THE RELATIONSHIP BETWEEN AND HERITABILITY ESTIMATES OF LIVE LAMB MEASUREMENTS AND CARCASS TRAITS

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By

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ABSTRACT

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LIVE LAMB MEASUREMENTS AND CARCASS TRAITS

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The lamb industry in this country is placing major emphasis on the improvement of the lamb carcass in an effort to meet competition from the other meat species and from imported lamb. One of the major deterants to improvement of meatiness and carcass desirability in lamb is the lack of a satisfactory estimate of these traits in the live animal. The objectives of this study were to evaluate the accuracy of live lamb measurements and then to discern the relationship between these measurements and numerous carcass characteristics. In addition, heritability estimates were made for a number of carcass and live animal measurements. The study consisted of 227 lambs representing three lamb crops in a ram progeny testing program.

In order to establish confidence in the live lamb measurements repeatability estimates were made by taking two assessments of each measurement and then calculating the correlation between them. The repeatability estimates were sufficiently high for all of the live animal measurements to give confidence in their accuracy. The height at withers and circumference of heart girth were the two measurements with the highest repeatabilities.

Simple correlation coefficients were obtained between seventeen live animal and forty carcass measurements. The live lamb measurements were examined in their relationship to carcass weight, weight of primal

cuts, carcass grade, leanness, and fatness. Slaughter weight was the one live animal measurement that correlated most highly with the most carcass traits. Slaughter weight was significantly correlated with not only carcass weight and weight of carcass cuts but also with carcass measures of leanness and fatness. Average width, length of foreleg, height at withers, and circumference of gaskins were other live lamb measurements that correlated highly with carcass measures of leanness. In one year's lamb crop a correlation of 0.54 was found between area of loin eye and live width of the loin; however, this result was not duplicated in the other two years.

In addition to slaughter weight the measurements most highly correlated with fatness in the carcass were loin width, average width, and circumference of heart girth.

Standard partial regressions were calculated and indicated that none of the live animal measurements accounted for a large fraction of the variation in carcass traits when the carcass weight was held constant.

Heritability estimates were calculated by the method of correlation between paternal half sibs. The highest heritabilities for live animal measurements were .36 for height at withers and .31 for circumference of forearm. Three carcass traits had high heritability estimates. The estimate for weight of kidney knob was .53. The heritability of leg area lean was estimated to be .76 and that of area of loin eye was estimated at .93.

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I. INTRODUCTION

The improvement of meatiness and carcass desirability of lamb is presently a cause for great concern among sheep producers. The consumers are demanding more lean and less fat in their meats. This is as true for lamb as it is for pork and beef. The recent threat of economic competition from other countries and the popularity of other meats with consumers has intensified interest in developing lamb with consumer appeal. Sheep growers organizations and some of the breed associations are advocating ram production testing programs to improve the quality of lamb carcasses. The problem for the breeder is that improvement in any meat animal carcass is limited by the lack of a satisfactory estimate of carcass desirability from the live animal.

The use of subjective live animal evaluation as an estimate of carcass desirability has met with only limited success, the results being strongly dependent on the experience of the individual making the subjective appraisal. Various attempts have also been made at relating objective live animal measurements to carcass desirability. The recent development of ultrasonic equipment and the use of live-probes have some promising possibilities.

This study was undertaken to discern the relationship between live animal measurements and desired carcass characteristics. In the present study repeatability estimates were made on thirteen live-lamb measurements to establish their dependability as a measuring tool. In addition it was desired to determine whether carcass characteristics and live-animal measurements could serve as satisfactory guides to the selection of breeding animals for lamb carcass improvement. Heritability estimates were calculated for a number of carcass and live animal measurements by the method of paternal half sib correlations. Finally, correlations were obtained between seventeen live animal measurements and forty carcass measurements to investigate the nature of the relationship between the live animal and its carcass.

One of the difficulties encountered in a study such as this, other than that of obtaining meaningful live animal measurements, is the lack of satisfactory critera of desirability within the carcass. It was not the design of this particular study to investigate the critera for carcass evaluation, but instead to examine only the live animal-carcass relationship. For this reason, the critera chosen for comparison in the carcass are the standard ones presently in use. A companion study was conducted on these same lambs to investigate the carcass interrelationships.

II. REVIEW OF LITERATURE

A. Subjective Estimates of Carcass Desirability.

The method most commonly used to evaluate a meat animal is visual appraisal of the live animal. Knapp *et al.* (1939) in subjective appraisal of cattle found that sire differences in progeny could not be picked up by judges of live animals. In addition carcass differences between the progeny of different sires also had gone undetected by visual appraisal. Harrington (1958) indicated that visual evaluation of swine muscling was subject to variation between judges. Orme (1958) found that carcass width could be more accurately predicted from live animal measurements than from subjective scoring. These and other studies indicate that subjective live animal evaluation is not a precise method of revealing sire differences in carcass traits.

B. Objective Estimates of Carcass Desirability.

1. Repeatability of live animal measurements.

Considerable emphasis has been placed on the use of objective live animal measurements to predict carcass desirability. For these measurements to be useful they must be highly repeatable. Lush (1928) found that maximum duplication of measurements on live cattle was possible only when measuring the rigid skeletal structures. Those measurements with the highest repeatability were heart girth, paunch girth, depth of chest, height at withers and rump, width at hooks, and pelvis width. Chest width, loin width, body length, and width at pins had poor repeatability. Tallis *et al.* (1959) examined the repeatability of body measurements on steers and found steer components high and error small. The repeatabilities were: heart girth (0.95), circumference at navel (0.90), height at withers (0.90), and height at hooks (0.96). Poor repeatabilities were obtained for circumference of forearm (0.13), width of chest (0.37), and depth of twist (0.04). High repeatabilities were also obtained for length of body (0.80), depth of chest (0.86), and width of hooks (0.66), but the measurement error components of the variance were large for these traits. Smith et al. (1950) found the repeatability to be high in beef cattle on live animal measurements of height at withers, depth of chest and length of body. Orme (1958), also working with cattle, found the best repeatability estimates were obtained from the various height measurements (withers .96, rump .96, and legs .94), circumference measurements (foreflank .98, hindflank .94, and middle .99) and the width measurements (round .88, rump .84, and shoulder .88).

