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ESTIMATION OF CLEAN-FLEECE WEIGHT FROM GREASE-FLEECE WEIGHT AND STAPLE LENGTH [1]

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INTRODUCTION

Clean-fleece weight is the most important measure of fleece value in breeding for improvement of sheep. This is particularly true within breeds when variations in grade and quality of wool are not great. Although most wool in the United States is sold on a grease-wool basis, the price is usually determined by the buyer's estimation of the amount of clean wool present. If this estimation is accurate, weight of clean wool is one of the most important factors affecting the income from wool.

The amount of clean wool per fleece can be determined exactly by scouring the entire fleece or approximately by scouring a representative sample of each fleece. However, even the latter practice requires much routine work when large numbers are involved, and adequate equipment and personnel are seldom available to carry on this routine continuously. This condition has prompted the search for methods that would make it possible to estimate clean-fleece weight from other fleece characters with a high degree of accuracy.

Correlations between various fleece characters of range Rambouillet sheep have been studied by Spencer and coworkers (*7, p. 45*).[2] They concluded:

> The scoured-fleece weights became greater as the weights became greater in the unscoured fleeces, and in the moisture, grease, and dirt per fleece. The length of staple was generally longer, the fineness a trifle less, and the character and density of the fleeces slightly more excellent as the yields of clean wool per fleece increased.

These writers showed that the weight of unscoured (grease) wool was the best factor for indicating the weight of scoured (clean) wool per fleece. Pohle and Keller (*4*), working with range Rambouillet, Targhee, Columbia, and Corriedale yearling ewes, found that with each centimeter (three-eighths inch) of increase in staple length there was an increase of about one-fourth to one-half pound, or almost 1 to 2.5 percent, of clean wool. Length of staple had a greater influence on clean-fleece weight than did body weight.

Lambert and coworkers (*2*) showed that fleece length in weanlings had some predictive value for estimating clean-fleece weight in yearlings in the Corriedale, Columbia, and Rambouillet breeds. Pohle (*3*) found in the same breeds that length of staple and percentage of clean wool in weanlings had a high relationship with these same characters in yearlings.

[1] Received for publication July 8, 1943.
[2] Italic numbers in parentheses refer to Literature Cited, p. 10.

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Previous work [3] with 186 Rambouillet ewes showed that fleece length and body weight at weanling or yearling ages were reliable in estimating clean-fleece weight in yearlings. The multiple correlation coefficients were 0.71 and 0.68 for weanling and yearling characters, respectively. Fleece length was more important than body weight in estimating clean-fleece weight, particularly in yearlings. The correlation coefficients of grease-fleece weight, fleece length, and body weight with clean-fleece weight were 0.69, 0.63, and 0.37, respectively, in yearlings. The multiple correlation coefficient between clean-fleece weight and the three variables was 0.786, as compared with 0.783 when body weight was omitted. Therefore, in yearlings, body weight did not add to the ability to estimate clean-fleece weight, probably owing to a fairly high relationship between body weight and grease-fleece weight. Other measures, such as fleece-character score, density score, density index, and fleece fineness at the side and thigh, had such low relationships with clean-fleece weight that they could have little value in its estimation.

The objects of this study, which involved several years' data from fairly large numbers of sheep of four breeds, were: (1) To develop multiple regression equations for the estimation of clean-fleece weight from grease-fleece weight and staple length; (2) to test the reliability of these equations; (3) to present a nomograph for the rapid estimation of clean-fleece weight; and (4) to develop formulas for annual corrections for variations in grease-fleece weight, staple length, and clean-wool yield. The work was conducted at the Western Sheep Breeding Laboratory and United States Sheep Experiment Station, Dubois, Idaho

MATERIAL AND METHODS

Data on grease-fleece weight, staple length, and clean-fleece weight from 1,037 Rambouillet, 253 Targhee, 214 Corriedale, and 211 Columbia yearling ewes were taken during the 3-year period from 1939 to 1941. These were fairly normal years with respect to clean-wool yield or shrinkage. In 1941 there were two groups of Rambouillet yearlings. Group A consisted of inbreds and group B of outbreds. The former animals were born a month earlier and were managed somewhat differently than the latter. The data for the two groups, therefore, are presented separately.

