A RELATIONSHIP BETWEEN SULPHUR CONTENT OF WOOL AND WOOL PRODUCTION BY MERINO SHEEP

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Summary

The sulphur content of wool from 66 Peppin Merino wethers maintained together at pasture was measured in midside staples representing 49 weeks growth. The distribution of sulphur values was normal with a mean of 3·43% and a range of 3·08–3·92%. The sulphur content of the wool was inversely related to wool production among these sheep. There were no significant differences in the relationship when wool production was expressed as fleece weight index (F.W.I.), i.e. clean fleece weight/body weight ($r = -0{\cdot}48$), as clean fleece weight ($r = -0{\cdot}42$), or as wool growth per unit area of skin ($r = -0{\cdot}37$). The mean sulphur content of wool from sheep with the 10 highest values for F.W.I. was 3·27%, compared with a mean of 3·55% sulphur for wool from sheep with the 10 lowest values for F.W.I.

An inverse relationship between sulphur content of wool and wool production was also observed in two groups of Peppin Merino ewes, from flocks genetically different in wool production, during periods of grazing and controlled feeding. The mean sulphur content of wool from the high producers was 3·13% (grazing) and 3·06% (controlled feeding), whereas mean sulphur values for the low producers were 3·55% (grazing) and 3·59% (controlled feeding).

I. Introduction

The sulphur content of wool may vary considerably under controlled feeding conditions, due mainly to nutritional effects within sheep and to differences between sheep receiving the same nutrition (Reis 1965*a*). Reis and Williams (1965) also found substantial variations in the sulphur content of wool from Merino sheep at pasture, due to seasonal variations related to available feed, and to differences between sheep; the wool from low producers had a significantly higher sulphur content than that from high proudcers.

In the present study, the distribution of individual values for the sulphur content of wool was studied in a flock of Merino wethers grazed on a grassland at Deniliquin, N.S.W. The phenotypic relationship between wool production and the sulphur content of the wool grown was also investigated. In order to ascertain whether there was also a genetic relationship, the sulphur content of the wool grown by sheep from flocks selected solely for high *v.* low clean fleece weight (fleece plus and fleece minus selection flocks at Trangie, N.S.W.) was compared.

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II. Experimental

(*a*) *Sheep*

(i) *Deniliquin Group.*—Sixty-six mature Peppin Merino wethers were grazed at a stocking rate of one sheep per 3·5 acres for approximately one year, commencing in July 1964, on a *Danthonia caespitosa* Gaudich.–*Kochia ciliata* F. Muell. grassland (Williams 1961).

(ii) *Trangie, Group A.*—Twelve Peppin Merino ewes were grazed together at a stocking rate of two sheep to 3 acres on a *Stipa falcata* Hughes–*Chloris acicularis* Lindl. grassland (Biddiscombe, Cuthbertson, and Hutchings 1954), from the age of 4–14 months, commencing in December 1963. Six of these sheep were from a fleece plus selection flock and six were from a fleece minus selection flock (Dun 1958; Ahmed, Dun, and Winston 1963).

(iii) *Trangie, Group B.*—This group comprised 18 mature Peppin Merino ewes (nine from the fleece plus and nine from the fleece minus selection flocks, born August 1962). The difference in relative clean fleece weights at 18 months of age was less for these groups (138 : 100) than for the whole flock (165 : 100), as the groups were selected at random after selections were made for breeding. The sheep were treated as follows over the period January–September 1965:

(1) December 31, 1964–January 28, 1965: kept indoors in single pens; diet 800 g/day lucerne pellets.

(2) January 28–March 31, 1965: grazed together on the *Stipa–Chloris* grassland at a stocking rate of two sheep to 3 acres.

(3) March 31–September 9, 1965: kept indoors in single pens; diet 800 g/day lucerne pellets.

(*b*) *Wool Sampling*

(i) *Deniliquin Group*

(1) *Fleece Samples.*—The sheep were shorn on July 14, 1964, and again on July 2, 1965. The greasy weight of each fleece was obtained at the 1965 shearing, and a sample (*c.* 100 g) was taken from the midside for the estimation of yield of clean wool.

