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THE RELATIONSHIP OF EWE BODY MASS

TO LAMB PRODUCTION

by

Sebhatu GebreIul

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Animal Science

Approved:



UTAH STATE UNIVERSITY
Logan, Utah

1984

ACKNOWLEDGEMENTS

This study is a final product of enormous amount of assistance from several people. A particular note of appreciation goes to my major advisor, Dr. Warren C. Foote, for the interest, support, and gentle but firm guidance he gave me throughout the study. Without his tolerant attitude, generous assistance and constant encouragement, this study could never been even attempted, let alone completed. I would like to thank him not only for taking the time to share his considerable knowledge with me, but also for being a friend who showed uncommon compassion and humanity at all times.

I would also like to sincerely thank my committee members for their invaluable assistance: Dr. James A. Bennett and Dr. Jeffrey L. Walters for donating many hours of their time in reviewing critically the progress of the work; Dr. Ronald V. Canfield for providing me with the insight of multivariate statistical techniques; and Dr. Thomas D. Bunch for his constant encouragement.

I am happy to acknowledge many of my friends who volunteered their time and ideas to help me in this research. Alma Maciulis, R. Cole Evans, Cesar Novoa, and Michael J. Huie assisted in measuring sheep in Logan as well as in Cedar City. Thanks also goes to Habtemichael Fissehaye and Getachew Belaineh.

I would also like to thank the ADVS department (USU) for providing me with financial assistance during the course of the work.

Finally, but certainly not the least, I would like to thank my lovely wife, Tebletz Emabye. From her reflection and demonstration of love and care, I found the hope, strength, and harmony that guided me through the wilderness during this past year and half. I am very grateful, Tebletz, and this work is dedicated to you.

Sebhatu Gebre1ul

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NOMENCLATURE

Genotypes

T=Targhee

F=Finnsheep

S=Suffolk

TXT=Targee X Targhee ewe, sire indicated first

FXT=Finn X Targhee ewe, sire indicated first

SXT=Suffolk X Targhee ewe, sire indicated first

Linear Body Measurements:

HW=Head width, cm

HL=Head length, cm

CW=Chest width, cm

CD=Chest depth, cm

BL=Body length, cm

HP=Hip width, cm

MT=Metatarsus length, cm

Carcass Measurements

HCW=Hot carcass weight, kg

CCW=Chilled carcass weight, kg

BF=Back-fat thickness, cm

KF=Kidney fat, kg

KK=Kidney knob, kg

CWS=Chest width, cm

CDS=chest depth, cm

BLS=Body length, cm

HPS=Hip width, cm

Weight and Size:

CS=Condition score, 1-9 pts

EBW=Ewe body weight, kg

BS=Ewe body size, cc

MBW=Metabolic body weight, kg to 0.75

MBS=Metabolic body size, cc to 0.75

Reproductive and Productive Traits:

PROL=Prolificacy, number of lambs born

WNRT>Weaning rate, number of lambs weaned

TWLB=Total weight of lamb born per ewe lambing, kg

WBBW=Weight of lamb born per unit ewe body weight, %

WBMW=Weight of lamb born per unit ewe metabolic body weight, %

NOMENCLATURE (continued)

WBBS=Weight of lamb born per unit ewe body size, %
WBMS=Weight of lamb born per unit ewe metabolic body size, %
TWLW=Total weight of lamb weaned per ewe lambing, kg
WWBW=Weight of lamb weaned per unit ewe body weight, %
WWMW=Weight of lamb weaned per unit ewe metabolic body weight, %
WWBS=Weight of lamb weaned per unit ewe body size, %
WWMS=Weight of lamb weaned per unit ewe metabolic body size, %

Partial Correlations

EBW/CS=Partial correlation of EBW with trait X adjusted for CS
EBW/BS=Partial correlation of EBW with trait X adjusted for BS
BS/EBW=Partial correlation of BS with trait X adjusted for EBW
BS/CS=Partial correlation of BS with trait X adjusted for CS
CS/EBW=Partial correlation of CS with trait X adjusted for EBW
CS/BS=Partial correlation of CS with trait X adjusted for BS

Miscellaneous

\bar{X} =Mean (Average)
CV=Coefficient of variation
CR=Coefficient of reliability
REP=Repeatability
SV=Source of variation
DF=Degree of freedom

ABSTRACT

The Relationship of Ewe Body Mass
to Lamb Production

by

Sebhatu GebreIul, Doctor of Philosophy
Utah State University, 1983

Major Professor: Dr. Warren C. Foote

Department: Animal, Dairy and Veterinary Medicine

Body size was estimated by multiplying the average of the hip and chest widths by body length and chest depth in 208 ewes of three genotypes: Targhee x Targhee (TXT), Finn x Targhee (FXT), and Suffolk x Targhee (SXT), and two seasons, fall (pre-breeding) and spring (post-lambing). The estimated ewe body size did not fluctuate with season, body condition or physiological stress and proved to be a constant measure of size. Measuring linear body dimension is time consuming; and hence ewe body size can best be approximated by the chest depth in a regression equation. In the absence of linear measurements, the ewe body weight remained to be the best measure of size.

In evaluating relationships, there was a tendency for ewe body size and weight to be positively ($P < .05$) related to reproductive traits and body condition to be negatively ($P < .05$) related. The heavier ewes were more prolific in the FXT ewes and the lighter ewes in the SXT ewes, the

TXT ewes being intermediate. Lamb production on per unit size or weight bases tended to be negatively ($P < .05$) related with weight and/or size in all the three genotypes. This relationship was stronger in the SXT ewes than in the TXT ewes, which in turn was stronger than in the FXT ewes, suggesting that the heavier/larger the ewe the less she produced in relation to her weight or size.

(148 pages)

INTRODUCTION

The role of sheep and goats in agricultural development plans is particularly important in less developed countries where there is inadequate levels of quality and quantity food. In developed countries, the sheep with its existing level of production of 1.0 to 1.5 lambs/ewe/year (Wilson, 1968) has almost been eliminated from any agricultural plan aiming at the intensification of production of animal protein. The potential is, however, considerable, 10 lambs/ewe/year. So far not more than 15% of this potential has been realized. In the future, it seems that net farm income could be increased through sheep because of greater opportunity to increase efficiency in sheep than in other classes of livestock. Sheep may become more efficient than most classes of livestock due to greater prolificacy, earlier puberty, shorter gestation period, and potential for reduced lambing interval.

Specific differences among sheep breeds have been noted in conception rate, embryo mortality, weight at birth and weaning, age at puberty, growth rate, lambing rate, ovulation rate, ovulation response to hormone treatment, body weights, etc. These large differences in productive and reproductive performance traits make possible the opportunity of increasing both efficiency and quality of lamb production through crossbreeding, and thus the production of an ideal genotype for each management and environmental system (Alonso, 1978). Among others, crossbreeding and selection have long been advocated as useful tools to that end.

There seems to exist a trend in sheep production to increase body weight to increase production in the USA. The same trend in increase in size is also true for beef cattle. The selection for heavier cattle among the purebreeds, infusion of blood from European beef and dairy breeds are responsible for the increase in size in beef cattle (Bennett, unpublished). Larger breeds of sheep have greater wool bearing area, give birth to larger lamb(s) and give more milk, and hence efficient meat and wool producers; while Large (1970) believed that the highest efficiency is obtained from smaller but more prolific ewes mated to larger breeds of ram. In general, however, the question of optimum body size was, and still is, debatable.

Among mammals in general, perhaps the most conspicuous difference is their size. A 4,000 kg elephant is a million times as large as 4 gm pygmy shrew, and the largest living mammal, the whale, can be another 25-fold larger. The question, "why do animals come in so many different sizes?", has interested both scientists and agriculturists equally. An animal farmer in particular is interested in an answer to the question, "Is there an optimum size that may maximize the yield of meat or milk or wool from a given amount of food?" (Taylor, 1977). The answers to these questions may, however, be linked to bioenergetics.

Larger or smaller body size may have important biological adaptation to climate, feed resources, seasonal grazing and marketing. In general, in hot and dry climates, with scarce seasonal grazing, the genetically smaller animals presumably are better adapted to forage, and

mature, reach market finish, and reproduce earlier than larger ones. Conversely, larger body size may have advantage in tolerance of cold stress and in more efficient use of abundant food supply. Environmental conditions that are conducive to larger size also contribute to higher level of production; thus larger cows may produce more milk, not simply because they are large, but because they are generally maintained under better conditions than smaller ones (Dickerson, 1978). Energetically, larger animals are more efficient than smaller ones because of smaller surface area per unit volume and smaller heat production per unit weight. On the other hand, smaller animals can convert food into animal protein at a faster rate, as demonstrated by Kleiber (1961). It seems, therefore, that from adaptation and energetics points of view, there is some advantage to being large and some advantage to being small.

The question of how much efficiency of productivity is dependent on body size has been repeatedly asked and debated by several researchers, breeders, productionists, etc., for several years; and if there were any optimum size we would have found it through trial and error during this time (Klosterman, 1972). The primary question of concern is what body size itself is. Most use the liveweight of the animal measured at some point of the life cycle as the expression of body size because the scale weight of an animal is relatively easy to get. This has a serious drawback as it usually ignores the condition and conformation of the animal. For instance, a 50 kg thin ewe could be taller and/or longer than a 50 kg compact, fat ewe. Some linear measurements and their combinations may sometimes be superior to express body size. Such measurements could

include the height at withers, body length, chest width and depth and many others. The usefulness of such measurements in estimating body size, however, depends on the accuracy in measurement procedures (Johansson, 1964).

The productivity of the ewe is composed of the weight of the fleece and the weight of lamb she produces; the latter being determined by the fertility, prolificacy, weaning rate and body weight of the ewe and the growth rate and survivability to weaning and market age of her lamb(s). The liveweight of the ewe is a function of both the skeletal size and the degree of fatness (Geisler and Fenlon, 1979) and is often the principal criteria for selection in replacement ewes. It is highly heritable with relative ease of measurement, and therefore widely used for selection purposes (Nicholas and Whiteman, 1966). The cost of producing lamb to weaning should include the amount of feed required by the breeding ewe during pregnancy and lactation, over and above her maintenance requirement. Except under controlled experimental conditions, it is usually not practicable to apportion the feed consumed by the ewe in order to estimate cost, but several calculations and estimations show that the maintenance requirement of the breeding ewe is about 75% of the total annual requirement. As the maintenance requirement is related to its metabolic body weight ($W^{3/4}$; Brody, 1945), the size of the breeding ewe may have a major impact on efficiency. Most sheep researches aim directly or indirectly to increase litter size in order to improve efficiency in meat production. Little emphasis is given to ewe body weight or ewe body size, although it is known to be a major component of effi-

ciency. More detailed investigations on the relationship of body size to production is, therefore, indispensable. It should first be admitted, however, that such a study is complex as it does not fall to any particular scientific discipline. On the contrary, it represents a realm of endeavors in which many varied disciplines must integrate and converge.

As body weight is a function of both body size and condition (Geisler and Fenlon, 1979), an experiment that relate linear measurements to body size and thus to production function of ewes is suggested. This could help provide specific information on the relationship of body size to production and thus define the role of ewe body size in production efficiency in sheep. Moreover, the information so gathered would also help develop a more precise indicator for estimating body size of sheep in particular, and other farm animals in general.

REVIEW OF LITERATURE

Physiology of Body SizeSurface area and body weight

Metabolism can broadly be defined as the biochemical process that makes it possible for the cell to continue living with the primary concern of making the energy in food available to the various physiological systems of the cell (Guyton, 1976). Basal metabolism, on the other hand, has been defined as the minimum energy cost when an animal is at rest in a thermoneutral environment and in a postabsorptive nutritional condition (Brody, 1945). Postabsorptive condition eliminates the rumen microflora metabolic contribution. The definition of basal metabolism implies standard conditions for measurement rather than minimum metabolism for life. The energy required to maintain life during basal metabolism tests is used to meet the cost of circulation, respiration, excretion, secretion and maintenance of muscle tone. Fasting metabolism is basal metabolism but not corrected for activities (Blaxter, 1962).

Metabolic rate can be measured in a variety of units. The units most commonly used are the volume of O_2 consumed by an animal per unit time (cc O_2 /hr; litres O_2 /day) and/or the heat in kilocalories lost by an animal per unit time (Kcal/hr, kcal/day) (Gordon, 1972). For purposes of comparing animals of different sizes, the volume of O_2 consumed (or kilocalories of heat liberated) is divided by the weight of an ani-

mal being measured. This gives the weight-relative or weight-specific metabolic rate (hence, O_2 /hr/kg or kcal/hr/kg) (Gordon, 1972). One liter of O_2 is approximately equal to 4.825 kcal and hence conversion from one unit to the other is easily employed.

The body of an animal is a mass subjected to gravitation force and this measured force has been expressed as the live weight of the animal (Moen, 1981). The live weight of the animal is composed of the metabolically active tissues (e.g. fat, muscle), tissue that have ceased major metabolic activity (e.g. hair, horn, bone, hoof), and ingested material that has not yet been digested and absorbed (Blaxter, 1962).

Interpretations of basal metabolic rate (BMR) have been made by physiologists for many years, and numerous disagreements have arisen over its relationship to surface area or body weight. The "surface area law" was formulated because heat loss from any object is proportional to its surface area, and since heat production must be proportional to heat loss if homeothermy is to be maintained, it was concluded that heat production must be proportional to surface area. The first evidence of the surface law was published by Rubner in 1883 (cited by Blaxter, 1962). Rubner (1883) measured the fasting metabolism of mature dogs ranging in weight from 3 kg to 31 kg and found that BMR per kg body weight decreased with increasing weight but when expressed per unit surface area, the same amount of heat (approx. 1000 kcal/sq.m/day) was produced. Several theories have been developed to explain this relationship and the five major ones were summarized by Kleiber (1947) as follows: 1) heat transfer between the animal and its environment is proportional to

the body surface area, 2) the intensity of flow of nutrients is a function of the sum of internal surface which is proportional to body surface, 3) the rate of oxidizable material is a function of the intensity of blood current, which is proportional to the area of the blood vessels, which in turn is proportional to body surface, 4) the anatomical and chemical composition of animals is a function of size; and hence the larger the animal the smaller the ratio of metabolically active to metabolically inert organs, and 5) the cells of the body have inherent requirement of oxygen consumption per unit weight, which is smaller the larger the animal. Kleiber (1947, p.524) pointed out that only two of the five theories were sound: the theories of heat transfer(1) and blood circulation(3), and integrated them into one, "In natural selection, those animals probably prove to be the fittest whose cells are adapted to such a level of oxygen consumption that the metabolic rate of the animal is most suitable for the maintenance of a constant body temperature and in line with more efficient transport of oxygen".

The one important factor in the surface law is the ill-definition of surface area itself (Kleiber, 1932; Brody, 1945). A standing animal has a greater exposed surface area than the same animal lying down or curled up. Thus, the exposed surface area of an individual is variable, and if one considers the complexity of heat exchange by radiation, conduction and evaporation, it becomes clear that exposed surface area is only one of several parameters operating on heat exchange and regulation (Moen, 1981). There is a list of surface-related processes within an animal: the uptake of oxygen in the lungs (Schmidt-Nielson and Larimer,

1958), the diffusion of oxygen through the capillaries (Schmidt-Nielson and Pennycuik, 1961) and food uptake in the intestines (Umminger, 1975) are few examples. In fact, all cells have exposed surfaces and the membrane processes must be related to the areas of these exposed surfaces. But, with regard to thermoregulation, Kleiber (1961) stated that if a steer was designed with a metabolic rate of a mouse, to dissipate heat at the rate it was produced, its surface temperature would have to be well above the boiling point. Conversely, if a mouse was designed with the weight-related metabolic rate of a steer, it would need to have surface insulation of at least 20 cm thick to keep it warm. Gordon (1972) pointed out that rates of heat loss through the body surface are neither passive nor constant as they are under physiological control; heat loss per unit area differs in the various parts of the same animal's body and it is not physiologically possible for exposed surface area to be the control mechanism for metabolic rate, since metabolic rate is under the control of a complex array of subcellular, endocrine, and neural factors. Thus, a simple relationship observed empirically between exposed surface area and heat production can hardly be called a "law" in view of the many associated variables (Taylor, 1977).

Kleiber (1932, 1961) and Brody (1945), both impressed by the difficulty of measuring exposed surface area, suggested that BMR would best be expressed as a power of body weight. Brody (1945) measured metabolic rates of species ranging in size from the mouse to the elephant and metabolic rate varied with 0.73 power of the body weight. Kleiber (1932) analyzed the relationship of metabolic rate and body weight of mammals

and birds ranging in size from the rat to the steer and found that BMR was more closely related to the weight in kilograms raised to the power of $3/4$ than to the power of $2/3$ ($r = 0.98$ vs 0.71). This relationship, called Kleiber's relationship or Kleiber's law has been invaluable in comparing a magnitude of metabolic dependent parameters of mammals of different weights and has served as a model for many anatomical and physiological comparisons (Taylor, 1977). According to Kleiber (1947) positive correlation exists between metabolic rate and body weight and negative correlation between metabolic rate per unit body weight and body weight.

Using Kleiber's relationship, a gram of tissue of a 25 gram mouse produces and loses heat at about 20 times the rate of a gram of a 4,000,000 gram elephant (Taylor, 1977). Thus, despite the fundamental uniformity at the cellular level and close similarity at the organ level in structure and function (Gordon, 1972) the BMR per unit weight decreases markedly as body weight increases. The positive correlation of BMR to body weight and the negative correlation of BMR to unit of body weight is now common knowledge to a student of biology. This relationship can be mathematically expressed in general terms as follows (Kleiber, 1961):

$$M = aW^b, \text{ as an exponential function, or}$$

$$\log M = \log a + b \log W,$$

where:

$$M = \text{BMR in kcal/day or cc } O_2/\text{g/hr}$$

M = BMR in kcal/day or cc O_2 /g/hr

W = Weight of an animal

a = constant, intercept

b = exponential

This equation states that, for each doubling of body weight, BMR increases approximately 68%, when $b = .75$. Though there has been little controversy over the values of W and a, because they are matters of experimental measurements, the value of b has been a center of controversy. Published values of b have ranged from .66 to .8. Brody and Procter (1935) suggested a value of .734, the National Research Council adopted the value of .73 in 1935, Brody's unit was .7 in 1945 and Kleiber (1961) used a value of .75. Though Kleiber's argument in using .75 was because it is mathematically simpler (which nowadays may not be regarded as a valid argument), the National Research Council adopted Kleiber's value in 1966. Thus, the body weight in kilograms raised to 0.75 power, measures the metabolic body weight of an animal in $kg^{3/4}$ power. Under standard conditions, the metabolic level of an adult homeotherms, from mice to cattle, averages $70 \text{ kcal/kg}^{3/4}/\text{day}$ or $2.92 \text{ kcal/kg}^{3/4}/\text{hour}$.

The equation above also states that the rate of oxygen consumption or the heat production per gram body weight is higher in small animals than in large animals, when $b=0.75$. But the weight of the animal, as indicated above, is composed of both the active and relatively inactive tissue. A disproportionate increase in the relatively inactive tissue with increasing total weight would perhaps result in an apparent decrease in weight-specific metabolic rate. However, the differential growth

of the inactive tissues, while known to occur (Bertalanffy, 1957), cannot account for the smaller per gram metabolic rate of larger animals when compared to smaller animals. The contribution of skeletal weight associated with increased body size accounted only for 7% of the decrease in metabolic rate in the shrew (Ultsch, 1974).

Physiology of the power law

The fact that the metabolic rate of small animals is higher than larger ones means that the cells of the smaller animal must be supplied with oxygen and nutrients at a higher rate than the larger animal. Schmidt-Nielson and Larimer (1958) studied the oxygen dissociation curves of mammals ranging in size from the mouse to horse and reported that the dissociation curve is related to body size in such a way that the blood of the smaller animal has a higher unloading tension for oxygen. Schmidt-Nielson and Larimer (1958) further reported that the slope of the oxygen dissociation curve becomes steeper and steeper as the animal decreases in size and related their finding to the higher metabolic need for oxygen of the smaller animal; the oxygen consumption was about 15 times as high in the mouse (22.8 g) as in the horse (544 kg). In order to supply oxygen to the cells at this high rate it was necessary that the diffusion gradient from capillary to the cell be 15 times as high. The diffusion gradient is composed of two variables, the diffusion distance from capillary to the cell and diffusion head; and a higher diffusion gradient can only be accomplished by shorter diffusion distance and higher diffusion head, both characterized by small animals

(Schmidt-Nielson and Larimer, 1958).

