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An Evaluation of Wool Density Sampling Procedures When Using the Wira Fleece Caliper

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AN EVALUATION OF WOOL DENSITY SAMPLING PROCEDURES WHEN USING THE WIRA FLEECE CALIPER

by

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Doyle J. Matthews

TABLE OF CONTENTS

FIGURES AND TABLES

INTRODUCTION

Purpose

Wool is still the most valuable and the most versatile fiber used by man. Many questions regarding its production have gone unanswered for centuries. This problem is undertaken in the hope of contributing information which might be used in further study on the problem of wool density.

It is recognized that wool density is one of the four major factors affecting the total clean wool production of a sheep. If length of staple, diameter of fiber, and total surface area remain constant, an increase in density brings about a corresponding increase in total production of clean wool.

Wool fibers are produced by glands, called fiber follicles, beneath the surface of the skin. Density is controlled by the number of these follicles functioning within a given area.

Before great improvement in density can be made, it is necessary to know the mode of inheritance, it is necessary to know the density of each individual involved. Counting the fibers from any sizeable area is not practicable. Therefore, a technique is necessary for sampling the sheep and estimating the density on the basis of sampling figures.

Scope

The Wira Fleece Caliper is probably the most popular instrument used in sampling for density.

To determine the most effective method of using the Wira Caliper, different-sized samples are taken from a given area. Both sides of each sheep are tested, and sheep from different breeds are sampled. Density on all samples is determined by a standard laboratory procedure. The results are statistically analyzed to determine the variation in density as obtained by the different sample sizes.

In addition to the main objective, the variation in density between breeds, between sheep of the same breed, and the variation in density between sides on the same sheep is determined.

REVIEW OF LITERATURE

Definition of Density

In order to recognize the various advantages of the several different methods of determining the fleece density, it is necessary to define the term "density" as accurately as possible. Probably one of the greatest difficulties in the search for a universal method of density analysis is the diversity of opinion regarding the definition of the term itself.

Bosman (1934) suggests that "the term density is used by the practical sheep judge to denote compactness in the fleece," and cites Rose (1930), who refers to density as "the close proximity of fiber growth on a given surface of skin;" also Duerden and Botha, who suggest "the volume of wool material of a certain length or the weight of wool material growing on a certain skin area." Burns and Miller (1931) define density as "the total amount of wool fibers growing on a definite unit area of skin, usually on the living animal." Bell, Spencer, and Hardy (1936), Burns (1937) and others usually refer to density as "the number of fibers per unit area of skin surface." Bosman (1934) compromises that most workers are agreed that the number of fibers growing per unit area of skin is the basis of density. However, he contends that number of fibers alone does not express density completely, and cites his own work in connection with his theory that density should also consider fiber diameter and be expressed in terms of percentage of skin surface area actually occupied by fiber. Many others, including Horlacher (1927), Cowley (1936), Hill (1931), Hultz and Paschel

(1930) and Nichols (1932) have offered definitions of density, each of which agrees with one or another of the foregoing.

Perhaps one of the reasons that no absolute definition has been arrived upon is that, according to Burns (1937), many methods exist by which one can express density, and no one method has proved outstanding. The three most successful are:

1. The number of fibers per unit area of skin.
2. The weight of clean wool per unit of skin.
3. The ratio of fiber cross-sectional-area to the unit area of skin.

Burns concludes that regardless of which definition one adopts or which method of expression one accepts, "the ultimate use of fleece density is in measuring the amount of clean wool that a sheep will produce."

Influence on Wool Production

Lush and Jones (1923) found that the weight of the fleece is controlled by three kinds of influence:

1. Permanent individual difference between sheep (called individuality).
2. Environmental influences which affect some sheep but not others (such as sickness, lambing, etc.).
3. Environmental forces which affect all sheep alike (such as age, drouth, etc.).

Differences due to individuality may be due to any one or all of the following:

1. Size of the sheep.
2. Length of staple.
3. Density.

4. Fineness or diameter of fiber.

Because estimation of density is so important in selection, accurate methods of evaluating individuals are necessary. Actual count of an area of any practical size is entirely unfeasible; therefore, an estimate derived from a sample is the only logical process.

Methods of Sampling the Fleece

Probably the most common means of estimating density is to grasp a handful of wool and, from the compactness and dense feel, estimate the density. While well qualified men may estimate accurately between breeds or within wide limits, Hardy, Spencer and Bell (1936) showed that this method is "grossly inaccurate" and usually selecting by this method actually selects for yolk, suint, dirt and lack of resiliency.

Burns (1934) reports that Nathusius (1866) was among the first to study fleece density. He used a skin-section method but had such trouble focusing his microscope that he regarded his results as inaccurate.

Cutting (1883) actually cut an area from the fresh pelt of a sheep and counted the fibers.

Burns and Miller (1931) report that since 1892 investigators have been attempting to develop instruments for use in density determinations.

Mentzel (1892) was probably the first to describe such an instrument. He described a modified caliper which when thrust into the fleece, measured a certain area, then compressed the fibers into a compact mass and measured the cross-sectional area. It had the disadvantage of measuring an unknown amount of space between the fibers.