Hetzer et al. (1950) found it necessary to take at least four separate assessments of each measurement on each animal when measuring live hogs. Phillips and Dawson (1936) studied three methods of obtaining measurements of live swine and determined that the use of metal calipers and steel tape were the most accurate.

Phillips and Stoehr (1945) determined the accuracy of measurements taken on live sheep. They found that measurements obtained from photographs were generally unsatisfactory. In addition they found that measurements taken on sheep just after shearing were generally more accurate then those made on animals in fleece. The measurements they described as most useful were: height at withers, width at shoulders, depth of chest, depth of middle, circumference of chest, circumference of middle, and circumference of foreshank. Using the coefficient of variation as a criterion they concluded that these measurements may be taken on live sheep with reasonable accuracy.

Thus the indications are that live animal measurements can be made with accuracy (repeatability).

2. Estimates of weight.

Lush (1928), Wanderstock and Salisbury (1946), Barton (1938) and Kidwell (1955) all reported high correlations (r = 0.90 to 0.99) between circumference of heart girth and body weight in cattle. In fact, several body measures have been found to have high correlations with body weight and have been used for prediction. Kidwell found correlations between live weight and width of thurls (r = 0.82) and chest depth (r = 0.81), while Wanderstock and Salisbury had correlations of 0.80 between body length and weight, and 0.73 between height at withers and weight.

Katada and Takada (1959) found close associations between live weight of lambs and hip width (r = 0.83) or width between thurls (r = 0.83). They reported, in addition, that live weight and carcass weight may be estimated with the use of multiple regression coefficients using the six body measurements: hip width, width between thurls, chest depth, chest width, body length and rump length.

Dawson *et al*. (1955a) attempted to evaluate cattle by the proportion of weight carried on the front and hind legs. They obtained a 0.66 correlation between percentage of live weight carried on hind legs and percentage of empty total body weights contained in hind quarters.

3. Estimates of grade and dressing percentage.

Numerous investigators have studied the relationships of live animal measurements with grade, or dressing percentage in cattle and lambs. Lush (1932), Cook *et al*. (1951) and Yao *et al*. (1953) all worked with cattle and in general found that the "fleshing measurements" (width and circumference measurements) were most highly correlated with slaughter grade, carcass grade, and dressing percentage. They found the steers of shorter height both at the withers and at the floor of the chest, and of shorter length tended to have slightly higher slaughter and carcass grades and dressing percentage. Also steers with larger foreflank circumference and wider in the shoulders tended to make higher slaughter and carcass grades.

These results were corroborated by Orme (1958) who found the best single estimate of carcass grade was circumference of barrel ($r = 0.78$). He also found high correlations between carcass grade and circumference of the foreflank ($r = 0.65$) and hindflank ($r = 0.69$). Kidwell (1955) got similar correlations between carcass grade and heart girth ($r = 0.69$), chest width ($r = 0.72$), and width at hooks ($r = 0.63$). Tallis et al. (1959) found that ratios between live weight and body measurements were highly correlated with dressing percentage in steers.

Working with lamb, Ljungdahl (1942) found average width (shoulder, rack, loin, and thurls) to be significantly associated with dressing percentage while Katada and Takada (1959) found it highly correlated with carcass weight ($r = 0.72$).

Butler (1957) examined the relation of conformation to carcass traits and expressed the opinion that differences in the shapes of animals made but small changes in the proportion of wholesale cuts. Recent work by Matthews (1959) with lamb disclosed that fatness was the one trait most closely related to carcass grade in lamb. In addition he reported that carcass grade was negatively associated with all measurements of muscling and meatiness in the carcass.

4. Estimates of carcass traits.

One of the real problems that faces anyone trying to relate the live animal to the carcass is the lack of a definite standard or criterion of desirability in the carcass. The use of weight, carcass grade and dressing percentage and how these are estimated from the live animal already has been discussed. In addition to these there have been numerous other attempts at evolving specific critera for carcass evaluation. Some of the more common ones will be reviewed.

Since it is lean meat the consumer demands, most standards represent some method of evaluating the lean meat content of the carcass. The problem is to establish some standard that can be used as an accurate measure of muscling in the carcass. The yield in weight or percentage of wholesale cuts (or primal cuts), the edible yield, the weight of entire muscles, and the percentage of separable lean are all used as estimates of carcass meatiness. Likewise, the area of the loin eye (longissimus dorsi), fat covering (particularly in swine), and density determinations have been used as indices of carcass merit.

Cole, Orme and Kincaid (1960) found the separable lean of various cuts of beef (round, chuck, sirloin, foreshank, and shortloin) were better indications of total carcass leanness or muscling than either linear carcass measurements or loin eye area. Their correlations ranged from 0.95 to 0.79 depending on the cut used.

Barton and Kirton (1958) examined the use of the leg and the loin as sample joints for estimating the lamb carcass composition with respect to fat, muscle and bone. They found that better estimates could be made using the leg and the loin together than using either joint alone or using the neck, thorax, shoulder and pelvis as sample joints. Botkin et al. (1959) reported that they found the area of the leg combined with the area of the loin a reliable measure of lean meat content of the carcass. Hammond (1932) had previously found that the composition of the leg could be used to accurately predict the percentage of fat, lean and bone in the lamb carcass. Contrary to Barton and Kirton, he found the shoulder was even a better sample joint of carcass composition.

Crown and Damon (1960) found that the physical composition of the 12th rib cut in beef could be used in predicting carcass yield. Pearson et al. (1958) reported the use of simple cut out indices in swine to evaluate the leanness of the swine carcass. They found that percentage of trimmed loin may be the most accurate measure of leanness. McMeekan (1941) found that either the loin or leg can be used as sample joints to estimate the total weight of bone, muscle or fat in the British bacon-pig carcass.

A fairly high correlation between the area of the loin eye and the weight of the separable lean in the lamb carcass ($r = 0.68$) was reported by Branaman (1939). However, Botkin et al. (1959) reported that they observed the cross sectional area of the leg to be a better measure of meatiness than the loin eye area in the lamb carcass. Mathews (1959) found a negative correlation between fatness and loin eye area in lambs. He observed that "the area of the eye' muscle was smaller in fatter lambs compared to leaner lambs of the same weight". Carcass evaluation in the same study determined that the area of the longissimus dorsi was not as highly correlated with either the percentage of wholesale cuts or separable lean in the rack as were fat measurements.

