefficient of fibre length on staple length is 0.89 ($P < 0.01$). These values indicate that it is possible to use staple length as a basis for the prediction of fibre length in the wool. One prediction was based on the following regression equation derived from the 16 samples measured for fibre length:

$$\hat{Y} = 7.7835 + 0.8905X$$

where X = staple length; \hat{Y} = predicted fibre length.

Another method in prediction of fibre length is to use the ratio of fibre length to staple length. The mean ratio is calculated for fleece weight selected and control flocks, respectively. The prediction equation was:

$$\hat{Y} = \frac{FL}{SL} X$$

where $\frac{FL}{SL}$ is the ratio of fibre length to staple length.

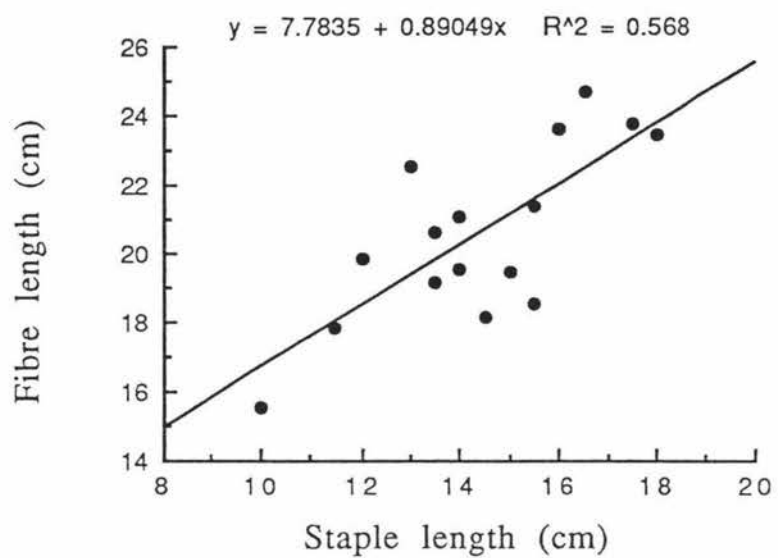


Fig. 1. The relationship between mean staple length and mean fibre length.

4.2. Fitted means for characteristics and components of fleece weight

Table 6 presents the mean value for each characteristic in each flock. There was a marked response to selection for greasy fleece weight, with the FW line being significantly higher ($P < 0.001$) than the C line. Relative to the control flock, clean fleece weight, staple length, fibre length, mean fibre diameter, clean scoured yield, fibre density and S/P ratio increased, but quality number decreased. There was no significant difference in body weight between the selected and control flocks.

Table 7 shows the mean value for each component of fleece weight. The mean values based on 16 ewes with measurement of fibre length are shown in Table 7 (a). There were significant differences in fibre length ($P < 0.01$), wool weight per unit area ($P < 0.05$) and fibre volume ($P < 0.05$) between the two flocks. By contrast, the differences in smooth body surface area, fibre density and fibre cross-sectional area were not significant.

The mean values for predicted fibre length of all 49 ewes are shown in Table 7(b). A highly significant difference between the two flocks was apparent in predicted fibre length ($P < 0.001$). Also, there were a significant differences in total number of fibres (follicles) ($P < 0.05$) and fibre cross-sectional area ($P < 0.05$) between the selected

Table 6. Mean value of each characteristic and its standard error for 49 ewes in fleece weight selected (FW) and control (C) flocks.

Characteristics	FW	C	Significance
Greasy fleece weight (kg)	4.44±0.089	3.37±0.099	***
Yield	0.75±0.007	0.73±0.008	*
Clean fleece weight (kg)	3.34±0.070	2.48±0.077	***
Body weight (kg)	35.64±0.744	33.53±0.824	NS
Fibre diameter (µm)	37.30±0.478	35.61±0.529	*
Staple length (cm)	14.65±0.332	12.59±0.338	***
Fibre length ^a (cm)	22.19±0.688	18.78±0.643	**
Fibre length ^b (cm)	21.09±0.482	18.51±0.533	***
Fibre length ^c (cm)	20.83±0.296	19.00±0.337	***
Fibre number(n/mm ²)	29.56±0.788	26.99±0.873	*
Quality number	47.3±0.497	49.09±0.551	*
Primary density(n/mm ²)	4.26±0.497	4.16±0.133	NS
S/P ratio	6.04±0.103	5.49±0.112	***

a: Fibre length measured for 16 ewes

b: Fibre length predicted by using the ratio of fibre length to staple length

c: Fibre length predicted by using the regression coefficients of the fibre length on staple length

NS = not significant; * P<0.05; ** P<0.01; *** P<0.001.

Table 7 (a). Mean values of clean fleece weight and its components for ewes in fleece weight selected (FW) and control (C) flocks. The values (mean \pm SE) were based on 16 ewes with fibre length measured.

