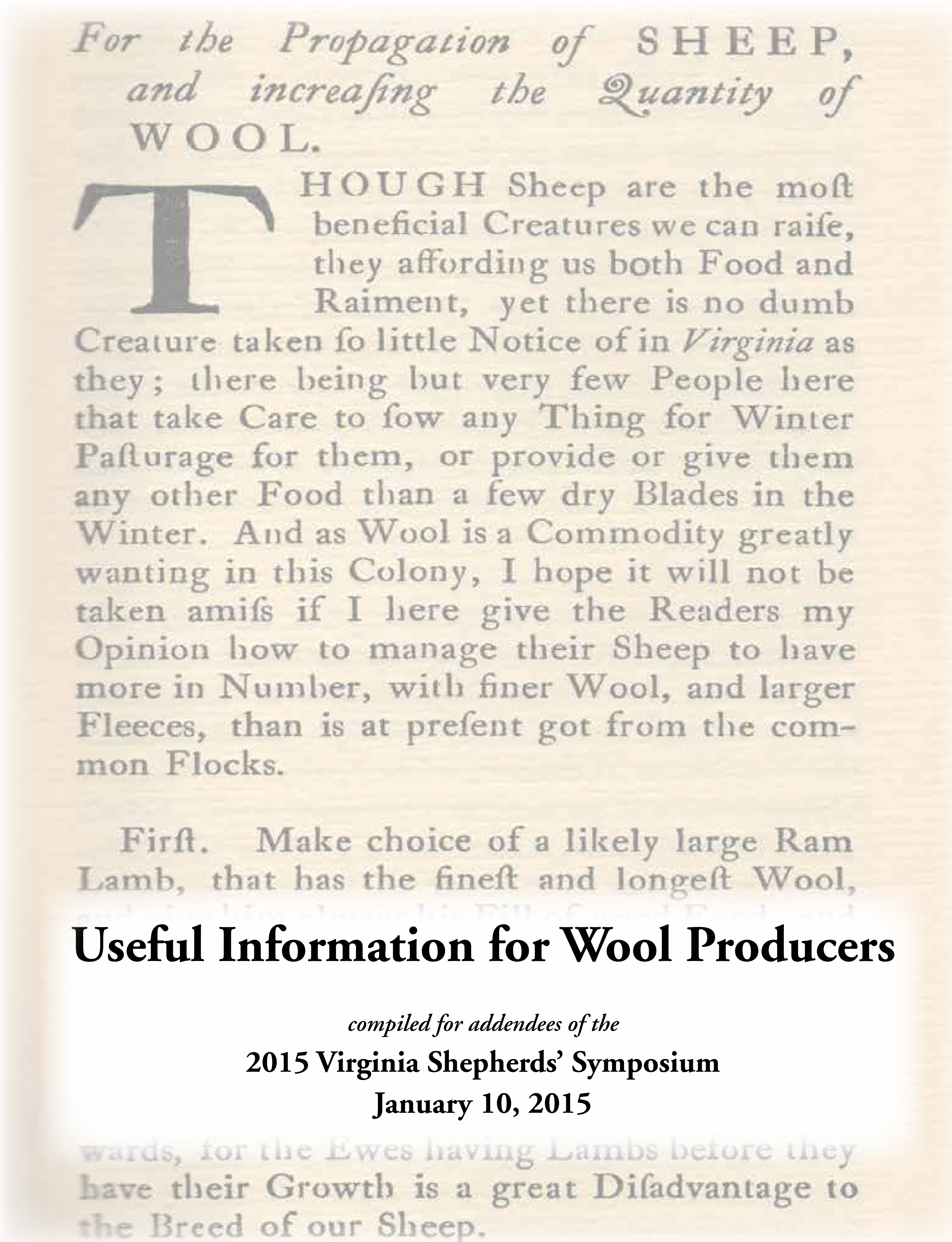

For the Propagation of SHEEP, *and increaſing the Quantity of* WOOL.

THOUGH Sheep are the moſt beneficial Creatures we can raiſe, they affording us both Food and Raiment, yet there is no dumb Creature taken ſo little Notice of in *Virginia* as they; there being but very few People here that take Care to ſow any Thing for Winter Paſturage for them, or provide or give them any other Food than a few dry Blades in the Winter. And as Wool is a Commodity greatly wanting in this Colony, I hope it will not be taken amiſs if I here give the Readers my Opinion how to manage their Sheep to have more in Number, with finer Wool, and larger Fleeces, than is at preſent got from the common Flocks.

Firſt. Make choice of a likely large Ram Lamb, that has the fineſt and longeſt Wool,

wards, for the Ewes having Lambs before they have their Growth is a great Diſadvantage to the Breed of our Sheep.

Useful Information for Wool Producers

compiled for addendees of the

2015 Virginia Shepherds' Symposium

January 10, 2015

Virginia's wool producers in 2015 are a diverse lot—owning flocks of a few animals to hundreds, with wool types from fine wools to dual-coated primitive breeds, hobby flocks to full-time sheep farmers. These shepherds market their wool with the same diversity. Some take all or part of their clip to finished products entirely by hand, some use the abundance of custom mills to scour, card, spin, dye, and knit or weave their fiber, some bale at the farm and haul their clip to the wool pool.

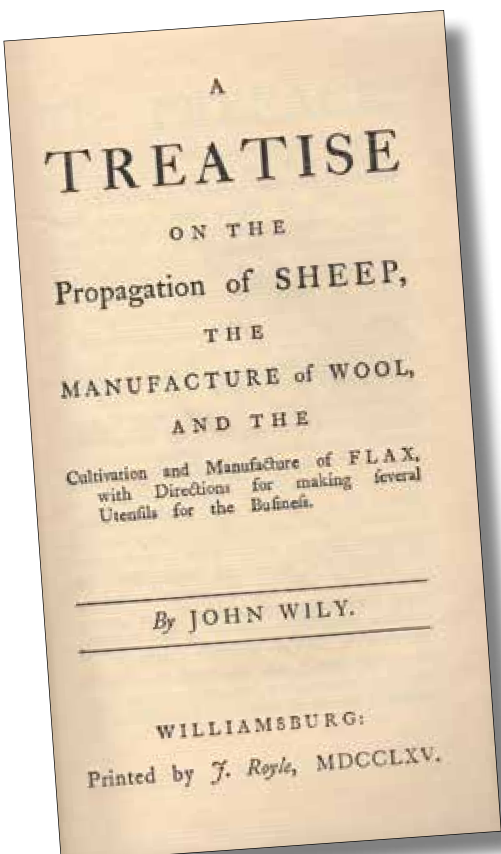
These producers do have common aspirations: to improve the quality and value of their flock's fiber, and their operation's profitability.

In addition to this Symposium's sessions on wool production and marketing, the Virginia Sheep Producers Association's Wool Outreach Fund Committee offers to producers this booklet of wool production information. We hope you find useful information from our speaker, Dr. Rodney Kott, from this booklet, and from your fellow shepherds at the symposium, to help advance your farm goals.

Virginia Wool Outreach Fund Committee
Martha Polkey, Chair
Robin Freeman, Naomi Smith, Cathie Shiff, Patti Price

Publication of this booklet was funded by the Wool Outreach Fund.

Kevin Ford, hand shearing a ewe.



A

TREATISE

ON THE

Propagation of SHEEP,

THE

MANUFACTURE of WOOL,

AND THE

Cultivation and Manufacture of FLAX, with Directions for making feveral Utenfils for the Bufinefs.

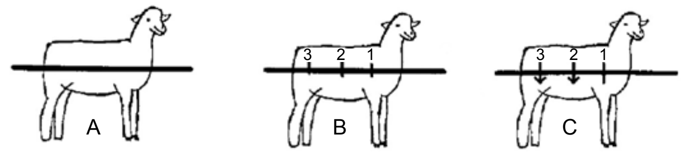
By JOHN WILY.

WILLIAMSBURG:
Printed by J. Royle, MDCCLXV.

Cover: The first page of an early reference for Virginia shepherds, published in 1765. Reproduction from archivees at Colonial Williamsburg.

Contents

Evaluating Wool on the Live Animal



by Paul E. Briggs, published in The Marker, *publication of the Natural Colored Wool Growers Association*

Evaluating the wool or fleece on the live animal is difficult for many people. Most of us are used to looking at shorn fleeces with the cut side out, compared to the weathered side out when evaluating the fleece of a live animal.

There are three times when you must evaluate a fleece on the live animal:

- when purchasing replacement animals away from your farm,
- when evaluating fleeces in your own breeding program, and
- when you are an official sheep judge.

First, evaluating a fleece is very important when selecting replacement rams and ewes away from your ranch. In some cases you will not be able to evaluate the fleece of the animal until after the animal is purchased and shorn.

Second, if you raise a wool breed of sheep you can save yourself time and energy by a pre-evaluation of your potential replacements before shearing. You can pick out your top-end animals and cull animals with obvious faults, thus spending more time evaluating fleeces from your top group.

Third, if you are a sheep judge, you must be knowledgeable about the breeds you are judging. It behooves you as a judge to know the wool scorecard standards adopted by the different breed associations. Judging or evaluating fleeces in the show ring shouldn't be any different than evaluating fleeces at home; however, the animal has been fitted for the show ring and the fleece has been adulterated by trimming. Fitting will affect staple length, uniformity of staple length, yield, and even density, which makes it more difficult to compare fleeces.

The best time to evaluate a fleece on or off the animal is when they are yearlings with a full 12-month fleece. Fleece traits are highly repeatable; therefore, selections made at 16 months of age can be a good indicator of future wool production. Evaluating aged ewe fleeces is difficult because of the differences in the physiological state of the animals and its effect on wool production. Barren ewes will have better fleeces than ewes that have raised lambs.

Now, to start analyzing the fleeces. Looking at the animal from the side, draw an imaginary horizontal line halfway between the top line and underline of the animal (see above). This should put your line at approximately the middle of the side.

Figure B shows three locations in which the fleece should be examined: Point 1 is on the shoulder, point 2 is in the middle of the side just past the last rib, and point 3 is on the face of the leg about the stifle or britch. Now, with both hands, make a wide split in the wool to look at the fleece, working from point 1 to point 3.

Look at and estimate the following criteria: fiber diameter or grade, uniformity of fiber diameter, staple length, character, yield, and density.

Fiber diameter or grade. Compare the animal you're evaluating with the grade of wool that its breed should be producing. The average of the three points should correspond with the range of diameters or grades representative of the breed.

Uniformity of fiber diameter. Both breeds and individuals within a breed will vary in fiber diameter uniformity. Breeds such as the Merino and Rambouillet, for example, should be uniform from front to rear. Columbias and Targhees are not quite as uniform from front to rear. Fiber uniformity is very important and animals that vary more than 5 microns from shoulder to britch should not be kept as replacement stock. The finest fibers are found on the shoulder and the coarsest fibers are located on the britch.

One way to judge the uniformity of a fleece is to closely examine the number of crimps per inch. For example, if the staple on the shoulder has 11 crimps per inch and the britch has only 5 crimps per inch, there is a high probability that the fleece is not very uniform. This method is only used to compare fiber diameter uniformity within a fleece and not between fleeces.

Staple length. Staple length and uniformity of length play a major role in determining the value of wool. Each grade of wool has a minimum length to be classified as staple, French combing or clothing wool.

Character. Character refers in general to the overall appearance of the fleece. This includes crimp, color, handle and lock formation. Crimp, the natural waviness of the

Parting the fleece.

wool fiber, is an important characteristic. Well-crimped wools usually possess a high tensile strength. Wools lacking in crimp have a tendency to break during processing. Uniformity of the crimp throughout the length of the staple is very desirable and is a trait worth selecting. Color is very important, especially if white or pastel shades of fabrics are to be made. Bright wools (genetics is key here) are more valuable and take up dyes more uniformly than discolored wools.