According to Schmidt-Nielson and Pennycuik (1961) a higher rate of oxygen delivery in the small animal can be accomplished by higher capillary density and higher unloading tension for oxygen, in which both vary in a way that oxygen delivery is facilitated in the small animal. The higher rate of oxygen delivery is explained by the Bohr-effect (blood acidification). Riggs (1960) studied the Bohr-effect in mammals of different sizes and found that Bohr-effect decreases with increasing size. Larimer and Schmidt-Nielson (1960) measured the concentration of carbonic anhydrase enzyme, an enzyme responsible for the acidification of the blood for higher unloading tension of oxygen, and found that the concentration of this enzyme in the red blood cells was significantly higher in the cells of smaller animals than in cells of larger animals, and hence the Bohr-effect in relation to body size was explained. Dunaway and Lewis (1965) counted the red blood cells in animals ranging in size from 5.4 g to 1381 g and found that red blood cell count per cubic centimeter was inversely related to body weight of the animals investigated.

In summary, as body size declines, capillary density in muscles increases, blood unloads oxygen under a higher oxygen pressure, the Bohr-effect becomes more pronounced, carbonic anhydrase concentration in the red blood cells increases and finally, the red blood cell count increase; when all are integrated, they facilitate a higher rate of oxygen delivery to the cells of the small animal. The secretion of the thyroxine hormone, a hormone responsible in metabolism, also increases with

decreasing size (Macfarlane, unpublished report).

As much as efficient oxygen delivery is required by the small animal to satisfy its high metabolic demand, an efficient nutrient delivery is also required. Kleiber (1947, p. 524) wrote, "In natural selection, those animals probably prove to be the fittest whose cells are adapted to such a level of oxygen consumption that the metabolic rate of the animal is most suitable for the maintenance of a constant body temperature and in line with more efficient transport of oxygen". To determine if there is any meaningful relationship between body size and circulating nutrient levels in animal, Umminger (1975) surveyed biological literature to accumulate values for whole blood sugar concentration (in mg/100 ml) for a series of 73 mammals ranging in size from a 6 gm bat to a 500 kg eland and found that the concentration of sugar was negatively correlated with body weight and that this negative correlation was related to the higher weight-specific metabolic demands of small animals. Umminger (1975) further reported that the increase in circulatory levels of sugar with decreasing body size indicated at least some nutrients are supplied to the cells of small animals in concentrations greater than for larger animals. The low blood sugar levels of ruminants could then be explained not only because of their peculiar digestive physiology, but also because they are large with low weight-specific metabolic rate (Umminger, 1975).

The weight of the animal is the summation of both metabolically active and relatively inert tissues. Welch et al. (1958) studied the relationship of oxygen consumption with various body components and found

that the correlations with total body weight, fat-free weight, and active tissues were 0.63, 0.85 and 0.91, and accounted for 35, 41 and 41 percent of the variation respectively. According to Ultsch (1974) about 7 percent decrease in metabolic rate was attributed due to an increase in skeletal weight associated with an increase in total body weight. Miller and Blyth (1956) studied subjects (human) of approximately the same weight but differing in linear body dimensions and body composition and reported that the metabolic cost of lifting the body was proportional to gross body weight with slight contributions from height or fat content. Miller and Blyth (1956) further reported that the correlation between metabolic cost and height, lean body mass, chest circumference and abdominal circumference were insignificant when the influence of body weight was eliminated, and thus, the contribution of body measurements and body composition to metabolic cost was largely due to their respective correlations to body weight.

Despite the tremendous variation in body weight, the lungs, heart, kidneys, and other major organs show much similarity in morphology and function in mammals of different sizes (Gordon, 1972). Most mammals have about 5-6 g/kg body weight as heart (Holt et al., 1968). Stahl (1967) collected data from the literature on respiratory variables and correlated them against body weight on the assumption of a log-log relationship and found correlation coefficients ranging from 0.90 to 0.99 for all respiratory variables and justified his finding by stating that in any complex mechanical-chemical system, such as the mammals, there must exist deterministic relationships between the total system size and

basic dimensional variables. Taylor (1980, p. 30) wrote, "Inputs such as food or oxygen; production outputs such as meat or milk; unproductive outputs such as gases or heat; time intervals such as gestation length or lifespan; metabolic tempo as exhibited by respiration rate or pulse rate - all these features, when examined over a range of different genotypes, show remarkable uniformities in their relationship to body weight".

Mathematical justification of the power law

McMahon (1973) used a mathematical approach to describe size and shape in biology. In relation to metabolic rate, McMahon (1973, pp. 1203-4) used the following mathematical logic to arrive at Kleiber's law: "Suppose a muscle, whose cross-sectional area is A , shortens a length Δl against force σA in time Δt . The power this muscle expends is $\sigma A \Delta l \Delta t$, where σA is the tensile stress developed, and is in general a function of the shortening velocity, $\Delta l / \Delta t$. Both σA and $\Delta l / \Delta t$ may be taken as constants,...., then the power output of a particular muscle and hence all the metabolic variables involved in maintaining the flow of energy to that muscle depend only on its cross sectional area, A . But this area is proportional to d^2 , (d is the diameter and weight(W) is proportional to ld^2 , where $l^3 = d^2$, and implies d is proportional to $W^{3/8}$) and hence maximum power output is proportional to $(W^2)^{3/8}$, which is $W^{3/4}$ ". With regard to total body surface area, MacMahon (1973) mathematically showed that surface area is proportional to $W^{5/8}$ and not to $W^{2/3}$ as it was traditionally accepted since the time of Rubner (1883).

Reproduction and Metabolism

McNab (1980) outlined physiological parameters in relation to reproductive output in small mammals and argued that the rate of metabolism varies with body mass and food habits; growth rate, gestation period and the number of offspring vary with body mass and metabolic rate; and finally, the population growth constant (r) varies with body mass, growth rate, gestation period and number of offspring. Though McNab (1980) admitted that correlations were easy to discover but separating causes and effects were more difficult, he concluded that in an animal with large body mass and low rate of metabolism, the reproductive output is relatively small while in an animal with smaller body mass and high metabolic rate, the converse was true. Levin (1982) stated that a high metabolic rate permitted a fast growth rate in the uterus because the synthesis of anything in the body is enhanced by high metabolic rate and thus positively correlated with reproductive output. Fenchel (1974) found a relation between the rate of natural increase (r) and body weight (W) of the form $r = aW^b$, where r was explained as a measure of the potential productivity per unit weight, a =constant and b =exponent. The fraction r /metabolic rate per unit weight measured how much an animal spent for reproduction relative to how much it spent for maintenance, and this fraction tended to increase with increasing body weight (Fenchel, 1974).

Reproductive Efficiency and Lamb Production

Reproductive efficiency is one of the most important traits to be considered in any specie of livestock raised for food or fiber (Sidwell and Miller, 1971), and yet the most difficult to improve as it is highly affected by environmental factors as evidenced by its low heritability (Turner, 1969; Lasley, 1972). The potential for increasing reproductive efficiency in sheep relates to increasing the number of lambs born per ewe and the frequency of lambing (Glimp, 1971). The lamb production (defined as the weight of lamb weaned per ewe) will then be determined by the reproductive efficiency of the ewe, the growth rate, weaning weight and survival of the lamb to market age (Sidwell et al., 1962).

Fertility, prolificacy, number of lambs weaned and marketed, and the total weight of lambs weaned and marketed were studied with Romnelet, Columbia, Suffolk and the North Country Cheviot breeds of sheep and their crosses (Vesely and Peters, 1974) and it was found that fertility was improved by crossbreeding ($P < .05$) but prolificacy was not. In this study, the total weight of lamb weaned per ewe during their lifetime averaged 149.5 kg for the Suffolk, 146.6 kg for the Romnelet, 119.0 kg for the Columbia, and 92.1 kg for the North Country Cheviot. Vesely and Peters (1974) further reported that longevity of the ewes was highest for the Romnelet and Columbia breeds and lowest for the Cheviot and at the end of 8 1/2 years of production, the percentage of ewes remaining in the Romnelet, Columbia, Suffolk, and Cheviot breeds were 22, 25, 5, and 0, respectively.

Differences in fertility, prolificacy and livability were studied in the Hampshire, Shropshire and Merino sheep breeds and their crosses and significant breed and breed-cross effects were found in fertility where the Merino and Hampshire were the most fertile (Sidwell et al., 1962). Among Columbia-Southdale, Targhee, Suffolk and Dorset breeds of sheep, Sidwell and Miller (1971) found the Targhee to be the most fertile, and the Columbia-Southdown to be the most prolific. In agreement with Sidwell and Miller (1971), Carter et al. (1971) found the Targhee to have the best overall reproductive performance in respect to the total weight of lamb weaned.

In Hampshire, Willamette (50% Columbia, 25% B. Leicester and 25% Dorset Horn), and Suffolk studied under two management systems, Hohenboken et al. (1976) calculated average fertility of 88.6 percent over all breeds and that fertility was not affected by management system, year, breed of dam or sire, or any other factor except by breed of dam x management system interaction. West et al. (1973) found no significant fertility difference between hormone treated and control ewes, and reported that hormone treatment seemed to adversely affect fertility in the Suffolk ewe lambs in particular. Humes et al. (1978) also reported lower reproductive values for hormone treated ewes and higher for control where the values for the latter were 77.9, 148.7, and 118.5 percent for fertility, prolificacy and weaning rate, respectively.

Atkins (1980) studied the Corriedale, Polwarth, South-Australian Strong-wool Merino, Peppeni (medium wool) Merino and Border Leicester x Merino and reported that the average number of lambs born per ewe joined was 0.96, 0.85, 0.78, 0.88, and 1.22, respectively; the proportion of ewes producing multiple births was significantly higher ($P < .05$) for half-bred (62%) than the purebreds (26-33%). Ewes of all possible reciprocal crosses between the Hampshire, Suffolk and Willamette breeds were compared with contemporary purebreeds for production as ewes lambs (Hohenboken and Cochran, 1976) and heterosis percentages of 25, 10, 14, and 30 for fertility, prolificacy, weight of lamb weaned/ewe lambing and weight of lamb weaned/ewe joined, respectively, were found. Hohenboken and Cochran (1976) further reported that of the total crossbred advantage for weight of lamb weaned/ewe joined, 58 percent was attributed due to heterosis for fertility, 23 percent due to heterosis for prolificacy and 19 percent due to maternal effect on lamb weaning weight.

Levine and Hohenboken (1978) studied lamb production in the Suffolk and Columbia dams and found little or no difference in fertility but the Suffolk dam bore 0.08 and weaned 0.08 more lamb than did Columbia and that lambs born to the Suffolk dam weighed 0.3 kg more at birth and 3.2 kg at weaning, with significant ($P < .05$) difference. In the same study, the Suffolk dam weaned 8.2 kg more lamb/ewe joined. The excellence of the Suffolk dam over Dorset was also reported in other works (Sidwell and Miller, 1971; Dickerson and Glimp, 1975), but Bradley et al. (1972) found that the Suffolk was inferior in terms of fertility and livability while Targhee was superior as exhibited in weight of lamb born per ewe

exposed.

Dahmen et al. (1978), when working with Panama and Finn x Panama ewes fed three levels of energy, reported 93 percent fertility in both breeds but the number of lambs born per ewe lambing and per ewe joined was 1.74 and 1.86 versus 1.21 and 1.31, respectively, ($P < .01$) with 41 percent more lambs born in the crossbred ewes. Similar results of the range of 40-50 percent advantage from the Finnish Landrace sheep are reported (Goot and Maijala, 1977; Duncan and Black, 1978; Walton and Robertson, 1974; and Speedy and FitzSimons, 1977). Dahmen et al. (1978) also reported that more lambs were weaned per ewe lambing and per ewe bred (1.62 and 1.50 vs 1.20 and 1.16, for Finn x Panama and Panama, respectively, $P < .01$), but in total weight of lamb weaned per ewe bred, although the crossbreds weaned more (49.9 vs 39.9 kg) the difference was not statistically significant ($P > .05$).

Matthews et al. (1977) found significant main effects of breed, age and year in total weight of lamb weaned per ewe. Among the three breeds Matthews et al. (1977) studied, (Targhee, Suffolk x Targhee, and 3/4 Suffolk x Targhee), the 3/4 Suffolk x Targhee was highest in weight of lamb born/ewe and in weight of lamb weaned/ewe (8.00, 6.77 and 6.14; 57.69, 48.43 and 45.63, for 3/4 SxT, SxT and TxT, respectively). Hohenboken et al. (1976) when studying genetic, environmental and interaction effects with three breeds of sheep - Hampshire, Suffolk and Willamette - reported overall average of 56.1 and 51.5 kg of lamb weaned per ewe lambing and per ewe bred, respectively. Hohenboken et al. (1976) further reported that the Suffolk breed tended to be lower

in percent fertility, Hampshire lower in lamb production per ewe; and heterosis for weight of lamb weaned per ewe lambing and per ewe bred were 8.6 and 13.5 percent, respectively. In a three years crossbreeding study conducted to evaluate the reproductive performance of several breeds and cross breeds, Humes, et al. (1978) reported that the percent of lambs weaned per ewe favoured straight-bred native breeds over the crosses; and Rambouillet x Native were the most fertile but the least prolific.

Among the 16 independent variables included in the model, Hohenboken et al. (1976) found only six, namely year, birth date, age of ewe, ewe body weight and breed of sire to be important source of variation for prolificacy, while Hohenboken and Cochran (1976) reported that prolificacy, which averaged 1.12, was not affected by any the genetic, environmental effects or interactions except for breed of dam and location interaction. The mean prolificacy over all breeds and crossbreeds was 1.64 (Hohenboken et al., 1976) and was negatively correlated to ewe body weight, contrary to what Torell et al. (1972) reported and positively correlated to date of lambing in agreement with other workers (Glimp et al., 1968, for example), who showed that lambing rate increased as the normal lambing season progressed.

Reproductive performance was studied in Sardinian crossbreeds with 25, 50 and 75 percent East Friesian inheritance (Boyazoglu et al., 1979) and was found that the performance was similar on the 25 percent East Friesian and the purebreeds, but the 50 percent and 75 percent East Friesians were significantly better; the 75 percent had the highest

litter size (1.63 vs 1.18 for purebreds), but the lowest pregnancy rate (88.5 vs 96.9 percent) and their progeny had the highest mortality rate (15.87 vs 8.17 percent). In another study, (Carter et al. 1971), the means for lambs born per ewe exposed were 1.45 and 1.47 for $3/4$ Hampshire x Rambouillet (HxHR) and North Country Cheviot x Border Leicester (NCxL) ewes, respectively. The study was conducted under two locations, Glad Spring and Ottawa, and difference in location was significant but neither breed nor breed x location interactions were significant. For the number of lambs born alive, Carter et al. (1971) reported 1.32 and 1.39 for HxHR and NCxL ewes at Glad Spring, and 1.44 and 1.66 at Ottawa, respectively.

In crossbreeding study in Israel, the lambing percentage averaged 64, 81, and 80; number of lambs born per ewe bred 0.80, 1.17, and 1.12; and proportion of multiple birth 24, 41, and 30 percent, respectively, for the German Mutton Merino, and their, F_1 and F_2 crossbreds (Goot, 1975). In 1978, in Sweden, the performance of 69154 ewes in 2031 flocks representing 48 percent of the total ewe population, the total number of lambs born and weaned per ewe averaged 1.82 and 1.65, respectively, and total lamb weight weaned per ewe ranged from 44.9 to 57.3 kg (Brasch, 1979).

In Mandya sheep breed in India, for AA and BB blood type ewes, the lambing percentage was 100 and 93 ($P < .01$) and weaning percentage was 83.3 and 85.5 ($P > .05$), respectively, (Bhaskar et al., 1978).

Size and Shape

McCurley and McLaren (1981) employed the principal component analysis to study the relationships of body measurements, body weight, age, and degree of fatness to size index (as defined by the coefficients of the principal components) and performance in Hereford and Angus cows and their progeny, and they found that the first two components (for size and shape) accounted for 72.5 and 67.2 percent of the total variance for cows and calves, respectively. For the same two beef breeds and nine skeletal measurements plus weight for three age groups, Brown et al. (1973) found that the first two components to account for about 75 percent of the total variance in size and shape. Brown et al. (1973) also found a significant correlation between the second principal component (for shape) and the three age groups (4, 8, and 12 months, for calves), and this significant correlation indicated that shape remained almost constant over age. Jolicouer and Mosimann (1960) have postulated that size of most organisms was more affected than shape by fluctuations of the external environment. Carpenter et al. (1978) studied mature Hereford and Charolais cows and reported that the total variance accounted by the first two principal components was about 85 percent. The first principal component was highly correlated ($r=0.93$) with mature body weight and Carpenter et al. (1978) explained this correlation as an evidence of using the body weight as a measure of cow size.

According to Brown et al. (1973), about 40 percent of the variation of the ten body measurements was explained by shape and this variation was interpreted to mean that extreme length was offset by decrease in depth and height, extreme height was offset by decrease in depth, and width was attained by sacrificing depth. Brown et al. (1973) further reported that due to lack of consistency of weighing between length and height in the second principal component, there was more variation in length in cattle of different heights and widths than there was in width for cattle of different heights and lengths.

In a stepwise regression, calf weaning weight (at 205 days) and calf shape index were mostly affected by calf fat thickness and cow weight ($R^2 = 10.7$ and 8.9 percent, for weaning weight and shape, respectively); calf wither height by calf fat thickness and cow wither height ($R^2 = 6.5$ percent); and calf size index by calf fat thickness, cow weight and cow shape index ($R^2 = 12.7$ percent) (McCurley and McLaren, 1981).

Wiener and Hayter (1974) studied body size and conformation from birth to five and one-half years of age in five sheep breeds - Scottish Blackface, Cheviot, Welsh Mountain, Lincoln Longwool, and Southdown, and their crosses (not all possible combinations) and crosses with Tasmanian Merino, and reported that the Cheviot and Southdown were wider at the chest and hip and shorter in the legs; the Lincoln Longwool was long at the legs; the Merino were narrow at the body; and the Welsh Mountain was narrow and short. Wiener and Hayter (1974) concluded that there was a

significant breed variation in shape and conformation which was independent of body weight.

The use of principal component analysis and/or factor analysis as a tool to describe shape and size in sheep, to the author's knowledge, is very scarce.

Growth and Body Composition

Growth is the multiplication and enlargement of cells (followed by differentiation) governed by growth hormone. The growth hormone, known as somatotropin, is a small protein molecule containing 188 amino acids in a single chain and having a molecular weight of 21,500 (Guyton, 1976). Brody (1945) defined growth as the relatively irreversible time change in magnitude of the measured dimension of function. Although the exact mechanism is not yet known, somatotropin brings about growth by enhancing amino acids transportation through the cell membrane, by enhancing protein synthesis by the ribosomes, by increasing formation of RNA and by decreasing catabolism of proteins and amino acid (Guyton, 1976). Growth usually begins slowly, becomes more rapid for some time, then slows down and finally stops yielding the characteristic S-shaped growth curve (Keeton, 1969).

Blaxter (1962) stated that fat and water content of the body are inversely related, and that in the fat-free body, the proportion of protein, water and ash change with age. In sheep containing less than 31 percent fat, the amount of protein, water, ash, and energy increased li-

nearly with increasing body weight; above this concentration of fat, the amount of water and protein increased at decreasing rate and the amount of fat and energy at increasing rate, as body weight increased (Burton and Reid, 1969).

In studying growth in sheep, Searle and McC.Graham (1972) suggested that the relationships between the various body components (water, protein, ash and energy) and body weight can be described in terms of four phases - milk feeding, rumen development, prefattening, and post-fattening phases. Body composition was determined from tritiated water space in the Camden Park Merino, Peppin Merino and Border Leicester x Merino breeds of sheep, (Searle and Griffiths, 1976) and the final fattening phase of growth commenced at mean liveweight of 22, 26, and 32 kg with average body fat content of 5.4, 5.1 and 6.2 kg, respectively. Searle and Griffiths (1976) further reported that at any given liveweight, the amount of fat was greatest in the Camden Park Merino and the least in the Border Leicester x Merino and was suggested that the only way to satisfy the preference of heavy, lean carcass is to use animals of large mature weight. In the Scottish Blackface and Finnish Landrace, Russel (1972) found no difference in total chemical fat in relation to fleece-free empty body weight, but significant difference in the rate of deposition at different depots where the Scottish Blackface deposited relatively more fat in the muscle.

Blaxter et al. (1982) studied growth in sheep to maturity and reported that body weight in sheep increased asymptotically and eventually

plateaued; the asymptotic weight defined as A in the equation $W = A - Be^{-kt}$ (where W was the weight in kilograms at time t , and B and k were constants), was related to mean daily feed intake, which in turn was proportional to $W^{3/4}$. Blaxter et al. (1982) further reported that the gain of the empty body in the sheep they studied consisted of 68 percent lipids, eight percent protein, one percent ash, and 24 percent water where the lipids in the carcass accounted for 88 percent of the total lipid gain and half of the accretion of the protein and ash was in the carcass.