Characteristics	FW	C	Pooled SE	Significance
W (kg)	3.56	2.52	0.164	***
S (m ²)	1.016	0.954	0.022	NS
N (fibres/mm ²)	28.31	27.52	1.316	NS
A (μ^2)	1133	1034	53.53	NS
L (cm)	22.39	18.78	0.636	**
S x N (million)	28.72	26.28	1.415	NS
N x A x L (mg)	10.05	7.47	0.643	*
A x L (mm ³)	0.254	0.194	0.013	*

W = clean fleece weight;

S = smooth body surface area;

N = mean number of fibres per unit area of skin;

A = mean fibre cross-sectional area;

L = mean fibre length (measurement);

S x N = total number of fibres (follicles);

N x A x L x 1.4 = wool weight per unit area (Van Wyk and Nel, 1940);

A x L = the volume per fibre.

NS = not significant;

* P<0.05; ** P<0.01; *** P<0.001.

Table 7 (b). Mean values of clean fleece weight and its components for ewes in fleece weight selected (FW) and control (C) flocks.

The values (mean \pm SE) were based on 49 ewes with predicted fibre length.

Characteristics	FW (n=27)	C (n=22)	Significance
W (kg)	3.34 \pm 0.070	2.48 \pm 0.077	***
S (m ²)	0.995 \pm 0.014	0.955 \pm 0.016	NS
N (fibres/mm ²)	29.56 \pm 0.788	26.99 \pm 0.873	*
A (μ^2)	1096 \pm 26.58	1002 \pm 29.45	*
PFL ^a (cm)	21.09 \pm 0.481	18.51 \pm 0.533	***
PFL ^b (cm)	20.83 \pm 0.296	19.00 \pm 0.327	***
S x N (million)	29.45 \pm 0.848	25.69 \pm 0.939	**

a: Predicted fibre length (PFL) was predicted by using the ratio of fibre length to staple length.

b: PFL predicted by using the regression coefficients of the fibre length on staple length.

For explanation of symbols, see footnote of Table 7 (a).

and control flocks. However, there was no significant difference in smooth body surface area.

4.3. Contribution of the components to differences in fleece weight between selected and control flocks

The relative contributions of the individual and combined components to changes in fleece weight are presented in Table 8. The percentage deviations for 16 ewes with measured fibre length are shown in Table 8(a). Table 8(b) shows the percentage deviations for 49 ewes with predicted fibre length which was derived from staple length.

From Table 8(a) and Table 8(b), it is clear that the two flocks differed significantly in clean fleece weight and mean fibre length. The percentage deviations in clean fleece weight were 41.27 and 34.68 for 16 and 49 ewes, respectively. The mean fibre length showed the greatest variation in the components between the two flocks. The measured fibre length accounts for 46.57% of the 41.27% total differences in fleece weight for 16 ewes. The predicted fibre length accounts for 27.77% to 40.20% for 49 ewes. The smooth body surface area, fibre density and fibre cross-sectional area account for 15.75%, 6.95% and 23.43%, respectively for 16 ewes and 12.08%, 27.45% and 26.96% for 49 ewes of total differences in fleece weight. The sum of the deviations for the individual components does not differ

Table 8(a). Contribution of the components to differences in fleece weight expressed as percentages of the control flock means. Values were based on 16 ewes with measurement of fibre length.

Components		Percentage deviations
Percentage deviation	W	41.27
in W and individual	S	6.50
component	N	2.87
	A	9.67
	L	19.22
	Sum	38.26
Combined deviations	S x N	9.28
	A x L	30.93
	N x A x L	34.54

For explanation of symbols see footnote of Table 7 (a).

Percentage deviation from fitted means of Table 7(a).

Table 8(b). Contribution of the components to differences in fleece weight expressed as percentages of the values of the control flock. Values were based on 49 ewes with predicted fibre length.

Components	Percentage deviations
W	34.68
S	4.19
N	9.52
A	9.35
PFL ^a	13.94
PFL ^b	9.63
Sum	37.00 (with PFL ^a)
	32.69 (with PFL ^b)

For explanation of symbols see footnote of Table 7(a).

Percentage deviation from fitted means of Table 7(b).

significantly from the deviation in fleece weight.

Among the combined deviations, wool weight per unit skin area contributes most of the deviation in wool weight and accounted for 83.7% of the total difference in fleece weight. Surface area contributed little to differences in fleece weight (15.8%).

4.4. Contribution of the components to differences in fleece weight between ewes within each flock

4.4.1. Correlations between the components within each flock

The correlation coefficients between each pair of components, as well as the correlation between wool weight and each component are given in Table 9. Within the fleece weight selected line Table 9(a), fleece weight was significantly ($p < 0.05$) correlated with L, A and S. The relationship between the number of fibres per unit area and fleece weight appeared low positive but non-significant. There were negative correlations of L with N and S. Also, L has a strong positive correlation with A. There was a negative correlation between N and A.

In the control line (Table 9 b), there were significant ($p < 0.05$) correlations of fleece weight with A and S. The mean staple length has a negative correlation with fibre density. Fibre density tends to have a

Table 9. Correlation of the components within fleece weight selected (a) and control (b) flocks.