It has already been reported that Cole _et al_. (1960), working with cattle, found separable lean of a particular cut was better than the loin eye area as an indicator of carcass lean.

Numerous investigators have examined the relationship of various live animal measurements to the percentage of primal cuts, wholesale cuts or preferred cuts. Working with cattle Green (1954) found live weight was the single measurement most closely correlated with the weight of preferred cuts. Orme (1958) found that the circumference of the fore-flank and the belly of cattle were both highly correlated ($r = 0.88$ and $r = 0.71$) with the rib weight. These measurements were also highly correlated with live animal weight. Since this is a part to whole correlation, the "ultimate weight of the wholesale beef rib will depend largely upon the weight of the animal". In addition he reported that live animal weights and various live animal measurements also showed high relationships to the weight of such wholesale cuts as chuck, shortloin, and a combination of sirloin plus round.

Ljungdahl (1942) working with lamb reported that live animal measurements of width of shoulder and width of rack were significantly correlated with weight of shoulder ($r = 0.71$) and weight of rack ($r = 0.39$) respectively, while live measurements of width of loin and width of leg did not indicate the weights of the respective areas of the carcass.

Robison _et al_. (1960) reported that their work with swine indicated that body weight and backfat at loin were the best live animal indicators of carcass merit. They also used numerous depth, length and width measurements. Hetzer et al. (1950) indicated that their measurements of swine showed the depth of middle to be most closely related to yield of the primal cuts. They also used other measures of the body but found they had little relation to the carcass.

Orme (1958) found that live animal measurements were well related to comparable carcass measurements in steers. In particular, it was found that all width measurements in the carcass were highly correlated with the corresponding live animal measurements. Holland and Hazel (1958), on the other hand, found live animal measurements (other then probe) of little value in determining carcass characteristics in swine. Generally they found their live animal measurements to be only slightly related to measurements of carcass characters.

Botkin et al. (1959) felt that while the measurements taken on the live leg of lamb were not as highly correlated with the leg lean area as were measurements taken on the carcass leg, at least live-leg measurements held promise if the measurement techniques could be refined.

There have been numerous reports of estimates of rib eye area from live animal measurements. Orme (1958), Young (1960), and Kieffer et al. (1958) report significant correlations between live animal or carcass weight and rib eye area. Orme also found the rib eye area significantly related to the circumference of the middle, the fore and hind flanks, the round, and the width of rump. Young (1960) found it significantly correlated with circumference of heart girth.

In lamb, Knight et al. (1959) found significant correlations between the live animal metatarsus plus tuber calis length, and eye muscle width (0.63) and area (0.66). Ljungdahl reported in his 1942 thesis that the area of the eye muscle was significantly correlated with the average live width of the rack (0.63) and the average live width of loin (0.50). Bailey et al. (1961) found live animal weight to be as highly correlated (r = 0.56) with loin eye area as any other weanling traits or carcass measurements studied. Botkin et al. (1959) observed various live leg measurements were better measures of overall carcass "meatiness" than they were indicators of loin eye area.

C. Recent Advances in Live-animal Measurements.

Thus far this review has discussed weights and linear measures of the live animal but recently interest has developed in new techniques in live animal measurements that show some promise, particularly in lamb.

The live animal probe to determine backfat thickness in swine is in general use at present. Hazel and Kline (1952), DePape and Whatley (1956), Hetzer et al. (1956), Pearson et al. (1957) all reported that mechanical live probe or lean meter produced good measures of fatness in live hogs and could be used to estimate percentage primal cuts, percentage lean meat in ham or loin, or total carcass leanness.

Live probes have been used to measure not only backfat thickness in hogs but also to measure loin eye depth. This work has been reported by three groups; Stouffer et al. (1958), Matthews (1959), Matthews et al. (1960) and Knight et al. (1959). Using the needle probe over the right transverse process of the 2nd lumbar vertebrae, Matthews found highly significant correlations between depth probes and actual depth of the longissimus dorsi muscle in two trials, (0.43 trial 1 and 0.63 trial 2). Width of the longissimus dorsi muscle was estimated by halving the measured distance between the lateral extremities of the transverse processes of the 2nd lumbar vertebrae. It was found that the width of the muscle estimated in this way was not a reliable indicator of actual width. However, the estimated cross sectional area of the longissimus dorsi muscle (depth probe x estimated width) was significantly correlated with the actual cross sectional area of the muscle as determined by planimeter reading, (0.55 and 0.69 in two trials). It was also found that the depth probe alone was significantly correlated with the actual cross sectional area of the eye muscle (0.56 and 0.59 in trials 1 and 2). The work of Matthews is confirmed by both Stouffer et al. (1958) and Knight et al. (1959) who also found needle probe depths in lamb were significantly correlated with loin eye area (0.42 and 0.53, respectively).

In addition to the mechanical live probe there has been some work with the use of ultrasonics to estimate loin eye size in the live animal. Hazel and Kline (1959) questioned the usefulness of ultrasonic measurements in hogs since the mechanical probe and lean meter have proven reliable. Stouffer et al. (1959) and Price (1960) used ultrasonics to estimate fatness and loin eye area in both cattle and hogs. Stouffer and his coworkers on the basis of 40 hogs and 100 cattle felt encouraged with early results on both species. Price, on the other hand, found considerably more accuracy in the use of ultrasonics when applied to hogs then when used on cattle. He found that the swine loin eye area could be predicted closely from the ultrasonic tracing ($r = 0.74$). However the loin eye area of cattle was not accurately measured.

Campbell et al. (1959) used ultrasonics to estimate the size of the longissimus dorsi muscle in sheep with fair success. They found correlations of 0.62 and 0.49 between the sum of three somoscope measurements and loin eye area (two trials).

Several other methods of measuring live animals have been used in an attempt to estimate carcass desirability but these have been only moderately effective. For example, Saffle et al. (1958) measured urinary and blood creatinine, and compared these levels with the live probe as a measure of estimating leanness in swine. They found, "the live probe was simpler to obtain and was more closely correlated with leanness". There have also been some attempts at estimating total body fat in the live animal using density determinations and fat soluble indicators as outlined by Harrington (1958).