Wiener and Hayter (1974) studied linear dimensions from birth to five and one-half years of age in five sheep breeds and reported that the body measurements differed in their rate of maturity such that 90 percent of the mature size was reached before six months for cannon bone and tibia length, 10-11 months for height and shoulder width, 13 months for body length and 14-15 months for hook width.

Workers have long used the condition score of an animal as a degree of fat cover of the animal in relation to its size (Evans, 1978; Russel et al., 1969; for example). When animals are scored, rather than measured, the high degree of subjectivity may lead to assessor's bias, a tendency for some assessors to score consistently high or consistently low (Evans, 1978) and suggested that the score be given by a single expert assessor, the mean score be given by participating assessors, or the mean score be give for all the experienced assessors.

Letting w be the weight of an animal in kilograms, s its condition score and f the percent fat in the fleece-free empty body, Russel et al. (1969) developed an equation that relates percent fat and score as $f = 8.69 \pm 2.69 + 2.54 (r = 0.94)$, or in terms of body weight, $f = 0.61w - 12.64 \pm 4.45 (r = 0.81)$. Sykes (1974) used body weight, red cell volume and tritiated water space to predict body fat and reported that body weight alone accounted for 46 percent of the variation, body weight and tritiated water space for 77 percent of the variation and inclusion of red cell volume did not improve prediction. According to Sykes (1974), total body fat (kg) can best be estimated by $f = 4.70 + 0.65 w - 0.64 TWS (r = 0.88)$, where f , w , and TWS , were respectively, total body fat in kilograms, weight of an animal in kilograms and tritiated water space.

In terms of effects of fat in the body, McC.Graham (1969) studied sheep groups that differ in percent fat and found that the most obvious effect of fatness was loss of appetite; net efficiency (the ratio of energy balance to metabolizable energy intake) was independent of fat, but gross efficiency (the ratio energy stored to gross energy intake) was influenced. The effect of fat-free body weight, age, prior growth rate and prior nutrition on BMR were examined and found to be significant contributors to BMR in the young lamb (McC.Graham et al., 1974) while McC.Graham (1969) found simple correlation between BMR and lean body weight but no evidence of age, breed or body condition contribution to this correlation. This could be due to the fact that equations commonly used to remove the effect of weight and component differences on metabolic rate in older animals, when applied to younger animals did not

usually yield satisfactory results (Blackmore, 1969).

Size and Production

Sheep

Information on comparison of genetically larger versus genetically smaller ewes in terms of lamb production, and particularly when production is measured per unit body weight and per metabolic body weight, is relatively scarce. On the other hand, the effect of nutritionally induced liveweight on ovulation rate, fertility, prolificacy, total lambs per ewe, and mortality is adequately documented (Quirke, 1979; Mavrogenis et al., 1980; Curll et al., 1975; for instance).

Ducker and Boyd (1977) argued that the liveweight of the ewe is a combination of both body size (skeletal) and body condition, and live weight may not and could not be a good indicator of body condition as a particular live-weight can be achieved in many ways, such as nutrition, and ewes of an average weight may be small in good body condition or large in poor condition or any degradation between these two extremes. Coop (1962) suggested that liveweight exerts two independent effects, a "static" effect due to the level of body weight at mating and a "dynamic" or "flushing" effect due to increasing body weight at mating.

Ewe liveweight, and functions related to body weight, such as growth rate and milk production, can have both biological and economic effects in the efficiency of production (Large, 1970). Large (1970) defined efficiency as the ratio of weight of carcass of lamb weaned per

100 units digestible organic matter consumed and argued that the latter was a function of body weight and thus maximum efficiency may be attained when a genetically larger breed of ram was mated to genetically smaller breed of dam, producing large and fast growing offspring(s). But birth weight, if large enough to cause difficulty in parturition may also contribute to poor maternal performance (Alexander, 1964) and hence to efficiency.

Guerra et al. (1972) studied the effect of components of body weight on reproductive efficiency on mature Merino ewes of large and small body weights and reported that the big ewes had more multiple ovulations than small ewes (14/41 vs 6/53, $P < .01$) and there was a significant relationship between ovulation rate and body weight. In a similar study, however, Ducker and Boyd (1977) found that liveweight did not significantly affect ovulation rate of the ewes, and although the larger ewes were 25 percent heavier than the smaller ewes, the ovulation rate and the number of lambs born were only influenced by changes in liveweights and body condition. In Guerra et al. (1972) study the liveweight of the ewe was significantly related to both ovulation rate and incidence of multiple ovulations, and thus prove to be a more effective predictor of ovulation rate than either body size or body condition. Ducker and Boyd (1977) found liveweight per se was not a good indicator of ovulation rate as body weight was a combination of both body size and body condition and that at the same liveweight small ewes in improving body condition had significantly ($P < .05$) higher ovulation rate than larger ewes in reducing body condition. In agreement with Guerra et al.

(1972), Gunn and Doney (1979) found a positive relationship between body condition and ovulation rate in the North and South Country Cheviot ewes. Curll et al. (1975) reported that the weight of lamb marketed was much greater from the ewes that increased from 51 to 58 kg during mid-pregnancy than those followed the reverse pattern in the Border Leicester x Merino ewes, results similar to that of Ducker and Boyd (1977). Adalsteinssen (1979) reported changes in liveweight and condition score on the Icelandic ewes did not affect ewe productivity. Cumming et al. (1978) increased liveweights from mating to prior to lambing in three groups of Border Leicester x Merino ewes (HH, HL, and LL where H and L stand for high and low liveweights, respectively), and reported that ovulation rates were 1.86, 1.91, and 1.76; prolificacy, 1.75, 1.60, and 1.22; weaning rates, 1.23, 1.19, and 0.93; and lamb mortality, 29, 25, and 23 percent, respectively, for the three groups and concluded that increasing ewe liveweight increased productivity even in those already in fat condition.

The use of pregnant mare serum gonadotrophin (PMSG) and increased body weight (Coop, 1962) are both reported to increase the number of lambs conceived by ewes. These two effects appear to be additive in that the primary effect of body weight was on barrenness while the use of PMSG merely increased the proportion of multiple fetuses in those ewes able to conceive (Hedges and Reardon, 1975). Guerra et al. (1971) reported that the ovulatory response to a standard dose of 750 I.U. of PMSG progressively increased with increased liveweight from 1.53 at 25.6 kg to 2.06 at 40.6 kg in the Merino ewes. Kleiber (1947) has suggested

that dosage should be given based on metabolic body size, and particularly, if the action of the biotic or hormone depends on the maintenance of a given concentration over a period of time.

In the Romney ewes with liveweight differences of 15 kg, Allison (1975) reported that treatment with PMSG increased ovulation rate ($P < .01$) with mean ovulation rates of 1.35, 1.97, and 3.88 in the low liveweight ewes and 1.54, 2.95, and 5.34 in the high liveweight ewes treated with 0, 600 or 1000 I.U of PMSG, respectively. Allison (1975) also reported that as the number of ovulations increased with hormone treatment, the proportion of embryonic mortality also increased.

An analysis of the breeding performance in relation to liveweight in Corriedale sheep revealed that the ewe and lamb mortality and fertility of 3.8, 12.0, and 94 percent, respectively, were relatively independent of liveweight except at liveweights below 40-45 kg (Coop, 1962). In a subsequent study, Coop and Clark (1966) reported that twinning was significantly and positively related to ewe body weight ($r=0.63$) and increased 8.2 percent for each 10 percent increase in ewe liverate, while weaning rate increased 1.8 percent for each 10 percent increase in body weight. However, because of low genetic potential for twinning, fairly substantial increase in body weight resulted in only relatively small number of additional lambs born (Hedges and Reardon, 1975). An increase in fertility of three to four percent for each four to five kg increase in body weight is also reported (Coop and Clark, 1966). Adalsteinssen (1979) reported that ewe prolificacy increased linearly with increase in

liveweight ($b = 1.05$ lambs/kg/100 ewes) and curvilinearly with body condition, and a ten percent increase in liveweight and body condition resulted in a predicted prolificacy of 21 lambs per 100 ewes alive at lambing. Curll et al. (1975) found that ewes that weighed 58 kg at mating produced 1.52 lambs per ewe compared to only 1.07 lambs per ewe from ewes weighing 48 kg and that the proportion of lambs reaching marker weights was directly related to liveweight gain of ewe during pregnancy.

In the Galway and Fingalway ewe lambs, there was no evidence of any effect in the nutritional treatment on conception rate or litter size where the mean body weights for ewes that lambed and those that failed to lamb were 44.9 and 41.5 kg, respectively (Quirk, 1979). Ewes in higher body condition had significantly more triplets and fewer singles with lambing rates of 1.83 vs 1.65 in the Masham ewes (Newton et al., 1980) and the Border Leicesters x Romney ewes (Hight and Jury, 1973). On the contrary, Geisler and Fenlon (1979) analyzed records of ewe weights at mating in several UK sheep flocks and found no significant relationships between performance and size or condition. Geisler and Fenlon (1979) further reported that the relationship between weight and condition was linear though there was considerable variation in weight at a fixed body condition, suggesting a substantial spread in skeletal size.

Gibbs and Treacher (1980) studied the effect of body condition at pasture and reported that intake of herbage and milk yield were indepen-

dent of body condition except at 9, 11, and 12 week of lactation although there was a tendency for fat ewes to produce more milk; and because of this tendency, daily growth rates of lambs during the first eight weeks and overall liveweight gains were significantly higher for lambs suckled by fat ewes. Mavrogenis et al. (1980) reported a negative correlation between liveweight and milk yield during lactation indicating a tendency for body loss at high milk yield.

The Tsigai sheep (Russin shlep) were divided into three groups—heavy, medium, and small; and body weight, height at withers, and heart girth, respectively, averaged 55.5 kg, 63.9 cm, and 93.8 cm in the heavy group; 50.6 kg, 62.8 cm, and 90.5 cm in the medium group; and 46.0 kg, 61.2 cm, and 88.4 cm in the light group (Zhiryakov and Mominov, 1973). In the three groups, clean wool weight averaged 2.4, 2.3 and 2.2 kg and yearly lamb production of lamb weaned was 27.7, 31.1, and 34.1 kg, respectively (Zhiryakov and Mominov, 1973). Scottish half-bred, Devon Longwool, Kerry Hill, and Welsh Mountain breeds of sheep weighing 78.6, 78.7, 57.6, and 33.4 kg, produced an average carcass weight of weaned lambs of 19.6, 21.1, 20.7, and 14.9 kg with efficiencies of 6.5, 5.8, 7.3, and 8.1 percent, respectively (Large, 1970). In studying the relationship between liveweight of the ewe at mating and the weight of the newly born lamb, Donald and Russel (1970) calculated regression coefficients (on log bases) of 0.721, 0.741, and 0.773 for singles, twins, and triplets, respectively, and none was significantly different. Donald and Russel (1970) further reported that litter weight at birth as a proportion of ewe weight tended to decline as ewe weight rises from small

to larger breeds, from 9.6 and 15.2 percent for singles and twins, respectively, at 25 kg ewe weight to 6.5 and 10.6 percent at 100 kg ewe weight. Eltan (1978) reported a positive correlation of lamb growth and ewe body weight and udder size for single born lambs. Pollott and Kilkenny (1976) found a correlation of 0.29 between ewe body weight and lamb birth weight in commercial sheep flock in Britain.

The onset of breeding season was not affected by body size weight of the ewe (Ducker and Boyd, 1977; Williams et al., 1974; Lee, 1966). Williams et al. (1974) and Lee (1966) independently reported that any management practice that alter liveweight was unlikely to affect the onset of breeding activity in the ewe. Hulet and Foote (1967) have shown that anaestrous ewes can be returned to normal estrous through hormone treatment only.

Positive correlations of ewe body weight with various traits is documented in the literature. Ewe body weight was correlated with fleece weight ($r=0.33$, Iskakov and Makbuzov, 1970; $r=0.47$, Krishnamurthy, 1977; $r=0.57$, Tomar, 1978; $r=0.24$, Coop, 1962; $r=0.32$, Nicholas and Whiteman, 1966); with skin-fold thickness ($r=0.864$, Choudbury et al., 1974); with kemp fiber and undercoat fiber ($r=0.27$ and 0.28 , respectively, Iskakov and Makbuzov, 1970); and with total number of lambs born, total number of lambs raised, average lamb birth weight, average 70-days lab weight and with average lamb gain from 70 to 140 days ($r=0.14$, 0.07 , 0.024 , 0.28 and 0.08 , respectively, Nicholas and Whiteman, 1966).

Tomar (1978) reported that of total variation in fleece weight, 42 percent was attributed due to variation in liveweight and only eight percent due to variation in age. Efner and Pieta (1979) reported a correlation of - 0.65 to 0.24 between ewe body weight and wool production per kg body weight. Liveweight and seven body measurements were recorded immediately after shearing on 327 Apulian Merino ewes and the correlation between the average wool yield over three years with liveweight plus bone measurements was 0.22 (Pilla and Taibi, 1980). Using linear body measurements, Galal et al. (1965) reported simple correlations between chilled carcass weight percent of liveweight and the area of ribeye muscles were 0.00 and -0.44 with metacarpus length, 0.80 and 0.51 with metacarpus lateral diameter, 0.46 and 0.51 with metacarpus anterior-posterior diameter, 0.31 and 0.37 with metatarsus lateral diameter, 0.32 and 0.57 with metatarsus anterior-posterior diameter and, 0.44 and 0.71 with hookbone width, respectively. Among all other variables considered, Galal et al. (1965) further reported that the single variable most highly related to weaning weight was birth weight ($r=0.57$).

The RNA content and osmotic fragility of erythrocytes were significantly correlated with body weight ($r=0.89$, and -0.41 , respectively) in the Valachian sheep breed of Czechoslovakia (Malik et al., 1978). Body weight was studied in relation to the contents of 20 proteins, albumin, globulin, and sulphhydryl groups in blood serum of the Volgograd Russina sheep breed and only the content of the sulphhydryl groups was correlated to body weight ($r=0.40$, Tsyrendondokov and Moshkova, 1977). Siemon and Moodie (1973) found a significant correlation between bone density and

body weight and stated that this relationship was important assessing bone dystrophy and its treatment.

Kustov and Yadrichev (1973) mated deep and wide chested rams to ewes that were wide, deep and shallow; narrow; and deep; and found that body conformation was an inherited traits, and body weight, fleece weight and carcass quality were best for progeny from mating between parents with wide, deep chest. In the Rambouillet, Chokla and their F_1 and F_2 crosses, Karla (1978) found significant differences in body measurements and the Rambouillet ewes had good body conformation, the smallest wool fiber, the shortest staple length, and the highest grease fleece weight; the Chokla ewes had the poorest body conformation and yielded the smallest return in meat and wool while the crosses had the best body conformation and the highest meat and wool return.

For 101 goats and 99 sheep, the correlation between body weight and heart girth were 0.940 and 0.774, respectively (Owen et al., 1977). In goats, milk production in the first and second lactation was correlated with body weight ($r=0.39$ and 0.43 , respectively) and with undercoat production ($r=0.27$) (Orlyanskii and Zaporozhtsev, 1974). In a similar study in goats, body weight was significantly correlated with the number of oestrous periods ($r=0.26$), with subsequent milk yield ($r=0.28$), and with incidence of dystocia ($r=0.25$), (Fehr and Sauvart, 1975).

Cattle

The question of optimum size in beef has generated a controversy for a long time among livestock producers and animal scientists who serve them and as Klosterman (1972) pointed out, if there were any efficiency size we should have found it by trial and error during this time. One reason for this continued controversy is that a full study requires an interdisciplinary approach, and such approach has not been started until the early 1970's (Morris and Wilton, 1976). There are at least two underlying problems, according to Morris and Wilton (1976); the criteria for definition of body size and the criteria for definition of efficiency. Most workers use the weight of the animal taken at a certain point of life as a measure of body size (Olson et al., 1982; McCurley and McLaren, 1981; to just mention only two) and Carpenter et al. (1978) justified the use when they found a high correlation between body weight and the first principal component. Most workers (Johansson, 1964, for example) acknowledged that the body weight has a serious setback as it usually ignores the condition and frame (skeletal) of an animal and hence the inclusion of measurements of body dimensions has been recommended. In particular, height/weight ratio has been used as an estimate of body condition (Olson, et al., 1982) and found to be highly correlated to most probable producing ability MPPA (Hays and Brinks, 1980).

Efficiency, broadly defined as input/output ratio, can be expressed biologically and/or economically (Dickerson, 1978), the latter being preferred as it includes total input costs and total output costs. Different combinations of input and output variables have been used in the literature; calf weaning weight/cow weight, and calf weaning weight/cow metabolic weight, (Olson et al., 1982), calf weaning weight/total feed consumed by cow and calf (Carpenter et al., 1972); metabolizable energy in food/metabolizable energy in feed (Fitzhugh et al., 1975).

The breeding female and her replacement constitute 40 to 70 percent of the production unit (Fitzhugh, 1978) and it has been estimated that a major portion (about 60 percent, Olson et al., 1982; over 50 percent, Dickerson, 1978) of the total feed energy necessary to produce and finish a calf to slaughter is required by the cow for maintenance; and thus the nutritional and financial cost of raising replacements and maintaining mature females represent the major portion of the inputs of the production unit (Fitzhugh, 1978). Those costs that are fixed per head per unit time, such as veterinary cost, taxes, labor and management, favor larger animals (Dickerson, 1978).

Carpenter et al., (1972) compared cow productive efficiency in the Hereford and Charolais with different cow sizes and concluded that size did not significantly affect efficiency but there was a trend for smaller cows to be more efficient; however, the relationship between productive efficiency and calf performance trait were positive and significant

indicating that cows having larger calves also tended to be more efficient.

In a computer simulation study with two herd management systems (dry lot and pasture), each with three body sizes, and with fixed annual expenditure, Long et al., (1975) reported that systems utilizing smaller cows required slightly higher capital investment because of accumulated effects of fixed cost per head and that larger cows were more profitable in the dry lot while smaller cows were more profitable in the pasture, although the smaller cows brought a higher net income. On the overall comparison, however, Long et al. (1975) concluded that considering the higher capital investment required for smaller cow system on pasture negated their advantage in the net income with the result that there were no major differences among cow sizes for return on investment. In a similar computer simulation study with an objective to maximize energetic efficiency (ME food/ME feed) comprising three body sizes and three slaughter ages, Fitzhugh et al. (1975) calculated energetic efficiencies ranging from 0.031 to 0.042 for all size-age combination with no major differences. In a linear programming method that included farm size, herd size, beef and feed prices, Morris and Wilton (1975) reported that larger cows produced larger farm gross income except under conditions where feed prices were exceptionally high.

Olson et al., (1982) divided Hereford cows into four sizes - small, medium, large, and very large - and compared to the herd average, weaning weight of calf/cow exposed were -1.5, 3.6, 11.2, and -6.7 percent;

calf weaning weight/cow metabolic body weight were 1.63, 1.39, 1.51, 1.15; and weight of calf slaughtered/cow exposed were 4.10, 3.44, 3.77, and 2.90, respectively, for the four sizes. Olson et al. (1982) further reported that birth weight, preweaning daily gain and adjusted weaning weight of calves were significantly greater for cows out of the medium and large cows than the calves of small or very large cows, and hence a curvilinear relationship. There is strong evidence in the literature that the calf weaning weight was highly correlated with cow body weight (Carpenter et al., 1972; Morris and Wilson, 1977; Smith, 1979; Rahnefeld et al., 1980).

In reviewing the influence of body size on the biological efficiency of the cow, Morris and Wilton (1976) concluded that efficiencies were superior for small cows when cow and calf feed requirements were considered, but negligible when requirements for replacement calves were included. Anderson (1978), reviewing productivity, concluded that there were no general relationships between size of cattle and economic and biological efficiencies; larger cows had normally the highest productive capacity for milk and beef, but also the highest requirement for maintenance.

According to Lasley (1978) and Melton et al. (1967), regardless of its size, a cow is a poor investment if she does not produce a calf in a given year and hence a fertile cow with high performance is more desirable than a mediocre cow of optimum size.

MATERIALS AND METHODS

Experimental Sites

Though the objectives of the present study were not to determine location effect on production, the study took place at two locations; Logan, in Northern Utah, and Cedar City, in Southern Utah. The objective in taking measurements in Logan was to develop and refine measuring techniques that could be duplicated at Cedar City on selected genotypes and larger numbers. Furthermore, slaughter data measurements from Targhee-type range ewes in Logan were taken in order to determine accuracy in external and internal body dimensional measurements. Moreover, the slaughter data were used to help understand and interpret the subjective condition score used with actual fat content of the animal.

In Logan, research facilities and animals were provided by the International Sheep and Goat Institute, Utah State University; and in Cedar City, by the Utah Agricultural Experiment Station.