(a) Correlation between the components within the selected flock (n=26)

Components	L ^a	A	N	S
W	0.395*	0.382*	0.082	0.401*
L ^a		0.442*	-0.097	-0.059
A			-0.308	0.013
N				0.142

(b) Correlation between the components within the control flock (n=21)

Components	L ^a	A	N	S
W	0.400	0.514*	0.126	0.497*
L ^a		0.468*	-0.154	0.274
A			-0.351	0.160
N				-0.287

a: mean staple length. * P<0.05.

negative correlation with fibre cross-sectional area and smooth body surface area.

4.4.2. Contribution of the components to differences in fleece weight within each flock

Table 10 presents the contribution of components to differences in fleece weight between ewes within each flock as assessed by the coefficient of determination (R^2) from simple linear regression. From Table 10, it appears that three components, L, A and S, are about equally important to differences in fleece weight between ewes within the selected flock. Within the control flock, A and S are more important than L. These values are in turn expressed as proportions and are shown in Table 11. Each of components L, A and S, accounts for 0.31, 0.35 and 0.34, respectively for variation in fleece weight within the selected flock and 0.22, 0.43 and 0.35, respectively, within the control line. The contribution of fibre density (N) to differences in fleece weight between ewes within each flock was negligible.

The contribution of components to differences in fleece weight between ewes within each flock was also analysed by the standardized partial regression coefficients of the log of each component on log fleece weight. The results are given in Table 12. Within the fleece weight flock, L appeared the most important contributor to differences in fleece weight within selected flock. The components of A and S were about equally important, both of them were more important than

Table 10. Contribution of components (in logarithms) to differences in W between ewes within each flock as assessed by the coefficients of determination (R^2).

Flocks	Coefficients of determination (R^2)				
	L	A	N	S	Sum
FW (n=26)	0.12	0.14	Negl	0.13	0.38
C (n=21)	0.12	0.24	Negl	0.19	0.55

Negl=negligible.

Table 11. Proportion of the sum of within-flock variation in fleece weight accounted for by each component. (Data from Table 10).

Flocks	Components of fleece weight			
	L	A	N	S
FW (n=26)	0.31	0.35	Negl	0.34
C (n=21)	0.22	0.43	Negl	0.35

Negl=negligible.

Table 12. Standardized partial regression coefficients of the log of each component on the log of clean fleece weight.

Flocks	Components				
	L	N	A	S	Sum
FW	0.40	0.18	0.30	0.27	1.15
C	0.05	0.59	0.69	0.29	1.62

contribution of N. Within the control flock, the main contributors to differences in fleece weight appeared to be A and N. By contrast, L was less important than other components in contribution to differences in fleece weight between ewes within the control flock.

4.5. Comparison of between and within flock contributions of the components to differences in fleece weight

The contribution of the components to differences in fleece weight between and within flock have been considered separately in sections 4.3 and 4.4. It is possible to consider these two analyses together. Fig. 2 shows comparison of between and within flock contributions of the components to differences in clean fleece weight, in which, the between flocks differences have been analysed by the percentage deviation technique, but the within flock differences were analysed by the coefficients of determination (R^2) from simple linear regression. The between flock contribution of L appeared more important than that within flock. The fibre density (N) made a greater contribution to between flock differences in fleece weight than that within flock. The contribution of fibre cross-sectional area (A) appeared more important in the control flock than that in the selected flock and between flocks. The influence of smooth body surface area (S) on fleece weight appeared greater within flock than between flocks.

In Fig. 3, the estimates of the contributions of the components to between flock differences are compared with the within flock

Fig. 2. Proportion of between and within flock change in clean fleece weight accounted for by each component.

(a) between flocks.

(b) within fleece weight selected flock.

(c) within control flock.

In (a), the values were expressed as percentage deviations (data from Table 8 b)

In (b) and (c), the values were expressed as coefficient of determination (R^2) from simple linear regression (data from Table 11).