Just prior to shearing, staple length was measured near the middle of the side of each ewe to the nearest 0.2 cm., the average of three measurements by different judges being used as the actual length. Grease-fleece weight was taken on the shearing floor to the nearest 0.05 pound. Clean-wool yields, in terms of percentage, were determined by scouring a small sample of wool from each ewe. The small sample, weighing 25 to 35 gm., was obtained with the use of an electric clipper from an area about 11 cm. long and 5 cm. wide near the middle of the side. The samples were immediately placed in individual moisture-proof containers, being scoured later as described by Hardy (*1*) to obtain the bone-dry clean-wool yields. The term "bone-dry" refers to wool from which practically all the moisture had been eliminated by drying in a conditioning oven at 212° F. for a period of 6 hours. The clean-wool yield of the whole fleece was calculated from that of the small sample by the method described by Schott and coworkers (*5*).

[3] TERRILL, CLAIR E. Unpublished data.

The clean-fleece weight was then obtained by multiplying the grease-fleece weight by the calculated clean-wool yield of the whole fleece. Grease-fleece weights, staple lengths, and clean-fleece weights were taken at about 400 days' growth and were adjusted to 365 days' growth

$$\left(\text{adjusted measurement} = \frac{\text{actual measurement}}{\text{actual days growth}} 365\right)$$

to minimize age differences.

Clean-fleece weights were also obtained from scoured whole fleeces of 85 Rambouillet, 46 Targhee, 55 Corriedale, and 55 Columbia yearling ewes. These fleeces were sent to the Agricultural Marketing Administration of the United States Department of Agriculture where they were scoured by the method described by Buck.[4]

DATA AND DISCUSSION

The general relationships among grease-fleece weight, staple length, and clean-fleece weight by breeds and years are shown by the averages, correlation coefficients, and standard partial regression coefficients in table 1. Correlations were highest between grease-fleece weight and clean-fleece weight and were lowest between grease-fleece weight and staple length. In every case grease-fleece weight was more important than staple length for the estimation of clean-fleece weight. However, staple length became progressively more important in the breeds with shorter staple and finer grades of wool.

TABLE 1.—*Average grease-fleece weight, staple length, and clean-fleece weight with correlation and standard partial regression coefficients for 4 breeds of sheep during a 3-year period*

Breed	Year data were taken	Sheep	Averages [1]			Correlation coefficients			Standard partial regression coefficients	
			Grease-fleece weight (X_1)	Staple length (X_2)	Clean-fleece weight (Y)[2]	r_{Y1}	r_{Y2}	r_{12}	$\beta_{Y1.2}$	$\beta_{Y2.1}$
		Number	*Pounds*	*Centimeters*	*Pounds*					
Rambouillet [3]	1939	195	8.29	5.65	2.77	0.78	0.57	0.40	0.65	0.31
	1940	272	9.11	5.68	3.09	.74	.67	.52	.53	.39
	1941A	308	9.33	5.95	3.42	.74	.63	.34	.59	.44
	1941B	262	8.96	5.67	3.26	.69	.62	.37	.54	.42
Average		1,037	8.98	5.75	3.17	.73	.63	.41	.57	.40
Targhee	1939	74	9.64	6.80	3.40	.73	.63	.41	.57	.39
	1940	91	10.33	7.34	4.07	.81	.62	.36	.67	.37
	1941	88	9.59	7.61	3.77	.79	.64	.45	.62	.36
Average		253	9.87	7.29	3.77	.78	.63	.41	.63	.37
Corriedale	1939	64	9.50	8.47	3.66	.72	.72	.46	.50	.49
	1940	72	9.38	8.36	3.83	.81	.61	.59	.69	.20
	1941	78	9.50	8.97	4.05	.83	.59	.35	.71	.35
Average		214	9.46	8.61	3.86	.79	.63	.46	.64	.34
Columbia	1939	61	9.86	7.89	3.78	.78	.59	.38	.65	.35
	1940	88	10.81	8.24	4.55	.77	.52	.30	.68	.32
	1941	62	10.61	8.59	4.27	.84	.59	.46	.72	.26
Average		211	10.47	8.24	4.24	.79	.56	.38	.68	.30

[1] All grease-fleece weights, staple lengths, and clean-fleece weights are for 365 days' growth.
[2] Clean-fleece weights are based on bone-dry yields.
[3] The two 1941 Rambouillet groups were kept separate because group A was inbred, born a month earlier, and managed somewhat differently than group B.