Animals

The distribution of animals by location and genotype is given in Table 1. A total of 66 animals were used in Logan. These were of two genotypes, Finn X Targhee and Targhee-type range ewes. The latter were bought in May, 1982, and after taking linear body measurements, they were slaughtered for carcass measurements a month later. Except for

being Targhee-type and above three years old ewes (as determined by their teeth), not much is known about their genetic background and management.

Table 1. Distribution of animals by location and genotype¹.

Cedar City		Logan	
Genotype	Number	Genotype	Number
FXT	31	FXT	44
TXT	67	T-type	22
SXT	110		
Total	208		66

¹F=Finnsheep, T=Targhee, S=Suffolk; sire indicated first.

Three genotypes of ewes, namely, the Targhee x Targhee (TXT), the Suffolk x Targhee (SXT), and Finnsheep x Targhee (FXT) were used in Cedar city. In each genotype the sire is indicated first. The total number of animals used in this study in Cedar City was 208. All ewes three years old and older were included in the study.

Measurements

Linear measurements, body weight and condition score

For each sheep in the study, the following linear measurements were taken:

1. Chest Width (CW)- measured horizontally in the lateral thoracic wall between the 5th and 6th sternal rib.

2. Chest Depth (CD) - measured vertically from the sternum bone to the 6th and 8th thoracic vertebrae.

3. Body Length (BL) - measured from the first thoracic vertebra to the posterior extremity of the tuber ischii bone (pin bone).

4. Hip Width (HP) - measured horizontally between the two hip bones (tuber ischii) over the tuber coxae.

5. Metatarsus Length (MT) - measured from the tuber calcis bone to the distal end of the metatarsus bone of the left hind leg.

6. Head Width (HW) - measured from right to left supra-orbital process of the frontal bone, measurement representing the maximum width.

7. Head Length (HL) - measured from the supra-orbital process of the frontal bone to the distal end of the mandible (lower jaw).

All of the above measurements were taken to the nearest 0.1 cm using calipers. In order to ensure uniformity and minimize measurement error, all linear body measurements were taken by the same person and the major supporting staff were also the same people.

Ewes were also scored for body condition. The score ranges from one to nine, where 1-3, 4-6, and 7-9 were referred to low, medium and high condition, respectively. The detailed breakdown of the condition score is as follows (adopted from Russel et al., 1969):

1= low-low: extremely emaciated and on the point of death.

2= low-medium: sharp transverse processes, fingers pass easily under the ends and possible to feel between each process; virtually no subcutaneous fat cover.

3= low-high: spinous processes prominent and sharp, ribs easily detected by fingers.

4= medium-low spinous processes prominent but smooth, transverse processes smooth and rounded and fingers can be passed under ends with little pressure; little subcutaneous fat cover.

5= medium-medium: spinous processes have virtually small elevation but still smooth, and fingers can be passed under process ends with very little pressure, little better subcutaneous fat cover than (4).

6= medium-high: spinous processes have only small elevation, are smooth and round, and individual processes can be felt only with pressure, moderate subcutaneous fat cover.

7= high-low: spinous processes have small elevation that can be detected through small pressure, transverse processes are smooth and very well covered, and firm pressure is required to feel over ends; longissimus dorsi full with moderate subcutaneous fat cover.

8= high-medium: spinous processes can be detected with pressure hard line between ends, transverse processes cannot be felt; longissimus

dorsi full with thick subcutaneous fat cover.

9= high-high: spinous processes cannot be felt even with firm pressure and there is depression in subcutaneous fat where spinous processes cannot be felt; longissimus dorsi very full with very thick subcutaneous fat cover; there may be large deposits of fat over rump and tail.

Since scoring an animal is very subjective, three judges scored each ewe and the score with the highest number of votes (i.e. 2 out of 3 minimum) was taken to be the condition of that animal. Evans (1978) has suggested that the score of an animal be given by a single expert assessor, the mean score be given by participating assessors or the mean score be given for all the experienced assessors. In scoring sheep in this study, there was always at least one expert assessor.

Ewe body weight was also recorded to the nearest pound (and later converted to the nearest 0.1 kg) at the time of each measurement.

All the above measurements, i.e. linear body measurements, body weights and condition scores, were repeated six times in the Finn-cross and three times in the Targhee-type range ewes in Logan; and two times in the Cedar City sheep, in Fall and Spring.

Reproductive and productive traits

For each ewe in the study, the birth and weaning weights, sex, type of

birth, date of birth and weaning of its lamb(s) were recorded. The number of lambs born and weaned per each ewe was also recorded. From the above, the following were calculated:

1. The total weight of lamb born and weaned per ewe lambing;
2. The total weight of lamb born and weaned per unit ewe body weight and per unit ewe metabolic body weight; where metabolic body weight was obtained by raising the ewe body weight to the $3/4$ power (Kleiber, 1961);
3. Total weight of lamb born and weaned per ewe body size (body size defined as volume in cubic metres) and ewe metabolic body size.

Carcass measurements

The Targhee-type range ewes were slaughtered and the following carcass measurements taken: hot and chilled carcass weights, kidney fat, kidney knob (fat + kidney), chest width, chest depth, hip width, body length, and backfat thickness.

Management of Flock

Three genotypes (breeding groups) in Cedar City consisting of Targhee x Targhee (TXT), Suffolk x Targhee (SxT) and Finnsheep x Targhee (FxT) ewes were used. These breeding groups were mated to Suffolk, Targhee and Finnsheep rams. The mating plan used and resulting offspring are shown in Table 2. A group mating system, with an average of one ram

per 35 ewes, was used.

The Suffolk rams originated from several purebred Suffolk flocks in the western USA and from the station purebred flock. Targhee rams were selected from several purebred breeders, state experiment station flocks, Utah station flock, and the U.S. Sheep Experiment Station, Dubois, Idaho.

Table 2. Mating system used and offsprings produced in Cedar City.

DAM	SIRE		
	Targhee(T)	Suffolk(S)	Finn(F)
TXT	TXT	SXT	FXT
SXT	3/4 TXS	3/4 SXT	FX(SXT)
FXT	3/4 TXF	SX(FXT)	-

All rams used were tested for fertility (physical examination and semen evaluation) at the beginning of the breeding season and rams judged to be fertile were used. The breeding season was initiated during the second week of November and continued for approximately 35 days. The ewes were bred on wheatgrass and alfalfa pastures. After the breeding season, the ewes were placed in a single range herd and were grazed under herded conditions, on a sagebrush-type winter range from about De-

ember 15 to March 20.

The ewes were shed lambed during April and early May and pastured on alfalfa and wheatgrass pastures until the second week of June. The ewes and lambs were placed in a single range herd during the second week of June and grazed, without herding, on fenced high mountain ranges (2440-2740 m). Except for stray lambs, which were gathered within a week, the lambs were weaned during the second week of September, at approximately 5 months of age.

Statistical Methods

Principal component analysis, stepwise regression, coefficients of reliability and variation, and analysis of variance were used to analyze the data. Simple and partial correlation were also determined. When analyzing for linear measurements and ewe body size, both the fall and spring data were included; for production functions of the ewe only fall data were used.

Estimating Ewe Body Size (BS)

There is no universally accepted method of estimating ewe body size. Williams et al. (1974) used the difference of ewe body weight and condition score as a best estimate of ewe body size while Ducker and Boyd (1977) and Wiener and Hayter (1974) used some linear body dimension combinations. In the present study, ewe body size is estimated by multiplying the width by length and depth, adopted after Ducker and Boyd

(1977). More specifically, ewe body size is estimated as follows:

$BS(cc) = 1/2 (\text{chest width} + \text{hip width}) \times \text{Body length} \times \text{chest depth}.$

Data Adjustments

Birth and weaning weights of lambs have been adjusted for age of ewe, sex of lamb and sire breed employed. No adjustments for type of birth and type of rearing were made. The adjustments were to a common age of ewe (4-6 years), common sire (Targhee), common age at weaning (150 days), and to a neutral or mid-sex. Multiplicative adjustment factors were developed from the data itself from the least-square means within each genotype of ewe.

RESULTS

Linear Body Measurements, Condition Score,
Ewe Body Weight, and Ewe Body Size

A total of six measurements in the FXT ewes and three measurements in the Targhee-type range ewes were made in order to refine and develop measuring techniques and as a check for accuracy of measurements. Results are given in Table 19 in the Appendix. Except for condition score and ewe body weight, the coefficient of variation ranged from 2.0% in head length to 5.8% in chest depth in the FXT ewes; and from 1.3% in metatarsus length to 4.7% in chest width in the Targhee-type range ewes. These values indicated that, in relation to the mean, the maximum variation observed was 5.8%. Coefficients of reliabilities and repeatabilities are also given in Table 19. Both these measures depend on the ratio of "Between" and "Within" variances, and yield high positive values when the "Between" variance is much larger than the "Within" variance. In the present study the "Between" variance was generally small in relation to the "Within" variance. A similar table for the Cedar City ewes is also given in Table 24 in the Appendix.

Means and standard errors for linear body measurements, condition score, ewe body weight and ewe body size for each period of measurements, Fall and Spring, are given in Table 3. Least-square analysis of variance is given in Table 21 in the Appendix. Significant ($P < .05$) genotypic differences were observed in fall in head width, head length, chest

Table 3. Linear body measurement means by genotype and season.¹

GENO- TYPE	SEA- SON	n	HV (cm)	HL (cm)	CW (cm)	CD (cm)	BL (cm)	HP (cm)	MT (cm)	CS (1-9)	EDW (kg)	ES ($\text{cc} \times 10^3$)
TXT	FALL	67	13.23±.06	21.79±.10	22.65±.17	30.94±.29	69.74±.32	21.18±.12	23.31±.10	5.89±.13	69.93±0.84	48.77±.60
	SPRG	67	13.33±.06	22.74±.09	22.25±.19	32.25±.22	69.57±.30	21.04±.12	23.16±.11	2.73±.15	63.42±0.97	47.19±.54
	CONB.	134	13.30±.04	22.03±.07	22.45±.13	31.59±.16	69.65±.21	21.11±.08	23.23±.07	4.31±.18	66.68±0.72	47.98±.41
FXT	FALL	31	13.09±.09	21.40±.15	22.22±.25	30.40±.29	67.68±.17	20.40±.17	22.57±.15	5.00±.19	67.16±1.24	45.05±.87
	SPRG	31	13.28±.08	21.48±.14	21.75±.27	31.70±.22	67.02±.44	20.48±.17	22.67±.16	2.29±.23	61.97±1.43	43.99±.80
	CONB.	62	13.19±.06	21.44±.10	21.09±.18	31.10±.23	67.35±.32	20.47±.12	22.71±.11	3.64±.26	64.56±1.05	44.52±.60
SXT	FALL	110	13.58±.05	22.49±.09	22.78±.13	32.98±.15	70.63±.24	21.62±.09	23.33±.08	6.43±.10	74.21±0.66	51.61±.47
	SPRG	110	13.75±.04	22.76±.07	22.60±.14	32.08±.17	70.60±.23	21.63±.09	23.37±.08	2.77±.12	65.85±0.76	50.39±.43
	CONB.	220	13.65±.03	22.64±.05	22.68±.10	32.53±.12	70.64±.17	21.62±.06	23.35±.06	4.60±.14	70.03±0.56	51.00±.32
OVERALL		416	13.48±.03	22.26±.05	22.50±.07	32.02±.09	69.83±.13	21.29±.05	23.22±.04	4.37±.10	68.13±.42	49.06±.26

¹See 'Nomenclature', pp ix-x, for description of abbreviations

depth, body length, hip width, metatarsus length, condition score, ewe body weight and ewe body size, where in general, the FXT ewes were smaller and/or lighter than the SXT ewes. The FXT ewes were also significantly ($P < .05$) shorter in body length, narrower at the hip, shorter at the leg (metatarsus) and smaller in body size than the TXT ewes. A similar trend was observed in spring except that all the three genotypes did not differ significantly ($P > .05$) in their condition, indicating that they were all under equally poor condition.

Within each genotype, measurements on head width, head length, chest width, head length, hip width, metatarsus length and ewe body size did not differ significantly ($P > .05$) between fall and spring. However, the condition and weight of the ewes were significantly ($P < .05$) lower in spring. This should be expected because spring condition and weight were associated with lambing and weaning stresses while fall condition and weight were associated with good pasture and comparatively no physiological stresses. On the chest depth measurement both the FXT and TXT ewes were deeper in spring than they were in fall. Although this was not expected, it could possibly be due to the fact that the 6 and 8 vertebrae, where the chest depth measurements were taken, were more prominent in spring than they were in fall and possibly inflated the value; or simply due to random unexpected variation.

A Short Note on Carcass Measurements

Twenty-two mature Targhee-type range ewes were slaughtered on June, 1982, and carcass measurements were taken on them. One of the objectives of slaughtering these sheep was to determine the relationship between the live measurements (external) and carcass (internal) measurements.

Simple means, and simple and partial correlations between the live and carcass measurements on chest depth and width, body length, and hip width are given in Table 4. Simple correlations between live and carcass were: chest width, $r=0.773$ ($P<.001$); chest depth, $r=0.426$ ($P<.05$); body length, $r=0.782$ ($P<.001$); and hip width, $r=0.691$ ($P<.001$). The relationships between the live and carcass chest measurements disappeared when the effect of ewe body weight was removed indicating that the chest relationships were simply through the ewe body weight. Other relationships were not significantly affected by removing the effects of ewe body weight, ewe body size, and condition score (except for chest depth when adjusted for ewe body size, Table 4).

Simple correlations between ewe body weight, ewe body size, and condition score with carcass measurements of hot carcass weight, chilled carcass weight (approximately 24 hours of chilling), backfat thickness, kidney fat, kidney knobs, chest width, chest depth, body length and hip width are given in Table 5. Except with backfat thickness, chest depth and body length, the ewe body weight was significantly ($P<.01$, $P<.001$), and positively, correlated with all the carcass variables measured. Ewe

Table 4. Means, simple and partial correlations of live and carcass measurements.¹

	MEANS		CORRELATIONS			
	LIVE	CARCASS	r	r/EBW	r/BS	r/CS
CW	23.5	20.8	0.773c	0.062	0.550b	0.694c
CD	32.2	33.0	0.426a	0.275	0.091	0.389a
BL	69.2	68.9	0.782c	0.747c	0.578b	0.779c
HP	21.6	22.0	0.691c	0.389a	0.391a	0.688c

a=P<.05; b=P<.01; c=P<.001

¹r=simple correlation; r/EBW=partial correlation, adjusted for EBW, etc

Table 5. Simple correlations between carcass measurements and weight, size¹, and condition score.

	HCW	CCW	BF	KF	KK	CWC	CDC	BLC	HPC
EBW	0.905c	0.903c	0.321	0.815c	0.780c	0.879c	0.404	0.404	0.563b
BS	0.787c	0.755c	0.188	0.656c	0.586b	0.689c	0.548b	0.653b	0.795c
CS	0.700c	0.748c	0.704c	0.603b	0.653b	0.607b	0.309	0.109	0.214

a=P<.05; b=P<.01; c=P<.001

¹See 'Nomenclature' pp.ix-x for description of abbreviations.

body size was also positively and significantly ($P < .01$, $P < .001$) related to all the carcass measurements but the backfat thickness. Condition score was positively and significantly ($P < .01$, $p < .001$) related with all carcass variables but chest depth, body length, and hip width. From the forementioned relationships and coefficients in Table 5 it can be seen that the only variable that was significantly ($r = 0.704$, $P < .001$) correlated with backfat thickness was the condition score of the animal. This may suggest that the subjective scoring of animals to assess the amount of fat was fairly accurate in the present study.

A stepwise regression was used to determine which, among the carcass measurements, best estimate the variation in condition score. At the first step, the variable that entered the model was backfat thickness with the following regression equation: $CS = 3.91 + (4.17 + 0.94)BF$, $R^2 = 0.495$; where CS = Condition score and BF = Backfat thickness. At the second step, kidney fat entered the regression model and improved the R^2 value by 14.9%. No other variable was added or deleted after this step when the significance level was set at the 5% level.

Size and Shape

Targhee X Targhee ewes

Coefficients (Loadings) of principal components, short description of components, correlation of measured variables with components and percent of variance accounted by each principal component are give in Table 6. The coefficients and correlations were calculated from within

cell correlation matrix since the observed responses were measured in different units (linear body measurements in centimeters, body weight in kilogram and condition score in dimensionless units).

The first principal components, as a measure of general size, accounted for nearly 35% of the total variation. Most of the loading was attributed to body size (0.928), ewe body weight (0.747) and chest width (0.692). The second principal component, as a general indicator of shape, accounted for less than 15% of the total variation and was mostly loaded by metatarsus length (-0.788) and body length (-0.676) which characterized the animal as being short in both body and leg. The third, fourth and fifth principal components accounted for 11.59, 9.61 and 8.58% of the total variation, respectively, and are considered to be added descriptors for shape. The total variation explained by the first five components was nearly 80%.

The correlation matrix (lower half of Table 6) was obtained by rotating the axes of the principal components. It, therefore, not only indicated the correlation between the observed response and principal components but also singled out major contributing variables that may not have been easily identified from the loading of the principal components. The ewe body size (0.902), chest depth (0.870) and chest width (0.582) were the variables most correlated with the first principal component (Table 6), while metatarsus length and condition score were the least correlated. This indicated that the contribution of the latter two measures to the definition of size was negligible. The two measures

Table 6. Loadings of principal components and correlations between variables and components based on within cell correlation matrix in the TXT ewes.¹

PC ²	1	2	3	4	5	DESCRIPTION
	LOADINGS					
HW	0.371	0.317	-0.154	0.497	0.645	1. Large, heavy and well-framed vs small, light and poor conditioned.
HL	0.513	-0.271	-0.013	-0.475	0.495	
CW	0.692	0.182	0.292	-0.168	-0.167	2. Short in body and metatarsus vs long and tall.
CD	0.632	0.331	-0.444	-0.386	-0.039	
BL	0.480	-0.676	-0.115	0.289	-0.242	3. Wide and shallow vs narrow and deep.
HP	0.596	0.132	-0.049	0.451	-0.133	
MT	0.361	-0.788	0.048	0.021	0.192	4. Wide but short head, shallow chest and wide hips.
CS	0.309	0.059	0.838	-0.059	-0.082	
EBW	0.747	0.241	0.256	0.123	-0.097	5. Large vs small headed animals.
BS	0.928	0.020	-0.260	-0.075	-0.193	
%VAR. ³	35.10	14.74	11.59	9.61	8.58	
%CUM.VAR.	35.10	49.84	61.43	71.04	79.62	
	CORRELATIONS					
HW	0.115	-0.033	0.021	0.951	0.077	
HL	0.288	0.172	0.133	0.101	0.817	
CW	0.582	0.062	0.555	-0.003	0.058	
CD	0.870	-0.154	-0.128	0.074	0.233	
BL	0.203	0.895	-0.007	-0.024	-0.043	
HP	0.447	0.305	0.197	0.407	-0.315	
MT	-0.050	0.770	0.073	0.007	0.434	
CS	-0.060	-0.001	0.073	0.007	0.120	
EBW	0.559	0.131	0.548	0.216	-0.092	
BS	0.902	0.348	0.116	0.134	0.081	

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

² PC = principal component

³ % Var= % variance; % Cum. Var= % cumulative variance

most correlated with the second principal components were body length (0.895) and metatarsus length (0.770). Chest width and ewe body weight, head width and hip width, and head length metatarsus length were the measures most correlated with the third, fourth and fifth principal components, respectively.

Finn X Targhee ewes

Loadings of the principal components, short description of components, correlations of measured variables with components in the FXT ewes are given in Table 7. The first principal component, as an indicator of size, accounted for nearly 44% of the total variation. The highest loadings were attained through ewe body size, ewe body weight, hip width and chest width with respective coefficients of 0.925, 0.866, 0.841, and 0.698. The second principal component accounted for additional 16.6% of the total variation where chest width, chest depth, and condition score contributed the highest loadings of 0.496, -0.672, and 0.830, respectively. Hence, the shape variation in FXT ewes was mostly of chest characteristics. The third principal component described additional chest characteristics plus length characteristics. The fourth and fifth components were description of head and metatarsus length, respectively. The total variation explained by the first five components was 87.28, and compared to the TXT ewes, more variation was explained in the FXT ewes.

Table 7. Loadings of principal components and correlations between¹ variables and components based on within cell correlation matrix in the FXT ewes.