Yield. Yield is the amount of clean wool that is obtained from grease wool after scouring and is expressed as a percentage. If all animals being evaluated have been run together since their last shearing the depth of dirt penetration and amount of yolk are a good indicator of yield.

Density. Density refers to the closeness or compactness of the fibers in a fleece. The more fibers per square inch, the denser the fleece. There are two ways to check for density on the live animal:

• When you part the fleece the amount of skin exposed is an indicator of the fleece density or, in other words, the less skin you see, the denser the fleece.
• The density can be evaluated by grabbing a handful of wool and squeezing it.

By doing this at point 1, 2, and 3 as seen in the illustration, you'll be able to get a feeling for how dense the fleece is when compared to other animals' fleeces. Wool having a shorter staple length will feel denser, therefore you should consider this when comparing animals with different staple lengths.

Two other factors you should consider in evaluating fleeces on the animal are belly wool and kemp.

Belly wool. Belly wool is wool that grows on the belly and is often uneven, tender, and shorter than wool from other pans of the body. Belly wool should be limited to the belly region. If belly wool is seen on the sides of the animal, it is a serious fault. When looking for belly wool, start at point 2 in Figure C and go down the fleece toward the belly until you see the belly wool and compare this point with where belly wool starts on other sheep.

Kemp. Kemp is an opaque fiber that lacks strength, elasticity and crimp. The fiber is medullated (hollow) and considerably coarser than other fibers in the same staple. Kemp fibers do not readily absorb dyes, therefore, wools containing kemp are limited to their end use. If a fleece contains kemp it is most prevalent in the britch wool. Kemp is acceptable on carpet wool breeds such as Scotch black faces and Drysdales. If kemp is found on a fine-wool sheep the animal should be culled.

Fiber Test Results: What They Look Like

by Martha Polkey

Testing fiber samples from individuals in your flock provides objective measurement of fleece characteristics, which you can use in selection of replacements to advance the quality and quantity of your clip.

Fleece samples were taken from the sides of the animals on the day before shearing, using hand shears, trimming as close to the skin as the electric shears would do, do get a realistic staple length measurement. Taking samples from side and britch area (or side, britch and shoulder) would provide a more comprehensive evaluation of the fleece (but not as comprehensive as core sampling and entire fleece).

The figures at right display the test results from an optical fiber diameter analyzer (OFDA) for individuals in a flock, with data on multiple characteristics. Plugging this data into a spreadsheet allowed the producer to sort columns according to characteristics such as micron count, comfort factor, and staple length, and then rank animals.

Glossary of abbreviations used in OFDA 2000 reports

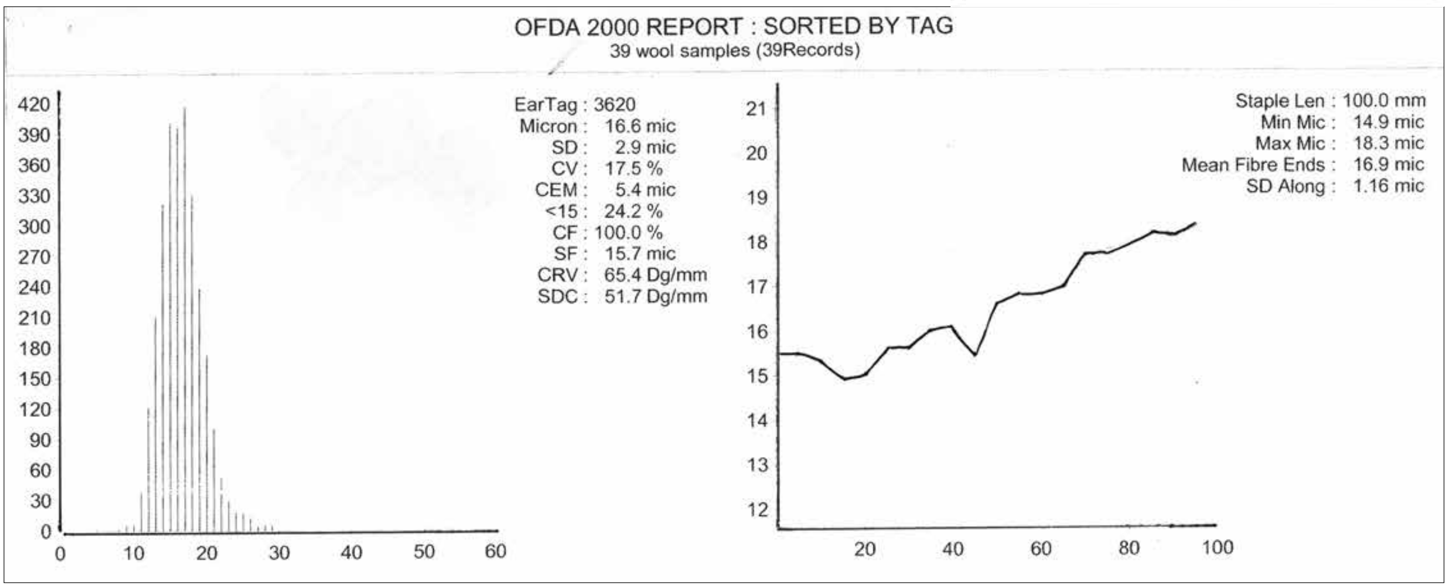
Mic Ave	Average fiber diameter of the testes sample expressed in microns
SD Mic	Standard deviation of fiber diameter expressed in microns
CV Mic	Coefficient of variation of fiber diameter expressed as a percentage (= [SD Mic ÷ Mic Ave] x 100)
CEM	Coarse edge micron. The number of microns above the average diameter where the coarsest 5% of fibers lie.
< 15%	The percentage of fibers finer than 15 microns
CF%	Comfort factor; the percentage of fibers equal to or less than 30 microns
SF Mic	Spinning fineness; it represents "spinning quality" and is calculated from CV Mic and Mic Ave
SL mm	Average relaxed staple length expressed in millimeters
Min Mic	The finest point along the staple expressed in microns
Max Mic	The coarsest point along the staple expressed in microns
FPFT mm	Finest point from the tip of the staple expressed in millimeters. The tip of the staple is at the left-hand side of the staple profile
MFE mic	Mean fiber ends; the average fiber diameter of the fiber ends (tip and base) expressed in microns
SD along	The standard deviation of fiber diameter measured along the staple, expressed in microns
CRV Dg/mm	Average fiber curvature expressed in degrees per millimeter, an estimate of crimp
SDC Dg/mm	Standard deviation of fiber curvature expressed in degrees per millimeter

Skirted fleece weights at shearing and visual characteristics were added to the data from the test, and other data on individuals (number of lambs born to mature ewes, comparison of sire and dam statistics to test results for projeny) was evaluated by the shepherd.

Results were used to identify replacement ewes and potential replacement rams, make culling decisions, plan breeding programs and set goals for future flock improvement—as well as to market fleeces to handspinners.

The analyses shown here were done at the Bill Sims Wool and Mohair Research Laboratory, Texas A&M Agrilife Research, 7887 U.S. Highway 87 North, San Angelo, Texas 76901-9714, 325-653-4576. The price per sample tested is $3.

Above right: the OFDA. At right: Go ahead, watch the marketing video of the manufacturer at http://www.ofda.com/Natural_fibres/Ofda2000.html!



Above are graphs of the fiber measurements for a mature ram. The narrowness of the fiber distribution (at left) is a visual representation of the uniformity of the sample. Below is a portion of a table of a group of fleece sample results. A producer can render these data in a spreadsheet, and sort to classify characteristics of flock individuals as part of a flock improvement plan.

Mic Ave	SD Mic	CV Mic	CEM	<15 %	CF %	SF Mic	SL mm	Min Mic	Max Mic	MFE Mic	SD Along	CRV Dg/mm	SDC Dg/mm
21.9	4.0	18.4	7.6	3.3	95.4	20.9	80.8	20.1	23.7	21.3	1.11	75.5	55.0
20.0	4.0	20.2	8.0	6.8	98.7	19.3	35.0	18.7	21.7	19.7	1.27	73.5	58.5
19.1	4.4	23.1	8.5	13.4	97.9	18.9	40.0	18.1	19.8	19.4	0.53	75.1	56.5
27.6	5.2	19.0	9.1	0	72.4	26.4	90.0	25.4	29.3	27.0	1.19	76.6	55.4
19.8	3.2	16.2	6.1	2.8	99.2	18.6	80.0	18.7	21.3	19.0	0.82	84.8	64.0
21.3	3.6	17.1	6.8	1.3	97.7	20.1	90.0	20.1	22.6	21.2	0.80	94.1	61.6
24.0	4.0	16.8	7.3	0.6	94.5	22.6	100.0	22.2	25.8	23.1	1.03	93.8	63.9
22.8	4.1	18.0	8.1	0.6	95.2	21.7	90.0	20.6	26.3	21.5	1.64	69.1	46.9
23.5	3.9	16.5	7.2	0.6	95.7	22.1	80.0	22.1	25.3	22.6	1.00	77.1	56.8
24.7	4.3	17.5	7.6	0.7	91.1	23.4	70.0	23.4	26.0	23.9	0.76	98.5	64.7
26.0	4.1	15.9	7.7	0	86.8	24.3	70.0	24.7	26.8	25.0	0.62	82.6	64.8
22.9	3.6	15.7	6.4	0.7	97.1	21.4	85.0	20.1	24.3	20.6	1.42	90.9	62.0
23.3	4.6	19.9	9.2	0.5	91.9	22.4	80.0	22.0	25.7	23.3	1.01	65.5	47.9
21.3	3.4	15.8	6.4	1.3	99.0	19.9	70.0	19.8	22.5	20.1	0.82	101.5	70.9
21.7	4.4	20.3	9.2	1.5	95.2	21.0	85.0	19.9	22.4	21.1	0.76	64.3	48.3
20.6	3.5	17.2	6.4	2.4	98.2	19.4	90.0	19.1	22.8	20.0	1.09	54.8	38.4
24.1	4.6	18.9	8.3	1.0	91.9	23.1	95.0	20.0	28.5	24.6	2.43	76.6	53.9
19.4	3.1	16.0	5.9	3.5	99.5	18.1	75.0	17.8	20.7	18.7	1.03	105.5	74.0
23.2	3.7	16.1	7.0	0.4	96.4	21.8	85.0	22.2	25.0	23.0	0.67	79.3	56.5

Selection for Fiber Improvement in Your Flock

Compiled from the SID Sheep Production Handbook and Montana Farm Flock Sheep Production Handbook

Selection is the most important tool you have to improve your wool clip and production efficiency. Many desirable wool traits are highly heritable, and so effective selection methods will lead to permanent gains not only in quantity but also in quality of stock and wool produced. Bottom line: Determine the economic importance of wool in your sheep operation and apply selection pressure accordingly.

Because the amount of selection that can be practiced for any single trait is limited, give emphasis to the traits that are most valuable and in which the most progress can be made. Pounds of wool, staple length and fiber diameter are the basics commonly included in selection programs.