D. Heritabilities.

Most of the studies that report heritabilities are concerned with production traits such as rate of gain, feed efficiency, weaning weight, reproduction rates and in sheep fleece characteristics, (Terrill 1958). However, there have been some studies with sheep showing heritability to be low for conformation and condition. Hazel and Terrill (1946a) reported a heritability of 0.07 for body type and 0.21 for condition in range Columbia, Corriedale and Targhee lambs. Terrill and Hazel (1943) had earlier reported a heritability of 0.12 for body type score in range Rambouillet ewes. Hazel and Terrill (1946b) also reported a low heritability of 0.13 for mutton type and a heritability of 0.04 for condition in range Rambouillet lambs. Hundley and Carter (1956) reported slightly higher heritability estimates for market grade in two breeds of lambs. They estimated heritability of market grade to be 0.28 in Hampshires and 0.31 in Southdown lambs. Taneja (1958) found heritability of mutton score to be 0.13 in Australian Merino sheep.

Some heritability studies of slaughter grade in cattle have shown somewhat higher estimates. Clark (1954) reported slaughter grade heritability at 0.42 while Dawson _et al_. (1955b) reported it to be 0.58.

Several estimates of heritabilities of body measurements in cattle have been made. Generally they report fairly high heritabilities for skeletal measurements such as height and lower heritabilities for fleshing measurements such as circumference and width. Schutte (1935), Dawson _et al_. (1955b) and Weber (1957) all reported high heritability estimates for height at withers being 0.76, 0.65 and 0.63 respectively. Buiatti (1954) reported estimates of 0.41 at six months and 0.60 at one year for the same trait in cattle.

Schutte, Dawson _et al_., and Weber also reported heritability of depth of chest to be 0.20, 0.40 and 0.36, and circumference of heart girth to be 0.35, 0.32 and 0.28. Schutte found high heritability estimates for length of body (0.48) and width at hooks (0.62) but Dawson _et al_. obtained values of 0 and 0.01 for similar traits. Dawson _et al_. reported all heritability estimates of width to be less then 0.10 (i.e. width of shoulder, chest, last ribs, loin and hips).

Only one study has reported heritabilities for live lamb measurements. Taneja (1958) found heritabilities for a number of body depth, length and width measurements all to be generally low. However, in one trial consisting of 284 spring lambs he obtained values of 0.29 for body depth, 0.48 for body width, and 0.30 for fore cannon length.

Estimates of the heritability of carcass grade have been confined to beef cattle. Dawson _et al_. (1955) estimated it at 0.67, Knapp and

Clark (1950) at 0.33, and Shelby *et al*. (1955) at 0.16. Shelby *et al*. and Dawson *et al*. reported heritability estimates of 0.73 and 0.69 for dressing percentage.

Most studies that have reported heritability estimates of carcass measurements emphasize loin eye area. However, Fredeen (1953), Anderson (1954), Whatley and Enfield (1957) and King (1957) all reported the heritability of carcass length in swine to be around 0.50. King (1957) and Anderson (1954) also reported heritability of leg length to be high (0.73 and 0.61). King (1957) gave heritability estimates for a number of additional carcass traits in British bacon pigs.

Loin eye area heritability estimates have, on the whole, been fairly large. In beef cattle, the following estimates have been made: Knapp and Nordskog (1946) 0.69, Knapp and Clark (1950) 0.68, Clark (1954) 0.67, Shelby *et al*. (1955) 0.72 and Kieffer *et al*. (1958) 0.56. In swine, Fredeen (1953) reported an estimate of 0.66 for area of the loin eye, and Whatley and Enfield (1957) an estimate of 0.79. In light of recent use of the live probe in measuring the depth of the eye muscle, it might be well to report that King (1957) obtained a heritability estimate of 0.29 for depth of eye muscle. No heritability estimates of lamb carcass traits were available.

III. OBJECTIVES OF STUDY

1. To determine if live animal measurements could be taken on lambs with suitable repeatability to warrant their use in predicting carcass characteristics.
2. To study the nature of the relationship between live animal body measurements and measurements taken on the carcass with particular interest being paid to the relationship with those carcass traits that are presently used as standards of desirability.
3. To determine the extent to which the variation observed among animals for the traits studied was the result of genetic differences among the animals. In other words, to determine heritability estimates for certain live animal and carcass traits.

IV. EXPERIMENTAL PROCEDURE

A. Animals used.

Two hundred and twenty-seven lambs were used in this study representing three lamb crops from a University ram progeny testing program. They were produced in three different years. The procedure used each year was as follows:

1. 1956-1957 animals.

Data were obtained on eighty-four lambs representing the offspring out of seventy-two white faced, Columbia cross western three-year-old ewes and by seven Shropshire and two Columbia purebred ram lambs. The ewes were allotted eight to a ram and bred at the University between November 15 and December 18, 1956. The lambs were dropped between April 11 and May 1, 1957. The ewes and lambs were turned out to pasture on May 10th without any creep feeding. The lambs were weighed, graded and weaned on August 9th and then placed on feed in dry lot. The lambs were slaughtered as they approached 85 pounds in weight.

2. 1957-1958 animals.

Forty-nine lambs were obtained from the mating of the same western ewes to five Suffolk and two Hampshire purebred ram lambs in the fall of 1957. The ewes, now four year olds, were allotted as uniformly as possible on the basis of the previous years progeny data and current live weight. The lambs were dropped between March 11 and May 1, 1958. The lambs were weighed, graded and weaned on July 30th and then placed on feed in dry lot. The lambs were slaughtered at around 95 pounds in weight.

3. 1958-1959 animals.

Data were obtained on ninety-four lambs. The ewe flock consisted of fifty-five of the orginal western ewes, now five-year-olds, upon which two years progeny data had been compiled. In addition sixteen western replacement ewes and twenty-five purebred Hampshires were added to the flock. Eight purebred Hampshire rams were used. The ewes were lotted on the basis of current liveweight and on previous lamb production records (i. e. total pounds of lamb per year and average area of the longissimus dorsi of their progeny) when available. The lambs were dropped between March 3 and April 25, 1959. The ewes and lambs were placed on pasture in mid-May without creep feeding. The lambs were weighed and weaned on August 20th and placed on a pelleted ration in dry lot. The lambs were slaughtered as they approached 95 pounds in weight.

The treatment of the lambs at slaughter time was the same all three years. The lambs were weighed and those to be slaughtered were sorted out and moved to holding pens in the afternoon. The next morning the lambs were again weighed, sheared, measured and slaughtered immediately.