(2) *Tattoo Patch Samples.*—Each sheep had a tattooed patch (*c.* 10 by 10 cm) on the left midside. Wool was removed from the patches on five occasions during the year with small animal clippers (Oster size 40).

(3) *Samples for Sulphur Analysis.*—The sulphur content of the fleece was estimated by measuring the sulphur content of wool in a staple taken posterior to the midside patch 1 week prior to shearing (*c.* 49 weeks growth). The sulphur content of this staple should be representative of the whole fleece (Reis 1965*a*).

"Maximum" and "minimum" values for the sulphur content of wool grown during the year by eight selected sheep (those with the highest four and the lowest four values for sulphur content of wool) were estimated by measuring the sulphur content of: (*1*) five weeks growth of wool collected from a strip *c.* 3 cm wide around the midside patch when the wool growth rate was high (September); (*2*) approxi-

mately 10 weeks growth of wool taken posterior to the midside patch when the supply of edible forage, and hence rate of wool growth, was very low (April).

(ii) *Trangie, Group A*

Samples for Sulphur Analysis.—A staple of wool, approximately 10 months growth, was collected from the midside.

(iii) *Trangie, Group B*

(1) *Fleece Samples.*—The sheep were shorn on December 31, 1964, and again on September 9, 1965. Each fleece from the latter shearing was separated into "burry" and "burr-free" portions; these were weighed and samples (*c.* 200 g) were taken for the estimation of yield of clean wool. The clean fleece weight was calculated as the sum of the clean weights for these two portions.

(2) *Samples for Sulphur Analysis.*—Staples of wool (grown between December 31, 1964, and September 9, 1965) were collected from the right and left midside. These staples had been dye-banded (Chapman and Wheeler 1963) at the following times: January 27, April 4, July 8, and August 26. The wool between the dye-bands was cut out for sulphur analysis as follows (dyed wool was avoided): January 27–April 4 (grazing period); April 4–July 8 (period on lucerne pellets).

(*c*) *Analytical*

(i) *Wool Cleaning.*—Fleece samples were cleaned as described by Chapman (1960); clean oven-dry weight was calculated from the conditioned weight. Wool samples from the tattooed patches were cleaned as described by Reis and Williams (1965). Wool samples for sulphur analysis were cleaned by the organic solvent method of Reis and Williams (1965).

(ii) *Sulphur Analysis.*—Sulphur (expressed as percentage in clean dry wool) was determined in duplicate samples of wool by the procedure of Reis and Schinckel (1963).

(*d*) *Expression of Wool Growth*

Wool growth by the Deniliquin group was expressed in three ways:

(1) *Clean Wool Growth per Unit Area of Skin*: Mean wool growth rate (expressed as mg clean dry wool/cm^2/day) was calculated from total wool growth on the tattooed patch during the year and the patch area. The area of the patch was taken to be the mean of values obtained in three previous years (measured during November–December each year).

(2) *Clean Fleece Weight*: The weight of clean wool obtained from shearing in July 1965.

(3) *Fleece Weight Index* (*F.W.I.*): This was calculated as clean fleece weight/body weight, both weights being in kilograms. The mean of each sheep's weight at shearing in July 1964 and July 1965 (minus the fleece weight on each occasion) was used as the body weight value.

Wool growth for the Trangie sheep was expressed only as clean fleece weight.

III. Results

(*a*) *Variation in Sulphur Content of Wool from a Merino Flock*

The sulphur content of left midside staples of wool from the Deniliquin sheep, representing 49 weeks growth, ranged from 3·08 to 3·92%. Figure 1 shows the distribution of sulphur values in the flock of 66 sheep. A χ^2 test indicated that the distribution was normal, with a mean of 3·43% (S.D. ±0·17) sulphur.