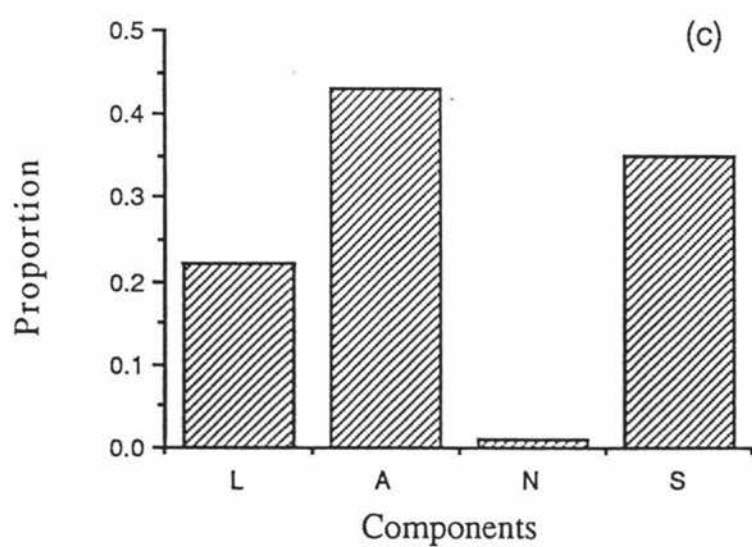
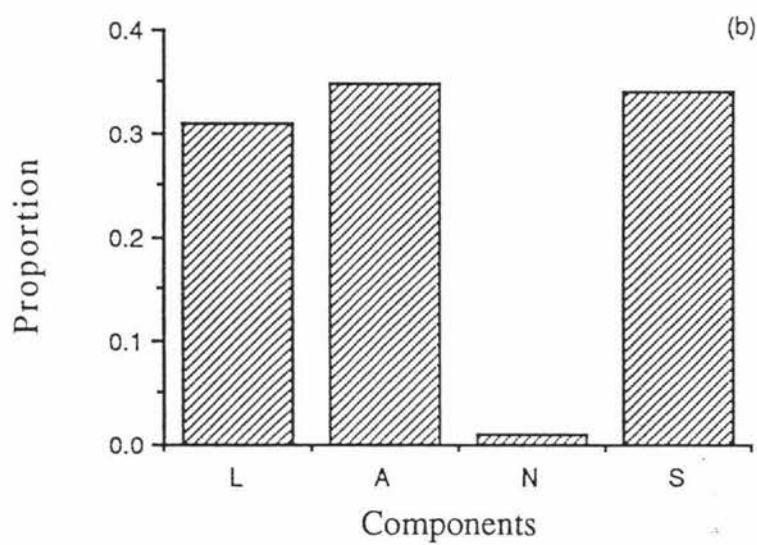
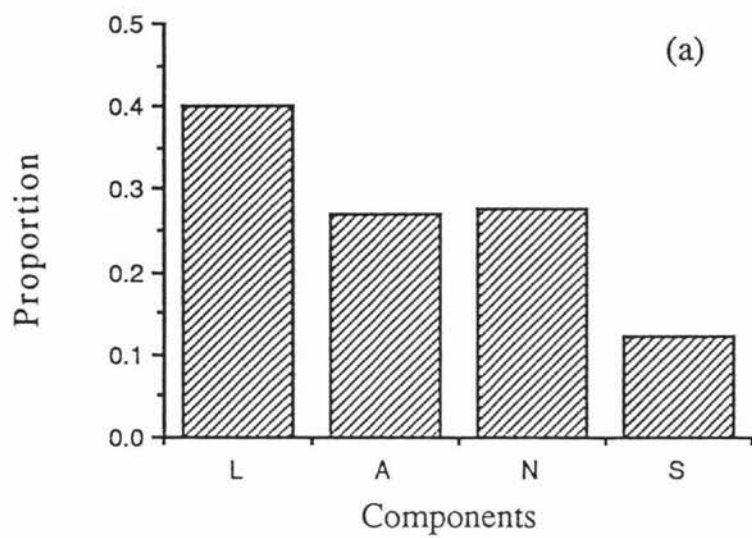


Fig. 3. Proportion of between and within flock change in clean fleece weight accounted for by each component.

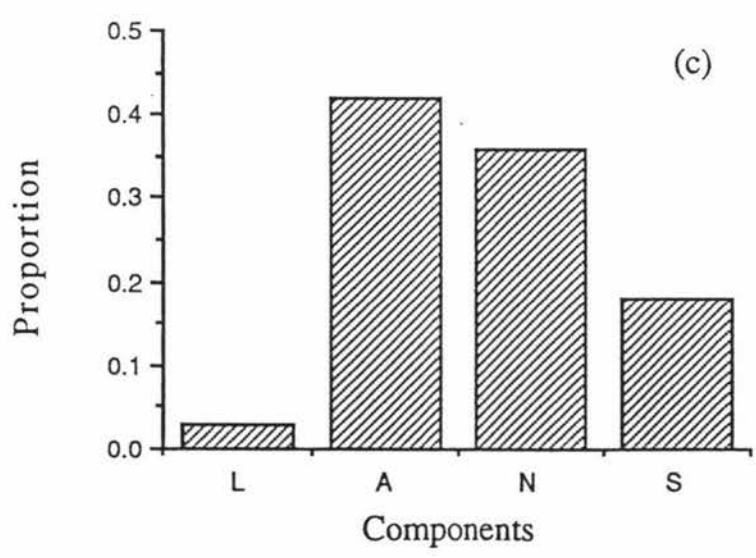
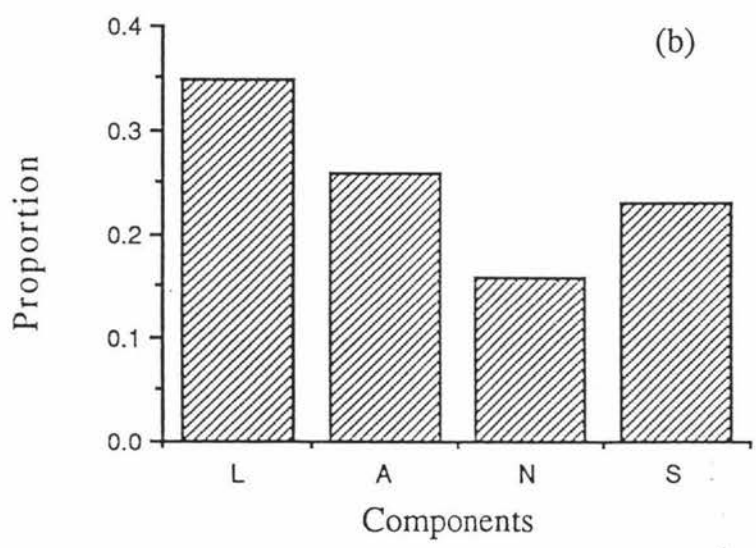
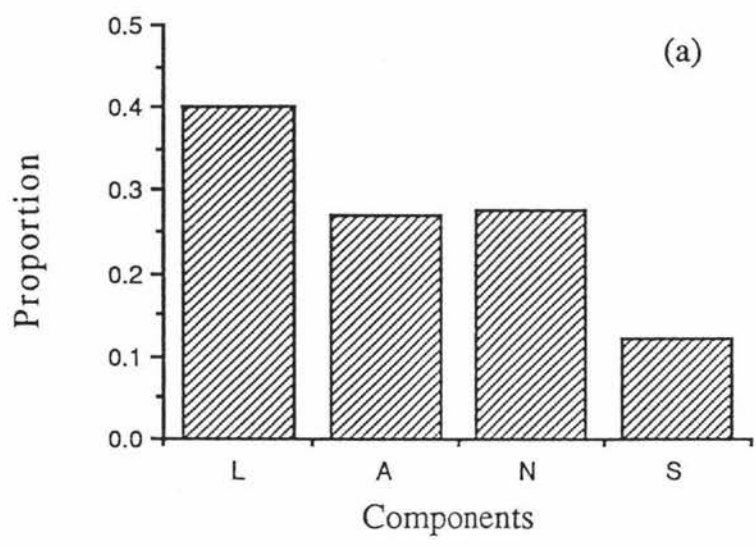
(a) between flocks.