Burns (1925) described the use of a pair of engineers' outside measuring calipers for separating a one-half inch square area from the other wool fibers.

Nordby's Idaho Wool Caliper (1928) consisted of one caliper mounted on another with the jaws crossing at right angles.

Duerdon (1929) described a forked caliper with cross pins passing at right angles through the jaws, thus delimiting a predetermined area.

The Wyedena Fleece Caliper method. The Wyedena Fleece Caliper, developed by the combined efforts of the Wyoming, Edinburg, and South Africa laboratories, was just an improvement of Duerdon's caliper and operated on the same principle.

The Wyedesa Fleece Caliper method. The Wyedesa Caliper is just an improvement of the Wyedena. The jaws operate at different widths and lock the sample firmly while it is being cut away from the skin and having excess fibers peeled away.

The Wira Fleece Caliper method. Wildman (1936) introduced the Wira Fleece Caliper. It is essentially a Wyedesa Caliper with a few mechanical improvements consisting of reshaped handles to increase the ease with which it can be inserted into the wool, and a knurled screw that holds the jaws at a constant width during sampling.

Hardy's method. Hardy (1934) outlines a simpler method. Using an electric clipper, he cut a swath 1 to 2 inches wide and 4 to 5 inches long. The total area can be calculated from measurements. By very simple proportions between weight and number, the approximate number of fibers per square unit area can be calculated.

The Triangular method. Burns and Miller (1931) describe a triangular method of density determination. By inserting a needle or porcupine quill in the fleece and placing it parallel with the skin, then forming an equilateral triangle by a similar action with two other quills, a definite triangular area can be delineated.

Photographic method. A photographic method, developed by Nichols (1930), is described by Burns and Miller (1931). The wool is clipped from an area approximately square. An object, such as a postage stamp, whose dimensions are accurately known, is placed in the center of the clipped area and photographed. The skin area can easily be calculated by simple proportional measurements.

Histological method. Carter (1939) outlines an histological method of density determination. It consists of removing small sections of skin from the body, pinning them to a solder block to avoid shrinkage, fixing and embedding in paraffin, sectioning under the microtome, and mounting on slides. By using a microscope with a special adaptation for delimiting an area exactly one square millimeter, the exact follicle population can be counted.

Comparing Wira Caliper with the Hardy method.

Most density sampling recently has been done with either calipers of the Wira type or the Hardy electric clipper method. Although Carter's method is basically sound, much work needs to be done to test its feasibility and accuracy. Shrinkage while fixing and while under the microtome would be a large component of the experimental error.

Madsen (1941), and Hardy and Wolf (1946) have published studies comparing the Wira type caliper with Hardy's electric clipper method. Madsen states that:

> the Wira method was more consistent when used on different areas of the sheep, and results by two observers agreed more closely than when the electric clipper method was used. Also wrinkling of the skin seemed lesslikely to distort estimates of density obtained by the Wira method.

Attesting to this conclusion, Hardy and Wolf state that the clipper works three times as fast, but requires twice as many samples for the same accuracy. Their estimation for the correlation coefficient between the two methods was 0.78.

Accuracy estimates on Wira Caliper and Hardy Method.

Christensen (1940), in his thesis evaluating the Wira Caliper, estimates it to be accurate within about 600 fibers per square centimeter.

Henrie (1940), in his thesis on density determination, refers to the Hardy Clipper method as not being able to measure differences of less than 5,262 fibers per square inch between sheep.

Methods of density analysis

Counting and weighing method. After proper scouring and conditioning, there are three major methods of determining density from the sample obtained from the sheep. The most direct is the counting, weighing method. A pre-determined number of fibers, usually about 100, is counted, then weighed. The total sample is also weighed. By the simple proportion WT:w100::N:100, where WT = total sample weight, w100 = weight of the 100 fibers, N = number of fibers in the total sample.

This is probably the most accurate method used today. It decreases the experimental error by removing estimation of diameter and length means. However, it does have the tedious task of counting the fibers.

The weight-volume method. A method termed by Bosman (1934) as the "weight, volume method," was compared by him to the counting weighing method and claimed to be faster and almost as accurate. The formula he used to calculate the number of fibers was $N = \frac{W}{(S)(A)(L)}$ in which W = total weight of sample, N = number of fibers, S = specific gravity, A = mean fiber thickness, and L = the mean straight length. This method has the advantage of removing the tedious counting of fibers, but an error in estimating the mean thickness or length, could greatly confound the results.

The cross-sectional-area method. The last major method of density determination from the sample is the cross-sectional-area method. After collecting the sample, calculating the sampled area, scouring and conditioning, the sample is placed in a notch under enough pressure to cause adjacent packing of the fibers. The area occupied by the cross-section ends of the fibers is then calculated. Knowing the mean diameter of the fibers by determination on a sample, the number of fibers can be calculated.

This method also removes the laborious counting. However, the error in estimating the mean diameter is still there. Also, the elliptical shape of the fibers themselves would indicate that perfect adjacent packing would be almost impossible and therefore bias the estimate.

Methods of Obtaining Representative Sub-samples.