Heritability

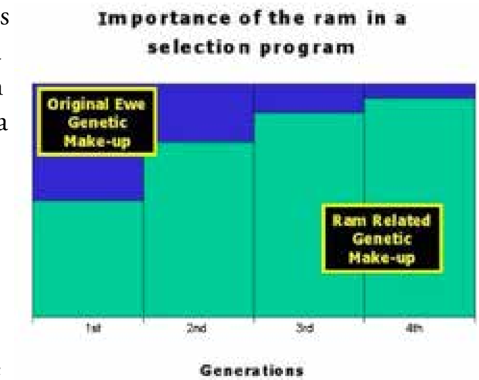
Estimates of heritability, which give the proportion of observed variation due to genetic construction, are useful in determining the relative progress you can make in selection to improve various traits. In sheep, estimates of heritablility have usually been obtained from relationships among relatives. Estimates are available for a large number of traits, but many are based upon relatively small numbers under varying conditions and therefore are quite variable. In general average heritability estimates over 40 percent have been classified as highly heritable, those from 20 to 40 percent as moderate, and those under 20 percent as low. See the table below for heritability estimates.

Genetic correlations show the relative change in one trait associated with selection for another trait, and in general, for wool traits these are positive correlations—for example, selection for higher grease or clean fleece weight alone will result in increased fiber diameter and staple length, and vice versa. There are some exceptions to the positive correlations in wool traits: selection for finer fiber may reduce fleece weight, and skin folds are negatively correlated with staple length, but positively related to fleece weight.

Heritability of Wool Traits

Characteristic	Range of heritability (%)
Face cover	35–55
Skin folds	20–50
Grease fleece weight	30–60
Clean fleece weight	25–60
Staple length	30–65
Fiber diameter	20–60
Variability of diameter	30–90
Yield	30–40
Crimp	20–50
Luster	20–30
Fiber density	20–60

That brings us back to selection for the traits that are economically important: higher grease and clean weights, longer staple length within the grade of wool you are producing, and gains in fleece density and uniformity of length and fineness. Voilá, a more valuable clip.



Breeding practices for obtaining the most rapid improvement in wool production are identical to those that apply to other traits:

- Identify individual sheep.
- Use objective and direct measures whenever feasible.
- Adjust for environmental effects such as age, type of birth, age of dam, or year effects, or select within like groups.
- Reduce generation intervals (defined as the speed with which each generation is replaced—ideally with superior animals), especially on the male side.
- Select only for the most important traits and maximum selection differentials (for example, annual clean wool weight of selected sires minus the average clean weight of the group from which the sires were selected).
- Emphasize selection of rams.

The ram

The greatest impact of selection on sheep performance can be made through ram selection. Small producers who feel that their sheep flock is not large enough to justify purchasing a quality ram should consider renting one, or purchasing one in partnership with another producer before using a poor quality ram. Remember, it does not take too many pounds of lamb and wool to justify using a good quality ram, instead of an average one.

Careful selection of rams can benefit the producer in two ways. It contributes to the production efficiency of every lamb and to the genetic improvement of economically important traits in the herd. Since relatively large numbers of ewe lambs are needed for replacements and often detailed production and genetic records are not available (increasing the role chance plays in the selection process) genetic progress through ewe selection is limited. In most sheep flocks 80 to 90 percent of the genetic progress comes from ram selection and only 10 to 20 percent comes from the selection of ewes.

Performance testing of rams is a method of objectively evaluating body weight gain, fleece quality and production of individual rams a common environment. But since you won't find such tests in the mid-Atlantic, as a producer you can look to good breeders, breed associations, go West for performance tested rams, or resort to an artificial insemination program using performance-tested rams.

Sheep Improvement Program

Incorporated in 1987, the National Sheep Improvement Program (NSIP) is a computerized, performance-based program for genetic selection. NSIP is designed to help purebred sheep producers identify the best genetic stock for their breeding programs. NSIP also gives breeders reliable information that they can use to advertise and sell their breeding stock. Wool breed groups that currently participate in NSIP include Border Leicester, Columbia, Coopworth, Dorset, Hampshire, Polypay, Rambouillet, Romney, Suffolk, Targhee and White Suffolk.

The methodology calculates performance and expresses it as flock expected progeny differences (FEPD) for each individual animal in the flock for each trait selected. Expected progeny differences (EPD) for an animal estimates how well its offspring compare to the breed average. Wool traits currently evaluated are fleece weight, staple length, fiber diameter, fiber diameter coefficient of variation (a measurement of uniformity), and fiber curvature (a measure of crimp).

An example of small flock producers collaborating to improve flock genetics was detailed at the 2014 American Sheep Industry Convention. Kreg Leymaster, of USDA's Agricultural Research Service, discussed the cooperative breeding program, the Mount Rushmore Consortium, initiated by a half-dozen Polypay breeders in the upper Midwest, who engaged two geneticists in the design and execution of a breeding program to increase the rate of genetic gain in their flocks—pooling their sheep numbers to gain the genetic diversity essential for an effective program. Having settled on common selection objectives, they established a breeding program to carefully select sire lines, planned matings to create genetic linkages, and carefully collected data to advance flock performance. The cooperative members gather once a year to transfer rams in an established pattern among the farms for the next round of breeding.

You can find out more about the NSIP and its results at nsip.org.

Are Australians serious about wool quality? Here a judge prepares to assess a Merino ram's fleece uniformity—yes, on the belly wool.

Effects of Nutrition On Wool Production and Quality

Compiled from the SID Sheep Production Handbook

Growth of the wool fiber is generally a continuous process that is regulated by genetics, nutrition, animal physiology and environmental factors. Potentials for wool production and wool quality are determined genetically. The degree of realization of that potential is a function of the level and consistency of nutrition and of environmental variables. Consequently, growth of the wool fiber may be altered by any interference with or lack of nutrient support for this process. Seasonal variations in wool growth are associated with length of day as well as availability and quality of feed/forage. More rapid growth has been measured during the season when days are longest. Wool growth may also be affected by age, temperature, physiological processes (e.g., lactation, parturition) and hormone therapy.

The effect of nutrition on wool production begins in utero while the fetus is nourished by maternal blood. The amount of wool grown by a sheep is determined by the number and size of fibers produced by the primary and secondary wool follicles (structural units in the skin of the animal). Primary follicles emerge in the fetal skin by the ninetieth day of gestation; secondary follicles develop from that time through the early postpartum period. Prenatal follicular development follows the rate of growth of the fetus and seems to set wool growth potential. Further maturation of follicles and production of wool fibers after birth are closely associated with the nutrition and growth rate of the lamb. The well-fed lamb my produce wool fibers from about 80 percent of the follicles at one month of age, whereas a poorly fed lamb my require 6 to 12 months before all follicles become functional. Feeding practices that do not restrict the birth weight or early postnatal growth of lambs will provide adequately for the initiation and maturation of wool follicles. This development is necessary if maximum wool production is to be achieved.

Wool production and quality in adult sheep is greatly affected by quality of feed/forage, its nutrient content, and its consistency of supply. Elevated feed intake (especially protein) can increase fiber diameter, lengthen and strengthen the staple, and increase the amounts of grease and scoured wool. Probably the most limiting nutritional factor in range sheep production is an insufficient amount of energy in the diet due to the lack of forage availability, low digestibility, or a poor balance of other nutrients that depresses intake. Variation in feed intake can sequentially increase and decrease the cross-sectional area of wool fibers by as much as fourfold. The small cross-sections (constrictions) are weak points causing "tender" wool or distinct "breaks" in the wool fibers. Tender wool usually results from a sudden and severe reduction in feed consumption brought about by drought, snow cover, illness, or lack of water. However, consistent marginally low nutrition usually will support growth of wool that is lower in quantity (lower fleece weights), but high in desirability (fine with adequate strength) for the wool trade. The critical dietary protein level for maintaining fiber fineness, staple length, amount of crimp, and fiber strength appears to be near 80 percent of the NRC recommended requirements. Below this level, production and quality are adversely affected.

See next pages of this booklet for a portion of the chapter on wool development from the SID Sheep Production Handbook for a more detailed discussion of wool development and production.

Effects of Environmental Conditions on Wool Quality

Taken from Sheep and Wool Science, Production and Management, *by M. P. Botkin, Ray A. Field, and C. LeRoy Johnson, Department of Animal Science, University of Wyoming*

I. Nutrition - most important
  A. Minerals and vitamins
    1. Sulfur-containing amino acids - cysteine and methionine
      a. Important in the chemical structure of wool
      b. Feeding excess has not increased wool growth
    2. Copper
      a. Deficiency results in harsh, nearly crimpless, steely wool
      b. Copper metabolism is closely related to dietary levels of molybdenum and sulfate.
      c. Zinc – deficiency results in growth of steely wool
  B. Protein – wool is pure protein with high cysteine content
    1. Optimum level – 10 percent
    2. Post-ruminal infusions of methionine and cysteine have been shown to increase wool growth dramatically
    3. Need to develop method to avoid ruminal degradation of methionine and cysteine
  C. Energy
    1. Wool growth increases with increases in energy provided diet contains 8-10 percent protein
    2. Wool growth more closely related to energy than protein levels
    3. Due to price of high-energy feeds, may not be profitable

II. Physiological State – degree of competition between wool growth and other body functions is directly related to the production states of sheep. Last 6 to 7 weeks of gestation and first 6 to 8 weeks of lactation are the most critical
  A. Demands must be met from body reserves and/or increased feed intake
  B. Competition for nutrients by lambs may reduce wool growth in two ways
    1. Ewes raising singles shear 10-20 percent lighter fleeces than dry ewes. Ewes raising twins shear an additional 4 percent less
    2. Determines whether or not lambs reach their genetic potential for density (secondary/primary follicle ratio)
      a. Supply of nutrients to the fetus during late gestation has been shown to affect the extent of initiation and probable degree of branching of secondary follicles. This is permanent
      b. The degree to which these follicles mature to produce fibers is affected by the level of nutrition of the lamb during early life. This inhibition of maturation may be either permanent or only a delay in the process
  C. Single- versus twin-born lambs
    1. Twins produce 2 to 5 percent less wool during their lifetimes than singles
    2. Reduction due to lower density and smaller size
    3. Selection for increased fleece weight tends to discriminate against twins
  D. Age
    1. Maximum fleece weights occur in 2- to 4-year-old sheep with an approximate 4 percent per year decline thereafter
    2. The effects of age on wool production should probably be ignored except when comparing fleeces in the selection of lambs for replacements
  E. The price of wool and the price of feed determines economic feasibility of increased nutrition during late gestation and early lactation

III. Diseases and Parasites – primarily external parasites
  A. Compete for nutrients
  B. Reduces fiber diameter and may cause breaks in wool

IV. Soil Type
  A. Feeds may have calcium-phosphorus imbalances and/or deficiencies and trace mineral deficiencies
  B. Alkaline soils cause abnormal weathering of the tips of fleeces
  C. Some soils tend to discolor fleeces

V. Season
  A. Photoperiod (day length) – grow coarser, longer fibers and therefore more wool in summer than winter
  B. Physiological state (e.g., pregnancy, lactation)
  C. Adaptability of breed – genetic-environmental interaction in different climates and weather situations
  D. Quantity and quality of feed – particularly in grazing situations
  E. Temperature – has a major effect on competition for nutrients and degree of circulation of blood, and therefore nutrients, to the skin