[4] BUCK, W. M. PROGRESS IN WOOL SHRINKAGE RESEARCH DURING YEAR 1939. U. S. Dept. Agr., Agr. Market. Serv. 32 pp. [Processed.] 1940.

Multiple regression and correlation coefficients for estimating clean-fleece weight from grease-fleece weight and staple length are given in table 2. The similarity of the multiple correlation coefficients, their range being from 0.80 to 0.89, indicates that the ability to estimate clean-fleece weight from the two factors did not vary much from year to year or from breed to breed.

TABLE 2.—*Multiple regression and correlation coefficients for estimating clean-fleece weight (Y) from grease-fleece weight (X_1) and staple length (X_2)*

Breed	Year data were taken	Regression coefficients			Correlation coefficient
		a	$b_{Y1\cdot2}$	$b_{Y2\cdot1}$	R
Rambouillet [1]	1939	−0.88	0.2644	0.2585	0.83
	1940	−.83	.2240	.3315	.81
	1941A	−1.14	.2519	.3712	.84
	1941B	−1.76	.2865	.4315	.80
Average within years		−1.10	.2513	.3500	.81
Targhee	1939	−1.78	.2792	.3665	.82
	1940	−1.74	.3391	.3124	.88
	1941	−1.42	.2934	.3118	.85
Average within years		−1.62	.3075	.3226	.85
Corriedale	1939	−1.98	.2573	.3770	.84
	1940	−.09	.2968	.1360	.83
	1941	−1.03	.3198	.2273	.89
Average within years		−.92	.2923	.2344	.85
Columbia	1939	−1.12	.2871	.2623	.84
	1940	−1.57	.3687	.2585	.83
	1941	−1.32	.3571	.2100	.87
Average within years		−1.35	.3420	.2442	.84

[1] The two 1941 Rambouillet groups were kept separate because group A was inbred, born a month earlier and managed somewhat differently than group B.

The significance of differences between the means of the characters studied was tested by analysis of variance, as shown in table 3. Breed differences were highly significant in each case, whereas yearly differences were not significant. The highly significant breeds-×-years interaction indicates that the breeds react differently to yearly environmental changes. The means for the two 1941 Rambouillet groups differed significantly in all three characters.

TABLE 3.—*Analysis of variance for grease-fleece weight, staple length, and clean-fleece weight*

Source of variance	Degrees of freedom	Grease-fleece weight		Staple length		Clean-fleece weight	
		Mean square	F [1]	Mean square	F [1]	Mean square	F [1]
Total	1,714	2.38		2.00		0.64	
Breeds [2]	3	158.91	11.49**	766.17	97.85**	91.96	10.69**
Years [2]	2	48.86	3.53	8.95	1.14	21.51	2.50
Breeds × years	6	13.83	6.92**	7.83	12.63**	8.60	20.00**
Rambouillet groups	1	17.57	8.79**	11.18	18.03**	3.59	8.35**
Error	1,702	2.00		.62		.43	

[1] ** $P<0.01$, highly significant.
[2] Mean squares tested with the breeds-×-years interaction.

Tests for significant differences of the *a* values are presented in table 4. These consist in comparing clean-fleece weights adjusted for average breed, yearly, or interaction variations in grease-fleece weight and staple length. The *a* values were significantly different for breeds, years, and breeds-×-years interaction. Consequently, the *a* values in the multiple regression equation should be determined for each breed each year. The procedure for determining the *a* values is given later in this article in the application of results. The difference in average grease-fleece weight and staple length between the two 1941 Rambouillet groups accounted for practically all the difference in clean-fleece weight; hence, this test is not given in table 4.

TABLE 4.—*Tests for significant differences of a values*

Source of variance	Degrees of freedom	Sum of squares for clean-fleece weight (Sy^2)	R^2	Errors of estimate			
				Degrees of freedom	$Sy^2-R^2Sy^2$	Mean square	F [1]
Error	1,702	728.95	0.68264	1,700	231.34	0.1361	
Error+breeds	1,705	1,004.82	.76242	1,703	238.73		
Breeds				3	7.39	2.46	18.07**
Error+years	1,704	771.97	.67516	1,702	250.77		
Years				2	19.43	9.72	71.42**
Error+(breeds×years)	1,708	780.57	.69534	1,706	237.81		
Breeds×years				6	6.47	1.08	7.94**

[1] **P<0.01, highly significant.