Accurate methods of obtaining a representative portion of the sample upon which to base the calculations are badly needed. Based upon the experiment by Burns (1932), the composite sampling technique is probably the most accurate method now used. It consists of subdividing the sample into many small locks of the same size. By selecting a sheaf of fibers from each lock, a composite sample may be obtained.

This technique provides greater uniformity in the sample and adjusts for the extreme variations of fiber fineness on contiguous areas.

Relationship of Density to Other Economic Factors

After determining density, it is important to know its relationship to other factors which influence wool production, such as length of staple, diameter of fiber and surface area. If density can be increased only at the sacrifice of one or more of the other factors, it is necessary to compare their relative economic importance.

It is generally thought that as density increases, length decreases. Between breeds of sheep, this relationship is obvious. Coffey (1929) makes the unqualified statement that "maximum density tends to be associated with shorter staple and finer fiber." Despite this thought, however, work by Bell, Spencer, and Hardy (1936) on American and Tasmanian Merinos has shown that density and length of staple are definitely not incompatible and can both be attained to a high degree on the same sheep. This same experiment showed the denser fleeced sheep to be much freer of dirt in the wool also much less greasy. They make the statement that apperently sheep do not produce an abundance of wool oil and also abundant fiber.

Work done by Garner (1937) also showed that within a breed, selection can lead to both long staple length and high density.

Because greater density can be attained along with improvements in the other factors of production, it seems important that density be given an important place as a criteria in selecting for increased production.

METHOD OF PROCEDURE

Animals Used

This study involved fifteen sheep from the flock owned by the Utah State Agricultural College. Five sheep from each of three breeds - Columbia, Hampshire, and Rambouillet - were selected at random. All the sheep used were kept in the same flock at all times. Because the environment was the same for all sheep involved, environment could not be responsible for any measureable differences. Sheep were about 5 months old; so pregnancy and other distortions were not present. Further studies on these same sheep at different ages will be correlated with the present study.

Equipment for Sampling

The following tools and materials were used during sampling:

1. Sampling crate.
2. Upholstery needles and black thread.
3. Cardboard rectangle 4 by 5 inches.
4. Wira Caliper with 1 square centimeter and 4 square centimeter attachments.
5. Scissors.
6. Envelopes to maintain sample's identity.

Method of Sampling

On sheep, wool growth follows a gradient from front to rear and from top to bottom in density, length, and fineness. Because the side area is in the center of both of these gradients, it is assumed that

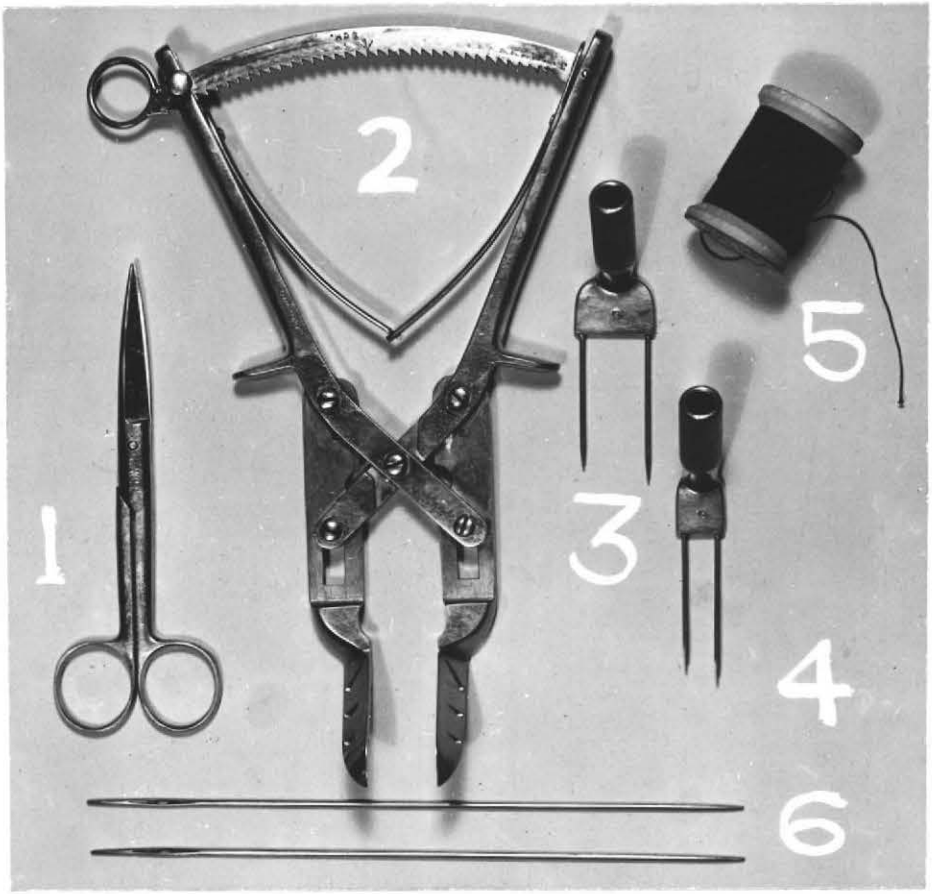

Figure 1. Instruments used in sampling. 1. Scissors. 2. Wira Fleece Caliper. 3. Inserting post used for taking 4 square centimeter samples. 4. Inserting post used for taking 1 square centimeter samples. 5. Thread for delineating areas. 6. Upholstery needles used for drawing thread through fibers.

density values from the sides would fall more closely to the real mean than values from any other area.