(b) within the fleece weight selected flock.

(c) within the control flock.

In (a), the values were expressed as the percentage deviations (data from Table 8 b)

In (b) and (c), the values were expressed as the standardized partial regression coefficients (data from Table 12)



contributions which are estimated by the standardized partial regression coefficients. Using this method of analysis, the results again indicated that L was the most important contributor between flocks and also within the selected flock. The A component appeared the most important contributor to within control flock differences, but S made little contribution to differences in fleece weight between flocks.

CHAPTER 5.

DISCUSSION AND CONCLUSIONS

5.1 Methods of predicting fibre length.

Mean fibre length can be derived from mean staple length in several ways. In the present study only two methods were used. One method was to use the mean ratio of fibre length to staple length in scoured wool. Ozcan (1956) found that the ratio of fibre length to staple length was reasonably constant, at least within a Merino strain. In the present analysis, the mean ratio in Romney sheep was found to be 1.44 for the fleece weight selected flock and 1.47 for the control flock. Since selection for fleece weight was accompanied by a decrease in crimp frequency (Blair *et al*, 1985), the ratio of fibre length to staple length was higher in control flock than in fleece weight selected flock.

Another method for prediction of fibre length was based on the regression coefficient of fibre length on staple length. Theoretically, there are several assumptions in regression analysis. One of them is that the measurements of the independent variable should be obtained without error. There are probably sizeable errors in sampling staples and measuring their length and, partly because of this, any proportion on staple length measurements of the variation in fibre length is controlled by the regression (R^2 for 16 ewes = 0.57). Consequently, the values predicted are likely to be less variable than

those obtained by measurement. This could have a considerable effect in the calculation of the contribution of this component to fleece weight.

Using the ratio of fibre length to staple length to predict fibre length is still not entirely accurate, but predicted values are more variable than those obtained using the regression method. Therefore, it is suggested that both of the methods are by no means perfect, but they have proved to be applicable in predicting fibre length from staple length.

5.2 Techniques for estimating the relative influence of each component on fleece weight.

Three techniques for estimating the relative influence of each component on fleece weight have been used in this study. They are the percentage deviation technique; simple linear regression and multiple regression using the log of fleece weight on the log of each component. Each of them has its own advantages and disadvantages.

The percentage deviation technique described by Turner (1951; 1958) was used in the present analysis to determine the components chiefly responsible for differences in clean fleece weight between flocks of sheep (Tables 8a, 8b). This method is based on the assumption that the percentage difference in clean fleece weight between the flocks will be approximately equal to the sum of the

corresponding percentage differences in the components. Absence of a significance test is a disadvantage of this method. However, it has several advantages. It has yielded some consistent results in Australian Merinos (Turner, 1956, 1958; Dun, 1958) and has the advantage of including all components in the analysis. Also, it is rapid and, in most of its applications, involves no assumptions about the linearity of relationships. As means are being analysed, the inaccuracies introduced by sampling and measurement errors are reduced. Moreover, different combinations of the components can be readily examined by summing their percentage deviations. It may be concluded that this technique is by no means perfect, but it has proved to be a useful tool in analysing the source of differences in clean fleece weight between flocks of sheep.