Reis and Williams (1965) obtained mean yearly sulphur values of 3·22–3·84% in wool grown by 12 of the sheep from this flock in a previous year (1962–63); in 6-weekly clippings the range was increased to 2·93–3·92% sulphur, due to seasonal variations and differences between sheep. If seasonal variations in sulphur content

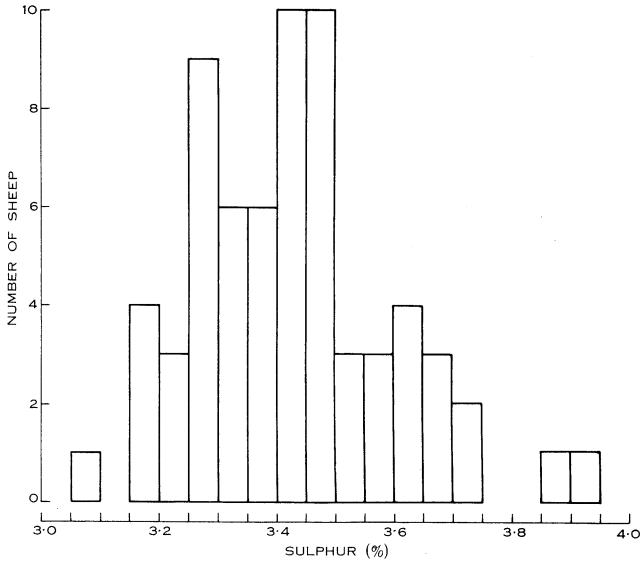

Fig. 1.—Distribution of sulphur values in wool from 66 Merino wethers maintained together at pasture. Sulphur values are percentage in clean dry wool; sulphur was measured on midside staples representing 49 weeks growth.

are taken into account in the present study, a range of values greater than 3·08–3·92% sulphur would be expected in wool grown at intervals during the year. Consequently, wool samples from the eight sheep with extreme values for sulphur content of wool [Section II(*b*)] were analysed for periods of "maximum" and "minimum" wool growth (Table 1). The range of sulphur values was widened slightly to 2·96–4·04% sulphur; also the extent of variation in sulphur was greater for those sheep with wool of low sulphur content.

(*b*) *Repeatability of Individual Differences in the Sulphur Content of Wool*

Twelve sheep (six high wool producers and six low wool producers) in the current observations at Deniliquin had been studied in a previous year, 1962–63 (Reis and Williams 1965). These earlier sulphur values and the current ones are

TABLE 1

VARIATION IN THE SULPHUR CONTENT OF WOOL FROM GRAZING MERINO SHEEP

Column 2 gives the value obtained from a midside staple of wool representing 49 weeks growth. "Maximum" and "minimum" values are for samples of wool collected in September and April respectively [see Section II(*b*)]

Sheep No.	Sulphur Content of Wool (%)		
	Whole Staple	"Minimum" Value	"Maximum" Value
627	3·08	3·00	3·38
748	3·16	3·06	3·44
754	3·17	2·96	3·54
725	3·18	2·96	3·50
517	3·71	3·56	3·94
823	3·75	3·68	3·94
614	3·87	3·87	4·02
36	3·92	3·89	4·04

TABLE 2

SULPHUR CONTENT OF WOOL FROM HIGH- AND LOW-PRODUCING SHEEP

Each value is a yearly mean for one sheep. Mean wool growth rate was determined from the total amount of wool grown on a midside patch. Sulphur values for 1962–63 are from Reis and Williams (1965), those for 1964–65 were measured on midside staples representing 49 weeks growth. All sheep were maintained on a *Danthonia* grassland except for six sheep (indicated by asterisk) that were on a *Stipa* grassland during 1962–63

Sheep No.	Sulphur Content of Wool (%)		Wool Growth (mg/cm^2/day)	
	1962–63	1964–65	1962–63	1964–65
High producers				
627*	3·22	3·08	1·40	1·19
519*	3·30	3·23	1·45	1·24
568*	3·54	3·43	1·38	1·21
714	3·39	3·23	1·47	1·42
773	3·40	3·38	1·29	1·27
621	3·51	3·48	1·27	1·29
Mean	3·39	3·30	1·38	1·27
	1962–63	1964–65	1962–63	1964–65
Low producers				
543*	3·49	3·30	1·07	0·90
770*	3·63	3·44	0·98	0·85
805*	3·67	3·57	1·05	0·96
628	3·63	3·50	0·79	0·74
641	3·68	3·49	0·78	0·72
823	3·84	3·75	0·76	0·75
Mean	3·66	3·51	0·90	0·82