Sheep were all secured in a standing position in a special sampling crate. The center of the side area was located by finding a point equidistant from the rearmost point of the scapula and the hip bone. The lower side of the sampled area was on a straight line back from the point of the shoulder.

The sampled area was approximately 4 by 5 inches. The area was subdivided into 6 equal parts by inserting upholstery needles in the wool and drawing black thread through the wool in a straight line. Each of the 6 small areas was assigned a letter with A, B, and C on top going from front to rear, and D, E, and F on the bottom row. Either a 1 square centimeter sample or a 4 square centimeter sample was taken from each small area. Whether a small sample or a large sample was taken was due to chance alone.

Both the right and left sides of each sheep were sampled. Three samples of each size were taken from each side. Each sheep was sampled a total of 12 times. The side that was sampled first and the order in which the small areas were sampled was completely randomized.

All samples were taken with the Wira Fleece Caliper. This instrument is essentially a Wyedesa Fleece Caliper; however, it has reshaped handles to aid in inserting the instrument into the fleece, and it has a knurled screw which holds the width setting constant during the sampling operation.

After determining which side would be sampled first and the order in which the areas would be sampled, the fleece was parted vertically in the first area to be sampled. The Wira Caliper was then set to the desired width and the jaws of the caliper were inserted into the fleece

Figure 2. Delineated areas on sheep in sampling crate.

adjacent to the skin at a right angle to the part. Either the 4 square centimeter post or the 1 square centimeter post was then inserted through the jaws of the caliper. This delineated the desired area. The caliper was then worked out from the body about one-half inch, clamped tight on the enclosed fibers, and the wool was clipped off close to the skin. The caliper was then removed from the fleece and all fibers that were not enclosed in the sampling area were stripped away leaving only those fibers which grew within the sampled area. Each sample was tied with black thread to insure against loss of fibers. The samples were then placed in an envelope which was labeled according to the sheep and location from which the sample was taken.

Preparation of Samples

Equipment. The following materials were used in the laboratory during scouring, counting fibers, conditioning, recleansing, and weighing:

1. Laboratory wool scouring equipment.
2. No. 16 mesh wire screens.
3. Black swatch for holding fibers.
4. Laboratory conditioning oven.
5. Gooch type crucibles with fitted sintered disc.
6. Suction flask.
7. Desicator.
8. Glass weighing bottles.
9. Chainomatic balances.

Scouring. Scouring was done by an emulsion process similar to the commercial method. The following order of vats was used:

Vat 1. 1/2 ounce of textile soda (sodium carbonate) to eight quarts of water, temperature 120°F.