Simple linear regression of the log of each component on the log of clean fleece weight was used to estimate the relative importance of the components to differences in fleece weight between ewes within each flock (Table 10). The coefficients of determination (R^2) have been used for assessing the proportionate reduction of total variation in fleece weight associated with any one of its components. One problem is that each coefficient (R^2) is only a descriptive measure of the degree of relationship between fleece weight and one of its components, but the interrelations among the components are ignored. Since there are correlations between the components, such as the negative correlation between A and N and the positive correlation between A and L, the influence on fleece weight of changes in one component will be

modified by changes in the other. The analysis showed N having negligible influence on fleece weight within each flock, but this result could be due to the negative indirect relationship of N through A to W cancelling out the positive direct relationship between N and W.

Estimates of the standardized partial regression of the log of fleece weight on the log of each component were also used to estimate the relative influence of each component on fleece weight within flock. Since all variables in the equations have been standardized, the partial regression coefficients can be used to compare the contributions of components measured initially in different units. Also, this technique has an advantage over simple linear regression in that the standardized partial regression coefficients consider the overall relationships of all components of fleece weight. During the calculation of the multiple regression coefficients, an attempt is made to produce an estimate of the direct relationship only. Theoretically, each partial regression coefficient is the regression coefficient expected if the other components do not vary.

The use of path analysis in defining causal relations and interrelations have been discussed by Li (1975) and path analysis are very useful in visualizing the interrelations of fleece weight (W) and its components (L, N, A and S). Fig 4 (a) shows the relationships between all components, as well as between fleece weight and all the components for the selected flock. Fig 4 (b) shows those relationships within the control flock. The path coefficients (P_{OL} , P_{OA} , P_{ON} and P_{OS})

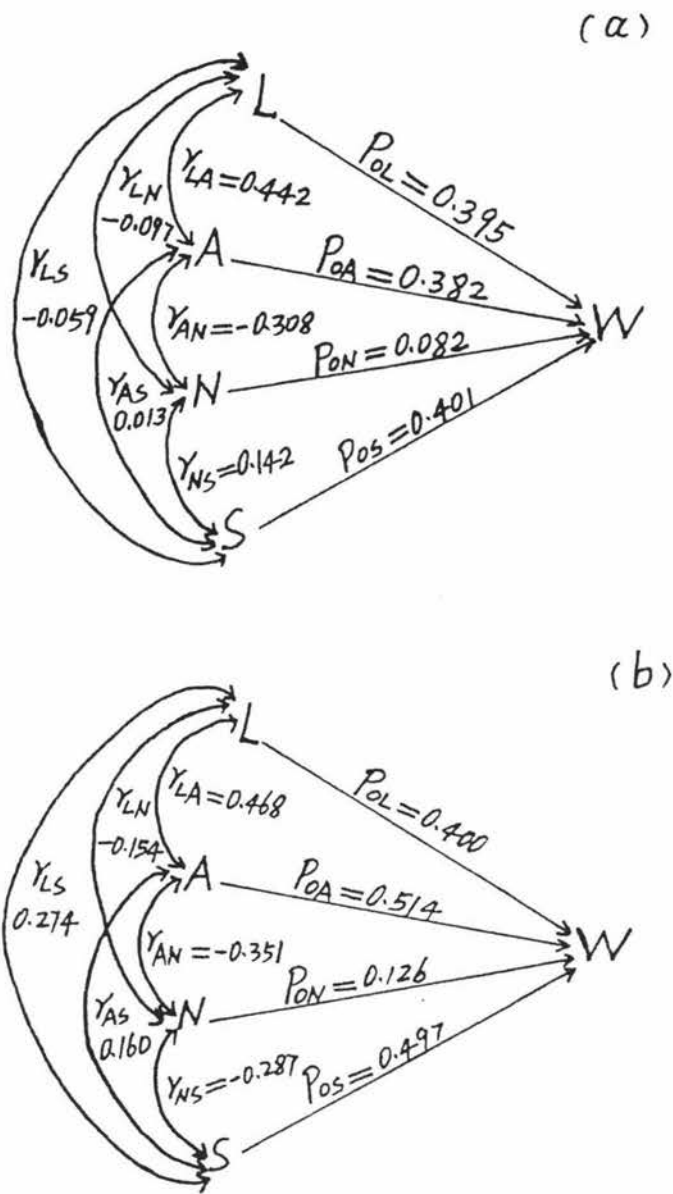


Fig. 4. Path diagram indicating the interrelations of components and clean fleece weight (W).

(a) within the selected flock.

(b) within the control flock.

P_{OL} , P_{OA} , P_{OS} and P_{OS} are the standardized partial regression coefficients.

Double-headed curves (r) are the correlations between components.

are represented by straight single pointed arrows which show the direction from each component to fleece weight, while the curved, double pointed arrows represent correlations between components. The path coefficients are in fact standardized partial regression coefficients. Theoretically, the sum of the standardized partial coefficients of the components is equal to 1, but it is actually not, since some errors probably come from measuring of the different components.