compared in Table 2; the sheep were ranked in a similar order in both years, demonstrating that individual differences in the sulphur content of wool are repeatable. The sulphur values were consistently lower during 1964–65, especially for the sheep that were on the *Stipa* grassland during 1962–63. These differences presumably reflect the level of nutrition as the mean annual wool growth rate was considerably higher on the *Stipa* grassland than it was on the *Danthonia* grassland (Table 2).

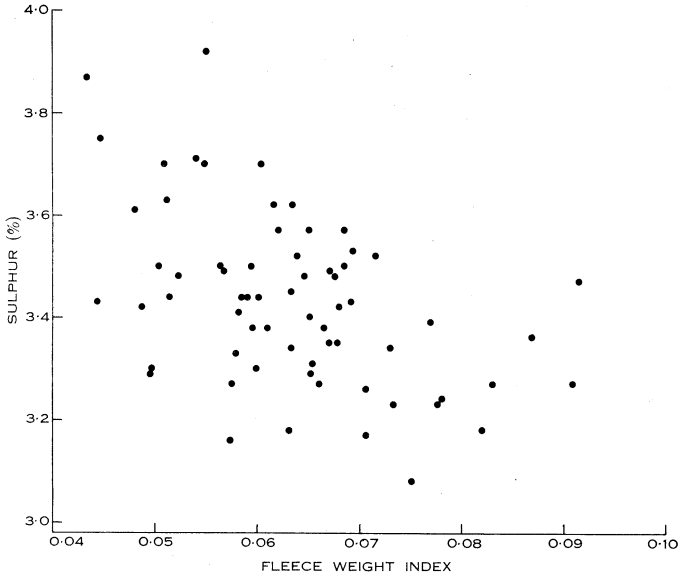

Fig. 2.—Relationship between sulphur content of wool and fleece weight index for 66 Merino wethers maintained together at pasture. Sulphur values are percentage in clean dry wool; fleece weight index is clean fleece weight/body weight. Sulphur was measured on midside staples representing 49 weeks growth.

(c) *Relationship Between Wool Growth and Sulphur Content of Wool*

(i) *In Sheep from an Unselected Merino Flock.*—Evidence on the relationship between sulphur content of wool and wool growth was obtained from the data for the 66 sheep in the Deniliquin group. Figure 2 shows the relationship between sulphur content of wool and F.W.I. Similar relationships were found between sulphur and fleece weight, and sulphur and wool per unit area of skin. Sulphur content and wool growth were negatively correlated for each expression of wool growth: F.W.I. ($r = -0\cdot48$), fleece weight ($r = -0\cdot42$), and wool per unit area ($r = -0\cdot37$). F.W.I. appears to be better correlated with sulphur content, however, as the 95% confidence limits (Dixon and Massey 1957) show that r (for F.W.I. *v.* sulphur) lies between $-0\cdot26$ and $-0\cdot65$, there is no significant difference between the three correlations.

Although these relationships between sulphur and wool growth are not close, there is a significant difference between the sulphur content of wool from sheep at the extreme ends of the range of wool growth. Thus, sheep with the 10 highest and

the 10 lowest values for F.W.I. were compared. The mean sulphur content of wool from the high producers (mean F.W.I. = 0·082) was 3·27%, compared with a mean sulphur content of 3·55% in wool from the low producers (mean F.W.I. = 0·048). With 95% confidence, the difference between the "true" means for sulphur content in wool is 0·28±0·15% sulphur. Similar differences were found when the 10 highest and 10 lowest producers, on the basis of fleece weight or wool per unit area, were compared.

(ii) *In Sheep from Two Merino Flocks Genetically Different in Wool Production.*—Table 3 shows the sulphur content of wool staples taken from 12 young Merino ewes (Trangie, group *A*) grazed together for 10 months. There are two discrete groups of sulphur values, with the low wool producers (fleece minus) having the high sulphur values. With 95% confidence, the difference between the "true" means is 0·30±0·11% sulphur. Individual values for wool growth are not available but the relative clean wool production by the fleece plus and fleece minus flocks during the above period was 181 : 100.