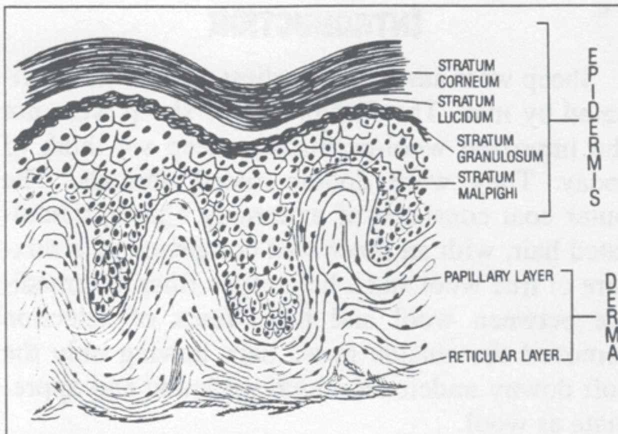
For Winter Paſturage for your Sheep, ſow Wheat, Rye, Clover, or Timothy, for them to feed on when the Earth is free from Snow; and ſow large Patches of Turnips, to feed them with in ſnowy Weather, when they have not the Opportunity of getting any green or moiſt Food. You ſhould take Care to dig your Turnips when your Earth is clear of Snow, and keep them in a Cellar, or Cave made for that Purpoſe, until you have Occaſion for them; then take them out and waſh them, and lay them in a clean Trough, and there with a Spade, or ſome cutting Utenſil, cut and chop them to Pieces; then lay them in long Troughs, for your Sheep to feed on. Oats or Peaſe is exceeding good Food for Sheep in the Winter; and ſometimes wet the Oats, and throw a little Salt amongſt them, for I look upon Salt to be very ſerviceable to all Kind of Stock. In the Winter Seaſon, have a good tight Roof for your Sheep to lie under; the Sides to be open, for the Benefit of the Air; have the Shelters often cleaned, and the Dung carried away; and give them freſh Litter. You ſhould take Care not to let your Paſture be eaten down about the Time of your Ewes yeaning, but to procure ſome good Grazing to turn your Ewes on juſt before their yeaning, which will occaſion them to have a Plenty of Milk for the Lambs, and will prevent there being ſo great a Loſs of them as is common where the Ewes have only dry Food to feed on. If any of your Ewes yean whilſt the Earth is covered with Snow, that they have not the Opportunity of grazing, you ſhould ſupply the Defect by giving them a greater Plenty of Turnips. If any of your Ewes refuſe to take their Lambs, put the Ewe and Lamb in a cloſe Houſe, and tie a Dog in the ſame Place, and they will own the Lamb immediately.

Excerpts from A Treatise on the Propogation of Sheep and the Manufacture of Wool, *1765, Williamsburg, Virginia.*

Biological Development of The Wool Fiber

■ *Structure of the Skin*

Wool and hair fibers are outgrowths of the integument or skin. Sheep skin is 1-3 mm thick and consists of an outer layer, the epidermis, and a much thicker layer, the dermis, which extends down to the muscle layer (Figure 1). The dermis is also known as the corium. Beneath the skin is a rather loose layer of connective tissue known as the tela subcutanea. Underlying this layer is the panniculus adiposis, a layer of subcutaneous fatty tissue.



(Source: McFadden, 1967)

Figure 1. Histological Drawing of Skin.

■ *General Development of Individual Skin Follicles*

The structure of the wool follicle is best understood if its development is followed in vertical sections of the skin of the unborn lamb and then between birth and up to 12 months of age. The two types of follicles that produce fiber on the sheep are known as primary and secondary follicles (Figure 2). The primaries are usually the largest, and usually arranged in rows in the skin in groups of trios. The secondaries are the most numerous and lie to one side of the primaries. The primary trio with its associated secondary follicles constitutes the follicle group, which is the basic unit of wool production.

The secondaries, being usually the smallest follicles, tend to grow finer fibers than the primaries. The fundamental difference between the two follicle types is that primaries have a sweat gland (sudoriferous gland) and an arrector pili muscle, whereas secondary follicles have neither of these. Both types of follicles have sebaceous (wax or grease) glands. The glands and the muscle are known as accessories and always lie on the side towards which the wool fiber slopes.

In the fetus, primary follicles are formed first (by 100 days), and the secondaries are formed later. All of the primaries have been formed and are growing fibers by the time the lamb is born. Although all or almost all of the secondaries are developed (initiated) before birth, many do not mature (produce fiber) until after birth. Most fol-

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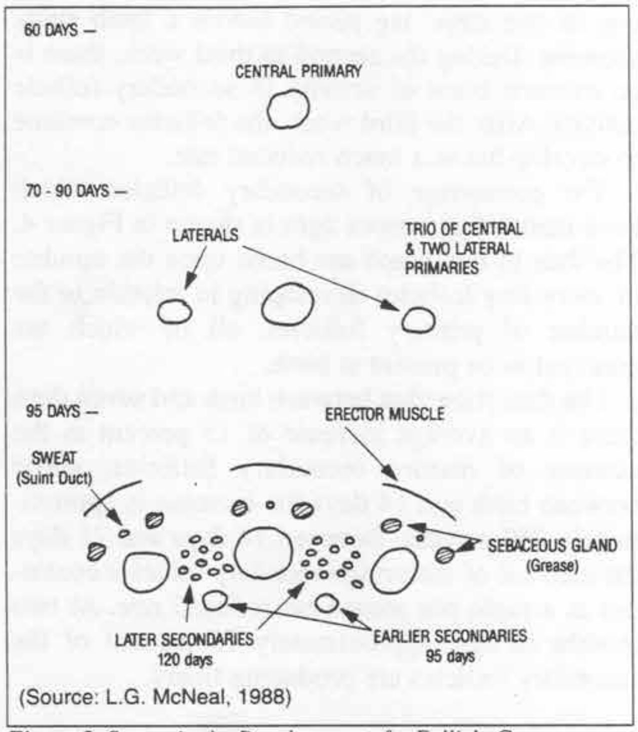

Figure 2. Stages in the Development of a Follicle Group.

licles are producing a fiber by about one month after birth.

■ *Development of the Follicle Population*

The sequence of initiation and the spatial arrangement of the different follicle types is an important feature in the development of the follicle population. The basic unit of measurement of follicle development and population is the trio group. This group of three primary follicles with varying number of secondary follicles develops prenatally and is normally classified into three different periods of development:

1. The Pre-trio Period of Central Primary Follicle Initiation
2. The Trio Period of Primary Follicle Initiation
3. Post-trio Period

Pre-trio Period

Initiation of central primary wool follicles begins on the face and poll about 35 to 40 days after conception. The follicles next appear on the neck, limbs, shoulder, and britch and by 54 to 55 days, central primary follicle precursors (anlagen) are found in these areas. Lastly, between 54 and 63 days, the anlagen appear over the back, midside, and withers. After 60 days of prenatal life, all of the skin is covered.

The average duration of the pretrio period of development is approximately 15 days. This 15-day period is fairly uniform in different regions of the fetal body.

Trio Period

The trio period of primary follicle initiation begins on the fetal face around 63 days. The trio groups are present in all regions of the body by about 75 days and completed in all regions by about 90 days after conception. The trio period differs from the initiation of central primary follicles in that the central primaries appear to initiate the lateral primaries. Thus, during the trio formation, small lateral primary follicles appear on both sides of each central primary.

It is during this period that the sweat glands of primary follicles appear. During the latter stages of trio initiation, sebaceous gland rudiments are formed in association with central primary follicles. The trio period lasts about 15 days in any one region of the fetus. It begins as early as the 55th day of gestation but usually commences on or about the 75th day. It is completed by the 90th day of prenatal life.

Post-trio Period

This period covers the final stages in the initiation and development of the follicle group. Two major aspects of this period are: (1) initiation of the secondary follicle anlagen, and (2) growth and development of the already formed follicles leading to the production of their fibers. This is known as the maturation stage of development to distinguish it from initiation. The post-trio period is the longest of the prenatal periods and occupies the remainder of the time until birth. Following completion of the primary trios, initiation of the secondary follicle anlagen starts at about 90 to 99 days in the different regions of the prenatal lamb. This activity is almost complete at birth.

The number of secondary follicles initiated in this way appears to be about five or six times the number of primary follicles. But it varies in differ-

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ent locations on the body, being lower on the poll and limbs. There are also differences among breeds.

This period brings the most rapid increase in follicle population and culminates in the birth coat of the lamb on or about the 150th day of gestation. By the end of this prenatal period, as many as eight derived secondaries may be associated with the original secondary, and nine fibers may use a single hair canal to reach the surface of the skin. By the time of birth, the follicle group is essentially the same as the adult arrangement. However, most secondary fibers do not emerge from the follicle until after birth. Another phenomenon which occurs at birth or shortly thereafter is the shedding of the fibers from the primary follicles. This shedding occurs first in the central primary follicles and then in the lateral primaries. The increase in area of the trio group covers an indeterminate time but is usually complete by the time the animal is 12 months old.

The density of primary follicles becomes less per unit area as the lamb increases in age (Figure 3). Because all the primary follicles are fully developed before birth, the decrease is a direct result of skin expansion accompanying growth. The greatest decrease in follicle density takes place between birth and one month of age. By the time the lamb is four months of age the major increase in skin expansion has taken place and only a small decrease in primary follicle density is measured between four and 16 months of age.

During the first week after the lamb is born, little activity takes place in follicle development. This period of inactivity is slightly longer than the usual

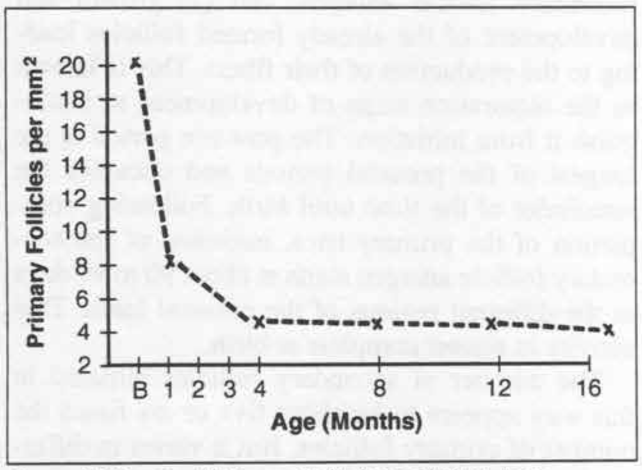

Figure 3. Density of Primary Follicles at Various Ages.

one to two days' lag period before a lamb starts growing. During the second to third week, there is an extreme burst of activity in secondary follicle activity. After the third week, the follicles continue to develop but at a much reduced rate.

The percentage of secondary follicles which have matured at various ages is shown in Figure 4. The data in this graph are based upon the number of secondary follicles developing in relation to the number of primary follicles, all of which are assumed to be present at birth.

The data show that between birth and seven days there is an average increase of 15 percent in the number of mature secondary follicles, while between birth and 14 days the increase is approximately 250 percent. Between 14 days and 21 days the increase of maturing secondary follicles continues at a rapid but somewhat reduced rate. At two months of age, approximately 75 percent of the secondary follicles are producing fibers.

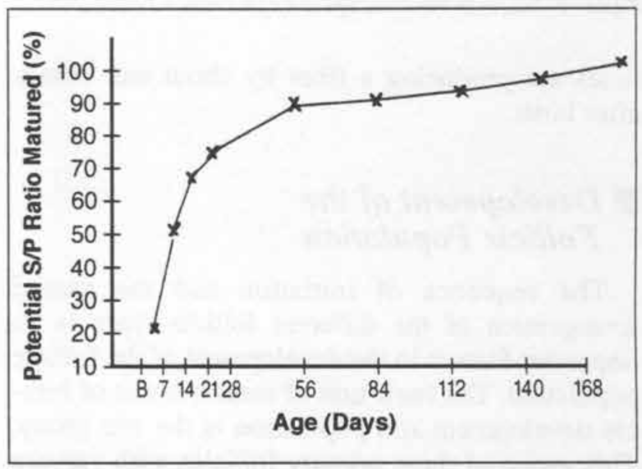

Figure 4. Progressive Percentage of Secondary/Primary Follicle Ratio at Various Stages.