Differences in the multiple regression coefficients were tested by an extension of the method given by Snedecor (*6*), as shown in table 5. Since the individual regressions for the two Rambouillet groups in 1941 were not significantly different, the average regressions ($b_{Y1\cdot2}$ and $b_{Y2\cdot1}$) were used for that year. The reduction in Sy^2 due to the average regression on grease-fleece weight or on staple length is shown in table 5. The additional reduction due to the four breed regressions was highly significant for both grease-weight and staple length, indicating that different regression coefficients should be used for each breed. Differences in yearly regressions were nearly significant, and those for the individual regressions for each breed each year were significant or highly significant. Breed differences in the regression coefficients were greater than yearly differences, but the breed regressions did not always occur in the same order. To estimate clean-fleece weight in succeeding years, it will be necessary to use the same regression coefficients each year. The above data indicate that these were not strictly homogeneous for the 3 years studied. However, the loss of information due to yearly variation in the actual regression coefficients is not likely to be large. In these data, errors of estimate of clean-fleece weight with the use of the average regression coefficients for each breed each year were 98.7 percent as large as the error of estimate with the use of the average regressions for each breed. Thus, the use of the four breed regression coefficients from year to year provides about 98.7 percent as much information as the calculation of new regression coefficients for each year. Likewise, the use of the average regression coefficients for all breeds and years provides about 97 percent as much information as the calculation of new regression coefficients for each breed each year. It seems worth while to use different regression coefficients for each breed, as no additional work is required to estimate clean-fleece weights.

TABLE 5.—*Test of regression coefficients by years and breeds*

Source of variance	Degrees of freedom	X_1 with X_2 fixed			X_2 with X_1 fixed		
		Sum of squares	Mean square	F[1]	Sum of squares	Mean square	F[1]
Error	1,702	728.95			728.95		
Reduction due to other variable	12	279.94			420.94		
Deviation from other variable	1,690	449.01			308.01		
Reduction due to average regression	1	222.52			80.92		
Additional reduction due to yearly regressions	2	.71	0.355	2.69	.79	0.395	2.99
Additional reduction due to breed regressions	3	1.67	.557	4.22**	1.54	.513	3.89**
Additional reduction due to individual regressions	6	2.14	.357	2.70*	2.79	.465	3.52**
Errors of estimate	1,678	221.97	.132		221.97	.132	

[1] ** $P<0.01$, highly significant; *$P<0.05$, significant.

A practical test was made of the average within-year regression equations for each breed for estimating clean-fleece weight. Both small samples and whole fleeces of 241 yearling ewes were scoured, so that clean-fleece weight could be calculated in three ways for each breed: (1) By scouring the whole fleece (W); (2) by scouring a small sample (S); (3) by estimating from the within-year regression equations with grease-fleece weight and staple length as independent variables and S as the dependent variable (E).

The correlation coefficients between these variables are shown by breeds in table 6. Each of the multiple regression coefficients was calculated so the correlation between the dependent variable (S) and the estimated value (E) is a maximum. In all four breeds, values for r_{WE} were larger than those for r_{SE}, although the latter are similar to the multiple correlations given in table 2. This would be expected if the small samples were subject to unbiased errors, which would make S higher than the corresponding W in some cases and lower in others. The predictive value of grease-fleece weight and staple length for estimating clean-fleece weight, therefore, is higher than indicated by the multiple correlation coefficients involving these two factors and clean-fleece weight as determined from small samples.

TABLE 6.—*Correlation coefficients by breeds between clean-fleece weight, calculated by scouring the whole fleece (W), scouring a small sample (S), and estimating from grease-fleece weight and staple length (E)*

Breed	Fleeces	r_{WE}	r_{WS}	r_{SE}
	Number			
Rambouillet	85	0.86	0.89	0.80
Targhee	46	.89	.84	.82
Corriedale	55	.87	.91	.80
Columbia	55	.86	.94	.82
Average		.87	.90	.81

In table 6 the average for r_{WE} was only slightly less than for r_{WS}, indicating that clean-fleece weight can be estimated almost as accurately from grease-fleece weight and staple length as from scouring a small sample.