TABLE 3

SULPHUR CONTENT OF WOOL GROWN BY SHEEP FROM TWO FLOCKS GENETICALLY DIFFERENT IN WOOL PRODUCTION

Each value is the percentage sulphur in the wool grown by one sheep over a period of approximately 10 months. Sheep from the genetically high and genetically low wool-producing flocks are designated fleece plus and fleece minus, respectively

Flock	Sulphur Content (%)						Mean Value
Fleece plus	3·14	3·18	3·26	3·28	3·36	3·40	3·27
Fleece minus	3·45	3·55	3·58	3·58	3·60	3·66	3·57

The relationship between wool growth and sulphur content of wool was studied in a further group of 18 Merino ewes (Trangie, group *B*) during a grazing period and a controlled feeding period [see Section II(*a*)]. Again, there were two discrete groups of sulphur values, the fleece minus ewes having the high values (Fig. 3). The results were similar for the two periods, indicating that nutrition was not very different during grazing and controlled feeding. Also, there were only slight differences in the ranking of individuals for sulphur content of wool, between the two periods. Mean sulphur content of wool from the fleece plus group was 3·13% (grazing) and 3·06% (controlled feeding), whereas mean sulphur values for the fleece minus group were 3·55% (grazing) and 3·59% (controlled feeding). With 95% confidence, the differences between the "true" means for sulphur content of wool from fleece plus and fleece minus sheep were 0·42±0·13% (grazing) and 0·53±0·16% (controlled feeding).

There was some overlap in wool growth between the two genetic groups (Fig. 3), but the mean clean fleece weights for the period December 31, 1964, to September 9, 1965, were substantially different (fleece plus, 2·09 kg; fleece minus, 1·62 kg).

IV. Discussion

This study has demonstrated that the sulphur content of wool is inversely related to wool production between sheep. This relationship should be clearly distinguished from the positive relationship between sulphur content and wool growth due to effects of nutrition within sheep (Reis 1965*b*). However, as the Deniliquin flock was not on controlled feeding it is important to consider whether differences in nutrition at grazing have influenced the sulphur : wool production relationship between sheep.

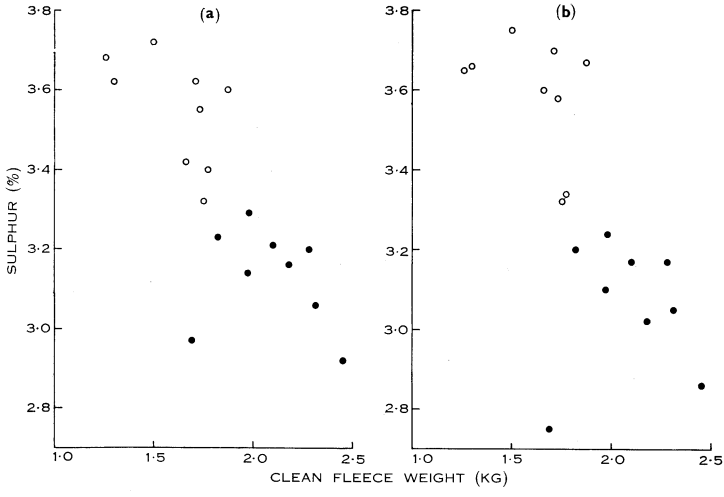

Fig. 3.—Relationship between sulphur content of wool and wool growth in sheep from two Merino flocks genetically different in wool production during a period of grazing on native pasture (*a*) and followed by a period of controlled feeding on 800 g/day lucerne pellets (*b*). Sulphur values (% in clean dry wool) are the mean of analyses of staples from the right and left midside. Clean fleece weight is the wool grown over the entire experimental period. Sheep from the fleece plus flock (●); sheep from the fleece minus flock (○).