The Secondary/Primary Ratio

The ratio of secondary to primary follicles in a trio group has been found to be a useful indicator of the quality (density and fineness) of wool fiber production in sheep. It is commonly referred to as the S/P ratio. This relationship is not constant among breeds of sheep as shown in Table 1.

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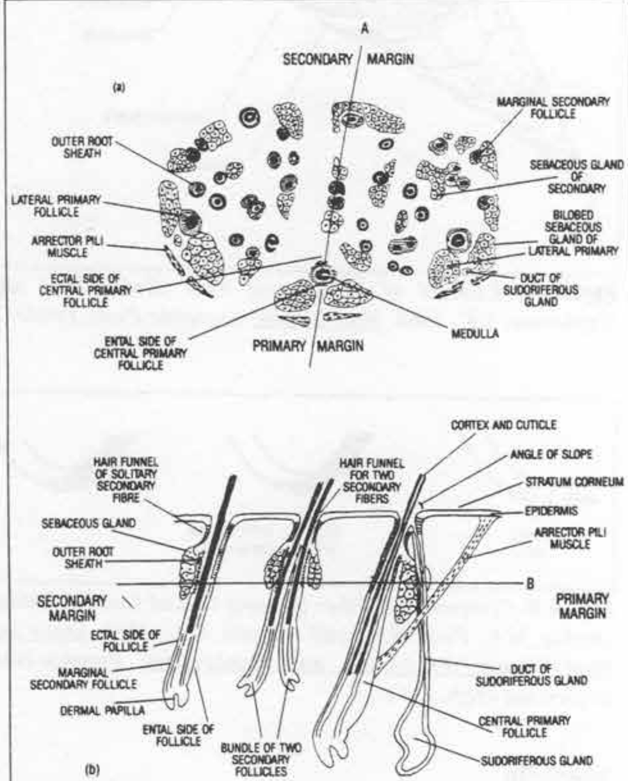
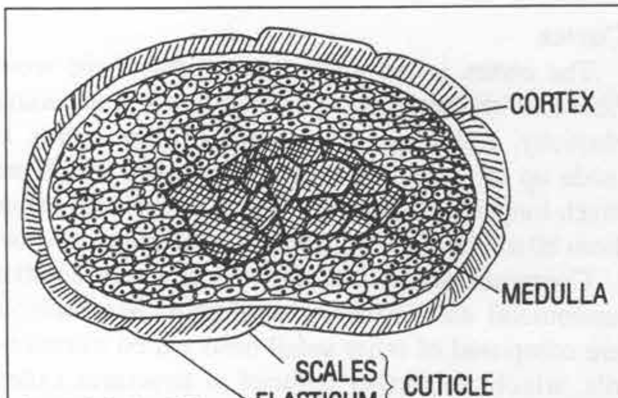
Table 1. Follicle Density, S/P Ratios, and Range of Average Fiber Diameter in Different Breeds of Sheep			
Breed	**Mean No. of Follicles/mm²**	**S/P**	**Average Fiber Diameter Range (µm)**
Fine Merino	71.7	19.1	19-20
Medium Merino	64.4	21.0	21-22
Strong Merino	57.1	16.5	23-26
Corriedale	28.7	10.8	25-31
Southdown	27.8	6.3	24-29
Dorset	18.5	5.4	26-32
Suffolk	20.4	4.8	26-33
Romney	22.0	5.5	32-39
Border Leicester	15.8	4.4	30-38
Lincoln	14.6	5.4	34-41
Cheviot	14.6	4.5	27-33
Wiltshire	11.4	3.3	26-31

Source: Adapted from Wool Handbook, Von Bergen, 1970, and Directory of U.S. Sheep Breeds, ASI, 1992.



(Source: Fraser and Short, 1960)

Figure 5. Diagram of a Follicle Group (a) in Transverse Section and (b) in Longitudinal Section.



(Source: McFadden, 1967)

Figure 6. Cross Sectional Representation of a Medullated Wool Fiber.

■ *Structure of the Fiber*

All wool and hair fibers have a similar gross structure consisting of a thin outer layer, the cuticle, surrounding the cortex which in turn surrounds a central medulla in medullated fibers (Figures 5 and 6).

Epicuticle

The epicuticle is a thin outer membrane covering the cuticle (Figures 6 and 7). It measures approximately 1/100th of a micron (1 micron = 10^{-6} m = 1/25,400 of an inch). When the epicuticle maintains its integrity, it protects the wool fiber from deterio-

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ration or damage due to chemicals and abrasion. The epicuticle also aids in giving wool its water-repellent property.

Cuticle

The cuticle makes up a protective layer of overlapping, flattened cells called scales. Scales encircling the wool fiber range in length from 10 to 30 µm and are approximately 0.5 to 1.0 micron thick. Scales overlap each other slightly and rarely more than two scale layers are found. The edges of scales on fine wools are more prominent than on coarse wools. Coarse wools tend to be smoother and more lustrous than fine wools. The protruding edges of the cuticular scales always point toward the tip of the fiber and are responsible for a differential directional friction effect which in turn produces the unique felting property of wool.

Cortex

The cortex is the major component of the wool fiber and imparts many special properties, including elasticity, resiliency, and durability. The cortex is made up of spindle-shaped cortical cells which are much longer than they are wide. Cortical cells range from 80 to 115 microns long and 2 to 5 microns wide.

Contained within the cortical cells are smaller anatomical units called macrofibrils. Macrofibrils are composed of other small units called microfibrils, which are further reduced to structures called protofibrils. Each protofibril contains three helical molecular chains.

Two types of cortical cells are found in the wool fiber: orthocortical cells and paracortical cells (Figure 7). In fine and many medium wools, the division is bilateral (Figure 8). Each type of cell has different chemical and physical properties. The paracortex is found on the inside of the curve of the crimp and the orthocortex is found on the outside of the curve. Because of this relationship between the cortical cells and crimp, it is believed that crimp is partially under the influence of the two types of cortical cells found in the fiber. The division of the ortho and paracortex is not similar in all breeds and genotypes of sheep (Figure 9).

The orthocortex is referred to as "soft" and has a higher affinity for dyes, whereas the paracortex is referred to as "hard" and exhibits less affinity for dyes.

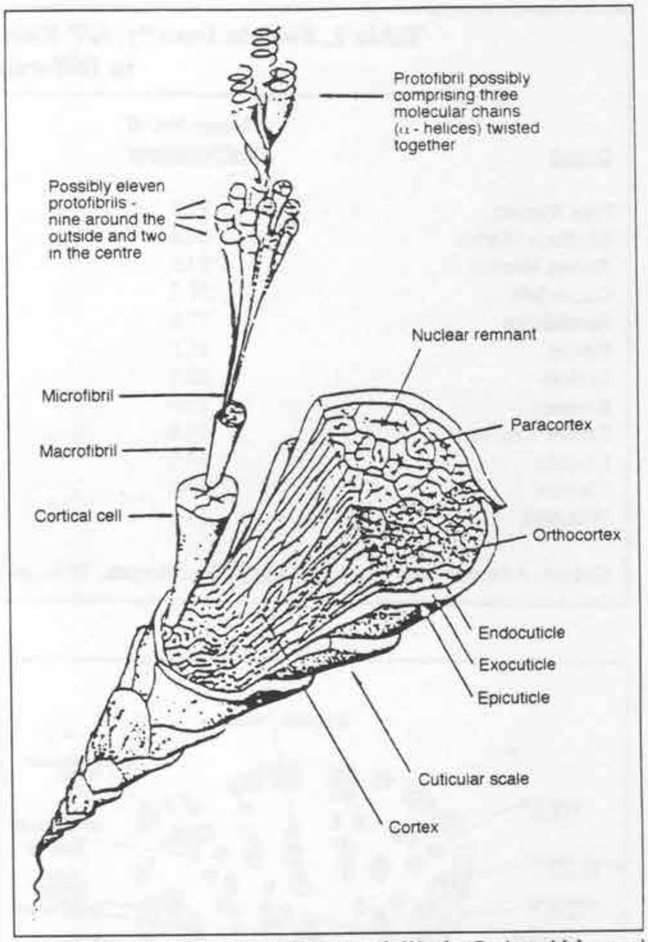

Figure 7. Example of Structure of Wool (Ryder, M.L. and Stephensen, S.K., 1968. Wool Growth, Academic Press, London.)

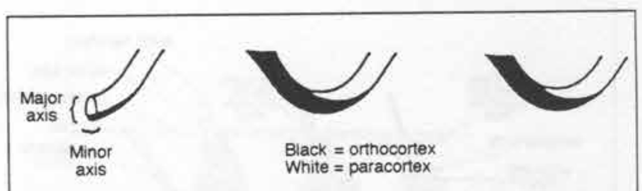

Figure 8. Crimped Wool Fiber Showing Typical Coil Formation. (Botkin, M.P., Field, R.A., and Johnson, C.L., 1988, Sheep and Wool Science, Production, and Management, Prentice-Hall, Englewood Cliffs, N.J.)

Medulla

The medulla, or central core, is found primarily in medium and coarse wools. Wool measuring less than 28 microns in diameter is unlikely to show medullation. Not all fibers coarser than 28 microns are medullated. Medullation is believed to result from incomplete keratinization (fiber cornification). Basically, the fiber is too wide for

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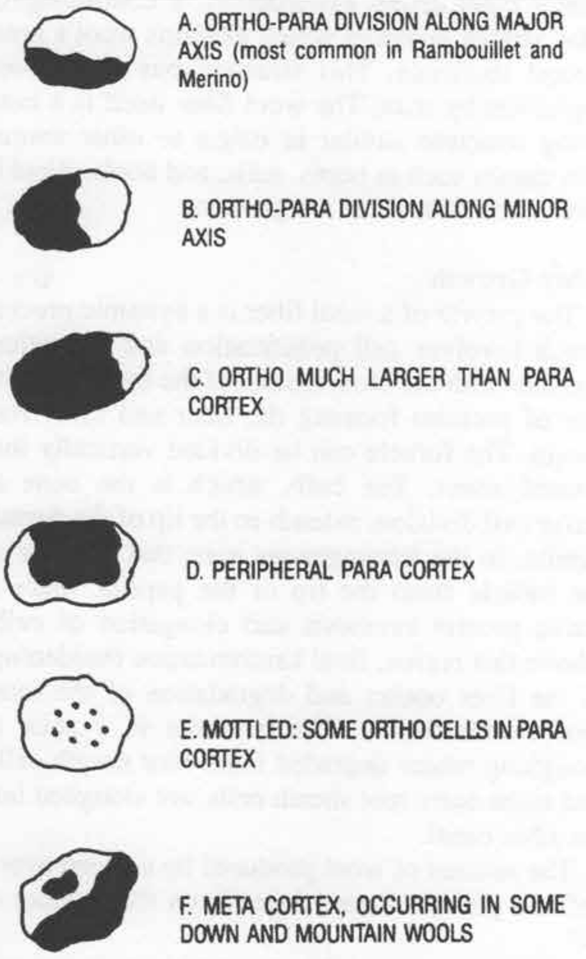
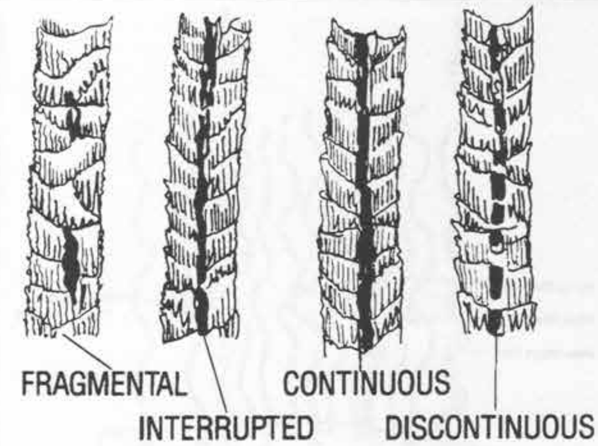


Figure 9. *Some Typical Arrangement of Ortho-paracortex Segments.*

the follicle to fill with keratin and a hollow or spongy core results.