APPLICATION OF RESULTS

The average within-year regression equations, obtained by the use of the average regression coefficients for each breed given in table 2, were used in constructing the nomograph presented in figure 1. Thus

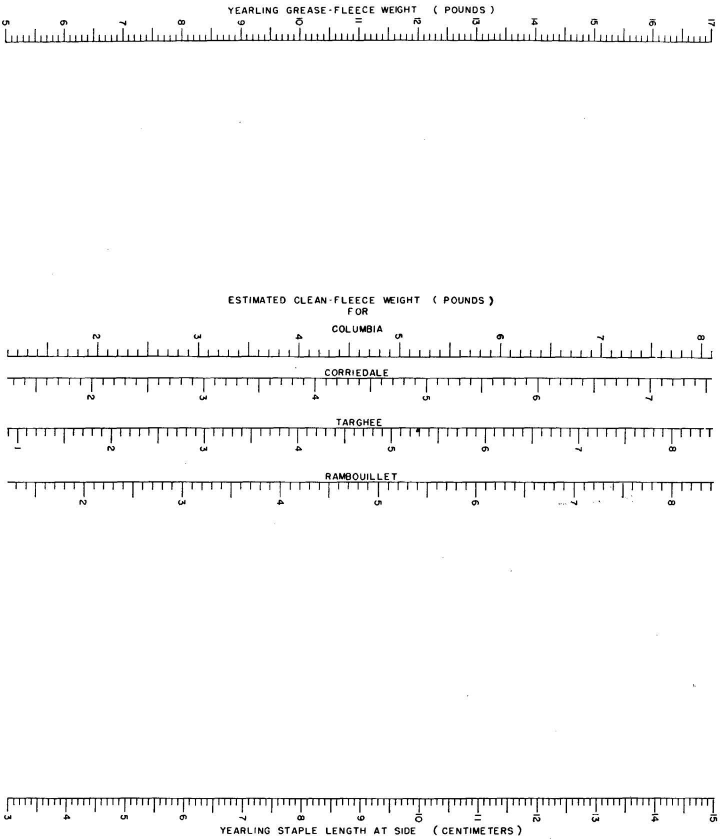

FIGURE 1.—A nomograph for the estimation of bone-dry clean-fleece weight from grease-fleece weight and staple length in four breeds of sheep. (Conversion may be made to an approximate commercial moisture basis by dividing the bone-dry weights by 0.88.)

by laying a ruler across the nomograph from a given grease-fleece weight on the left-hand scale to a given staple length on the right-hand scale, the estimated clean-fleece weight may be read directly from the middle scale for the respective breeds.

These clean-fleece weights will be adequate for use in a breeding program in which it is sufficient to rank individuals on clean-fleece weight each year. There will be yearly variations, however, in grease, dirt, moisture, and other foreign material that cannot be measured by a regression equation developed in previous years. Presumably variations of this kind were responsible for the significantly different *a* values as shown in table 4. In order to estimate clean-fleece weights that will be comparable from year to year and that will approach the actual clean-fleece weights, it will be necessary to obtain the average percentage clean yields for each year. If small samples are scoured, percentage clean yield of whole fleeces (X) can be predicted from percentage clean yield of small samples (Y) by the simple regression equation $\frac{Y-a_{y\cdot x}}{b_{y\cdot x}}=X$, as shown by Schott and coworkers (*5*). With the same breeds used in this study, they found that $b_{y\cdot x}=1.08$ could be used for each of the four breeds. The values of $a_{y\cdot x}$ were -2.86, -1.62, -0.84, and 0.73 percent for Rambouillets, Targhees, Corriedales, and Columbias, respectively, for small side samples. Then the average clean weight of a group of whole fleeces can be obtained by multiplying the estimated percentage clean yield of the whole fleeces ($\bar{X}$) by the average grease-fleece weight ($\bar{G}$).

Annual variations in average clean-fleece weight, grease-fleece weight, and staple length can be expressed as deviations from the *a* values used in the multiple regression equations so that annual corrections for the *a* values may be applied directly to the estimated clean-fleece weights obtained with the nomograph. Only one correction will need to be calculated for each breed each year. These corrections for the *a* values are as follows:

Rambouillet $\left(\frac{\bar{Y}+0.0286}{1.08}\right)\bar{G}-0.2513\bar{G}-0.3500\bar{L}+1.10$

Targhee $\left(\frac{\bar{Y}+0.0062}{1.08}\right)\bar{G}-0.3075\bar{G}-0.3226\bar{L}+1.62$

Corriedale $\left(\frac{\bar{Y}+0.0084}{1.08}\right)\bar{G}-0.2923\bar{G}-0.2344\bar{L}+0.92$

Columbia $\left(\frac{\bar{Y}-0.0073}{1.08}\right)\bar{G}-0.3420\bar{G}-0.2442\bar{L}+1.35$

where $\bar{Y}$=average clean-wool yield from small side sample of a representative group of ewes, $\bar{G}$=average grease-fleece weight for current year, and $\bar{L}$=average staple length for current year.