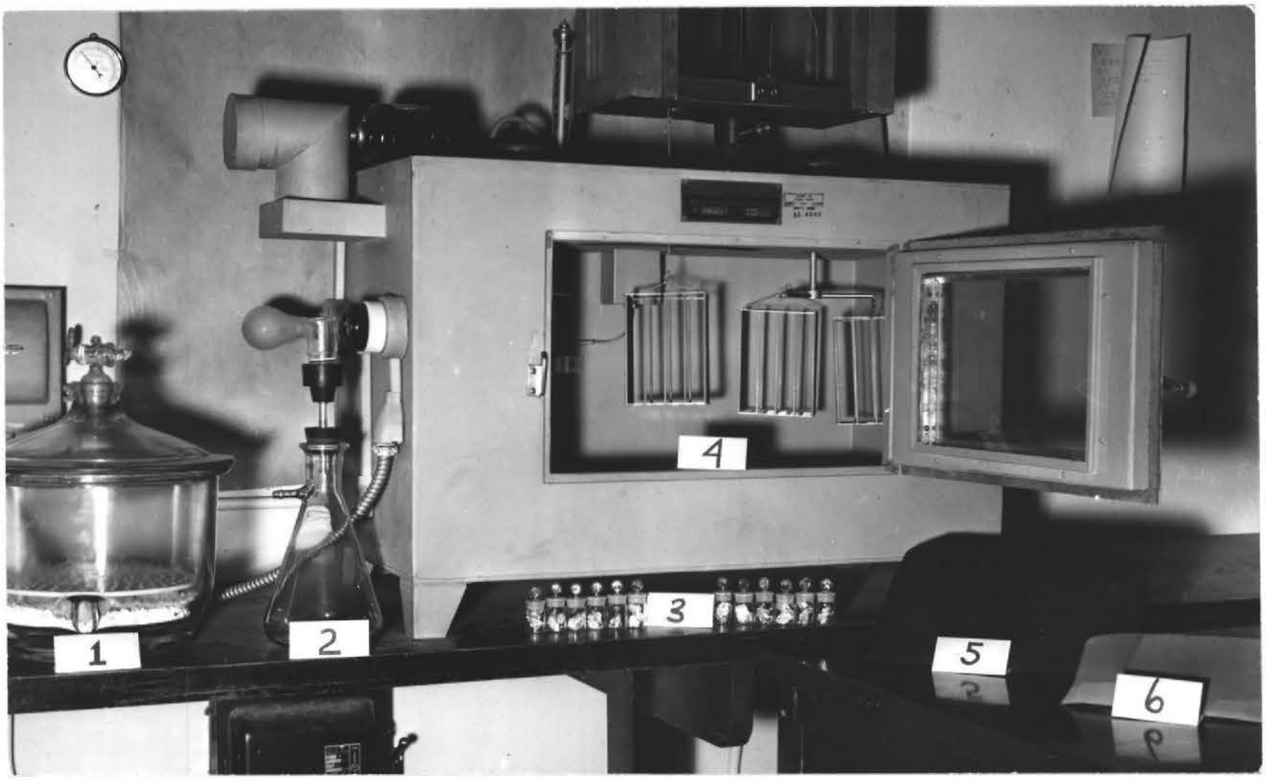

Figure 3. Material used in laboratory analysis of density samples. 1. Desicator for maintaining constant humidity. 2. Gooch type crucible with fitted sintered disc for processing with solvent after scouring. 3. Glass weighing bottles. 4. Conditioning oven. 5. Black swatch for holding fibers. 6. No. 16 mesh wire screen for holding fibers during scouring.

Vat 2. 1/2 ounce of textile soda and four ounces of neutral soap to eight quarts water, temperature 120°F.

Vat 3 and 4. Water only, temperature 110°F.

Samples were obtained, then brought into the laboratory for density analysis. Each sample was removed from its envelope and the information on the envelope was transferred to a sheet designed for density work. The thread was cut away from the sample, and the sample was spread out on scouring screens. The screens were folded and secured with clips which insured against loss of fibers during the scouring process. Samples were put through the scouring vats in the order 1-2-3-4. The purpose of vats 3 and 4 was to rinse the soap thoroughly from the samples of wool.

After the emulsion scouring, each sample was bathed in carbon tetrachloride to make sure any adhering wool fat was removed. Samples were placed in a Gooch type crucible with a fitted sintered disc and after a thorough washing with carbon tetrachloride, the solution was filtered off by a suction flask. The samples were then freed of vegetable material by teasing the fibers apart with the fingers.

<u>Counting</u>. In order to obtain a representative portion of the sample upon which to base the density calculations, samples were subdivided into 16 parts in accordance with Burns' technique (1932). A wisp of fibers was taken from each of the 16 divisions, and combined into one composite sample.

By uniformity trial, run on the counting technique, it was found that calculations based on 500 fibers were significantly more accurate than those based on either 200 or 300 fibers.

Five hundred fibers were counted out of each composite sample and set aside to await conditioning. The 500 fibers and the rest of the sample were kept separate, but their identity was retained at all times.

Conditioning and Weighing. A uniformity trial was run on wool to estimate the value of conditioning. Wool is a very hygroscopic material, and small fluctuations in the relative humidity of the atmosphere will cause changes in the weight of a given amount of wool.

Different balances and different weighers were also tested to determine the most accurate method of arriving at weight figures.

Weights on conditioned wool were significantly more reliable than those on unconditioned wool. The most accurate balance and the most reliable weigher did all the weighing.

All wool was conditioned in small glass weighing bottles. The dry weight of the weighing bottles was determined by placing the empty bottles in the conditioning oven and leaving them there for three hours at a temperature of 212°F. The bottles were then placed in a desicator to cool 90 minutes. Following the cooling, the weights of the empty bottles were determined on the chainomatic balance.

The five hundred fibers and the rest of the sample were separated by a small piece of tin foil and placed in the weighing bottles. After conditioning in the same manner as the empty bottles, the weight of the five hundred fibers and that of the rest of the sample was obtained by determining the total weight, removing the five hundred fibers and weighing again, then removing the rest of the sample and weighing the empty bottle and the tin foil. By sequential subtraction, the weights of the two fiber groups were obtained without exposing the wool to the atmosphere.

Calculating Density. From the dry weight of the samples as obtained above, the number of fibers in the sample was calculated by the portion:

$$WT: w500 = N: 500$$

in which WT = total weight of sample plus the 500 fibers; $w500$ = weight of 500 fibers, and N = the number of fibers in the entire sample.

By solving the above equation for N, the result is:

$$N = \frac{500\ WT}{w500}$$

The result gives the number of fibers in the area sampled. To compare the four square centimeter samples with the one square centimeter samples, the figure arrived at for the four square centimeter sample was divided by 4. These figures were then multiplied by 6.442, to convert the number to fibers per square inch. Numbers were rounded off two decimal places and expressed to the nearest 100 fibers.

RESULTS AND DISCUSSION

Presentation of Data

All data in this study have been statistically analyzed in accordance with Snedecor (1946).

For convenience in analysis and tabular presentation, all density values are given in hundreds of fibers.