B. <u>Live animal body measurements.</u>

The measurements on the live shorn lambs were taken as the lambs stood on a trimming and blocking table. The height, width, depth, and length measurements were made with metal calipers containing built in levels. They were manufactured by Bio Metric Instruments Inc., Berkeley, California. The calipers consisted of a calibrated bar upon which two arms were attached. Measurements were made by reading off the distance between the two arms on the calibrated bar. The measurements were taken to the nearest milimeter and were expressed in centimeters to the nearest tenth. The circumference measurements were made in two manners. In 1957 and 1958 a string was used and the length of the string then read off the 180 centimeter straight bar of the Bio Metric equipment. In 1959, in an attempt to increase the accuracy of the measurements, a Lufkin 200 centimeter flexible steel rule was used. At this time several new measurements of depth were also instituted using the steel rule. The measurements used were:

1. Width of thurls - taken with the calipers from the topline at the widest point of the thurls.
2. Width of loin - taken with the metal calipers at the mid point of the loin.
3. Width of rack - taken from the topline with the metal calipers at the narrowest width behind the shoulders.
4. Average width - an average of the three above measurements.
5. Length hock to twist - taken with the metal calipers by setting the metric rod prependicular to the table top and then sighting the crossarm of the calipers (parallel to tabletop) at the hock and at the twist.
6. Depth rear flank - one arm of the calipers was placed on the top of the back directly above the rear flank and the arm leveled so that it was parallel to the table top, the other arm of the caliper was raised until it touched the rear flank; the distance between the two arms was termed depth of rear flank.

7. Depth of forerib - the distance from the chest floor to the topline directly behind the shoulder, measured with metal calipers.

8. Height at withers - the distance from the table top to the highest point of the withers, measured on the metric stick.

9. Circumference of gaskins - measured with string in 1957 and 1958 and with steel tape in 1959. It was difficult to establish reference points on the leg for this measurement in order that it would be taken at the same place on all animals. The measurement was made keeping the measuring device in a parallel plane with the table top and making the circumference measurement at the point on the gaskin where the inside of the leg is met by the rear twist.

10. Circumference of forearm - made with string or steel tape directly below the elbow joint.

Additional live animal measurements made in 1959.

11. Length of foreleg - distance from the elbow to the table top measured on the metric rod.

12. Depth of hind - made with the steel tape and was an attempt at measuring muscling in the leg. The measurement was made from the base of the dock to the break in the twist.

13. Depth to rear flank - made with the steel tape in an attempt to measure the contour or fullness of the loin region instead of merely the depth from the topline to the rear flank as in measurement number six. The measurement was taken from the

center of the lumbar vertebrae to the rear flank.

14. Circumference of heart girth - taken with the steel tape by passing it around the lamb behind the shoulders on the top and around the foreflank.

C. Weight measurements.

Weight off test and slaughter weights were taken on lambs on a Toledo scale Model 2181 that was checked for accuracy by the Michigan Department of Agriculture's Inspector of Weights and Measures. The weights were taken to the nearest tenth of a pound.

1. Weight off test was made just prior to shearing.
2. Slaughter weight was made directly after shearing.
3. Wool weight of lambs was determined by difference between weight off test and slaughter weights.

D. Carcass measurements.

All of the carcass measurements were made by personnel of the Meats Department at Michigan State University under the supervision of Dr. R. J. Deans. Considerable improvement in procedures was made in obtaining the 1959 carcass data and therefore these data have been treated separately. Heritability estimates were only determined on those carcass traits that were felt to have been measured with the same accuracy for the duration of the study.

VI. RESULTS OF EXPERIMENT

A. Repeatability Estimates of Live Animal Measurements.

If live animal measurements are to be of any value in predicting carcass desirability it is essential that the measurements can be taken with an accuracy that makes them useful and easily duplicable. In an attempt at establishing some degree of confidence in the live animal measurements repeatability estimates were made on thirteen traits measured on the ninety-four 1959 lambs. This was done by taking independent duplicate live animal measurements. All thirteen of the live animal measurements were taken from an animal and then the entire procedure was repeated. In this manner no particular measurement was taken consecutively. Thus the second measurment should not have been influenced by knowledge of what the first record was. The repeatability estimates of live animal measurements were calculated as the correlation between the two measurements taken on the same individual.

In order for measurements to be highly repeatable it is necessary to establish definite reference points on the animal which are easily detectable. Many live animal measurements are affected by the movement and temperment of the animals at the time the measurements are made. Therefore, measurements were made on the lambs only as they stood quietly and squarely on a trimming and blocking table.

The repeatability estimates obtained are given in Table 1. They ranged from 0.71 for length hock to twist to 0.91 for circumference of heart girth. All of the repeatability estimates were significant at the 1% level. The highest estimates were for the circumference of the heartgirth (0.91) and the height at the withers (0.90). These measurements have been continually reported as having high repeatabilities in cattle as well as sheep by Lush (1928), Phillips and Stoehr (1945),

TABLE 1

Repeatability Estimates of Live Animal Measurements

Measurement	Number of Animals[a]	Repeatability Estimate
Depth hind (tape)	94	.90
Depth to rear flank (tape)	89	.85
Depth of forerib	94	.82
Depth rear flank	94	.82
Width of thurls	94	.75
Width of loin	94	.83
Width of rack	94	.75
Length hock to twist	93	.71
Length of foreleg	93	.74
Height at withers	94	.90
Circumference of gaskins	94	.72
Circumference of forearm	94	.80
Circumference of heart girth	94	.91

.267 required for significance at P.01

[a]Unequal numbers are due to the failure of the investigator to obtain duplicate measurements for some traits.

Tallis et al. (1959), and Orme (1958).

High repeatabilities were also obtained for tape measurements of depth of hind (0.90) and depth to rear flank (0.85). The lowest repeatability was for length hock to twist (0.71) and this was understandable since it was obtained by sighting the two bars of the calipers. The circumference of the gaskins was also lowly repeatable (0.72) and likewise reflects difficulty in duplicating the measuring technique.