Although there are no data on the amount and composition of the feed eaten by the Deniliquin sheep, it can be deduced that the inverse relationship between sulphur content of wool and the amount of wool grown by high and low wool producers is one between sulphur content and efficiency of conversion of feed to wool. Thus, it has been shown that high and low wool producers under grazing conditions are ranked similarly during pen-feeding and that the high-producing sheep are more efficient feed converters on restricted feeding (Dolling and Moore 1960; Williams and Winston 1965) and on *ad libitum* feeding, whether they have higher intakes (Schinckel 1960; Hutchinson 1961; Ahmed, Dun, and Winston 1963) or the same intake (Williams and Miller 1965; Williams 1966). The present authors are not aware of any data showing that low producers have intakes greater than high producers. It is reasonable to conclude, therefore, that the low producers in this study were the least efficient converters of feed to wool and that their feed intake was equal to or less than that of the high producers. The similar seasonal pattern of

body weight responses shown by high and low producers from the Deniliquin flock (Williams 1964; Reis and Williams 1965) suggests that there were no substantial differences in feed intake between these groups. Moreover, if there were any differences in feed intake between high and low producers, they would be in the direction of a higher intake by high producers, and would tend to increase the sulphur content of wool from high producers relative to that of low producers and reduce the difference between the two groups in the sulphur content of their wool.

The differences in sulphur content of wool observed between the fleece plus and fleece minus sheep during the period of controlled feeding are clearly due to inherent differences and are not confounded by any variations in feed intake. During this period the two groups of sheep did not differ significantly in body weight. Thus, the high producers under these conditions are more efficient converters of feed to wool. The similarity of the sulphur values obtained for individual sheep during the periods of grazing and controlled feeding is evidence that individual differences in intake during grazing were not great. This conclusion is supported by the results of Williams and Miller (1965) and Williams (1966), who found no difference in the voluntary feed intake of sheep from the fleece plus and fleece minus flocks. The similarity of individual sulphur values during grazing and controlled feeding also supports the conclusion that reliable estimates of individual differences in sulphur content of wool between sheep can be determined during grazing.

The data in Table 1 indicate that there may be substantial differences between sheep in the range of values over which the sulphur content of wool may vary. This supports the observation of Reis (1965*a*) that some sheep grow wool with a sulphur content that is high and less responsive to changes in nutrition.

The present results confirm the inverse relationship between sulphur content and wool growth previously observed by Reis and Williams (1965) in a small group of sheep. The existence of an inverse relationship between sulphur content and wool growth in groups of sheep genetically different in wool production suggests that sulphur content is also genetically determined. Consequently, the phenotypic relationship between sulphur content and wool growth in the unselected flock is most probably also genetic in origin. Piper and Dolling (1966) have also observed an inverse relationship between sulphur content and wool growth in two genetically different groups of sheep selected for high *v.* low clean fleece weight.

In a group of sheep a considerable range of values for the sulphur content of wool is encountered. Some of these differences between sheep are the result of an inverse relationship between wool growth and sulphur content of wool. Possible explanations for this inverse relationship have been discussed by Reis and Williams (1965) and Gillespie and Reis (1966), who suggested that this relationship may be related to the balance between supply of substrate to the follicles and the rate of synthesis of wool proteins. It is apparent that there may be considerable differences in the sulphur content of wool from sheep growing wool at similar rates under the same conditions, even if the sheep are from groups genetically different in wool production. It is suggested that the factors controlling wool protein synthesis and the ability to reduce the sulphur content of wool to a low level are fairly closely linked, but this ability is not a prerequisite for high wool growth rates. Nevertheless,

the ability to reduce the sulphur content of wool substantially during periods of inadequate nutrition would appear to be advantageous for sustaining wool growth.

A consequence of the inverse relationship between sulphur content and wool growth is that selection for high clean wool production in a flock would tend to lower the sulphur content of the wool. The extent of this lowering would depend on the level of nutrition during the period of comparison with unselected sheep. It is obviously important to know whether this change in chemical composition of wool has any effects (either desirable or adverse) on the physical properties of individual fibres and on the textile properties of the fleece.

V. Acknowledgments

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