Analysis of Variance. Because the Rambouillet sheep are more variable in density figures, they are analyzed separately from the other two breeds. Tables 10, 11 and 12 (in the appendix) give breed averages that illustrate the superior density of the Rambouillets.

Table 1. Comparison of mean squares obtained when taking 4 square centimeter or 1 square centimeter samples from Columbia and Hampshire breeds.

Source of Variation	d.f.	4 sq. cm.		1 sq. cm.	
		Mean Sq.	"F"	Mean Sq.	"F"
Between breeds	1	1663	0.94	5358	3.52
Between sheep within breeds	8	1774	43.2**	1521	6.01**
Between sides within sheep	10	41	0.66	253	1.39
Between samples within sides (Sampling Error)	40	62		182	
Total	59				

** Highly significant, $P < 0.01$

Table 2. Comparison of mean squares obtained whdn taking 4 square centimeter or 1 square centimeter samples from the Rambouillet breed.

Source of Variation	d.f.	4 sq. cm.		1 sq. cm.	
		Mean Sq.	"F"	Mean Sq.	"F"
Between sheep within breed	5	9470	9.70*	9427	2.02
Between sides within sheep	5	976	1.77	4692	2.97*
Between samples within sides (Sampling Error)	20	550		1579	
Total	29				

* Significant, $p < 0.05$

By comparing mean squares between samples within sides, the sampling errors of the 4 square and 1 square centimeter samples are illustrated. This comparison is the main objective of the experiment. In both tables 1 and 2, the error of the 1 square centimeter sample was approximately 3 times greater than that of the larger sample. On the basis of this information, it would take 3 times as many 1 square centimeter samples to duplicate the reliability of the larger sample. Because the Wira Caliper is equipped with inserting posts of either size, the large sample is just as easily obtained and processed as the smaller one.

Only the 1 square centimeter samples on the Rambouillet show any significant difference between right and left sides. This difference is probably due to chance because other measures of difference between sides did not even approach the significant level. Because no difference was detected between sides, it is safe to assume that values based on samples from one side are as reliable as when both sides are tested.

Tables 1 and 2 show that a great deal of variation of density exists among sheep of the same breed. Variation between sheep of the same breed is either statistically significant or highly significant in 3 out of the 4 tests using both 1 and 4 square centimeter samples. The 1 square centimeter sample does not measure a significant difference in the sheep of the Rambouillet breed. This fact is caused by the larger sampling error of the 1 square centimeter sample which makes that sample less reliable, and may also indicate greater uniformity of density in the Rambouillet breed.

Table 1 shows that on the basis of the sheep sampled, there is very little difference between the densities of the Hampshire and Columbia breeds.

<u>Effect of size of sample on accuracy of estimate</u>. Tables 3, 4, 5, and 6 show how the confidence interval* (at .95 probability) is effected by using 4 square centimeter or 1 square centimeter samples. These tables also show the effect of different numbers of sheep <u>n</u>, different sides <u>k</u>, and different numbers of samples <u>k'</u>, on the confidence interval for sheep groups. On the basis of information in these tables, the same confidence interval can be based on fewer Rambouillets and on only half as many Hampshires and Columbias when using the larger sample. These tables also show that in estimating breed means, reliability is increased much more rapidly by sampling additional sheep than it is by taking more samples per sheep. There is no need to sample both sides of the sheep because accuracy is not increased corresponding to the expense of labor and time.

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* The confidence interval at 0.95 probability is the width of the range necessary to avoid being in error more than once in twenty times.

Tables 3, 4, 5, and 6 were obtained by applying the following equation:

$$\tfrac{1}{2}\ \text{C.I.} = 2\sqrt{\frac{1}{n}\left(\sigma^2\text{sheep} + \frac{\sigma^2\text{sides}}{k} + \frac{\sigma^2}{kk'}\right)}$$

Table 3. Effect of different methods of sampling for density on one-half the confidence interval (P = 0.95) when testing Columbias and Hampshires with the 4 square centimeter sample.

No. of sheep n	No. of sides k	No. of samples per side k' 1	2	3	4	5
2	1	13.2	12.6	12.4	12.3	12.2
	2	12.6	12.3	12.2	12.1	12.1
4	1	9.3	8.9	8.8	8.7	8.7
	2	8.9	8.7	8.6	8.6	8.5
6	1	7.6	7.3	7.1	7.1	7.1
	2	7.3	7.1	7.0	7.0	6.9
8	1	6.6	6.3	6.2	6.2	6.1
	2	6.3	6.2	6.1	6.1	6.1

Table 4. Effect of different methods of sampling for density on one-half the confidence interval (P = 0.95) when testing Columbias and Hampshires with the 1 square centimeter sample.

No. of sheep n	No. of sides k	No. of samples per side k' 1	2	3	4	5
2	1	16.4	14.8	14.2	13.8	13.6
	2	14.5	13.6	13.2	13.1	13.0
4	1	12.2	11.0	10.6	10.4	10.2
	2	10.9	10.2	7.9	9.9	9.7
6	1	10.3	9.3	9.0	8.9	8.7
	2	9.2	8.7	8.5	8.4	8.3
8	1	9.2	8.4	8.1	7.9	7.8
	2	8.2	7.8	7.6	7.6	7.5

Table 5. Effect of different methods of sampling for density on one-half the confidence interval (P = 0.95) when testing Rambouillets with the 4 square centimeter sample.