As with Orme's data (1958) the width measurements showed a lower repeatability than the height measurements. Width of the loin (0.83) appeared to be more accurately measureable than either width of the rack (0.75) or width of the thurls (0.75). The most surprising result is the relatively low repeatability for the linear skeletal structure the length of foreleg (0.74). In general, the results of this study agreed with those expressed in the literature and all indications are that live animal measurements may be taken with reasonable accuracy on sheep.

Although usefully high repeatabilities were obtained for all measurements there were some possible sources of error of which the investigator must be constantly aware. The basic problem is that the body contours do not readily lend themselves to linear measurement. For those areas where circumference measurements were made, the exact place of measuring, as well as the snugness of the measuring tape, can have a large effect upon the results.

B. <u>Relationships between live animal measurements and carcass traits.</u>

The literature review revealed some of the many relationships that have been found between live animal measurements and carcass measurements by other workers. The present study consisted of seventeen live animal measurements and forty carcass measurements between which simple product moment correlations were calculated. This shotgun approach to the problem was used to test for high relationships between live animal objective measurements and desirable carcass traits.

The data from ninety-four lambs in 1959 have been handled separately from the combined data from one hundred and thirteen lambs in 1957 and 1958. The 1959 data contained more complete live animal measurements and in addition had the benefit of improved laboratory techniques for obtaining more accurate and complete carcass measurements. It was the belief of this investigator and Dr. R. J. Deans of the M. S. U. Meats Department that more credulity could be placed in the 1959 carcass data. For this reason, major emphasis was placed on the more recent data with the 1957 and 1958 studies serving for comparison purposes.

The calculation of correlation coefficients were obtained through the use of digital computor methods which greatly reduced the time of calculation and increased the volume of data that could be analysed. The complete record of all the correlation coefficients for 1957-1958 and 1959 are reported in the appendix. The following discussion includes only the results that appeared most meaningful.

1. Weight of carcass (Table 2).

Weight is not a single satisfactory criteron of a desirable carcass but there has been considerable interest in methods of estimating carcass weight in the live animal. As might be expected, the two live animal measurements which had the highest correlation with carcass cutting weight were slaughter weight (r = 0.85) and circumference of

TABLE 2.

Correlations between live animal measurements and carcass weight.

Live animal measurement	Carcass Cutting Weight	Hot carcass Weight
Slaughter weight	0.85**	0.86**
Circumference of heart girth	0.75**	0.73**
Width thurls	0.13	0.13
Width loin	0.59**	0.57**
Width rack	0.63**	0.61**
Average width	0.64**	0.63**
Depth hind (tape)	0.22	0.25
Depth to rear flank (tape)	0.41**	0.43**
Depth rear flank (calipers)	0.00	0.02
Depth of forerib	0.21	0.22
Length hock to twist	-0.17	-0.16
Length of foreleg	0.35**	0.39**
Height at withers	0.30*	0.32*
Circumference of gaskin	0.46**	0.47**
Circumference of forearm	-0.13	-0.16

* Significant P = .05
** Significant P = .01

heart girth (r = 0.75). The weight of the carcass represents such a large part of the slaughter weight that the close association between them was expected. Numerous workers (Lush 1928, Wanderstock and Salisbury 1946, Barton 1938 and Kidwell 1955) have reported a close association between heart girth and live weight in beef cattle and since a similar situation appeared to exist in sheep ($r = 0.61$) it was not surprising that heart girth was also correlated highly with carcass weight.

It is interesting to note that two of the width measurements were highly correlated with carcass weight. The width of the rack ($r = 0.63$) and width of loin ($r = 0.59$) both were highly significantly correlated with carcass weight while the width of thurls was only slightly correlated ($r = 0.13$). The average width was correlated 0.64 with the carcass weight. This was in agreement with, but not as high as, a similar relationship of 0.72 reported by Katada and Takada (1959). The circumference of gaskins ($r = 0.46$) and depth to rear flank ($r = 0.41$) were also found to be significant indicators of carcass weight.

2. Weight of carcass cuts. (Table 3).

An examination of the data indicated one striking result--slaughter weight was the one live animal measurement that was correlated most highly with the carcass weights. Green (1954) reported that live weight was the single measurement in cattle that was most closely correlated with weight of the preferred cuts. Orme (1958) agreed that the weight of the animal largely determines the ultimate weight of the wholesale cut. Similarly it was found in this study that the weight of the various cuts was correlated closely with the slaughter weight of the animal. Slaughter weight was correlated 0.81 with the weight of the fore and 0.81 with the weight of the hind. The weight of the leg, untrimmed loin, trimmed loin, rack and kidney knob were correlated with slaughter weight by 0.80, 0.33, 0.55, 0.61 and 0.51, respectively, in 1959. The correlations of slaughter weight to the same measurements in the 1957-1958 data showed similar results.

Circumference of the heart girth was the next most highly correlated

TABLE 3.

Correlations between live animal measurements and weights of carcass cuts.

	Weight Fore	Weight Hind	Weight Leg	Weight Un-trimmed Loin	Weight Trimmed Loin	Weight Rack	Weight Kidney Knob
Slaughter weight	0.81**	0.81**	0.80**	0.33*	0.55**	0.61**	0.51**
Circumference of heart girth	0.73**	0.67**	0.62**	0.28*	0.37**	0.55**	0.52**
Width of thurls	0.20	0.04	0.29*	0.22	-0.11	0.02	0.24
Width of loin	0.53**	0.54**	0.53**	0.19	0.50**	0.54**	0.44**
Width of rack	0.62**	0.56**	0.46**	0.28*	0.29*	0.49**	0.45**
Average width	0.65**	0.54**	0.63**	0.35*	0.28*	0.48**	0.28*
Depth hind (tape)	0.22	0.24	0.18	0.03	0.10	0.06	0.14
Depth to rear flank (tape)	0.30*	0.46**	0.27	0.22	0.47**	0.41**	0.51**
Depth rear flank (calipers)	0.04	0.01	-0.14	0.07	0.32*	0.22	0.30*
Depth of forerib	0.25	0.18	0.36**	0.04	0.15	0.13	-0.08
Length hock to twist	-0.07	-0.20	-0.08	0.53**	-0.07	-0.06	-0.34*
Length of foreleg	0.32*	0.36**	0.54**	0.17	0.28*	0.25	0.09
Height at withers	0.31*	0.30*	0.45**	0.24	0.26	0.28*	0.13
Circumference of gaskin	0.37**	0.45**	0.46**	0.42**	0.47**	0.49**	0.31*
Circumference of forearm	-0.12	-0.16	0.17	-0.24	-0.42**	-0.43**	-0.53**

* Significant at P = .05
** Significance at P = .01

measurement with various carcass cut weights. Weight of fore (r = 0.73), weight of hind (r = 0.67), weight of leg (r = 0.62), weight of rack (r = 0.55) and weight of kidney knob (r = 0.52) all were significantly correlated with circumference of heart girth. However, neither the weight of the trimmed nor the weight of the untrimmed loin were as closely associated with the heart girth measure.