In "kemp" fibers (coarsest fiber grown by sheep), the medulla occupies a major proportion (more than 60 percent or more of the fiber diameter when viewed in longitudinal section) of the fiber. By definition, the medulla of med fibers occupies less volume (less than 60 percent of fiber diameter). In some fibers, the medulla is narrow and not always continuous along the length of the fiber (Figure 10). It also has been found that during the winter months, when wool growth is slower than in other seasons, the medulla may not appear at all.



(Source: McFadden, 1967)

Figure 10. *Types of Medullation Found in Wool.*

Three Types of Fibers Produced by Sheep

Adult sheep produce three main types of fibers: (1) true wool fibers, (2) med fibers, and (3) kemp fibers (Figure 11). True wool fibers can grow from both primary and secondary follicles, depending upon the breed. Kemp and med fibers grow only in primary follicles. Primary and secondary follicles in young lambs can produce a variety of birthcoat fiber types.

This variation in the lamb birthcoat is related closely to the type of fleece that is later grown by the adult sheep.

Wool Fibers

The "true" wool fiber is the fiber and market commodity that is associated with the sheep industry. The main distinguishing features of wool are its lack of medullation and crimp, the degree of waviness. Most commercially produced wool falls into the range of 17 to 40 microns in average diameter. In cross section, wool fibers are somewhat elliptical in shape, increasingly so as diameter increases.

Med Fibers

Med (hair, gare, or heterotype) fibers are medullated and tend to be finer than kemp fibers. Med fibers are usually as long as "true" wool fibers but may lack crimp. These fibers are very difficult to detect with the naked eye.

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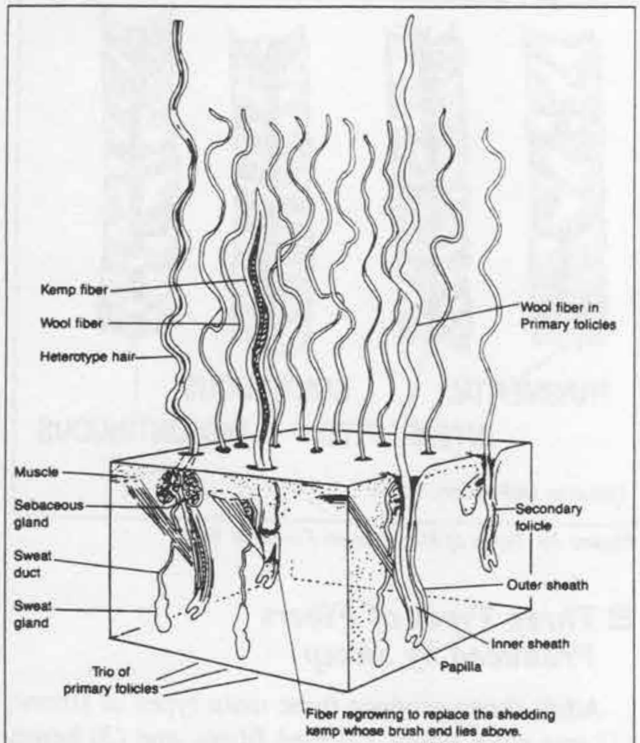

(Source: M.L. Ryder and S.K. Stephenson in *Wool Growth*, Copyright ®1968 by Academic Press.)

Figure 11. Dimensional Drawing Showing a Wool Follicle Group with the Three Types of Fiber and the Two Types of Follicles in the Skin.

Kemp Fibers

Kemps are the coarsest fibers grown by sheep and are typically shed seasonally. Kemps tend to be short, chalky white, brittle, and do not appear to accept dyes well. Kemp is harsh to handle and is undesirable as a fiber grown by fine and medium wool sheep. It should be genetically selected against, unless it is an important characteristic of the sheep being bred, e.g., some carpet wool breeds. Also, kemp is essential in manufacturing tweed fabrics.

■ *General Chemical and Physical Properties*

Chemically, wool is composed of 19 different amino acids combined into keratin-type protein and linked in polypeptide chains (Figures 12 and 13). Nature has folded these chains back upon themselves in such a way that they act like coiled springs. This inner elasticity is in addition to the fiber's outer crimp extensibility, a continuing or relay stretch potential which explains wool's great natural resilience. This structure has never been duplicated by man. The wool fiber itself is a non-living structure similar in origin to other animal skin tissues such as horns, nails, and hoofs. Wool is considered part of the integument.

Fiber Growth

The growth of a wool fiber is a dynamic process which involves cell proliferation and migration, together with the biosynthesis of the complex mixture of proteins forming the fiber and inner root sheath. The follicle can be divided vertically into several zones. The bulb, which is the zone of active cell division, extends to the tip of the dermal papilla. In the keratogenous zone that extends up the follicle from the tip of the papilla, there is active protein synthesis and elongation of cells. Above this region, final keratinization (hardening) of the fiber occurs and degradation of the inner root sheath begins. Finally, there is a zone of sloughing where degraded inner root sheath cells, and some outer root sheath cells, are sloughed into the fiber canal.

The amount of wool produced by a sheep over a defined period of time depends on the number of

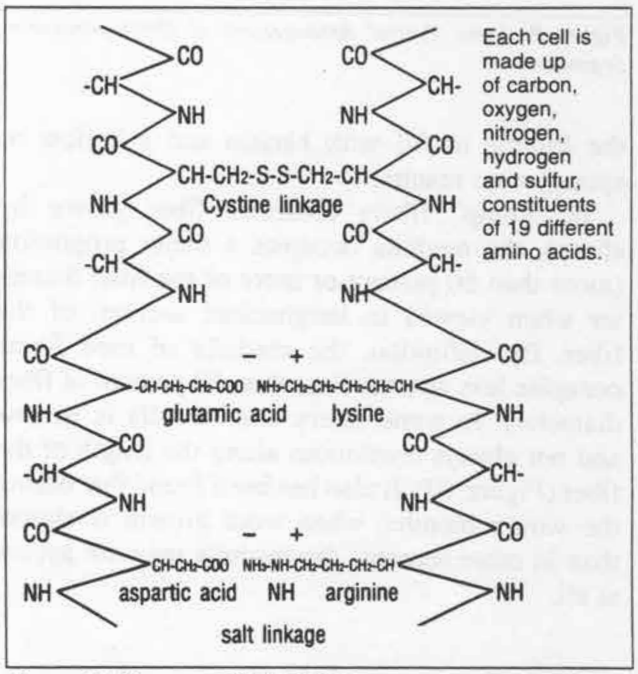

Figure 12. Diagrammatic Representation of the Chemical Structure of the Wool Fiber.

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follicles actually growing a fiber and the rate of growth of each fiber, which in turn is related to nutrition, health, and numerous other factors. Rate of growth can be divided into two components, length and cross-sectional area.

Chemical and Physical Properties

The protein of the wool fiber has been given the name keratin. The chemistry of the wool fiber is not homogeneous within the fiber.

The main molecular chains of wool keratin are capable of assuming two different configurations, depending on whether or not the fiber is in a stretched state. Alpha keratin refers to the molecule in its relaxed state, while beta keratin is the designation of the molecule in the stretched state (Figure 13). Beta keratin is analogous to other fiber molecules, while the alpha type is uniquely associated with wool. There is no chemical difference between the two types. It is a property of beta keratin to reassume the alpha form when stress is removed from the fiber. Therefore, the mechanism of the unusual elasticity of the wool fiber is that of a molecular spring.

Action of Sunlight

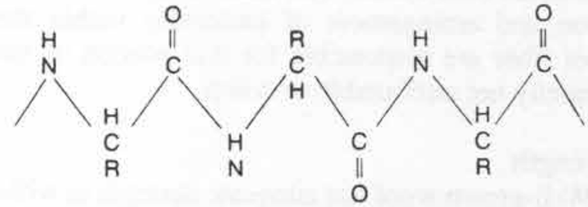
When exposed to ultraviolet rays in sunlight, a photochemical reaction occurs at the disulfide bond and elsewhere in the keratin molecule. A complex sequence of reactions is subsequently expressed by a browning or yellowing of the tips of the exposed wool. This accounts for the "frowzy" tip of crossbred, medium wools which have little grease to filter out the ultraviolet rays of the sun.

Temperature Effects

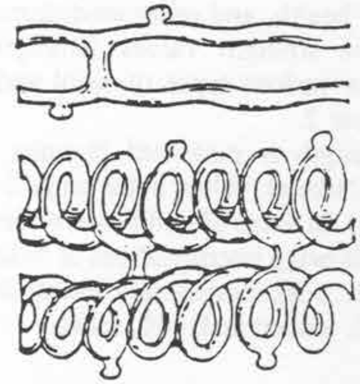
When wool is heated to 212 degrees Fahrenheit (°F) it becomes harsh but regains its soft handle when it picks up moisture. If 212°F is exceeded for any length of time, wool decomposes, acquires a yellow color and eventually turns brown. The extent to which the disulfide bond is affected may be determined by the release of ammonia and hydrogen sulfide. Although wool fibers are self-extinguishing, wool can actually be burned, but only with a very intense heat source. Grease wool burns more readily than scoured wool.

Moderately low temperatures have no effect on the wool fiber. However, under extremely low temperatures (i.e., liquid nitrogen), the fiber becomes very brittle.

Amino Acids (the "building blocks" of wool)
Alanine, Arginine, Aspartic acid, Cystine, Glutamic, Glycine, Histidine, Hydroxylysine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Proline, Serine, Threonine, Tryptophan, Tyrosine, Valine.



These are linked up in polypeptide chains.



Chains are arranged in spring-action folds, or coils.

Figure 13. The Amino Acids in Wool.

Action of Water

When wool is immersed in water, water absorption causes the fiber to swell in both width and length. However, the percentage increase in diameter is greater than the percentage elongation in length. This is because water is not absorbed into the cellular portion of the fiber but rather is absorbed on the surface of the molecule.

Action of Acids and Bases

Because the wool fiber is composed of many amino acids (some of which are acidic and some of which are basic), it is "amphoteric" in its chemical reactivity, i.e., it exhibits both acidic and basic properties. Strong bases readily hydrolyze wool. Wool is more resistant to acids but will hydrolyze in concentrated acids or hot dilute acids.

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Elasticity

The elasticity of the wool fiber is the result of two factors: crimp and molecular structure. Crimp in wool is influenced by the cellular arrangement within the fiber cortex. The basic chemical composition and arrangement of molecules within the wool fiber are responsible for that portion of the elasticity not attributable to crimp.

Strength

Well-grown wool has adequate strength to withstand the stresses and strains of manufacturing processes. The strength of wool fibers is influenced by nutrition, health, and other environmental factors. Relative strength values (strength/unit of thickness) for various types of wool and hair are shown in Table 2.

Staple strength is measured in units of Newtons/kilotex (N/ktex). Values in the range 2-100 have been recorded. In terms of traditional subjective estimates, the following interpretations of N/ktex values are acceptable: >30, increasingly sound; 20-30, part tender; 10-20, tender; and, <10, rotten.