No. of sheep n	No. of sides k	No. of samples per side k'				
		1	2	3	4	5
2	1	32.4	30.3	29.5	29.1	28.9
	2	29.7	28.7	28.1	27.9	27.7
4	1	23.0	21.4	20.9	20.6	20.4
	2	21.0	20.1	19.9	19.7	19.6
6	1	18.7	17.5	17.0	16.8	16.7
	2	17.1	16.5	16.2	16.1	16.0
8	1	16.2	15.1	14.8	14.6	14.5
	2	14.8	14.2	14.0	13.9	13.9

Table 6. Effect of different methods of sampling for density on one-half the confidence interval (P = 0.95) when testing Rambouillets with the 1 square centimeter sample.

No. of sheep n	No. of sides k	No. of samples per side k'				
		1	2	3	4	5
2	1	60.6	57.3	56.1	55.5	55.1
	2	55.0	53.1	52.5	52.2	51.9
4	1	42.9	40.5	39.7	39.2	38.9
	2	38.8	37.5	37.1	36.9	36.7
6	1	35.0	33.1	32.4	32.1	31.8
	2	31.7	30.6	30.3	30.1	30.0
8	1	30.3	28.6	28.1	27.8	27.6
	2	27.5	26.6	26.3	26.1	26.0

If __t1__ equals the time or money required to prepare a sheep for sampling, and __t2__ equals the time or money necessary to evaluate a single sample, then __T__, the total time or money spent in sampling, can be expressed by the following equation:

$$T = n\,(t1 + k't2)$$

in which __t1__ = 30, __t2__ = 1. These values were obtained by estimating the relative time spent in this experiment for the different phases of the sampling procedure.

Then, holding __T__ constant, it is possible to show the efficiency of various sampling procedures shown in tables 3, 4, 5, and 6.

Because the 4 square centimeter sample was 3 times more reliable than the 1 square centimeter sample, the smaller sample is not considered in these figures.

The optimum value of __k'__ is independent of the total time spent in sampling, and the greatest efficiency is obtained when only one side is sampled, when only 3 or 4 samples are taken per sheep, and all additional time or money is spent in sampling additional sheep.

The optimum value of k' is given by the following equation:

$$k' = \sqrt{\frac{t1\,\sigma^2}{t2\,\sigma^2 sheep}}$$

The formula, when applied to proper ^{2} values, reveals that in this study 3 or 4 samples are the most efficient; and that when estimating a group mean, any additional money would increase accuracy more if spent on obtaining more sheep than if spent on obtaining more samples per sheep.

__Effect of location.__ The gradient of decreasing density and fineness of fiber from front to rear and from top to bottom over the sheep's body as a whole has been quite well established. To see if this gradient could be identified on the small area sampled, estimates from the two front-most samples are paired, those from the two middle areas are paired, and those from the two rear areas are paired. The front area is called location 1; the middle area is location 2; and the rear area is location 3.

Table 7 indexes mean values showing location estimates for each breed.

Table 8 is an analysis of variance showing the location effect on the Columbias and Hampshires.

Table 9 is an analysis of variance showing the location effect on Rambouillets.

Table 7. Mean estimates for the three locations sampled on Columbias, Hampshires, and Rambouillets.

	Front	Middle	Rear	Average
Columbia	137	133	125	131
Hampshire	118	118	114	117
Rambouillet	285	299	306	297

Table 8 shows a significant difference in locations in sampling breeds 1 and 2. Table 7 shows that the front region is the most dense area and that the areas are progressively less dense as sampling approaches the rear.

Table 9 shows that any location effect on Rambouillets was not measured by the technique. The trend, as shown in Table 7, actually runs opposite to the trend shown in the other breeds. This trend was not significant and may not be a real effect but due to chance alone.

Table 8. Analysis of variance showing location effect in sampling Columbias and Hampshires.

Source of Variation	d.f.		Mean Square	"F"
Breed	1		6498	2.27
Sheep within breeds	8		2858	16.9**
Sides within sheep	10		169	0.87
Location within sides	40		194	0.23
Location		2	818	5.08*
Location X Sides		38	161	
Total	59			

* Significant, P<0.05
** Highly significant, P<0.01

Table 9. Analysis of variance showing location effect in sampling Rambouillets.

Source of Variation	d.f.		Mean Square	"F"
Sheep within breed	4		17,894	5.59*
Sides within sheep	5		3,198	2.35
Location within sides	20		1,363	.55
Location		2		
Location X Sides		18		
Total	29			

* Significant, P < 0.05

This information could indicate greater uniformity of density on the Rambouillet. It can be stated that the average figure in table 7 is the best estimate of the true mean density of the breeds.

It is evident that a gradient does exist; and that when sampling Columbias and Hampshires, the gradient is marked enough to cause an effect due to location. The importance of this effect would depend upon the size of the area sampled.