The other live animal measurements that were closely associated with the weights of the various carcass cuts were width of loin, width of rack, average width and depth to rear flank (tape). In addition the circumference of the gaskin was significantly correlated with the weight of all the carcass cuts. Generally the depth of hind, depth rear flank (calipers), depth of foreribs, length hock to twist, length of foreleg, height at withers and circumference of forearm were all measures that exhibited little relationship with the weight of the primal cuts.

More specifically the various live animal width measurements seemed related to the weight of the area they measured in the carcass. Width of the thurls was significantly correlated (0.29) with the weight of the leg. The width of the rack was correlated (r = 0.49) with the weight of the rack. The width of the loin was correlated (r = 0.50) with the weight of the trimmed and loin but in 1959 not significantly with the weight of the untrimmed loin. This later finding is in agreement with Ljungdahl (1942) who found live animal loin width a poor measure of untrimmed loin weight (r = 0.18). However, in the 1957-1958 data the width of the loin was highly correlated to the weight of the untrimmed loin (r = 0.57) as well as to the weight of the trimmed loin (r = 0.62).

The highly significant correlations between length of foreleg and weight of hind (0.36) and weight of leg (0.54) were not expected. Another unexpected result was the significant negative correlations between circumference of forearm and weight of trimmed loin (-0.42), weight of rack (-0.43) and weight of kidney knob (-0.53). This would mean that the larger the forearm of the lamb in circumference the lighter the weight of these particular carcass cuts. A similar negative relationship was not noted in the 1957-1958 data.

3. Linear carcass measurements.

A number of the linear live animal measurements were significantly related to their counterpart measurements in the carcass. For example, the length of the foreleg in the live animal was a good measure of length of forecannon ($r = 0.54$), and weight of forecannon ($r = 0.68$) in the carcass. The depth of the forerib in the live animal was highly related to the depth of the thorax in the carcass ($r = 0.58$). However, circumference of the gaskins was correlated lowly with the circumference of the leg ($r = 0.12$). The circumference of the forearm in the live animal was likewise poorly related to the circumference of forearm in the carcass ($r = 0.25$), and the loin width was correlated lowly with loin eye width ($r = 0.20$) but strangely was significantly related to loin eye depth ($r = 0.44$).

4. Carcass grade. (Table 4).

None of the live animal measurements taken in 1959 showed a significant correlation with carcass quality grade but in the 1957-1958 data carcass quality grade was correlated with slaughter weight 0.56, depth of rear flank 0.40, depth of forerib 0.60, width of rack 0.41 and width of loin 0.54.

The depth of the rear flank and the circumference of the forearm were the only two live animal measurements that had highly significant correlations with conformation grade in 1959. In 1957-1958 slaughter weight, depth of forerib, width of loin and width of rack were also significantly correlated with conformation grade.

TABLE 4.

Correlations between live animal measurements and carcass grades.

	Carcass quality grade		Conformation Grade		Final grade	
	1959	1957-58	1959	1957-58	1959	1957-58
Slaughter weight	0.19	0.56**	0.34*	0.53**	0.24	0.16
Circumference of heart girth	0.19	--	0.27	--	0.36**	--
Depth rear flank (calipers)	-0.19	0.40**	0.46**	0.36**	-0.20	0.01
Depth of forerib	-0.07	0.60**	0.08	0.66**	-0.08	0.02
Width thurls	-0.18	0.17	0.18	0.16	-0.18	0.00
Width loin	0.15	0.54**	0.23	0.55**	0.30*	0.29*
Width rack	0.22	0.41**	0.29*	0.46**	0.40**	0.39**
Average width	0.07	--	0.35*	--	0.23	--
Circumference of forearm	0.12	-0.08	0.38**	0.08	-0.29*	0.02
Height at withers	-0.24	0.14	0.27	0.05	-0.29*	-0.33*

* Significant at P = .05
** Significant at P = .01

In 1959 final grade was highly correlated with circumference of the heart girth (r = 0.36) and width of rack (r = 0.40), and less highly correlated with the width of the loin (r = 0.30). There was a negative association between height at withers (r = -0.29) and final grade. Thus the lambs which were lower at the withers and wider in the rack and loin tend to grade higher. Similar conclusions were indicated by the 1957-1958 data. This corroborated the findings in cattle of Lush (1928), Cook et al. (1951) and Yao et al. (1953). In cattle, Kidwell (1955) and Orme (1958) both reported significant correlations between heart girth and grade although they were somewhat higher than the present results (i. e., r = 0.65 and r = 0.69).

5. Carcass lean. (Table 5).

TABLE 5.

Correlations between live animal measurements and carcass lean.

	Shoulder Cross Section Lean	Leg area Lean	Area L. dorsi	Combined Lean
Slaughter weight	0.16	0.59**	0.39**	0.53**
Width thurls	0.24	0.25	0.12	0.31*
Width loin	0.13	0.34*	0.54**	0.37**
Width rack	-0.06	0.13	0.25	0.09
Average width	0.17	0.35**	0.44**	0.39**
Depth of forerib	-0.09	0.34*	0.27	0.29*
Length of foreleg	0.37**	0.63**	0.29*	0.64**
Height at withers	0.34*	0.59**	0.20	0.59**
Circumference of gaskin	0.23	0.37**	0.43**	0.39**
Circumference of forearm	0.08	-0.01	0.05	0.08
Circumference of heart girth	-0.04	0.32*	0.37**	0.27

* Significant at P = .05
** Significant at P = .01

Several workers have recommended the use of weight of primal cuts as indicators of total carcass leanness. (Reviewed by Harrington 1958).

The weight-live animal measurement relationships have already been discussed. Cole et al. (1960), Barton and Kirton (1958) and others have studied the use of separable lean of a sample cut or joint as an index for total carcass leanness. In the present study, however, no physical separation was performed in the carcass analysis so these relationships were not examined.