The multiple regression of fleece weight on some or all components superficially appears an attractive technique, but Turner and Young (1969) questioned its use and stated that the multiple regression model ($\hat{Y} = \sum b_i X_i$) was not applicable since variation in the estimates of b_i in the multiple regression model would result mainly from variation in the accuracy of measuring the different X_i , rather than through any real differences in biological influence. Furthermore, the X_i values and their errors are likely to be correlated. However, the simple linear regression and correlation methods which are the main alternatives for within flock assessments of components, suffer from these same deficiencies plus some others.

5.3 Comparison of the importance of components

The main purpose of the study was to examine the effects of selection for greasy fleece weight on the components of fleece weight in New Zealand Romney sheep. The results have shown that there

were correlated responses in component traits of fleece weight following selection on greasy fleece weight. Significant correlated responses in the clean fleece weight, yield, staple length, predicted fibre length, fibre diameter and the number of fibres (follicles) per unit area were observed (Table 6). These results agree well with expectations based on realized correlated responses estimated by Blair (1981) and several other workers. The genetic correlation between greasy fleece weight and clean fleece weight ranged from 0.84 to 1 (Blair 1981) based on earlier data from the same flocks. The genetic correlations between greasy fleece weight and yield are variable, being -0.5 to +0.9 (Bigham et al. 1983; Mullaney et al. 1970; Blair 1981). There are also high and positive genetic correlations between greasy fleece weight and staple length and fibre diameter. However, no estimates of the genetic correlation between greasy fleece weight and follicle density are available for Romney sheep. Selection experiments involving Merinos have shown that the realized genetic correlation between clean fleece weight and follicle number per unit area ranged from +0.20 to +0.23 (Barlow 1974).

Comparisons of the mean values of the components between selected and control flocks have shown that there were highly significant differences ($p < 0.001$) in fibre length (Table 7 b). Also, significant differences ($p < 0.05$) were found in fibre cross-sectional area and number of fibres per unit area, but no differences in smooth body surface area were observed. The differences in significance are most likely due to true differences in the magnitude of the genetic response

to selection for fleece weight in the different components, but the lower significance of some components could be due to greater variation associated with environmental factors or measurement errors.

In this study, the contribution of the components to differences in fleece weight between the selected and control flocks was examined by using the percentage deviation technique. The results suggest that the mean fibre length was the most important contributor to fleece weight differences between-flock. Most studies to date suggest that fibre length may be of greater importance in coarser-woolled sheep, such as the Romney, than in the Merino.

Fibre cross-sectional area and number of fibres (follicles) per unit area were about equally important in between flock differences in fleece weight (Table 8b). There was a negative relationship between fibre cross-sectional area and the number of fibres per unit area, with the correlation coefficient being -0.20 . This relationship suggests that the contribution of fibre cross-sectional area may be reduced by its negative association with the number of fibres per unit area. Hence, the response in fibre cross-sectional area was not as big as expected based on the genetic correlation (0.8) between greasy fleece weight and fibre diameter (Blair, 1981). The increasing number of fibres per unit area would lead to a decrease in the fibre cross-sectional area. Selection experiments for clean wool weight in Merinos with a restriction limiting either crimp number or fibre diameter have shown

that the number of fibres per unit area was the most important contributor to changes in clean fleece weight (Turner and Young, 1969). However, Dun (1958) found that in a flock with no such restriction, the number of fibres per unit area and fibre volume (fibre cross-sectional area x fibre length) were almost equally important in responses in clean fleece weight.

In comparison with other components, the contribution of the smooth body surface area to differences in fleece weight between flocks was relatively small. Such a result could be explained by the small positive genetic correlation between fleece weight and liveweight. Selection experiments in Australian Merino sheep have also shown that, when selection was for clean fleece weight, there was little change in wool-growing surface area of liveweight and wrinkle score (Barlow 1974).

The contribution of combined components was also examined for 16 ewes in present study (Table 8a). It was found that wool weight per unit area ($N \times A \times L$) had far greater influence on fleece weight than wool-growing surface area (S), with the apportionment being about 84 : 16. The mean fibre length made the greatest individual contribution to wool weight per unit area differences.

Fibre volume ($A \times L$) was found to be more important than total fibre number ($S \times N$) in contributing to differences in fleece weight between flocks. A significant difference was observed between the

selected and control flocks in fibre volume, but there was no statistically significant difference in total fibre number. This result agrees with that reported by Turner *et al.* (1970). It must be pointed out that in the Merino data, fibre cross-sectional area was found to have most influence on fibre volume, but for these Romney data, fibre length was more important than fibre cross-sectional area.

The contribution of the components to differences in fleece weight between ewes within each flock has also been examined. Despite the fact that other workers have published a number of papers with results of similar analyses (Turner, 1958, Henderson and Hayman, 1960), it is doubtful that any statistical technique can adequately resolve the contributions of the different components of fleece weight using typical within flock data. The present results must be viewed with this reservation in mind.

The correlations were calculated between fleece weight and its components within each flock. Within the selected flock, smooth body surface area showed the highest correlation of 0.40 ($P < 0.05$) with fleece weight (Table 9 a). Significant correlations were also found with fibre length and fibre cross-sectional area. There was no significant correlation between the number of fibres per unit area and fleece weight. Since these are phenotypic correlations, it was somewhat surprising that differential nutrition did not lead to strong positive associations of smooth body surface to length and cross-sectional area. Animals with high smooth body surface presumably had more follicles.