PC ²	1	2	3	4	5	DESCRIPTION
	LOADINGS					
HW	0.531	-0.106	0.693	0.023	-0.038	1. Large, heavy and well-framed vs small, light and poor condition.
HL	0.461	-0.276	-0.196	0.766	0.233	
CW	0.698	0.496	-0.327	-0.254	0.067	2. Wide and good vs narrow and poor condition.
CD	0.422	-0.672	-0.423	-0.206	-0.051	
BL	0.655	-0.195	0.453	-0.017	-0.331	
HP	0.841	-0.005	-0.050	0.247	-0.174	3. Narrow and shallow chested vs long bodied animals.
MT	0.621	-0.149	0.287	-0.249	0.643	
CS	0.308	0.830	0.056	0.173	-0.016	4. Long vs short headed animals.
EBW	0.866	0.300	-0.173	-0.042	0.017	
BS	0.925	0.184	-0.188	-0.174	-0.172	5. Tall vs short legged animals.
%VAR. ³	43.83	16.59	11.80	8.80	6.46	
%CUM.VAR.	43.83	60.42	72.02	80.82	87.28	
	CORRELATIONS					
HW	0.039	0.790	-0.108	0.073	0.364	
HL	0.092	0.072	0.108	0.966	0.091	
CW	0.936	-0.022	-0.023	-0.031	0.176	
CD	0.169	0.052	0.885	0.174	0.093	
BL	0.215	0.834	0.155	0.077	0.102	
HP	0.587	0.474	0.148	0.457	0.028	
MT	0.238	0.224	0.119	0.101	0.913	
CS	0.589	0.049	-0.672	0.052	-0.054	
EBW	0.854	0.240	0.036	0.211	0.199	
BS	0.693	0.432	0.511	0.183	0.153	

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

² PC = principal component

³ % Var = % variance; % Cum. Var = % cumulative variance

The correlation between measured responses and principal components in the FXT ewes are given in lower half of Table 7. As indicated earlier this correlation matrix singled out major contributing variables. In the first principal component, the chest width, ewe body weight and ewe body size were the most correlated with respective coefficients of 0.936, 0.854 and 0.693. The head width and head length were the least correlated with first principal component and hence of negligible contribution to size definition of the animal. The head width, body length and hip width were the variable most correlated with the second principal component while chest depth and condition score with the third. Head length and metatarsus length were the variables most correlated with the fourth and fifth principal components.

Suffolk X Targhee ewes

Coefficients of principal component loadings, brief description of components, correlations between observed responses and components, and percent variance contributed by each component based on within cell correlation matrix in the SXT ewes are given in Table 8. Ewe body size, ewe body weight, body length and chest width with respective coefficients of 0.923, 0.726, 0.675 and 0.636 were the major variables contributing most to the first principal component. This component accounted for nearly 38% of the total variation in the multivariate system, and is considered to be a general descriptor of size. The second, third, fourth, and fifth components accounted for 12.41, 10.95, 9.34 and 8.24% of the total variation, respectively.

Table 8. Loadings of principal components and correlations between variables and components based on within cell correlation matrix in the SXT ewes.

PC ²	1	2	3	4	5	DESCRIPTION
	LOADINGS					
HW	0.434	0.023	-0.077	-0.713	0.439	1. Large, heavy and well-framed vs small, light and poor.
HL	0.614	-0.047	0.487	-0.141	0.278	
CW	0.636	0.101	-0.374	0.175	0.040	2. Shallow vs deep.
CD	0.576	-0.301	-0.378	0.356	0.378	
BL	0.675	-0.188	0.409	-0.044	-0.345	3. Long head, body and legs vs short head, body and legs.
HP	0.570	-0.277	-0.223	-0.317	-0.510	
MT	0.470	0.147	0.478	0.425	0.095	4. Wide at the chest and tall vs narrow and short animals.
CS	0.285	0.854	-0.252	0.010	-0.120	
EBW	0.726	0.459	0.118	-0.068	-0.045	5. Large head and narrow hip. (See text)
BS	0.923	-0.253	-0.214	0.145	-0.061	
%VAR. ³	37.61	12.41	10.95	9.34	8.24	
%CUM.VAR.	37.61	50.02	60.97	70.91	79.15	
	CORRELATIONS					
HW	0.110	0.046	0.117	0.084	0.926	
HL	0.156	0.708	0.103	-0.026	0.419	
CW	0.618	0.069	0.230	0.377	0.073	
CD	0.907	0.081	0.016	-0.053	0.088	
BL	0.089	0.626	0.615	-0.016	0.027	
HP	0.186	-0.030	0.868	0.050	0.144	
MT	0.217	0.747	-0.074	0.151	-0.166	
CS	0.010	-0.012	-0.014	0.942	0.026	
EBW	0.180	0.481	0.254	0.611	0.238	
BS	0.751	0.307	0.549	0.118	0.115	

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

² PC = principal component

³ % Var = % variance; % Cum. Var = % cumulative variance

In the correlation matrix (lower half of Table 8) the first principal component was mostly explained by chest depth, ewe body size and chest width with respective coefficients of 0.907, 0.751 and 0.618. The contribution of condition score, body length, head width and head length to the description of general size was negligible. The second principal component was mostly description of length where metatarsus length (0.747), head length (0.708) and body length (0.626) were the major contributing variables. Hip width (0.868) and body length (0.615) were most correlated with the third principal component describing long and wide at the hip animals.

The total variation explained by the first five principal components was 79.15% in the SXT ewes. This was approximately equal to that of the TXT ewes (Table 6). Moreover, the variance contributions of each component were similar in magnitude in both the SXT and TXT ewes, indicating that these two genotypes vary similarly in size and shape.

Identifying Contributing Factors to Ewe

Body Size, Ewe Body Weight and

Condition Score

A multiple stepwise regression was used to determine the relative importance of linear body measurements in estimating ewe body size, ewe body weight and condition score. The minimum acceptable level of significance was set at a rejection region of 5%, i.e., a measured response entered the regression model as an independent variable if, and only if,

Table 9. Stepwise regression of ewe body size, ewe body weight and condition score on the TXT ewes.¹

	CNST. ²	CD	BL	CW	HP	R	R ²	ΔR^2
BS	-9.670	1.838				0.782	0.611	0.611
	-67.904	1.814	0.845			0.927	0.860	0.249
	-83.708	1.598	0.752	1.280		0.976	0.952	0.092
	-94.268	1.509	0.678	1.095	1.076	0.999	0.999	0.047
EBW	CNST.	CW	HP	CD	CS			
	-11.101	3.577				0.564	0.318	0.318
	-41.570	3.106	1.955			0.619	0.383	0.065
	-53.500	2.776	1.715	0.791		0.650	0.423	0.040
	-52.910	2.386	1.606	0.873	1.352	0.678	0.460	0.037
CS	CNST.	EBW						
	2.308	0.051				0.341	0.116	0.116

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

² CNST=constant (intercept)

it was significant at $P < .05$ or less. In other words, the variable entered the model when the null hypothesis that the coefficient of the said variable is equal to zero, was rejected.

Stepwise regression tables are given in Tables 9, 10 and 11 for the TXT, FXT and SXT ewes, respectively. The order in which the independent variables entered the model is also shown. For instance, in Table 9, in the fall, when ewe body size was the dependent variable, the first independent variable that entered the model was chest depth, followed by body length, chest width, and hip width, in that order. These four independent variables called for four different regression equations: the first with only chest depth in the model with intercept (constant) of -9.670 and regression coefficient of 1.838; the second with both chest depth and body length in the model and intercept of -67.904 and regression coefficients of 1.814 and 0.845, respectively, and so on.

Targhee X Targhee ewes

The coefficients of stepwise regression, corresponding coefficients of multiple correlation (R) and determination (R^2), and changes in R^2 at each variable inclusion (or exclusion) step in the TXT ewes are given in Table 9. Chest depth explained about 61% of the total variation in ewe body size and it was the single most important variable. The inclusion of body length, chest width and hip width raised the R^2 value by 24.9, 9.2 and 4.7%, respectively. These four measurements, namely, chest depth, body length, chest width and hip width, explained almost the

total variation in ewe body size, and this should be expected as ewe body size was originally estimated using the same four variables.

In estimating ewe body weight from linear body measurements, chest width was the first variable to enter the model and explained 31.8% of the total variation. Hip width, chest depth, and condition score improved the R^2 value by 6.5, 4.0, and 3.7%, respectively.

The condition score in the TXT ewe was best explained by ewe body weight. The R^2 value was, however, relatively small but significant (11.6%). This suggested that the amount of variation in the amount of fat in an animal's body could not be accurately estimated from either ewe body weight or the skeletal measurements as it is probably a function of other complex but undefined variables. Different combinations of variables, such as the ratio of ewe body weight to ewe body size and its reciprocal, the ratio of ewe body weight to metatarsus etc were used to estimate the condition score and none proved to be more satisfactory than ewe body weight.

Finn X Targhee ewes

Stepwise regression coefficients, coefficients of multiple correlation (R), and determination (R^2) and changes in R^2 values for the FXT ewes are given in Table 10. In the FXT ewes, the hip width and chest were the first and second variables, respectively, that entered the regression model and, together, explain 76.1% of the total variation in ewe body size. Chest width and body length were the next variables

Table 10. Stepwise regression of ewe body size, ewe body weight and¹ condition score on the FXT ewes.

BS	CNST. ²	HP	CD	CW	BL	R	R ²	ΔR^2
	-27.840	3.511				0.752	0.565	0.565
	-57.560	2.906	1.385			0.873	0.761	0.196
	-61.730	1.902	1.447	1.026		0.942	0.887	0.126
	-88.353	1.016	1.414	1.074	0.660	0.998	0.997	0.110
EBW	CNST.	CW	HP					
	10.808	2.535				0.779	0.606	0.606
	-27.888	1.812	2.677			0.865	0.749	0.143
CS	CNST.	DIFF						
	0.562	0.191				0.549	0.301	0.301

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

² CNST = constant (intercept)

entering the model, and accounted for additional 23.6% of the total variation. Regardless of the order, these four variables explained more than 99% of the total variation in ewe body size. As indicated earlier, ewe body size was originally estimated using these same four linear body measurements.

Chest width and hip width were the only two independent variables that explained 74.9% of the total variation in ewe body weight (Table 10). The only variable that explained 12.2% of the variation in condition score was the ewe body weight (Table 10).

Suffolk X Targhee ewes

The coefficients of stepwise regression, multiple correlation (R), determination (R^2) and changes in R^2 for the SXT ewes are given in Table 11. Chest depth explained 52.9% of the total variation in ewe body size and was the first variable to enter the regression model. Body length, chest width and hip width improved the R^2 value by 27.7, 14.2 and 5%, respectively. It may be recalled that chest depth was the first important variable that entered the model in the TXT ewes (Table 9).

Condition score accounted for 23.5% of the variation in ewe body weight and body length, head length and chest depth for additional 20.1, 5.6 and 2.0%, respectively. The total ewe body weight variation explained by the forementioned four linear measurements was 51.3%.

Table 11. Stepwise regression of ewe body size, ewe body weight and¹ condition score on the SXT ewes and all genotypes combined.

SXT EWES:																
BS	CNST. ²	CD	BL	CW	HP	R	R ²	ΔR^2								
	-21.795								2.249				0.727	0.529	0.529	
	-79.931	1.951	0.958			0.898	0.806	0.277								
	-90.563	1.615	0.844	1.297		0.974	0.948	0.142								
	-99.777	1.546	0.713	1.139	1.121	0.999	0.998	0.050								
EBW	CNST.	CS	BL	HL	CD	R	R ²	ΔR^2								
	50.289								3.716			0.485	0.235	0.235		
	-39.531								3.663	1.276		0.661	0.436	0.201		
	-70.464								3.614	0.931	2.472	0.702	0.493	0.056		
	-85.089								3.586	0.890	2.228	0.723	0.716	0.513	0.020	
CS	CNST.	EBW														
	1.741	0.063				0.485	0.235	0.235								

COMBINED:																
BS	CNST. ²	CD	BL	CW	HP	R	R ²	ΔR^2								
	-21.843								2.323			0.771	0.594	0.594		
	-77.025								1.884	0.946		0.920	0.846	0.252		
	-90.721								1.650	0.830	1.289	0.980	0.961	0.115		
	-95.789								1.515	0.690	1.112	1.085	0.999	0.998	0.037	
EBW	CNST.	CW	BL	CD	HP	R	R ²	ΔR^2								
	14.542								2.527			0.475	0.226	0.226		
	-42.708								2.092	0.960		0.588	0.346	0.120		
	-60.544								1.797	0.840	1.045	0.632	0.400	0.054		
	-81.615								1.550	0.620	0.772	1.005	0.669	0.447	0.047	
CS	CNST.	EBW														
	0.337	0.078				0.507	0.257	0.257								

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

² CNST=constant (intercept)

The only variable that explained 23.5% of the variation in condition score was the ewe body weight (Table 11).

Ewe Reproductive and Productive Traits

Reproductive traits refer to the total number of lambs born alive at lambing (prolificacy) and to the total number of lambs weaned at weaning (weaning rate). No estimates for percent fertility was made as all calculations were based on ewes that weaned at least one lamb. In other words all estimates are on per ewe lambing basis. Productive traits are classified into two broad categories, 1) on the basis on the total weight of lamb born per ewe, and 2) on the basis of total weight of lamb weaned per ewe.

Means and standard deviations for reproductive and productive traits for TXT, FXT and SXT are given in Table 12. Least analysis of variance is given in Table 22 in the Appendix. The FXT ewes were significantly ($P < .001$) more prolific than either the TXT or the SXT ewes while no difference ($P > .05$) was observed between the latter two genotypes. The FXT ewes had an average advantage of 0.59 and 0.51 more lambs born alive compared to the TXT and SXT ewes, respectively. In weaning rate, the FXT also significantly ($P < .001$) excelled the TXT and SXT ewes with an average advantage of 0.44 and 0.39 more lambs weaned, respectively. The three genotypes did not differ ($P > .05$) in total weight of lamb born per ewe, total weight of lamb born per unit ewe body weight and per unit ewe metabolic body weight, and total weight of lamb born per ewe body

Table 12. Means (and SD) of reproductive and productive traits¹ in the TXT, FXT and SXT ewes.

GENOTYPE	TXT	FXT	SXT
N	67	31	110
PROL	1.67 (0.07)	2.26 (0.10)	1.75 (0.05)
WNRT	1.54 (0.08)	1.98 (0.10)	1.59 (0.05)
TWLB (kg)	7.27 (0.30)	7.13 (0.44)	7.47 (0.23)
WBBW (%)	10.42 (0.42)	10.70 (0.61)	10.12 (0.32)
WBMW (%)	30.10 (1.20)	30.55 (1.76)	29.64 (0.93)
WBBS (%)	15.48 (0.64)	16.39 (0.94)	14.98 (0.50)
WBMS (%)	40.50 (1.66)	42.04 (2.44)	39.77 (1.30)
TWLW (kg)	62.73 (2.39)	71.99 (3.52)	66.55 (1.87)
WWBW (%)	89.97 (3.42)	107.88 (5.03)	90.35 (2.67)
WWMW (%)	259.71 (9.76)	308.12 (14.30)	264.45 (7.62)
WWBS (%)	133.63 (5.23)	165.05 (7.70)	133.57 (4.09)
WWMS (%)	349.50 (13.48)	432.72 (19.81)	354.60 (10.52)

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

size and per ewe metabolic body size (Table 12).

The FXT ewes weaned significantly ($P < .01$) more kilograms of lamb per ewe (71.99 kg) over the TXT (62.73 kg) and SXT (66.55 kg). In terms of weight of lamb weaned per ewe body weight and per ewe metabolic weight, the FXT ewe had significantly ($P < .05$) higher ratios (107.88 and 308.12%) than either the TXT (89.97 and 259.71%) or the SXT (90.35 and 264.45%). When weaning weight was expressed as a ratio of ewe body size and ewe metabolic body size, the FXT ewes had significantly ($P < .01$) higher ratio (165.05 and 423.72%) than either the TXT (133.63 and 349.50) or the SXT (133.57 and 354.60%) ewes. The SXT and TXT ewes did not significantly ($P > .05$) differ from each other

Relationships between Reproductive and Productive

Traits with Ewe Body Weight, Ewe body

Size and Condition Score

Targhee X Tarhee ewes

Simple and partial correlations between reproductive and productive traits and weight, size and condition score in the TXT ewes are given in Table 13. No significant ($P > .05$) relationship was observed between ewe body weight and prolificacy although there was a slight tendency to be positive. This relationship numerically decreased when it was adjusted for condition score and body size. The simple correlation between ewe body weight and weaning rate was positive (0.204) and significant ($P < .05$) but decreased to a non-significant level ($P > .05$) of 0.164 and

0.116, respectively, when the effect of condition and ewe body size were held constant. This indicated that when one controls the effect of condition and size, the weaning rate was similar irrespective of the weight of the ewe.

The correlation between ewe body size and prolificacy, and weaning rate is also given in Table 13. The simple correlation between ewe body size and prolificacy was positive (0.227) and significant ($P < .05$), and decreased to a non-significant ($P > .05$) level of 0.144 when the effect of ewe body weight was held constant, implying that the relationship was only through ewe body weight. When the relationship between ewe body size and prolificacy was measured independent of the condition of the animal, the level of significant was not altered suggesting that the condition score of the animal was only a linking variable between ewe body size and prolificacy. There was no significant ($P > .05$) relationship observed between ewe body size and weaning rate, adjusted or unadjusted for ewe body weight or condition score (Table 13).

The condition of the animal seemed to have some influence in prolificacy and weaning rate (Table 13). A positive ($r = 0.250$) and significant ($P < .05$) relationship was observed between the condition score of the animal and the number of lambs born alive, and this relationship was unaffected when measured independent of ewe body weight and/or ewe body size. This may suggest that the ewe body weight and ewe body size were only contributing variables to the relationship between the conditional

Table 13. Simple and partial correlations between¹ reproductive traits and weight, size, and condition in the TXT ewes.

	PROL	WNRT
EBW	0.194	0.204
EBW/CS	0.119	0.164
EBW/BS	0.079	0.116
BS	0.227	0.190
BS/EBW	0.144	0.091
BS/CS	0.205	0.175
CS	0.250	0.149
CS/EBW	0.200	0.087
CS/BS	0.215	0.097

a= $P < .05$; b= $P < .01$; c= $P < .001$

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

state of the animal and prolificacy. When the relationship between condition score and weaning rate was measured no significant ($P>.05$) relationship was detected, with or without adjustments. These results suggested that the animal's ability to give birth to greater number of lambs was a function of its conditional status at breeding while its ability to raise lambs up to weaning was not.

Simple and partial correlation between the total weight of lamb born per ewe, total weight of lamb born per ewe body weight and per ewe metabolic body weight, and total weight of lamb born per ewe body size and per ewe metabolic body size with ewe body weight, ewe body size and condition score in the TXT ewes are given in Table 14. A positive and significant ($P<.05$) relationship was detected between ewe body weight and the total weight of lamb born per ewe. This relationship remained positive and significant ($P<.05$) when the effects of condition score and body size were held constant, revealing the fact that the heavier the ewe the higher the weight of its lamb(s) at birth. No other major relationships were detected between ewe body weight and productive traits at birth.

There were no significant ($P>.05$) correlations observed between ewe body size and total weight of lamb born per ewe, per ewe body weight and ewe metabolic body weight and per ewe body size and ewe metabolic body size (Table 14) except for a negative (-0.239) and significant ($P<.05$) relationship with the total weight of lamb born per ewe body size when the effect of ewe body weight was held constant. The relationships of

Table 14. Simple and partial correlations between productive traits and weight, size, and condition in the TXT ewes.¹

	TWLB	WBBW	WBMW	WBBS	WBMS
EBW	0.264a	-0.073	0.014	0.094	0.138
EBW/CS	0.243a	-0.082	0.002	0.073	0.117
EBW/BS	0.228a	-0.056	0.017	0.217a	0.220a
BS	0.134	-0.047	-0.001	0.140	-0.072
BS/EBW	-0.022	-0.067	-0.010	-0.239a	-0.187
BS/CS	0.124	-0.049	-0.005	-0.151	-0.083
CS	0.101	0.012	0.035	0.077	0.083
CS/EBW	0.013	0.039	0.032	0.048	0.039
CS/BS	0.011	0.039	0.031	0.025	0.021
	TWLW	WWBW	WWW	WWBS	WWMS
EBW	0.252a	-0.098	-0.010	-0.067	0.113
EBW/CS	0.238a	-0.099	0.015	0.049	0.097
EBW/BS	0.232a	-0.060	0.013	0.209	0.216a
BS	0.110	-0.085	-0.037	-0.175	-0.107
BS/EBW	-0.045	-0.035	-0.038	-0.226a	-0.212a
BS/CS	0.101	-0.084	-0.038	-0.184	-0.116
CS	0.085	-0.014	0.010	0.059	0.066
CS/EBW	0.001	0.021	0.015	0.039	0.029
CS/BS	-0.006	0.018	0.011	0.013	0.008

a= P<.05; b= P<.01; c= P<.001

¹See 'Nomenclature' pp.ix-x for description of abbreviations.

condition score to the total weight of lamb born per ewe, per ewe body weight and metabolic body weight and per ewe body size and ewe metabolic body size were non-significant but positive (Table 14).