For example, the correction for the *a* value for Corriedale yearling ewes in 1942 can be determined from the average clean-wool yield of 53.05 percent determined from small samples, the average grease-fleece weight of 7.9 pounds, and the average staple length of 10.1 cm. Thus the correction for the *a* value $=\left(\frac{0.5305+0.0084}{1.08}\right)(7.9)-0.2923(7.9)-0.2344(10.1)+0.92=0.2$. Therefore, 0.2 pound should be added to the clean-fleece weight estimated from the nomograph for each Corriedale yearling ewe in 1942. A Corriedale yearling ewe in 1942 with a grease-fleece weight of 9.8 pounds and a staple length of 10.4 cm. would have an estimated clean-fleece weight of 4.4 pounds as determined from the nomograph. The corrected clean-fleece weight would be 4.6 pounds. All estimated clean-fleece weights would be for 365 days' growth since grease-fleece weight and staple length should first be adjusted to this basis. The clean-fleece weights obtained may be converted from bone-dry weights to a commercial moisture basis by dividing by 0.88.

The number of ewes from each breed that would need to be sampled for clean-fleece yield each year can be estimated from data presented by Schott and coworkers (*5*). If entire fleeces were scoured, a reasonable degree of accuracy could be obtained by scouring fleeces from 19 ewes selected at random for each breed. The standard error for the mean whole-fleece yield would then be

$$0.0075\left\{=\sqrt{\frac{\sigma x^2}{n}}=\sqrt{\frac{10.709}{19}}=0.75 \text{ percent}\right\}.$$

The same degree of accuracy could be obtained by scouring a representative small sample from each of 30 ewes

$$\left\{\sqrt{\frac{\sigma y^2}{(b_{y.x})^2(n)}}=\sqrt{\frac{19.449}{(1.1664)(30)}}=0.75 \text{ percent}\right\}.$$

It should be remembered that the regression equations presented in this paper apply only where conditions are similar to those near Dubois, Idaho. Marked differences in climatic conditions, plane of nutrition, or other environmental factors may require different *a* and *b* values for the regression equations. Although the method outlined is general, the specific application of these equations can be tested only by developing similar equations for flocks in widely separated regions. Wool laboratories maintained in most of the important sheep-producing States can perform valuable service in this respect, thereby placing the selection of improved breeding stock and the marketing of grease wool on a more reliable basis than is possible where individual clean-fleece weights and average percentage clean yield are not known.

SUMMARY

Multiple regression equations of clean-fleece weight, as determined from small samples, on grease-fleece weight and length of staple (taken from middle of side) were calculated on 1,037 Rambouillet, 253 Targhee, 214 Corriedale, and 211 Columbia yearling ewes during the 3-year period from 1939 to 1941. Multiple correlation coefficients for these four breeds were 0.81, 0.85, 0.85, and 0.84, respectively.

Grease-fleece weight was more important than staple length for the estimation of clean-fleece weight. However, staple length became progressively more important in the breeds with shorter staple and finer grades of wool.

Analysis of variance was used to test for differences between means, *a* values, and the multiple regression coefficients. Breed differences were highly significant, but yearly differences were not significant for the means for each of the three characters. The *a* values were significantly different for breeds, years, and breeds×years, indicating that the *a* values should be determined for each breed each year. Significant differences were found in the regression coefficients for breeds but not for years.

The multiple regression equations were tested on data from 241 of the yearling ewes for which whole fleeces had been scoured. The within-year regression equations for each breed appeared to be somewhat more accurate than indicated by the multiple correlation coefficients for the larger group of data for which clean-fleece weights were calculated by scouring small side samples. The accuracy of grease-fleece weight and staple length for predicting clean-fleece weight was slightly less than that obtained by scouring a small sample.

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A nomograph is presented for the rapid estimation of clean-fleece weight. Formulas are given for making annual corrections in the *a* values. These formulas account for annual variations in grease-fleece weight, staple length, and clean-wool yield as determined by scouring samples from a small group of ewes from each breed.

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