Within the control flock, fibre cross-sectional area showed the highest correlation of 0.51 ($P < 0.05$) with fleece weight (Table 9 b). There was a significant correlation between smooth body surface area and fleece weight, but the correlations for length and number of fibres per unit area were not statistically significant. These correlations suggest that the number of fibres per unit area is less important in the phenotypic differences between sheep within flock than in the genetic differences between the flocks, while smooth body surface area and fibre cross-sectional area are more important in the phenotypic differences of the sheep within a flock, but the differences could be due to the effects of differences in the accuracy of measurements.

There was a consistently negative correlation between the number of fibres per unit area and fibre cross-sectional area in all analyses and these agreed with results in Merinos (Turner 1956). There was also a negative correlation between fibre length and the number of fibres per unit area within each flock. A significant ($P < 0.05$) positive correlation between fibre length and fibre cross-sectional area was observed, with the correlation coefficients being 0.44 and 0.47, for within selected and control flocks, respectively. These figures agreed well with those found in Romney lambs by Henderson and Hayman (1960).

The within flock differences were also analysed by simple linear regression of the log of each component on log fleece weight. The

contribution of components to differences in fleece weight between ewes within each flock was assessed by the coefficient of determination (R^2) resulting from simple linear regression (Table 10). Within both the selected and control flocks, three components, cross-sectional area, smooth body surface area and fibre length were important contributors to fleece weight differences. The fibre cross-sectional area and smooth body surface area were relatively more important than fibre length. The number of fibres per unit area had a negligible effect. These results are different from the results of analyses of Merino data. Turner (1958) stated that the number of fibres per unit area and fibre length exhibited the greatest influence on fleece weight, with fibre cross-sectional area having a negligible effect for within-flock differences. If it is not an artifact of the statistics, the Merino-Romney difference in the contribution of fibres per unit area may indicate greater variation in this trait in Merinos.

The contributions of the components to differences in fleece weight between ewes within each flock have also been examined by using standardized partial regression coefficients of the log of fleece weight on the log of each component. Within the selected flock, fibre length was the most important contributor to differences in fleece weight. The coefficients for fibre cross-sectional area and smooth body surface area were nearly the same, both of them were higher than the number of fibres per unit area in contributing to within selected flock differences. In the control flock, fibre cross-sectional area and the number of fibres per unit area appeared to be the most important

sources of variation in fleece weight between ewes, with fibre length having little effect. The results obtained by using standardized partial regression coefficients did not agree with those obtained by using simple linear regression of the log of each component on log fleece weight (Table 10 and Table 12).

Comparison of between and within flock contributions of the components to differences in fleece weight were made in Fig 2 and Fig 3. Fibre length appeared more important for between flock differences than that within flock differences, whereas the fibre cross-sectional area seemed more important within flock than that between flocks. The number of fibres per unit area generally appeared less important within flock than that between flocks. This was especially the case when the within flock assessment was based on simple linear regression analysis. The smooth body surface area appeared to have a greater role in determining fleece weight within than between flocks.

The apparent differences in the contributions of the different components in the between flock situation compared with within flock probably arise mainly from two factors:

- (1) The between flock estimates will largely reflect genetic differences that have arisen during 30 years selection. The within flock estimates of the role of the components, in addition to genetic effects, could reflect the impact of differences in the environment that each sheep was affected by. The variation due to the environment is probably greater than that due to genetic factors.

(2) The statistical techniques used for the within flock analyses were not the same as those between flocks. The within flock techniques are less reliable and more affected by chance in the allocation of variation to different components; the results will strongly reflect the accuracy of the techniques used to measure the different components.

5.4 Conclusions

The analyses in this study indicate that selection for high fleece weight in this Romney flock increased all of the components of fleece weight.

The contribution of the components to differences in fleece weight between the selected and control flocks was analysed by using the percentage deviation technique. It was found that the mean fibre length was the most important contributor to between flock differences in fleece weight, the fibre cross-sectional area and mean number of fibres (follicles) per unit area were about equally important, but the contribution of the smooth body surface area was relatively small. Since the mean fibre length was derived from the staple length, this suggests that, in Romneys, the staple length could be a useful indirect selection criterion for increasing fleece weight.

The relative importance of the components to differences in fleece weight between ewes within each flock was estimated by using either simple linear regression or multiple regression techniques. Within each flock, the fibre cross-sectional area and smooth body surface area appeared relatively more important than that between flocks, but the mean fibre length seemed to be less important. The within flock techniques are less reliable and more affected by chance in the allocation of variation to different components; the results will strongly reflect the accuracy of techniques used to measure the different components. If the within flock results truly reflect the biological situation, they can be interpreted as reflecting a balance of environmental pathways as well as the genetic pathways. The greater importance of liveweight via its derivative surface area may indicate that environmental factors causing variation in the general thrift and sign of the sheep are the most important causes of differences in fleece weight among the sheep within a flock.

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