Apparently Rambouillets do not show this gradient to the degree that it would influence the density values arrived upon by sampling.

Future work. This study will be correlated with another density analysis on these same animals at approximately one year of age. Galpin (1947) claims that fiber follicle number increases until about 7 months of age and that later density depends on the number of follicles at 7 months plus the skin expansion ratio after that time. Density will be correlated with fleece weight and body weight to establish its economic importance.

SUMMARY AND CONCLUSIONS

An analysis of variance study of 180 samples taken from 15 ewes was made to test the significance of variation between 4 square centimeter and 1 square centimeter samples, between sides on the same sheep, between the sheep of each of 3 breeds, and between the breeds.

The Rambouillet breed averaged much higher in density than the Columbias or Hampshires. The Columbias and Hampshires did not differ greatly.

Sheep of the same breed differed greatly and in the Hampshires and Columbias, the sheep of the same breed differed more than the averages of the breeds themselves.

No difference was detected between sides on the same sheep. This is further evidence for the theory of bi-lateral development and removes the necessity of sampling both sides of a sheep in testing for mean density.

Mean density estimates based on samples taken by the 4 square centimeter post were 3 times more reliable than those taken with the 1 square centimeter post. In other words, if the 1 square centimeter sample is taken, it will take 3 times as many samples to make as reliable an estimate as when using the larger sample. Four square centimeter samples are just as easy to take and analyze; therefore, they should be recommended in preference to the smaller samples for density analysis.

This study indicates that when sampling in an effort to establish a group mean density, the greatest efficiency is obtained when only one side is sampled, when only 3 or 4 samples are taken per sheep, and all additional time or money is spent in sampling additional sheep.

The Columbia and Hampshire sheep showed a definite density gradient. The forward location was most dense, the middle location was next, and the rear location was least dense. This gradient was fairly well defined in the small area sampled and so it must be considered when sampling these breeds for density. This gradient was not detected in the Rambouillet breed, which indicates that the Rambouillet may be more uniform in density over the entire body.

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A P P E N D I X

COLUMBIA BREED

Table 10. Comparison of density values for individual samples, sheep means, and breed mean.

A602				A212			
Right Side		Left Side		Right Side		Left Side	
4 Sq.	1 Sq.	4 Sq.	1 Sq.	4 Sq.	1 Sq.	4 Sq.	1 Sq.
129	158	127	161	148	164	148	139
127	115	122	155	147	122	164	117
127	173	124	165	153	137	146	149

A822				A744			
Right Side		Left Side		Right Side		Left Side	
4 Sq.	1 Sq.	4 Sq.	1 Sq.	4 Sq.	1 Sq.	4 Sq.	1 Sq.
103	111	97	110	108	116	98	115
99	112	92	122	120	114	105	116
90	113	88	117	138	140	129	122

A202			
Right Side		Left Side	
4 Sq.	1 Sq.	4 Sq.	1 Sq.
139	166	138	129
140	192	130	146
148	159	152	156

Breed Mean

131

Sheep Mean

A602	A212	A822	A744	A202
140	144	105	118	149

RAMBOUILLET BREED

Table 11. Comparison of density values for individual samples, sheep means, and breed means.

A292				A450			
Right Side		Left Side		Right Side		Left Side	
4 Sq.	1 Sq.	4 Sq.	1 Sq.	4 Sq.	1 Sq.	4 Sq.	1 Sq.
300	241	239	198	347	343	269	354
277	396	261	323	320	307	290	249
295	303	302	261	324	295	284	420

A522				A764			
Right Side		Left Side		Right Side		Left Side	
4 Sq.	1 Sq.	4 Sq.	1 Sq.	4 Sq.	1 Sq.	4 Sq.	1 Sq.
343	324	354	302	293	246	237	235
323	441	291	297	223	258	232	198
301	270	283	298	213	242	231	213

A390			
Right Side		Left Side	
4 Sq.	1 Sq.	4 Sq.	1 Sq.
348	304	346	244
352	356	333	278
334	430	344	285

Breed Mean

297

Sheep Mean

A292	A450	A522	A764	A390
283	317	319	235	329

HAMPSHIRE BREED

Table 12. Comparison of density values for individual samples, sheep means, and breed mean.

A870				A 20			
Right Side		Left Side		Right Side		Left Side	
4 Sq.	1 Sq.	4 Sq.	1 Sq.	4 Sq.	1 Sq.	4 Sq.	1 Sq.
129	140	127	128	116	112	120	108
127	138	135	135	110	122	120	119
130	155	122	126	101	118	116	119

A540				A920			
Right Side		Left Side		Right Side		Left Side	
4 Sq.	1 Sq.	4 Sq.	1 Sq.	4 Sq.	1 Sq.	4 Sq.	1 Sq.
100	125	104	88	130	104	118	102
106	101	104	109	118	121	129	137
106	116	88	96	117	103	115	118

A332			
Right Side		Left Side	
4 Sq.	1 Sq.	4 Sq.	1 Sq.
112	118	105	142
102	125	115	114
114	104	117	108

Breed Mean

117

Sheep Mean

A870	A20	A540	A920	A332
133	115	104	117	114