A correlation matrix between ewe body weight, ewe body size and condition score with weaning weight traits for the TXT ewes is given in the lower half of Table 14. The relationship between ewe body weight with the total weight of lamb weaned per ewe was positive and significant ($P < .05$) with or without the independent effects of ewe body size and condition score. However, the relationship between ewe body weight and the total weight of lamb weaned per unit ewe body weight and per unit ewe metabolic body weight was small and non-significant ($P > .05$). Although, the correlation with total weight of lamb weaned per unit ewe body size and per unit ewe metabolic body size was non-significant, it became positively and significantly ($P < .05$) related to ewe body weight when the effect of ewe body size was removed.

The correlation coefficients, between ewe body size and weaning weight traits are also given in Table 14. These relationships were generally negligible except with total weight of lamb weaned per unit ewe body size and per unit metabolic body size when the effect of ewe body weight was held constant. Moreover, none of the correlation coefficients between condition score and weaning productive traits given in Table 14 were significant ($P > .05$).

Coefficients of relationships between linear body measurements (chest width, chest depth, body length and hip width) and the reproduc-

tive and productive traits for the TXT ewes are given in Appendix Table 24. Except for the positive correlation between chest depth and width with prolificacy ($r=0.207$ and 0.260 , $P<.05$), respectively) no other linear body measurement was significantly ($P>.05$) related to any of the reproductive and productive traits. The relationships between the linear body measurements and ewe body weight and ewe size (Appendix Table 25) were generally positive and significant ($P<.05$, $P<.01$, $P<.001$), while condition score, comparatively, was not highly correlated except with chest width ($P<.001$) and chest depth ($P<.001$) when adjusted for ewe body weight and ewe body size.

Finn X Targhee ewes

The simple and partial correlation coefficients between prolificacy and weaning rate, with ewe body weight, ewe body size and condition score for the FXT ewes are given in Table 15. In the FXT ewes, prolificacy was positively (0.319) and significantly ($P<.05$) related to ewe body weight. When this relation was measured with the condition score of the animal being constant, the correlation was raised to 0.584 and to a higher significant level of $P<.001$. However, when adjustment for ewe body size was made, the correlation coefficient was reduced to a non-significance level of $r = 0.061$. These result indicated that the condition score has covered the strong relationship between ewe body weight and prolificacy and also that this relationship was only due to a third variable, namely the ewe body size. The relationship between ewe body weight and weaning rate was non-detectable, ($P<.05$).

Table 15. Simple and partial correlations between¹ reproductive traits and weight, size, and condition score in the FXT ewes.

	PROL	WNRT
EBW	0.319a	0.091
EBW/CS	0.584c	0.168
EBW/BS	0.061	-0.003
BS	0.377a	0.125
BS/EBW	0.220	0.086
BS/CS	0.452b	0.141
CS	-0.368a	-0.127
CS/EBW	-0.604c	-0.189
CS/BS	-0.445b	-0.143

a= $P < .05$; b= $P < .01$; c= $P < .001$

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

Ewe body size was positively (0.377) and significantly ($P < .05$) correlated with prolificacy, but this relationship was reduced to a non-significant ($P > .05$) level of $r = 0.220$ when measured independent of ewe body weight (Table 15). This indicated that these two measurements, namely ewe body weight and ewe body size, are compatible to each other. And this would not be unexpected as both of them are highly related to each other ($r = 0.746$, Table 23)). When the relationship between ewe body size and prolificacy was measured holding the effect of condition score constant, the relationship became significantly ($P < .05$) positive ($r = 0.452$). This explained the fact that the strong relationship between prolificacy and ewe body size was covered by the effect of the conditional status of the ewe. The simple and partial correlations between weaning rate and ewe body size were all positive but non-significant, adjusted or unadjusted for ewe body weight and condition score.

Significant ($P < .05$, $P < .001$ and $P < .01$) negative correlations were detected between the condition of the animal and prolificacy but non-significant ($P > .05$) negative relationships with weaning rate in the FXT ewes (Table 15).

In Table 16, simple and partial correlations between ewe body weight, ewe body size and condition score with birth weight traits for the FXT ewes are given. With the exception of the weight of lamb born per unit ewe body weight ($r = -0.285$, $P < .05$), the correlation between ewe body weight and the total weight of lamb born per ewe, per unit ewe me-

tabolic body weight, per unit body size and per unit metabolic body size were all non-significant ($P>.05$) with a tendency of being negative.

A significant ($P<.05$) but negative simple correlation was detected between ewe body size, and total weight of lamb born per unit ewe body size ($r = -0.338$) which became non-significant ($P>.05$) when held constant for ewe body weight ($r=-0.228$) with no major change when the effect of body condition was held constant ($r=-0.335$). This was due to the fact that the body condition and size were uncorrelated ($r=0.111$, $P>.05$, Table 23). There were no significant ($P>.05$) correlations observed between the condition score of the animal and any of the birth weight traits (Table 16).

Simple and partial correlations between ewe body weight, ewe body size, and condition with total weight of lamb weaned per ewe, per unit ewe body weight, per unit ewe body size and per unit ewe metabolic body size in the FXT ewes are given in lower half of Table 16, and no significant ($P>.05$) correlations were detected in any of the weaning productive traits.

Coefficients of relationships between linear body measurements and reproductive and productive traits in the FXT ewe are given in Appendix Table 26. Chest width and depth were positively correlated with prolificacy. Body length and hip width were in general, not significantly ($P>.05$) related to any of the reproductive and productive traits studied. The relationships between linear measurements to ewe body weight and ewe body size were generally positive and significant ($P<.05$), but

Table 16. Simple and partial correlations between productive¹ traits and weight, size, and condition in the FXT ewes.

	TWLB	WBBW	WBMW	WBBS	WBMS
EBW	-0.029	-0.285a	-0.226	-0.257	-0.204
EBW/CS	-0.013	-0.251	-0.195	-0.261	-0.203
EBW/BS	-0.008	-0.183	-0.143	-0.008	-0.008
BS	-0.032	-0.220	-0.176	-0.338a	-0.267
BS/EBW	-0.015	-0.012	-0.012	-0.228	-0.177
BS/CS	-0.028	-0.208	-0.166	-0.335a	-0.264
CS	-0.039	-0.139	-0.117	-0.054	-0.050
CS/EBW	-0.029	-0.013	-0.018	0.072	0.048
CS/BS	-0.036	-0.119	-0.100	-0.017	0.021
	TWLW	WWBW	WWW	WWBS	WWMS
EBW	0.051	-0.246	-0.176	-0.227	-0.160
EBW/CS	0.122	-0.161	-0.092	-0.186	-0.110
EBW/BS	-0.026	-0.216	-0.170	-0.012	-0.014
BS	0.092	-0.139	-0.084	-0.295	-0.202
BS/EBW	0.080	0.069	0.072	-0.193	-0.126
BS/CS	0.107	-0.117	-0.062	-0.284	-0.189
CS	-0.126	0.236	-0.212	-0.140	-0.138
CS/EBW	-0.167	-0.145	-0.152	-0.043	-0.075
CS/BS	-0.137	-0.225	-0.205	-0.113	-0.119

a= P<.05; b= P<.01; c= P<.001

¹See 'Nomenclature' pp.ix-x for description of abbreviations.

not with condition score (Appendix Table 25).

Suffolk X Targhee ewes

The coefficients of relationships of prolificacy and weaning rates with ewe body weight, ewe body size and condition score for the SXT ewes are given in Table 17. The correlation between ewe body weight and ewe body weight adjusted for condition score and prolificacy was not significant ($P > .05$); but became significant ($P < .05$) when adjusted for ewe body size. This suggested that the positive relationship between ewe body weight and prolificacy was masked due to the effect of ewe body size. There was no significant ($P > .05$) relationship detected between ewe body weight and weaning rate.

There was generally no significant ($P > .05$) correlation detected between ewe body size and prolificacy on the SXT ewes; the only notable exception being the negative but significant ($P > .05$) relationship with ewe body size adjusted for ewe body weight ($r = -0.196$). In weaning rate, a significant ($P < .05$) negative relationship was found with ewe body size ($r = -0.159$) and ewe body size adjusted for ewe body weight ($r = -.168$). These relationships became non-significant ($P > .05$) when the effect of body condition was removed indicating that the relationships were spurious without the effect of condition of the animal. The condition score was not related to either the prolificacy or weaning rate traits of the SXT ewes (Table 17).

Table 17. Simple and partial correlations between reproductive traits and weight, size, and condition in the SXT ewes.¹

	PROL	WNRT
EBW	0.157	0.028
EBW/CS	0.102	0.011
EBW/BS	0.235b	0.062
BS	-0.086	-0.159a
BS/EBW	-0.196	-0.168a
BS/CS	-0.106	-0.151
CS	0.142	-0.079
CS/EBW	0.076	-0.075
CS/BS	0.155	-0.060

a= P<.05; b= P<.01; c= P<.001

¹See 'Nomenclature' pp.ix-x for description of abbreviations.

Relationship coefficients between ewe body weight, ewe body size and condition score with the total weight of lamb born per ewe lambing, per unit ewe body weight and per unit ewe metabolic weight, and per unit ewe body size and per unit ewe metabolic ewe body size in the SXT ewes are given in Table 18. The total weight of lamb born per ewe lambing was not significantly ($P > .05$) related to ewe body weight although there was a tendency of being positive. This relationship became positive (0.165 and 0.189) and significant ($P < .05$) when measured independent of condition score and ewe body size, respectively, and suggested that both condition score and ewe body size acted as covering agents in the positive relationship that existed between ewe body weight and total weight of lamb born per ewe lambing when the ewes were in relatively better condition. The total weight of lamb born per unit ewe body weight was negatively ($r = -0.185$, $P < .05$) related to ewe body weight, and this relationship was lost when measured with the effects of both condition score and ewe body size removed. This indicated a spurious correlation between ewe body weight and total weight of lamb born per unit ewe body weight without the condition and size of the animal. No significant ($P > .05$) correlations were observed between ewe body weight and ewe body weight adjusted for condition score with the total weight of lamb born per unit ewe body size and per unit ewe metabolic body size (Table 18). However, the relationships were positive ($r = 0.201$ and 0.206) when measured independent of ewe body size.

Ewe body size was only negatively and significantly ($P < .05$) related to the total weight of lamb born per ewe lambing when adjusted for ewe

body weight. The relationship between ewe body size and the total weight of lamb born per unit ewe body weight and per unit ewe metabolic body weight were negative and significant ($P < .05$) except when adjusted for ewe body weight. These results suggested that the condition score has no major influence in these relationships while the ewe body weight did and this was expected as ewe body weight and ewe body size were strongly related ($r = .629$, $P < .001$) to each other. The relationship between ewe body size and the total weight of lamb born per unit ewe body size and per unit ewe metabolic body size was strongly negative ($P < .01$, $P < .001$), with or without the removal of the independent effects of condition and weight of the animal (Table 18). These results suggest that body size was a constant measure in the sense that the influence of weight and condition on this relationship were negligible.

There was no significant ($P > .05$) relationships observed between the conditional status of the animal and the birth weight traits examined (Table 18). The only exception was the relationship with the total weight of lamb born per unit ewe body weight ($r = -0.193$, $P < .05$) which actually disappeared when measured independent of ewe body weight without major change when adjusted for ewe body size.

Simple and partial correlations between the ewe body weight and the total weight of lamb weaned per ewe lambing, per unit ewe body weight and metabolic body weight, and per unit ewe body size and metabolic body size in the SXT ewes are given in lower half of Table 18. In total weight of lamb weaned per ewe lambing, there was no significant ($P > .05$)

Table 18. Simple and partial correlations between productive traits and weight, size, and condition in the SXT ewes.¹

	TWLB	WBBW	WBMW	WBBS	WBMS
EBW	0.123	-0.185a	-0.109	-0.003	0.027
EBW/CS	0.165	-0.107	-0.038	-0.032	0.065
EBW/BS	0.189	-0.090	-0.019	0.206a	0.201a
BS	-0.076	-0.216a	-0.182a	-0.333	-0.273
BS/EBW	-0.163a	-0.143	-0.148	-0.385c	-0.334c
BS/CS	-0.071	-0.196a	-0.166a	-0.328c	-0.268b
CS	-0.043	-0.193a	-0.158	-0.064	-0.060
CS/EBW	-0.119	-0.120	-0.120	-0.072	-0.084
CS/BS	-0.034	-0.171a	-0.138	-0.023	-0.027
	TWLW	WWBW	WWMW	WWBS	WWMS
EBW	0.078	-0.268a	-0.186a	-0.079	-0.037
EBW/CS	0.122	-0.184a	-0.109	-0.035	0.002
EBW/BS	0.166	-0.148	-0.070	0.177a	0.174
BS	-0.126	-0.287b	-0.251b	-0.412c	-0.347c
BS/EBW	-0.193a	-0.181a	-0.184a	-0.438c	-0.382c
BS/CS	-0.108	-0.267b	-0.232b	-0.406c	-0.341c
CS	-0.060	-0.230b	-0.191a	-0.084	-0.080
CS/EBW	-0.112	-0.119	-0.118	-0.057	-0.071
CS/BS	-0.045	-0.204a	-0.166a	-0.035	-0.038

a= $P < .05$; b= $P < .01$; c= $P < .001$

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

correlation observed with ewe body weight and ewe body weight adjusted for condition score. But the relationship was positive and significant ($P < .05$) when measured independent of ewe body size revealing the fact that the positive relationship between ewe body weight and total weight of lamb weaned per ewe was hidden due to the effect of ewe body size. The total weight of lamb weaned per unit ewe body weight and per unit ewe metabolic body weight were negatively ($r = -0.268$ and -0.186 , respectively) and significantly related to ewe body weight. These relationships were non-existent when measured independent of ewe body size (Table 18). The total weight of lamb weaned per unit body size and per unit ewe metabolic body size were not related to ewe body weight and ewe body weight adjusted for ewe condition score. But real ($P < .05$) positive relationships were observed when the effect of ewe body size was removed.

The ewe body size was negatively (-0.193 , $P < 0.05$) related to the total weight of lamb weaned per ewe when ewe body weight was held constant (Table 18). The total weight of lamb weaned per unit ewe weight and per unit ewe metabolic body weight, and per unit ewe body size and per unit ewe metabolic body size were strongly and negatively ($P < .01$) related to ewe body size.

No relationship was detected between the condition of the animal and the total weight of lamb weaned per ewe, although there was a tendency to be negative (Table 18). The correlation between condition score and the total weight of lamb weaned per unit ewe body weight and

per unit ewe metabolic body weight was real ($P < .05$) and negative. No real ($P > .05$) relationships were observed between condition and total weight of lamb weaned per unit ewe body size and per unit ewe metabolic body size.

Chest width and depth were negatively related with most traits studied (Appendix Table 28) and body length (when adjusted for ewe body size) was positively related with all but prolificacy. The relationships between the linear body measurements and weight and size (Table 29 in the Appendix) were mostly positive and significant ($P < .05$, $P < .01$, $p < .001$).

DISCUSSION

Linear Body Dimensions, Size and Shape

The three genotypes of ewes in the present study, Targhee x Targhee (TXT), Finn x Targhee (FXT), and Suffolk x Targhee (SXT) differed in linear body dimensions where the SXT ewes were generally deeper in the chest, longer in the body, taller in stature, wider at the hips, larger at the head than either the FXT or TXT ewes with no real difference in chest width. As a consequence, they were larger in volume as measured by their body size. Breed difference in linear body measurements have been reported by Wiener and Hayter (1974), although different breeds than those used in the present study were used in their study. Galal et al. (1965) have found difference in linear body measurements as affected by breed, year, sex, and age in 1400 lambs they measured. Differences in body size were noted in the Merino ewes (Guerra et al., 1972), Greyface ewes (Ducker and Boyd, 1977) and Cheviot ewes (Gunn and Doney, 1979). All these studies confirm the findings of the present study. Within each genotype, there was no seasonal fluctuation observed in the linear body measurements taken because all the ewes in the study were mature ewes (3 years or older) and no increase in skeletal measurements were expected. However the seasonal difference in chest depth observed in the FXT and TXT ewes was an exceptional case to general expectations and observations with no apparent explanation except for possible random error. There was large seasonal variation in ewe body weight

and condition which were associated with the physiological stresses of raising lamb and abundance of food supply in fall.

Loadings and correlations for the first five principal components with brief description were given in Tables 6, 7 and 8 for the TXT, FXT, and SXT ewes, respectively. The loadings of ewe body size and ewe body weight to the first principal components were 0.928 vs 0.747, 0.925 vs 0.866 and 0.923 vs 0.726 for TXT, FXT and SXT ewes, respectively. These results indicated that the calculated body size was a better estimate for the general definition of size than the body weight or any other linear body measurement. These results may also suggest that the weight of the animal was the best measure of size if estimate of body size was not available. This is so because, in all the three genotypes studied the second highest loading to the first principal component was always the ewe body weight. The second principal component, as an indicator of shape, distinguished length characteristic in the TXT and SXT ewes and chest characteristic in the FXT ewes. In this study, the percent variation contribution of the second and third principal components were comparable in magnitude indicating some degree of overlapping. This could be seen from the third principal component which described chest characteristic in the TXT and SXT ewes and length characteristic in the FXT ewes. The third principal component is taken to be an added description of shape. The first, second and third components together accounted for 61.4, 72.0 and 60.4% of the total variation in size and shape in the TXT, FXT and SXT ewes, respectively. The fact that more than 60% of the total variation of the ten body measures was explained by the general

size and shape would indicate that positive correlations among all body parts do exist; and this is evidenced by the significant positive relation observed between linear body measurements and weight and size estimates (Appendix Tables 25, 27, and 29) in the three genotypes studied. The fact that more than 60% of the total variation in size and shape was explained by the first three principal components also indicated that more than 60% of the information provided by the original ten measurement was contained in only three newly generated orthogonal variables and hence, an advantage in reduction of total number of variables.

Comparisons of size and shape in sheep in terms of principal component coefficients and correlation with the literature was not possible because such studies were rare in sheep and it is likely that they do not exist; and even if they do exist, the author was not able to get any of them. However, linear body measurements and interpretation of such measurements was not uncommon in sheep, though different statistical tools were used. For instance, Wiener and Hayter (1974) used the ratio of the linear measurement to body weight raised to some unknown power (b) to determine the breed constant k, as follows: $k = \text{linear Dimension (LD)}/\text{Weight (WT)}$ to the power of b and by taking the natural logarithms in both sides of the equation yielded the following simple regression equation, as:

$$\log (\text{LD}) = \log k + b \log (\text{WT})$$

The calculated values for k and b were then used to determine the variation in shape in animals involved in the study. This approach has the

disadvantage that, first, it cannot be used to estimate and compare body sizes of different subjects simply because dividing by the body weight eliminated that possibility (it was not the intention of the study, however); and secondly, only one linear dimension can be used at a time and hence eliminates simultaneous weightings of different linear measurements for wider interpretation of shape and size. Other workers, notably, Ducker and Boyd (1977) and Guerra et al. (1972) estimated body size by multiplying the average width of hip and shoulder by body length and depth but did not relate the body size to other measurements but only to production responses. Galal et al. (1965) measured different body dimensions but only reported their correlations to each other and to birth weight and weaning weights in sheep.

The concept of size and shape are fundamental to the analysis of variation in living organisms, and yet, until the development of principal component analysis, there was no general agreement on a practical definition of size and shape. Partitioning variation into size and shape components is often highly desirable as the size of most organisms is more affected than their shape by fluctuations of external environment. Shape tends generally to provide more reliable information than size or weight in the internal constitution of the organism; and this makes the analysis of size and shape a basic step on the study of biometrical variation (Jolicoeur and Mosimann, 1960).

The computer revolution has affected the multivariate analysis of principal component analysis which has found considerable application on

the investigation of size and shape in beef cattle in the last 10 to 15 years (for instance, Carpenter, 1971; Brown et al., 1973; Carpenter et al., 1978; McCurley and McLaren, 1981). A problem associated with the use of principal components analysis in animal production is the desire to give each principal component a name and to attach causal significance to it (Morris and Wilton, 1975). Brown et al. (1973), using nine skeletal measurements and body weights in Angus and Hereford bulls at four, eight and twelve months of age, have reported that 75% of the total variation in size and shape was explained by the first two principal components, in close agreement with McCurley and McLaren (1981). Brown et al. (1973) further reported that shape did not change with the range of ages examined because of high correlation in the second principal component. Carpenter et al. (1978) have shown that the first and second principal components accounted for nearly 90% of the total variation in size and shape and that the first principal component was highly correlated with average cow body weight ($r = 0.93$), justifying the use of cow body weight as a measure of cow size. The reports of Carpenter et al. (1978), Brown et al. (1973) and McCurley and McLaren (1981) were generally consistent with the present findings, except there seemed to be a need to go to the third or even fourth principal component in the sheep studied to account for the same amount of variation explained by only the first two components in cattle, which may lead to inconclusive conclusion that there is more size and shape variation in sheep than there is in cattle. Moreover, the first principal component in the present study was highly correlated to ewe body size than ewe body weight where-

as it was highly correlated with cow (or bull) weight in cattle. This may be so because no estimates of cow size, except the weight were put in the principal component model in the forementioned reports.