Table 2. The Tensile Strength of Wool in Relation to Other Protein Fibers

Fiber	Relative tensile strength percent
Human Hair	100
Mohair	90
Long Wools	80
Camel Hair	75
Medium Wools	70
Merino Wools	62

Specific Gravity

Wool is among the least dense of textile fibers which permits the production of bulky fabrics of relatively low mass. The specific gravity has been determined at between 1.304 and 1.305. Naturally, medullated wools have a lower specific gravity than non-medullated wools.

Moisture Relationships

Wool is the most hygroscopic of textile fibers and the moisture content of wool varies with relative humidity and the previous history of a particular fiber (Figure 14). For example, a fiber that has previously been bone-dried will contain less water when equilibrated at a specific relative humidity than an identical fiber that was conditioned from a saturated state. The capability of wool to absorb and retain water (resulting in the evolution of a small amount of heat) contributes to the comfort of wool clothes, particularly on damp, cold days. Conversely, the ability of wool to lose moisture to a dry atmosphere (accompanied by heat absorption by the fibers) also contributes to garment comfort, particularly in warm weather.

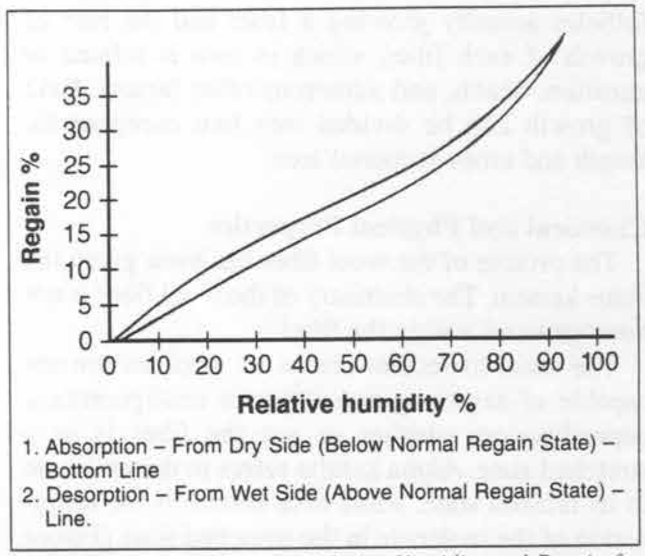

Figure 14. *Relation between Relative Humidity and Regain for Wool at 77°F (25°C).*
Wool moisture regain absorption and desorption are presented as functions of relative humidity. Absorption - From Dry Side (Below Normal Regain State) = Bottom Line. Desorption - From Wet Side (Above Normal Regain State) = Top Line. Source: Wool Research, Vol. 2 - Physical Properties of Wool, ©1955.

Electric Properties

Wool is a poor conductor of electricity but an excellent producer of static electricity in the presence of low relative humidities. At high relative humidities, negligible static electricity is produced. Thus, wearers of wool garments and users of wool carpets in damp climates rarely experience the discomfort of static electricity discharge.

Thermal Qualities

Wool is an excellent insulator. Most people are familiar with the warmth of a wool garment. Actually the excellent thermal qualities of wool are due

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to its physical properties when made into cloth. The crimp, bulk, and resilience of wool allow it to be knitted or woven into fabrics having numerous trapped air spaces which result in a structure of high insulating value. In cold weather, a thick layer of woolen cloth insulates the body against the cold air by means of the tempering effect of water absorbed on the fiber, while in warmer weather a light-weight, high-twist yarn construction allows for rapid wicking and subsequent evaporation of perspiration with its resultant cooling effect.

Value-Determining Characteristics Of Wool

The value of wool is determined to a large degree by its suitability to specific end uses. Conversely, the relative value of different products that can be manufactured from wool has a direct influence on the price paid for the raw material. The price received for a particular grade or quality of wool is further determined by such factors as degree of preparation, and to a greater degree, by world and local supply and demand at the time of sale. This results in short-term, significant changes in wool prices. Despite this, the characteristics that determine wool value at any particular time remain fairly constant. The relative importance of these characteristics has been determined by researchers and textile manufacturers. In general terms, the woolen system of producing yarns is more versatile and less demanding in terms of fiber properties than the worsted system. Consequently, the fiber, style, and fleece characteristics prioritized in Table 3 may be somewhat modified for the woolen segment of the industry. These properties, together with fleece weight, are the same wool characteristics that would be of interest to the sheep breeder.

Table 3. Raw Wool Characteristics Prioritized for the Worsted Industry

Yield	**MOST**
Average fiber diameter	**IMPORTANT**
Quantity and type of vegetable matter	MAJOR
Average staple length	
Staple strength/position of break	
Color	
Colored fibers	
Variability of fiber diameter	SECONDARY
Variability of staple length	
Cotted or felted fleeces	
Crimp/resistance to compression	
Condition of staple tips	MINOR
Age/breed/type	
Style/character/handle	

* Primary source: Australian Wool Corporation

■ *Yield*

Yield is normally quoted in terms of a percentage of clean wool fibers present (CWFP) in a greasy sample. By definition, CWFP is the weight of the wool base present in the raw wool, adjusted to a moisture content of 12 percent, an alcohol-extractives content of 1.5 percent, and a mineral matter content of 0.5 percent. Wool base is bone-dry, extractives-free, wool fibers. Prices paid to producers for grease wool are dependent upon yield. Often this value is subjectively assessed by the woolbuyer. However, there is an increasing trend for this important characteristic to be objectively measured at a commercial testing laboratory, enabling more accurate assessments. It is virtually impossible to evaluate a grease price without knowing the yield. Objective measurement minimizes the growers risk in marketing wool.

Table 4 shows that within an individual breed, a range of yield values is actually present. Thus, a major opportunity exists for producers to select for relatively high-yielding fleeces concurrent with selection for increased clean-fleece weight. It is not uncommon in the major-wool producing countries to find fine- and medium-wool fleeces yielding in excess of 70 percent. The genetic potential is already available in the U.S. and should be utilized to maximize returns from wool.

■ *Average Fiber Diameter*

Average diameter is the most important wool fiber property in the context of quality and value. For coarser wools, diameter has a rapidly decreasing affect on price. Diameter has a major influence on many loose wool, top-making, spinning, and

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fabric properties. For example, as diameter increases, the harshness of loose wool increases while its propensity for felting decreases. In carding and combing, fiber breakage and noil production decrease as fiber diameter increases. The limiting yarn count (direct system) that can be spun from a particular batch of wool, yarn hairiness, and thickness all decrease as fiber diameter decreases. An increase in fiber diameter results in increased fabric harshness, as well as flexural rigidity and abrasion resistance, while fabric felting propensity, breaking strength, and pilling propensity decrease; resistance is unaffected.

The first U.S. grade standards for wool were introduced in 1926. These standards were based entirely on subjective, visual appraisal of average fiber diameter. Recognizing the limitations of this method of quality assessment and with advancements in fiber sampling and objective measurement, the United States Department of Agriculture (USDA) developed and introduced a revised set of official standards for grades of wool in 1966. Assignment of grade is based on objectively determined average diameter and standard deviation (a measure of variability) of diameter. For each of 14 grades, the USDA specifies a range for average diameter and a maximum standard deviation. Samples having standard deviations greater than the specified maximum are downgraded to the next lower grade designation (Table 5).

It is interesting to note that the numbers used to express wool grade are the same as those used in the English Worsted Yarn Count System. When used to quantify yarn count, a number followed by the letter "s" represents the number of hanks (each 560 yards in length) of yarn that can be spun from one pound of top. At one time, it was theoretically possible to manufacture 64s yarn from 64s grade wool. Because of increased machine speeds and greater productivity, this is no longer practical in today's worsted industry. The double meaning of the symbol for count has been a source of confusion for many people involved with the U.S. sheep and wool industries.

The practice of using wool grades for production, marketing, and manufacturing is declining on an international basis. It seems likely that the use of specifications for grades of wool will also decline in the U.S. and ultimately will be replaced by a measurement of diameter (in microns) and variability (standard deviation, also in microns).

The range of average diameter for the major sheep breeds is listed in Table 4. While these are commonly accepted limits, it would not be unusual to find individuals of the breed producing wool that measures outside of these ranges. The breeder is advised to select and breed for uniformity of fiber diameter throughout the fleece. Even in fine wool breeds, there is a tendency for the britch wool to be coarser than the bulk of the fleece. This difference can be minimized by selective breeding. Generally, the bulk of a skirted, fine-wool fleece will be composed of one or two grades of wool. This tendency decreases as the average diameter of the fleece increases. It would not be unusual to find areas representing four or more grades in fleeces from cross-

Table 4. Sheep Breeds, Wool Diameter, Fleece Weight, and Yield Ranges*

Breeds	Range of Average Diameter (µm)	Range of Ewes Grease Fleece wt.(lb)	Range of Yield (%)
Border Leicester	38-30	8-12	60-70
Cheviot	33-27	5-8	50-65
Columbia	30-23	9-14	45-60
Cormo	22-19	10-14	60-70
Corriedale	31-24	9-14	45-60
Debouillet	23-18	9-14	45-55
Delaine-Merino	22-17	9-14	40-50
Dorset	32-26	5-8	50-65
Finnsheep	31-24	4-8	50-70
Hampshire	33-25	6-10	50-60
Lincoln	41-34	10-14	55-70
Merino (superfine)	<18	6-9	60-70
Merino (fine)	19-20	6-11	60-70
Merino (medium)	21-22	9-13	65-75
Merino (strong)	23-26	11-15	65-75
Montadale	30-25	7-11	50-60
Oxford	34-28	7-10	50-60
Rambouillet	23-19	9-14	45-60
Romney	39-32	8-12	55-70
Shropshire	33-25	6-10	50-60
Southdown	29-24	5-8	40-55
Suffolk	33-26	4-8	50-60
Targhee	25-21	9-14	45-60
Texel	33-28	7-10	60-70

*Primary source: Producer Education and Research Council, American Sheep Industry Association

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bred, medium, or long wool breeds of sheep. Consequently, these wools are more difficult to grade and sort.

■ *Quantity and Type of Vegetable Matter*

The vegetable matter base (VMB) of greasy wool is the oven-dry weight of scoured burrs, seeds, twigs, leaves, and grasses, free from mineral matter and alcohol-extractable material, expressed as a percentage of the sample of grease wool from which it was isolated. Vegetable matter is normally reported as vegetable matter present (VMP), which is the VMB adjusted to a moisture content of 12 percent, an alcohol-extractives content of 1.5 percent, and a mineral matter content of 0.5 percent. The American Society for Testing and Materials (ASTM) recognizes five major types of vegetable matter: bean burrs, spiral burrs, sand burrs, cockle-

560 yds hanks per 1 lb wool

Table 5. Specifications for Grades of Wool*

how wool buyers talk

American Blood Grade	Spinning count Grade crimp	Range for Average Fiber Diameter (µm)	Maximum Standard Deviation (µm) variability of fleece
Fine	Finer than 80s	under 17.70	3.59
	80s	17.70 to 19.14	4.09
	70s	19.15 to 20.59	4.59
	64s	20.60 to 22.04	5.19
Half blood	62s	22.05 to 23.49	5.89
	60s	23.50 to 24.94	6.49
Three-eighths blood	58s	24.95 to 26.39	7.09
	56s	26.40 to 27.84	7.59
Quarter blood	54s	27.85 to 29.29	8.19
	50s	29.30 to 30.99	8.69
Low quarter blood	48s	31.00 to 32.69	9.09
	46s	32.70 to 34.39	9.59
Common	44s	34.40 to 36.19	10.09
	40s	36.20 to 38.09	10.69
Braid	36s	38.10 to 40.20	11.19
	Coarser than 36s	over 40.20	

*ASTM Standard Specification D 3991

burrs, and shives (a composite of small plant fragments and slivers).