The stepwise regression tables given in Tables 9, 10, and 11 for the TXT, FXT and SXT, respectively, suggested that among the six linear body measurements, chest depth, chest width, body length and hip width explained more than 99.8% of the total variation in the calculated body size. (This should not be confused with the 35.1, 43.8 and 37.6% of the variation in general size, explained by the first principal component in the TXT, FXT, and SXT ewes, respectively; Tables 6, 7, 8. The latter percentages refer to the variation in general size from the population of sheep sampled while the former refer to the variation in the calculated body size as explained by the linear measurements). Chest depth was the single most important variable that explained more than 50% of the total variation in size in the TXT and SXT ewes and hip width in the FXT. The estimation of ewe body weight from the linear measurements was not very satisfactory when compared with the estimation of ewe body size. The ewe body weight was the only variable that explained approximately 15% of the variation in condition score. There was not any direct contribution of ewe body size or any linear measurement in the estimation of fat, indicating that the ewe body size or the linear measurement played no role in the condition of the animal. This supports the idea that the ewe body weight is composed of two independent components, the condition and skeletal size. Guerra et al. (1972) used the ratio of ewe body weight to ewe size as an estimate of condition score.

This method was mathematically sound as it is expressed as weight per unit volume, but was found less predictive when applied to this study.

Reproductive Efficiency

From results given in Tables 10, the FXT ewes were more prolific and weaned more lambs than either the TXT or SXT ewes. Significant breed differences in total number of lambs born per ewe (Atkins, 1980; Boyazoglu et al., 1979; Dahmen et al., 1978; Hohenboken and Cochran, 1976; Laster et al., 1972) and in total number of lambs weaned per ewe (Levine and Hohenboken, 1978; Humes et al., 1978) have been reported, confirming the present finding in breed difference. Dahmen et al. (1978) have reported an increase of 41% in prolificacy by incorporating the Finnsheep in a crossbreeding programs. Similar results of the range of 40-50%, mostly in accelerated lambing program, have been reported (Duncan and Black, 1978; Goot, 1975; Speedy and FitzSimons, 1977; Walton and Robertsen, 1974). The present study revealed the superiority of the FXT ewes in both prolificacy and weaning rate of about 36 and 28.5%, respectively, over the straight-bred TXT ewes.

The genotypic differences in total weight of lamb weaned per ewe in the present study was significant ($P < .01$), where the FXT ewes superior (72.0 kg) over the TXT ewes (62.7 kg) and SXT ewe (66.5 kg). The FXT ewes were lighter in weight (64.6 vs 66.7 and 70.0 kg) and smaller in volume (44.5 vs 48.0 and 51.0 cc), and hence lower in metabolic body weight and size; but had weaned more lambs (2.26 vs 1.75 and 1.61) than

the SXT and TXT ewes, respectively. When lamb production was expressed as per unit body weight and size, and per unit metabolic body weight, and size, the FXT ewe significantly ($P < .001$) surpassed the SXT and TXT ewes (Table 12), indicating that the FXT ewe produced more weight of lamb in relation to its weight and size. The higher performance of the Finn-cross ewe could be due to its higher weaning rate or lighter in weight and smaller in size or both. It has been reported that milk production was higher in heavier cows than lighter cows, but when milk production was expressed per unit body weight, the lighter cows produced more than the heavier ones (Brody, 1945). Kleiber (1932, 1947) has stated that the basal metabolic rate per unit body weight decreased with increased body weight. The rate of oxygen consumption (Schmidt-Nielsen and Larimer, 1958), the nutrient concentration in the blood (Umminger, 1975), the reproductive rate in rodents (McNab, 1980) and maintenance requirements (Blaxter et al., 1969) have been shown to increase with declining weight, although the magnitude of weight ranges examined were ten or more fold between the light and heavy animals and different species of animals were involved. All the forementioned factors favor the FXT ewe (although it is doubtful if such generalization can be directly applied to a particular genotype of sheep) and would probably lead to the conclusion that smaller but more prolific sheep could bring higher economic return in the sheep industry in general, and to the sheep farmer in particular. Large (1970) had reached the same conclusion in terms of efficiency in meat production from sheep. However, it has also been reported that the fixed cost (veterinary, labor, taxes, and management

costs) always favor larger animals (Dickerson, 1978). In particular, the fixed cost of labor is one of the important limiting factor in the sheep industry in the United States of America. Searle and Griffiths (1976) have suggested the use of animals of large mature weight to satisfy the lean carcass preference of the Australian lamb shoppers. Thus, fixed cost and market preferences seem to favor the use of larger but productive breeds of sheep. Hence the decision on what size of sheep to use should depend on availability of feed, market preferences, labor availability, and management. Larger or smaller size has its own advantage and merits under a given environment and management system. And within given environment, management system and genotype (or breed) it is doubtful if differences in weight and size could bring significant difference in reproductive and productive efficiencies.

Relationships

Ewe body weight and size were positively and condition score negatively correlated with prolificacy in the FXT ewes with a tendency to be positive in the TXT and SXT ewes. A prolific breed of ewe has to metabolize much of its body fat reserves (or even protein when necessary) in order to nourish and support the growing number of fetuses in the uterus up to delivery. Hence its condition should decrease with increasing number of lambs born. A constant condition would be expected to raise the relationship between ewe body weight and size with prolificacy in the FXT sheep. As shown in Table 15, the correlation coefficient (r) between ewe body weight and prolificacy increased from 0.319 ($P < .05$) to

0.584 ($P < .001$). On the contrary, there was a tendency for the relationship between ewe body weight and size with prolificacy to decrease at a constant condition in the TXT and SXT ewes (Tables 13 and 17, respectively), suggesting that in less prolific ewes there was, comparatively, no significant increase in fat metabolism for reproductive purpose. It has been shown that reproductive rate increases with increased metabolic rate in small mammals (McNab, 1980) and that the fraction of energy spent for reproduction tended to decrease with increasing body weight (Fenichel, 1974), and justify the present finding. The results also suggest that in a genetically lighter breed of ewe, the heavier ewes were more prolific whereas in genetically heavier ewes, the lighter ewes tend to be more prolific while medium-sized breeds of ewes fall somewhere in between. This could be due to genetic differences more than anything else. Guerra et al. (1972) have found a significant relationship between ovulation rate and body weight ($r = 0.42$) and body size ($r = 0.33$) and a non-significant relationship between body size and ovulation rate at constant body weight and concluded that body weight appeared to be a more useful tool in predicting ovulation rate (and hence total number of lambs born) than either the body size or condition. Increase in prolificacy with increase in ewe body weight have been reported by several workers (for instance Coop, 1962; Adalsteinsson, 1979; Curll et al., 1975) confirming the present findings.

Holding either ewe body weight constant and measuring the relationship between ewe body size and prolificacy, or holding the ewe body size constant and measuring the relationship between prolificacy and ewe body

weight rendered a non-significant relationship suggesting that the ewe body weight and ewe body size are biologically indistinguishable in terms of ovulation rate and prolificacy and that one is the cause of the other. Increase in size is associated with increase in weight as evidenced by their high positive relationships ($r = 0.592$ to 0.629 , $P < .001$, Table 23). The linear dimension of an animal must increase as a power of 3 to support the weight of the animal up to a certain stage and the diameter should then increase until the weight of the animal is proportional to the length x diameter squared (McMahon, 1973). This indicates that an animal cannot carry its own weight without proportionally increasing its skeletal structure in length and diameter and hence in body size. Various linear measurements can be expressed as a power function of body weight in the form of $Y = aW^b$ (Stahl, 1967), where x is the skeletal function and b is the slope of the least - square regression line in a log-log allometric relationship.

If all ewes were at a relatively constant good condition (as was the case in Fall) results given in Tables 13, 15 and 17 indicated that the number of lambs weaned per ewe is independent of ewe body weight. Within a given genotype, however, there was a tendency for the heavier ewes to wean more in the genetically smaller ewes and the lighter ewes to wean more lambs than the heavier ewes in the genetically heavier ewes. The results indicated the importance of maternal environment, particularly nourishment of the young at early age of life, in the survival and growth ability of the lamb up to weaning. If a ewe is under relatively good condition, regardless of its weight, has enough energy

reserves to produce milk for the young without affecting its maintenance requirement. However, if a large ewe is at a relatively poor condition, it has to sacrifice its productive functions to maintenance function due to its higher requirement.

The trend of relationship between ewe body size and weaning rate tended to be positive in the FXT and TXT ewes and negative in the SXT ewes. The condition score, on the other hand, tended to be negative in the FXT and SXT ewes and positive in the TXT ewes indicating the effect of the number (in the FXT ewes) and the weight (in the SXT ewes) of lamb weaned in which both had a similar effect in draining the body reserves of the respective dams. There are reports in the literature that indicate that the weaning rate and lamb mortality increased with increasing body weight (Cumming et al., 1978; Nicholas and Whiteman, 1966) but no effects of condition were given.

The relationships between ewe body weight and total weight of lamb born per ewe tended to be small ($P > .05$) but negative in the FXT ewe (Table 16), positive and significant ($P < .05$) in the TXT ewes (Table 14) and small ($P > .05$) but positive in the SXT ewes (Table 18). A positive correlation should be expected between the ewe body weight and total weight of lamb born per ewes due to a positive relationship between prolificacy and body weight in the FXT ewes (Table 16). But since the birth weights of lambs that reached weaning age were only included in the analysis, the correlations given in Tables 16 may not represent the actual total weight of lamb born per ewe. This is also the case for the

TXT and SXT ewes.

There was a tendency for the total weight of lamb weaned per ewe to be positively related to ewe body weight in the FXT and SXT ewes and positively ($P < .05$) in the TXT ewes. The total weight of lamb weaned per ewe is a function of both the weaning rate and the weaning weight of the lamb, where the former is a function of the survival ability of the lamb when the right material environment is provided and the latter is a function of the growth ability of the lamb. Results given in Table 13, 15, and 17 indicated that there was more positive relationship between the ewe body weight and weaning rate in the TXT ewes than there was in the FXT or SXT ewes, revealing that there was much higher chance for lamb from the intermediate genotype to survive upto weaning than either of the two extremes. It has been reported that extremely small or extremely heavy lambs at birth have less chance to survive upto weaning than intermediate lambs (Alexander, 1964). Within each genotype group, the medium group weaned more lamb and therefore more weight of total lamb per ewe than either extremes, revealing a quadratic relationship.

The relationship between ewe body weight and size and total weight of lamb born per unit ewe body weight and size was negative and higher ($P < .05$) in the SXT ewes than the FXT and TXT ewes suggesting that the heavier or the larger the ewe the less it produces in relation to her body weight or size.

SUMMARY

A study was carried out to estimate the functional ewe body size and investigate relationships of ewe body size and weight to her reproduction and production function. The study was conducted at two locations, Logan and Cedar City, Utah. A total of 208 ewes from Cedar City representing three genotypes: Targhee x Targhee (TXT), Finn x Targhee (FXT), and Suffolk x Targhee (SXT) were used in the study. Targhee-type range ewes and FXT ewe were used from Logan.

Seven linear body measurements: chest width, chest depth, body length, hip width, metatarsus length, head width, and head length - ewe body weight and ewe body condition score were taken in the fall (pre-breeding) and in Spring (post-lambing) in Cedar City and 3 to 6 times in Logan. From these linear measurements, ewe body size was calculated by multiplying the average width of hip and chest by body length and chest depth. This was the same as calculating the volume of a rectangle. Fertile or non-fertile ewes were indentified, the total number of lambs born alive at lambing and the total number of lambs weaned were recorded for each ewe. The birth and weaning weights of lambs were also recorded. From these records, prolificacy, weaning rate, total weight of lamb born per ewe lambing, per unit ewe body weight and size, and per unit ewe metabolic body weight and size, were calculated and represented reproductive and productive traits of the ewe. Moreover, 22 mature Targhee-type range ewes were slaughtered and carcass measurements, that included hot and chilled carcass weight, weight of kidney knob and fat,

back fat thickness, chest width, chest depth, body length, chest depth, body length and hip width, were recorded.

Principal component analysis, stepwise regression, simple and partial correlation analysis, estimation of coefficients of reliability and variation, and analysis of variance were used to analyze the data. Principal component analysis was mainly used to describe size and shape variations, stepwise regression to identify factors of major significance, and simple and partial correlation analysis to investigate relationships of ewe fall weight and size to the productive parameters. Birth and weaning weights of lamb were adjusted to a common age of ewe (4-6 years), common weaning age (150 days), common sire (Targhee) and to a neutral or mid-sex; and productivity of ewe was based on those adjusted values. The data included only ewes that have weaned at least one lamb. Both fall and spring data were included when analyzing for linear measurements and ewe body size, and only fall data for reproductive and productive functions of the ewe.

There was significant ($P < .05$) genotypic differences in all linear measurements except for chest depth, where the FXT ewes were generally smaller in skeletal measurements and size than the SXT ewes and TXT ewes. There was significant ($P < .05$) difference in body weight and condition in Fall where the difference in body condition disappeared in Spring.

The live measurements of chest depth, chest width, body length and hip width were significantly ($P < .05$) related with their respective meas-

urements in the carcass with simple correlation coefficients of 0.773, 0.426, 0.782, and 0.691, respectively. Except for a low correlation with backfat thickness ewe body weight and size were positively ($P < .01$) related to slaughter measurements that included hot and chilled carcass weight, kidney fat and kidney knob and skeletal measurements. Backfat thickness was only significantly ($P < .001$) correlated with the condition score of the animal ($r = 0.704$). The difference in ewe body weight and was significantly ($P < .01$) correlated with all carcass measurement but chest depth, body length and hip width.

The first, second and third principal components accounted for 61.4, 72.0 and 60.4% of the total variation in size and shape in the TXT, FXT, and SXT, respectively. The loadings of ewe size and weight to the first principal components were 0.928 vs 0.747; 0.925 vs 0.866; and 0.923 vs 0.726, in the three genotypes, respectively, indicating that the calculated body size was a better estimate of general size than body weight. The second and third principal components distinguished length characteristics in the TXT and SXT ewes and chest characteristics in the FXT ewes.

More than 99.8% of the variation in calculated ewe body size was explained by four of the seven skeletal measurements taken, namely chest width, chest depth, body length and hip width, although the order in which they entered the stepwise regression model differed in the three genotype. Chest depth alone explained 61.1 and 52.9% of the total variation in calculated ewe body size in the TXT and SXT ewes, respectively;

and hip width 56.5% in the FXT ewes.

In terms of reproductive and productive traits, the FXT ewes were more prolific (2.26) than either the TXT (1.67) or SXT (1.75) and weaned more lambs (1.98 vs 1.59 and 1.63). The three genotypes did not differ ($P > .05$) in total weight of lamb born per ewe, per unit ewe fall weight and size, and per unit ewe metabolic body weight and size. The FXT ewe weaned significantly ($P < .01$) more weight of lamb per ewe (72.0 kg) than TXT (62.7 kg) and SXT (66.6 kg). When lamb productivity was expressed as per unit fall weight and size, and as per unit metabolic weight and size, the FXT ewe significantly ($P < .01$) surpassed both the TXT and SXT ewes.

Relationship between prolificacy and ewe fall weight and size was positive ($P < .05$) in the FXT ewes with a tendency to be positive ($P > .05$) in the TXT and SXT ewes. Body condition was negatively ($P < .01$) related to prolificacy in the FXT, positive ($P < .05$) in the TXT with a tendency to be positive ($P < .10$) in the SXT ewes. There was a tendency for weaning rate to be positively ($P > .05$) related to ewe fall weight in all three genotypes studied. Body size, however, was negatively ($P < .05$) related to weaning rate in the SXT ewes with a tendency to be positive ($P > .05$) in the TXT and FXT ewes. The relationship of weaning rate to body condition was positive ($P < .05$) in the TXT ewes and negative in SXT and FXT ewes.

Weight of lamb weaned per ewe lambing was positively ($P < .05$) related to ewe fall weight in the TXT ewes and was positive but insignificant

($P > .05$) in the SXT and FXT ewes. Strong negative relationships ($P < .05$, $P < .01$) were detected between the weight of lamb weaned per unit ewe fall weight and size and per unit ewe metabolic body weight and size with ewe fall weight and size in the SXT ewes. Similar relationships were observed in the FXT and TXT ewes but were not as strong as in the SXT ewes.

CONCLUSIONS AND RECOMMENDATIONS

From the data collected and analyzed for the purpose of estimating ewe body size and investigating relationships of ewe fall weight and size to her production functions, the following conclusions are reached:

I. Estimating Ewe Body Size

In the three genotypes of ewes studied in Cedar City, namely Targhee x Targhee (TXT), Finn x Targhee (FXT), and Suffolk x Targhee (SXT) ewes; and the Finn x Taghee (FXT) and Targhee-type range ewes in Logan, the following have been revealed:

a. the live-measurements of chest depth, chest width, body length, and hip width were highly related ($P < .05$) to their respective measures at slaughter,

b. more than 99.8% of the total variation in calculated ewe body size was explained by the chest width, chest depth, body length, and hip width; where chest depth, and hip width were the important single measures,

c. the highest loadings (contributions) to the first principal component, a measure of general size, ranging from 0.923 to 0.928, were due to calculated ewe body size followed by the ewe body weight,

d. there was significant ($P < .01$) positive relationship between ewe body size and ewe body weight but no relationship ($P < .05$) between ewe

body size and body condition, and

e. the calculated ewe body size did not fluctuate with changes in season when compared to ewe body weight and body condition.

From the above it is concluded that:

1. The estimation of ewe body size by multiplying the average of chest and hip width by body length and chest depth was found to be a reasonable working definition of size as no other estimate of size was better explained by the first principal component or the linear body measurements.

2. The calculated ewe body size is relatively free of fat and does not fluctuate with changes in body condition, season or physiological stresses, i.e., it is a relatively constant measure of size.

3. Due to the difficulty and time-consuming nature of measuring linear body dimensions, ewe body size can best be approximated by,

$$BS = -9.670 + 1.838 CD, r = 0.782 \text{ in the TXT ewes}$$

$$BS = -27.840 + 3.511 HP, r = 0.752 \text{ in the FXT ewes}$$

$$BS = -21.795 + 2.249 CD, r = 0.727 \text{ in the SXT ewes}$$

and when combined yield a common equation as follows:

$$BS = -21.843 + 2.323 CD, r = 0.771 \text{ in all genotypes.}$$

4. Whenever linear body measurements are not available, ewe body weight is the second best measure of size.

II. Relationships of Ewe Fall Weight and Ewe Body Size to Production Functions and Efficiency of Production

A. The degree of relationships varied from genotype to genotype. Within each genotype, however, the following general trend of relationships were revealed.

1. Ewe body weight and ewe body size were positively related to prolificacy, weaning rate and total weight of lamb weaned per ewe lambing and negatively related to the total weight of lamb weaned per unit ewe weight and size and per unit ewe metabolic weight and size.

2. Body condition was negatively related to production functions in the genetically lighter (FXT) ewes, positive in the intermediate (TXT) ewes, with no major effect in the genetically heavier (SXT) ewes.

B. When the degree of relationships were examined across genotypes:

1. The heavier ewes were more prolific in the genetically lighter/smaller ewes (FXT) and the lighter ewes were more prolific in the genetically heavier/larger ewes (SXT). The TXT ewes were intermediate. A similar trend was observed in weaning rate, although the relationship was stronger in the TXT ewes.

2. The total weight of lamb weaned per ewe lambing, which is the function of both weaning rate and weaning weight of lamb, was positively related to ewe fall weight and size but the relationship was stronger in the TXT ewes than either the FXT or SXT ewes. This suggested that there

was a better chance of lamb survival to weaning in the intermediate genotype than either the two extremes. Mortality rates were 7, 16, and 28% for the TXT SXT and FXT ewes, respectively.

3. Lamb production on per unit fall weight or size basis was negatively related with fall weight or size in all genotypes, but the degree of relationship was stronger in the SXT than in the TXT ewes, which in turn was stronger than in the FXT ewes. This suggested that the heavier the ewe the less she produced in relation to her own weight or size.