The presence of an excessive amount of vegetable matter in raw wool is regarded as a defect and the wool is discounted accordingly. Discounts are justified by the extra mechanical and/or chemical processes to which the wool must be subjected in order to remove the plant parts, as well as the resulting weakness and brittleness of the fibers which cause excessive fiber breakage and waste in carding (see carbonizing, page 1154). The vegetable and non-wool content of major wool lines can be minimized by careful management and by skirting off bellies, topknots, cheek wool, and crutchings.

■ *Average Staple Length*

Staple length of wool is categorized into three classes: staple, French combing, and clothing (Table 6). There are no official USDA or ASTM specifications for length classes, and individual buyers may require lengths differing from those of Table 6. The length of wool fibers (which is highly correlated with staple length) determines primarily which system may be used to spin the fibers into yarn, i.e., worsted, woolen, and short-staple (cotton) systems.

Fine-wool sheep, in particular, have been

Table 6. Staple Length Requirements by Grade

Grade	Length Class: Staple	French Combing	Clothing
64/70s	2-3/4" and longer	1-1/4" to 2-3/4"	Less than 1-1/4"
60/62s	3" and longer	1-1/2" to 3"	Less than 1-1/2"
56/58s	3-1/4" and longer	2-1/4" to 3-1/4"	Less than 2-1/4"
50/54s	3-1/2" and longer		Less than 3-1/2"
46/48s	4" and longer		Less than 4"
36/40/44s	5" and longer		Less than 5"

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selected and bred to produce staples longer than three inches. The selection pressure on this trait should not be over emphasized, however, since exceptionally long wool provides no technical advantage to the manufacturer. In fact, production lots containing wool staples longer than five inches can cause serious problems in manufacturing. Most of the longer wools are combed into worsted-type yarns. However, some staple length wools are processed on the woolen system. There are no real mechanical limitations governing the length or diameter of fibers used to produce woolen textiles.

A highly significant linear relationship exists between the staple length of sound wools and average fiber length in top. In turn, fiber length in top has a major influence on spinning speeds, yarn count, yarn uniformity, and, ultimately, yarn quality. Thus, mean staple length is also a very important, value-determining characteristic of wool.

■ *Staple Strength/Position of Break*

Wool fiber strength is a major factor determining the strength of yarns. It also has an important effect on the percentage of short fibers (noils) formed and mean fiber length (hauteur) in top making. Low tensile strength in the form of "tender wool" and "broken wool" is the greatest contributing factor to fiber loss. The term "broken wool" is used when staples pull apart very easily and in a specific position. This type of fault is associated with stress-causing environmental influences such as changes in nutrition, the production status of ewes, severe weather, or diseases, all of which limit nutrient availability to the root bulb. In comparison, tenderness in wool is indicated when the overall strength is low and the staple breaks over a wider, indefinite area compared to a clean break.

Wool is discounted once a buyer determines subjectively that it contains breaks or is tender. The position of the weakness along the staple is also important in assessing price. Although objective measurement is possible, it is not commercially available in the U.S. at this time. Australian growers are receiving premiums for wools that have been tested for staple strength (and length) using the Automated Tester for Length and Strength (ATLAS) instrument.

■ *Color*

The lack of color in wool is of importance when the fibers are not to be dyed or are to be dyed to pastel shades. White wools offer a broad dyeing range without bleaching and are, therefore, more valuable to the textile industry. A high degree of whiteness can be obtained in a clip only by skirting out all the urine-stained and fecal-contaminated wool. Many spinners are now specifying minimum whiteness of the tops they purchase.

Production of colored wools is a specialized segment of the industry catering primarily to handspinners and weavers. This subject is discussed in a later section of the chapter.

■ *Colored Fibers*

The presence of colored fibers in white wool is extremely detrimental to value since it limits the utility of this wool to products that will be dyed to medium or dark shades. The source of these colored fibers—whether it is the sheep themselves (i.e., naturally pigmented, urine-, or fecal-stained) or from other species—is irrelevant from the point of view of the manufacturer. Lots containing an excessive number of colored fibers receive discounted prices. The presence of colored fibers is most critical and undesirable in bleached white, natural, and pastel shades. Even two or three colored fibers per square yard can be grounds for rejection of a fabric by a quality-conscious cutter. Colored fibers can be eliminated in white fleeces by selection, management, and wool preparation practices.

■ *Variability of Fiber Diameter*

Compared to average fiber diameter, variability of diameter has a relatively minor influence on spinning performance, yarn, and fabric properties. However, in the U.S. system of grading wool by diameter, an excessively high standard deviation of diameter requires a sample to be downgraded. This is a rare occurrence even in "choppy," poorly prepared wools. High variability of diameter may be indicative of low quality fine wool stock and/or poor blending practices prior to the manufacturing stage. In such cases, yarns and fabrics may be

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excessively hairy and prickly. "Coarse edge" is a term used by the textile industry to describe the abnormal but significant presence in a fine wool clip of coarse (one and one-half times mean diameter) fibers. Levels in excess of 1.5 percent are reported to cause excessive "ends down" or disruptions of worsted spinning of "critical" yarn counts. This "coarse edge" results in a reduction of spinning efficiency and should be actively selected against. Prickle in fabrics worn next to the skin has been shown to be caused by fibers coarser than 30 μm. These fibers do not readily bend when pressed next to the skin, thus causing a prickling sensation.

■ *Variability of Staple Length*

This characteristic, though moderately genetic, is also related to staple strength, weak or tender wool, and/or poor shearing. Collectively, these factors contribute to length variability in top. Normally, top makers specify the coefficient of variation of fiber length in the top, because it has a small but significant effect on spinning performance and yarn properties. The producer can minimize length variability through adequate selection, management (skirt belly, leg, head, and other short wool), good shearing practices (no second cuts), and health maintenance practices (healthy sheep produce sound wool). Wool with coefficients of variation of staple length less than 12 percent are considered to have very good uniformity.

■ *Cotted or Felted Fleeces*

Cotted or felted wool arises when loose fibers bind with other fibers in the fleece to form a felted mass. Fine fibers having abnormally low crimp are particularly susceptible to this fault and animals exhibiting uncharacteristically low crimp levels should be culled. Cotting can also cause severe problems in long wool breeds. Cotted and matted fleeces are discounted because, like tender wool, they are wasty. When carded and combed, these fleeces produce an excessive amount of card waste and comber noils because fibers break when torn apart in processing.

■ *Crimp*

Crimp and fiber diameter are usually highly and inversely correlated. Subjective assessments of wool fineness are usually influenced more by crimp than by actual diameter. Nevertheless, visual appraisal of crimp frequency and definition still forms an important part of buying strategy in the U.S. The influence of crimp in processing, yarn, and fabric properties is poorly understood and controversial. Low-crimp wools tend to entangle and felt during the scouring process. Excessive nepa production in carding and combing may be associated with excessive fiber crimp. Crimp is highly correlated to resistance to compression and bulk, properties that are sometimes measured to give an indication of crimp. Producers should cull animals with uncharacteristic (too little, too much) crimp for corresponding grade.

■ *Minor Characteristics*

Weathered fiber tips break in carding and are removed as either card waste or noilage in combing. In either case, the yield of top is reduced. Excessively weathered tips can be associated with an inadequate amount of protective wool grease or excessive exposure to rainfall, alkaline soils, and sunlight in fleeces that lack density. However, it has been shown that fine-wool sheep with tippy fleeces tend to be lower yielding and more prone to fleece rot in higher rainfall areas.

When most of the other value-determining characteristics are known, the age/breed/type characteristics of the sheep are of only minor importance. If, on the other hand, only age/breed/type information is available, it at least provides a general indication of the ranges that may be expected for the more important fleece and fiber properties.

Handle is closely related to average fiber diameter. Style and character are both characteristics of uncertain definition for which no objective measurement techniques currently exist. Style is dependent upon vegetable matter content, staple strength, tip damage, color, crimp, alignment of fibers in the staple, and dirt penetration. Character is related to style and in particular to crimp definition, regularity, and configuration of the staple tip. These are terms best understood and used by wool buyers. Attempts are being made to measure these elusive characteristics using image analysis technology.

A Timeline for the Ewe and Her Lambs

The Ewe

DAYS 0–7 ➡
Greatest risk of embryo loss due to heat and humidity stress

DAYS 30–90 ➡
Critical period for placental and mammary gland development. Reduced fetal growth, birth weights, vigor, and lower milk production result from poor nutrition at this time. Macro- and micro-mineral supplementation is vital. Impairment cannot be made up for later.

DAY 60 ➡
Booster vaccination (following pre-breeding vaccine) protects ewe against chlamydiosis and vibriosis abortions

DAYS 100–BIRTH ➡
Nutritional demands of fetuses place greatest demand upon ewe

DAY 120 ➡
Vaccination against respiratory, clostridial diseases and tetanus stimulates high level of antibodies in colostrum, (forming by about day 136). Periparturient rise of internal parasite egg production: deworm to protect lambs.

BIRTH ➡
Colostrum production ceases; 24–36 oz available to lambs.

DAYS 21–28 ➡
Maximum milk production attained. Maximum production requires maximum nutrition. Feed best hay, match grain amounts to number of nursing lambs.

DAY 60 ➡
Many ewes producing less than half of the amount of milk they produced at peak production.

0 DAYS FROM CONCEPTION
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150 OR BIRTH
10 DAYS AFTER BIRTH
20
30
40
50
60
70
80
90
100

The Lambs

⬅ **DAYS 20–24**
Embryos implanted in uterine wall

⬅ **DAY 35**
First primary fiber follicles form

⬅ **DAYS 60–63**
Most primary fiber follicles formed; lateral primary follicles begin to form

⬅ **DAYS 90–100**
Secondary wool follicles begin forming

⬅ **DAYS 100–BIRTH**
70% of fetal growth occurs

⬅ **DAY 120**
Fetal lambs immunocompetent: capable of forming some antibodies

⬅ **BIRTH**
Antibody-rich colostrum (received within 24 h of birth) provides passive immunity for up to 10 weeks; primary follicle fibers shed

⬅ **DAYS 7–14**
Lambs begin eating creep feed; some rumen function by day 14; 250% increase (from birth) in growth/maturity of secondary follicles

⬅ **DAYS 28–42**
Lambs convert from high-milk, low-feed to low-milk, high-feed diet

⬅ **DAYS 42–56**
Rumen becomes fully functional; lambs vulnerable to coccidiosis (add coccidiostat to feed)

⬅ **DAY 60**
75% of secondary follicles growing fiber; lambs vulnerable to high parasite loads (deworm)

⬅ **DAY 70**
Disease immunity of lambs, gained by colostrum, depleted (vaccination vital)

⬅ **DAYS 91–98**
In vaccinated lambs, antibody titers peak; booster of vaccine at this period "confirms" to immune system that antibody production is important

Compiled by Martha Polkey

If you would like to join a network of Virginia wool producers, and participate in future educational and marketing initiatives, please fill out the form below, copy and send or email to Martha Polkey (address below).

Name ____

Farm name ____

Address ____

City, state, zip ______________________________________

Phone ____

Email ____

Website ____

AREAS OF INTEREST

- ☐ Cooperative marketing
- ☐ Cooperative production value-added wool products
- ☐ Virginia Make It With Wool competition
- ☐ Wool Handling School
- ☐ Wool Classing School
- ☐ Wool speakers
- ☐ Other: ____

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