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APPENDIX

APPENDIX DESCRIPTION

HW=Head width, cm
 HL=Head length, cm
 CW=Chest width, cm
 CD=Chest depth, cm
 BL=Body length, cm
 HP=nip width, cm
 MT=Metatarsus length, cm

HCW=Hot carcass weight, kg
 CCW=Chilled carcass weight, kg
 BF=Back-fat thickness, cm
 KF=Kidney fat, kg
 KK=Kidney knob, kg
 CWS=Chest width, cm
 CDS=chest depth, cm
 BLS=Body length, cm
 HPS=Hip width, cm

CS=Condition score, 1-9 pts
 EBW=Ewe body weight, kg
 BS=Ewe body size, cc
 MBW=Metabolic body weight, kg to 0.75
 MBS=Metabolic body size, cc to 0.75

PROL=Prolificacy, number of lambs born
 WNRT>Weaning rate, number of lambs weaned
 TWLB=Total weight of lamb born per ewe lambing, kg
 WBBW=Weight of lamb born per unit ewe body weight, %
 WBMW=Weight of lamb born per unit ewe metabolic body weight, %
 WBBS=Weight of lamb born per unit ewe body size, %
 WBMS=Weight of lamb born per unit ewe metabolic body size, %
 TWLW=Total weight of lamb weaned per ewe lambing, kg
 WWBW=Weight of lamb weaned per unit ewe body weight, %
 WWMW=Weight of lamb weaned per unit ewe metabolic body weight, %
 WWBS=Weight of lamb weaned per unit ewe body size, %
 WWMS=Weight of lamb weaned per unit ewe metabolic body size, %

EBW/CS=Partial correlation of EBW with trait X adjusted for CS
 EBW/BS=Partial correlation of EBW with trait X adjusted for BS

\bar{X} =Mean (Average)
 CV=Coefficient of variation
 CR=Coefficient of reliability
 REP=Repeatability
 SV=Source of variation
 DF=Degree of freedom

Table 19. ANOVA, means, coefficients of variation, reliability, and¹ repeatability in the FXT and T-type range ewes in Logan.

GENOTYPE	SV.	DF	HW	HL	CW	CD	BL	HP	MT	CS	EBW
FXT	BETWEEN	43	1.30	2.48	9.38	9.67	30.81	6.30	5.37	0.40	326.23
	WITHIN	220	0.08	0.24	1.51	2.91	4.53	0.74	0.37	0.16	68.87
	X		13.1	22.6	23.5	29.4	69.5	21.4	22.6	4.9	70.3
	CV,%		2.2	2.0	5.2	5.8	3.1	4.0	2.7	8.2	11.8
	CR,%		94.7	92.4	84.1	78.6	87.5	88.4	93.3	77.5	93.6
	REP,%		71.4	60.9	46.5	27.9	49.1	55.6	69.1	19.8	38.4
T-type	BETWEEN	23	0.68	1.41	4.68	3.60	19.01	1.78	1.62	2.82	201.30
	WITHIN	48	0.08	0.36	1.23	1.85	2.40	0.16	0.09	0.26	6.22
	X		13.5	22.0	23.5	32.1	69.5	22.6	23.5	5.7	67.5
	CV,%		2.0	2.7	4.7	4.2	2.2	1.8	1.3	9.0	3.7
	CR,%		88.6	75.2	82.3	47.0	89.8	92.2	94.4	92.6	98.1
	REP,%		72.8	49.1	48.3	24.0	69.7	77.2	85.0	76.4	91.3

¹See 'Nomenclature' pp.ix-x for description of abbreviations.

Table 20. ANOVA, means, coefficients of variation, reliability, and repeatability in the TXT, FXT, and SXT ewes in Cedar City.¹

GENOTYPE	SV	DF	HW	HL	CW	CD	BL	HP	MT	CS	EBW
TXT	BETWEEN	73	0.36	1.09	2.64	6.14	9.08	1.28	1.32	1.74	82.00
	WITHIN	74	0.10	0.51	0.72	3.13	2.35	0.41	0.21	6.34	45.85
	\bar{X}		13.3	22.0	22.4	31.5	69.7	21.1	23.2	4.3	66.7
	CV,%		2.4	3.2	3.8	5.6	2.2	3.0	2.0	57.2	10.2
	CR,%		73.2	61.5	74.6	61.9	73.9	68.3	84.9	37.0	72.2
	REP,%		66.8	49.2	69.0	44.4	70.5	63.9	81.5	0.0	39.6
FXT	BETWEEN	36	0.37	0.86	3.54	3.66	11.71	1.60	0.71	3.02	67.59
	WITHIN	37	0.13	0.18	1.71	2.44	2.58	0.27	0.12	4.54	27.42
	\bar{X}		13.2	21.4	21.1	31.1	67.3	20.5	22.7	3.6	64.6
	CV,%		2.8	2.0	6.0	5.0	2.4	2.5	1.5	59.2	8.2
	CR,%		68.7	79.8	53.2	62.2	77.9	83.0	82.2	55.4	80.5
	REP,%		59.7	76.3	47.4	29.5	74.7	80.4	79.9	0.0	55.0
SXT	BETWEEN	118	0.44	1.06	3.91	3.97	11.60	1.75	1.69	1.46	100.83
	WITHIN	119	0.09	0.26	0.61	0.84	1.11	0.24	0.19	7.34	61.50
	\bar{X}		13.7	22.6	22.7	32.5	70.6	21.6	23.3	4.6	70.0
	CV,%		2.2	2.2	3.4	2.8	1.5	2.3	1.5	58.9	11.1
	CR,%		83.2	79.5	84.6	88.0	90.4	86.1	93.0	47.9	75.8
	REP,%		76.8	72.5	81.9	75.7	88.7	83.9	91.7	0.0	34.8

¹See 'Nomenclature' pp.ix-x for description of abbreviations.

Table 21. ANOVA (significant levels) for linear measurements, weight,¹ size, and condition.

	SEASON			GENPTYPE			
	FALL	SPRG	COMB	TXT	FXT	SXT	COMB
SV	GEN	GEN	GEN	SSN ²	SSN	SSN	SSN
DF	2	2	2	1	1	1	1
HW	0.000	0.000	0.000	0.083	0.137	0.012	0.010
HL	0.000	0.000	0.000	0.001	0.638	0.067	0.000
CW	0.161	0.021	0.004	0.068	0.269	0.410	0.043
CD	0.000	0.002	0.000	0.000	0.001	0.000	0.000
BL	0.000	0.000	0.000	0.685	0.332	0.811	0.424
HP	0.000	0.000	0.000	0.385	0.919	0.886	0.531
MT	0.004	0.000	0.000	0.317	0.618	0.756	0.507
CS	0.000	0.166	0.000	0.000	0.000	0.000	0.000
EBW	0.000	0.024	0.000	0.000	0.003	0.000	0.000
EMW	0.000	0.023	0.000	0.000	0.003	0.000	0.000
BS	0.000	0.000	0.000	0.052	0.340	0.060	0.004
MBS	0.000	0.029	0.000	0.054	0.331	0.065	0.005
ERROR DF	205	205	412	132	60	218	412

¹See 'Nomenclature' pp.ix-x for description of abbreviations.

²SSN = Season

Table 22. ANOVA (significant levels) for reproductive and productive¹ trait.

	SEASON			GENPTYPE			
	FALL	SPRG	COMB	TXT	FXT	SXT	COMB
SV	GEN	GEN	GEN	SSN ²	SSN	SSN	SSN
DF	2	2	2	1	1	1	1
PROL	0.000	0.000	0.000	-	-	-	-
WNRT	0.001	0.001	0.000	-	-	-	-
TWLB	0.749	0.749	0.559	-	-	-	-
WBBW	0.665	0.995	0.815	0.065	0.314	0.005	0.000
WBMW	0.888	0.996	0.969	0.160	0.438	0.030	0.007
WBBS	0.407	0.542	0.224	0.694	0.745	0.737	0.553
WBMS	0.709	0.792	0.564	0.764	0.807	0.791	0.645
TWLW	0.091	0.091	0.008	-	-	-	-
WWBW	0.006	0.060	0.001	0.061	0.248	0.002	0.000
WWMW	0.014	0.062	0.001	0.151	0.378	0.015	0.004
WWBS	0.001	0.004	0.000	0.695	0.705	0.678	0.499
WWS	0.005	0.009	0.000	0.756	0.778	0.742	0.598
ERROR DF	205	205	412	132	60	218	412

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.² SSN = Season

Table 23. Relationships between ewe body weight, size and condition¹
in the TXT, FXT, and SXT ewes in Fall and Spring.

GENOTYPE		FALL		SPRING	
		EBW	BS	EBW	BS
TXT	CS	0.341	0.112	0.459	0.078
	BS	0.577	1.000	0.676	1.000
FXT	CS	0.451	0.111	0.546	0.153
	BS	0.746	1.000	0.592	1.000
SXT	CS	0.485	0.128	0.456	0.287
	BS	0.510	1.000	0.629	1.000

¹See 'Nomenclature' pp.ix-x for description of abbreviations.

Table 24. Simple and partial correlations between reproductive and¹ productive traits and linear body measurements on the TXT ewes.

	PROL	WNRT	TWLB	WBBW	WBMW	WBBS	WBMS
CW	0.207	0.166	0.103	-0.071	-0.026	-0.042	-0.006
CW/CS	0.145	0.130	0.078	-0.078	-0.038	-0.068	-0.032
CW/EBW	0.121	0.064	-0.056	-0.037	-0.041	-0.116	-0.102
CW/BS	0.092	0.067	0.029	-0.053	-0.032	0.052	0.046
CD	0.260	0.158	0.034	-0.101	-0.067	-0.173	-0.122
CD/CS	0.270	0.160	0.073	-0.101	-0.067	-0.174	-0.122
CD/EBW	0.204	0.087	-0.076	-0.079	-0.079	-0.229	-0.193
CD/BS	0.135	0.015	-0.114	-0.103	-0.107	-0.104	-0.107
BL	0.045	0.129	0.140	0.086	0.102	-0.017	0.023
BL/CS	0.043	0.128	0.139	0.086	0.101	-0.018	0.022
BL/EBW	0.004	0.090	0.089	0.104	0.101	-0.038	-0.007
BL/BS	-0.086	0.037	0.083	0.129	0.119	0.065	0.070
HP	-0.057	-0.030	0.117	-0.001	-0.029	-0.045	-0.004
HP/CS	-0.094	-0.051	0.105	-0.003	0.025	-0.056	-0.016
HP/EBW	-0.150	-0.124	0.013	0.030	0.026	-0.092	-0.066
HP/BS	-0.220	-0.162	0.053	0.029	0.035	0.637	0.041
	TWLW	WWBW	WWMW	WWBS	WWMS		
CW	0.144	-0.039	0.007	-0.013	-0.025		
CW/CS	0.126	-0.037	0.004	-0.032	-0.006		
CW/EBW	0.003	0.020	0.016	-0.062	-0.047		
CW/BS	0.098	0.014	0.036	0.116	0.111		
CD	0.040	-0.102	-0.067	-0.178	-0.127		
CD/CS	0.040	-0.102	0.067	-0.178	-0.127		
CD/EBW	-0.066	-0.069	-0.069	-0.222	-0.187		
CD/BS	-0.075	-0.057	-0.062	-0.067	-0.070		
BL	0.100	0.035	0.053	-0.058	-0.019		
BL/CS	0.099	0.035	0.052	-0.059	-0.020		
BL/EBW	0.049	0.057	0.056	-0.074	-0.045		
BL/BS	0.050	0.092	0.083	0.038	0.042		
HP	0.028	-0.106	-0.074	-0.142	-0.101		
HP/CS	0.017	-0.105	-0.079	-0.152	-0.112		
HP/EBW	-0.083	-0.073	-0.076	-0.185	-0.161		
HP/BS	-0.038	-0.071	-0.064	-0.057	-0.052		

a= $P < .05$; b= $P < .01$; c= $P < .001$

¹ See 'Nomenclature' pp.viii-ix for description of abbreviations.

Table 25. Simple and partial correlations between linear body¹ measurements and weight and size estimates on TXT ewes.

	HW	HL	CW	CD	BL	HP	MT
EBW	0.299	0.109	0.564	0.390	0.212	0.402	0.129
EBW/CS	0.306	0.152	0.517	0.416	0.221	0.383	0.096
EBW/BS	0.196	-0.042	0.335	-0.120	-0.121	0.129	-0.025
BS	0.250	0.385	0.597	0.782	0.541	0.543	0.258
BS/EBW	0.099	0.343	0.403	0.746	0.791	0.416	0.226
BS/BS	0.247	0.373	0.592	0.788	0.517	0.536	0.247
CS	0.034	0.141	0.291	-0.005	0.013	0.133	0.113
CS/EBW	-0.005	0.104	0.275	-0.159	-0.057	0.081	0.086
CS/BS	0.005	0.104	0.275	-0.159	-0.057	0.081	0.086

a=P<.05; b=P<.01; c=P<.001

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

Table 26. Simple and partial correlations between reproductive and productive traits and linear body measurements on the FXT ewes.

	PROL	WNRT	TWLB	WBBW	WBMW	WBBS	WBMS
CW	0.206	-0.047	-0.099	-0.270	-0.231	-0.260	-0.224
CW/CS	0.481	0.018	-0.092	-0.233	-0.201	-0.269	-0.230
CW/EBW	-0.072	-0.189	-0.122	-0.079	-0.091	-0.098	-0.106
CW/BS	-0.065	-0.176	-0.105	-0.169	-0.155	-0.049	-0.064
CD	0.429	0.255	0.128	0.042	0.064	-0.108	-0.050
CD/CS	0.345	0.277	0.122	-0.007	0.025	-0.134	-0.072
CD/EBW	0.384	0.242	0.139	0.116	0.123	-0.050	-0.003
CD/BS	0.264	0.229	0.192	0.242	0.232	0.149	0.161
BL	0.054	0.000	-0.051	-0.147	-0.125	-0.251	-0.205
BL/CS	0.087	0.001	-0.048	-0.139	-0.118	-0.248	-0.202
BL/EBW	-0.085	-0.040	-0.043	-0.038	-0.039	-0.168	-0.138
BL/BS	-0.272	-0.109	-0.040	-0.005	-0.014	-0.043	-0.042
HP	0.226	0.052	-0.160	-0.354	-0.309	-0.401	-0.346
HP/CS	0.337	0.082	-0.156	-0.334	0.293	-0.399	-0.344
HP/EBW	-0.005	-0.020	-0.201	-0.223	-0.217	-0.322	-0.294
HP/BS	-0.093	-0.065	-0.207	-0.292	-0.272	-0.236	-0.229
	TWLW	WWBW	WWW	WWBS	WWMS		
CW	-0.081	-0.290	-0.243	-0.291	-0.244		
CW/CS	-0.022	-0.205	-0.162	-0.258	-0.204		
CW/EBW	-0.194	-0.162	-0.172	-0.187	-0.193		
CW/BS	-0.191	-0.267	-0.251	-0.133	-0.150		
CD	0.203	0.098	0.126	-0.089	-0.015		
CD/CS	0.171	0.019	0.058	-0.147	-0.067		
CD/EBW	0.196	0.166	0.175	-0.037	0.023		
CD/BS	0.188	0.246	0.234	0.134	0.150		
BL	0.044	-0.077	-0.048	-0.207	-0.147		
BL/CS	0.054	-0.062	-0.033	-0.199	0.138		
BL/EBW	-0.026	0.023	0.024	-0.130	-0.092		
BL/BS	-0.020	0.017	0.008	-0.021	-0.021		
HP	0.017	-0.212	-0.158	-0.280	-0.209		
HP/CS	0.046	-0.170	-0.117	-0.259	-0.186		
HP/EBW	-0.029	-0.052	-0.046	-0.173	-0.138		
HP/BS	-0.079	-0.165	-0.144	-0.094	-0.090		

a= $P < .05$; b= $P < .01$; c= $P < .001$

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

Table 27. Simple and partial correlations between linear body¹ measurements and weight and size estimates on FXT ewes.

	HW	HL	CW	CD	BL	HP	MT
EBW	0.327	0.307	0.779	0.234	0.399	0.720	0.446
EBW/CS	0.298	0.326	0.716	0.465	0.411	0.714	0.480
EBW/BS	0.095	0.068	0.568	-0.467	-0.172	0.363	0.140
BS	0.359	0.354	0.665	0.636	0.650	0.752	0.490
BS/EBW	0.183	0.498	0.201	0.713	0.578	0.464	0.263
BS/BS	0.349	0.353	0.707	0.723	0.648	0.750	0.488
CS	0.140	0.035	0.497	-0.344	0.073	0.218	0.040
CS/EBW	-0.008	0.121	0.260	-0.518	-0.130	-0.173	-0.202
CS/BS	0.108	-0.004	0.569	-0.541	0.002	0.205	0.017

a= $P < .05$; b= $P < .01$; c= $P < .001$

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

Table 28. Simple and partial correlations between reproductive and productive traits and linear body measurements on the SXT ewes.

	PROL	WNRT	TWL ^B	WBBW	WBMW	WBBS	WBMS
CW	-0.085	-0.096	-0.112	-0.202	-0.187	-0.281	-0.242
CW/CS	-0.126	-0.079	-0.105	-0.169	-0.154	-0.274	-0.235
CW/EBW	-0.150	-0.092	-0.166	-0.158	-0.160	-0.298	-0.268
CW/BS	-0.036	0.011	-0.083	-0.092	-0.090	-0.088	-0.087
CD	-0.176	-0.219	-0.116	-0.183	-0.168	-0.296	-0.254
CD/CS	-0.183	-0.217	-0.115	-0.180	-0.165	-0.295	-0.253
CD/EBW	-0.231	-0.219	-0.157	-0.140	-0.144	-0.307	-0.272
CD/BS	-0.166	-0.152	-0.089	-0.039	-0.052	-0.083	-0.085
BL	0.020	-0.021	-0.083	-0.048	-0.016	-0.095	-0.053
BL/CS	0.018	-0.020	0.084	-0.046	-0.014	-0.094	-0.052
BL/EBW	-0.059	-0.009	0.030	0.041	0.038	-0.105	-0.073
BL/BS	0.100	-0.109	-0.174	0.123	0.137	0.169	0.170
HP	0.100	-0.037	-0.054	-0.132	-0.113	-0.203	-0.168
HP/CS	0.095	-0.033	-0.052	-0.126	-0.107	-0.201	-0.166
HP/EBW	-0.060	-0.030	-0.093	-0.085	-0.086	-0.211	-0.184
HP/BS	0.187	0.071	0.016	-0.006	-0.007	-0.009	-0.010
	TWL ^W	WBBW	WBMW	WBBS	WBMS		
CW	-0.152	-0.160	-0.236	-0.333	-0.293		
CW/CS	-0.141	-0.215	-0.198	-0.326	-0.282		
CW/EBW	-0.190	-0.185	-0.187	-0.329	-0.298		
CW/BS	-0.092	-0.099	-0.098	-0.091	-0.092		
CD	-0.186	-0.263	-0.247	-0.387	-0.342		
CD/CS	-0.185	-0.263	-0.246	-0.386	-0.341		
CD/EBW	-0.216	-0.205	-0.208	-0.383	-0.345		
CD/BS	-0.139	-0.082	-0.098	-0.139	-0.139		
BL	-0.072	-0.080	-0.043	-0.131	-0.083		
BL/CS	0.073	-0.078	-0.041	-0.130	-0.082		
BL/EBW	-0.042	0.050	0.047	-0.110	-0.075		
BL/BS	0.204	0.146	0.162	0.197	-0.199		
HP	-0.045	-0.140	-0.118	-0.218	-0.175		
HP/CS	-0.042	-0.133	-0.111	-0.210	-0.172		
HP/EBW	-0.070	-0.072	-0.069	-0.201	-0.171		
HP/BS	0.036	0.037	-0.038	-0.040	-0.039		

a=P<.05; b=P<.01; c=P<.001

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

Table 29. Simple and partial correlations between linear body¹ measurements and weight and size estimates on SXT ewes.

	HW	HL	CW	CD	BL	HP	MT
EBW	0.296	0.430	0.343	0.272	0.456	0.281	0.341
EBW/CS	0.290	0.475	0.262	0.294	0.513	0.296	0.336
EBW/BS	0.184	0.273	0.013	-0.167	0.191	-0.028	0.220
BS	0.282	0.427	0.656	0.727	0.649	0.599	0.317
BS/EBW	0.159	0.267	0.595	0.711	0.544	0.540	0.176
BS/BS	0.274	0.427	0.650	0.729	0.653	0.588	0.308
CS	0.089	0.031	0.250	0.032	0.015	0.045	0.099
CS/EBW	-0.065	-0.225	0.102	-0.119	-0.264	-0.108	-0.080
CS/BS	0.056	-0.026	0.222	-0.089	-0.089	-0.037	-0.063

a=P<.05; b=P<.01; c=P<.001

¹ See 'Nomenclature' pp.ix-x for description of abbreviations.

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