The carcass measures of leanness used in the study were: area lean of shoulder cross section, leg area lean, area of longissimus dorsi and combined lean, which includes the three previous measures and the area of sirloin.

The lean area of the shoulder cross section was highly significantly correlated with only one live animal measurement, the length of foreleg (r = 0.37). It was less highly correlated (P = .05) with height at withers (r = 0.34). In the data from the two previous years, the lean area of the shoulder was also correlated with slaughter weight (r = 0.53), width of loin (r = 0.50), and depth of forerib (r = 0.52).

Botkin et al. (1959) found the leg area lean to be a good measure of meatiness in lambs. He felt that live animal measurements of the leg held promise for predicting leg lean. In the present study, the leg area lean was highly correlated with slaughter weight (r = 0.59), length of foreleg (r = 0.63), height at withers (r = 0.59), and circumference of gaskins (r = 0.37). It was also significantly, but not as highly, correlated with average width (r = 0.35), width of loin (r = 0.34), and circumference of heart girth (r = 0.32). Similar results were obtained in the 1957-1958 lambs with the additional correlation of 0.44 between leg lean and width of thurls. In 1959 the live animal leg measurements width of thurls, depth of hind, and length hock to twist were not significantly correlated with the leg area lean.

Branaman (1939) and Palsson (1939) reported the area of the loin eye to be a good indication of carcass lean. Botkin et al. (1959) felt the leg a better measure of total lean than the loin eye area. Matthews (1959) reported the area of the loin eye was not a good measure of leanness. However, as the eye muscle represents the highest priced part of the lamb carcass, any measure of its size on the live animal is valuable. The area of the longissimus dorsi muscle was correlated 0.54 with the width of the loin measured in the live animal. This compared closely with the correlation of 0.50 obtained in lamb by Ljungdahl (1942) for the same relationship. It also compared favorably with the correlations found between needle probe depths of loin eye and area of loin eye by Matthews (1959) ($r = 0.56$ and 0.59), Stouffer et al. (1958) ($r = 0.42$) and Knight et al. (1959) ($r = 0.53$). In addition, Ljungdahl reported a correlation of 0.63 between area of the eye muscle and width of the rack (live animal) but this result was not duplicated in the present study. However, the area of the longissimus dorsi was found to be significantly correlated with average width ($r = 0.44$), circumference of gaskin ($r = 0.43$) and circumference of heart girth (0.37). The only significant live animal measurement with area of the longissimus dorsi in the 1957-1958 study was circumference of the forearm ($r = 0.39$). This relationship was non existant in the 1959 lamb data ($r = 0.05$).

The combined lean in the lamb carcass (i. e. shoulder, loin, sirloin and leg lean areas) was significantly correlated with length of foreleg (0.64), height at withers (0.59), slaughter weight (0.53), circumference of gaskin (0.39), average width (0.39), and width of loin (0.37). It was also correlated significantly but not as highly with the width of thurls (0.31) and depth of forerib (0.29). Similar, although somewhat higher, relationships were found in 1957-1958 with the exception that the circumference of gaskin was not and the width of the rack was (0.47) significantly correlated with combined lean.

6. Carcass fat. (Table 6)

Estimates of fatness were made in the carcass from weight, linear and area measurements of fatty areas and from ether extractions. The weights taken were kidney knob, caul, and ruffle fat. The linear measures were of fat thickness at 12th rib and at sirloin (average of three measurements). The fat area measurements were made with the planimeter from tracings of the shoulder cross section fat area and leg cross section fat area. Ether extract determinations were made on the loin eye muscle. The ether extract of the loin eye muscle was not significantly correlated to any of the live animal measurements. Most of the live animal measurements that were significantly correlated with carcass weight were also highly correlated with fat in the carcass.

The width of rack was the one body measurement that was highly correlated with the most carcass measures of fat, being correlated 0.37 with shoulder cross section fat, 0.39 with fat thickness 12th rib, 0.45 with weight of kidney knob, 0.58 with combined fat, 0.30 with ruffle fat, 0.39 with caul fat and 0.60 with fat thickness of sirloin. Slaughter weight, circumference of heart girth, depth of rear flank, width of loin, average width and circumference of gaskin were also body measurements that were significantly correlated to fat in the carcass.

The circumference of the forearm was negatively associated with all

TABLE 6.

Correlations between live animal measurements and carcass fat.

	Shoulder Cross Section Fat	Fat Thickness 12th rib	Weight Kidney Knob	Combined Fat	Ruffle Fat	Caul Fat	Leg Cross Section Fat	Fat Thickness Sirloin
Slaughter weight	0.21	0.30*	0.51**	0.50**	0.36**	0.44**	0.09	0.47**
Depth to flank (tape)	0.15	0.24	0.51**	0.45**	0.20	0.43**	0.32*	0.31*
Width loin	0.06	0.28*	0.44**	0.39**	0.27	0.44**	0.04	0.40**
Width rack	0.37**	0.39**	0.45**	0.58**	0.30*	0.39**	0.27	0.60**
Average width	0.10	0.25	0.28*	0.32*	0.34*	0.30*	0.03	0.43**
Length hock to twist	-0.07	0.12	-0.34*	-0.25	0.03	-0.30*	-0.09	-0.27*
Circumference of gaskin	-0.06	0.25	0.31*	0.24	0.32*	0.15	0.12	0.45**
Circumference of forearm	-0.16	-0.17	-0.53**	-0.39**	-0.16	-0.27	-0.15	-0.08
Circumference of heart girth	0.22	0.43**	0.51**	0.57**	0.46**	0.53**	0.06	0.67**

* Significant at P = .05
** Significant at P = .01

measures of fatness in the carcass just as it was with weights of carcass cuts. The length hock to twist also indicated a negative association with several fat measurements.

7. Effect of holding carcass cutting weight constant.

Since many of the body measurements and carcass traits were influenced by body weight, standard partial regressions were calculated between the live animal measurements and carcass traits holding the effects of carcass weight constant. The standard partial regression coefficients obtained between nine live animal measurements and seven carcass characters are listed in Table 7.

With the carcass weight held constant, the length of the foreleg accounted for 25 percent of the variation in both leg cross section lean area and combined lean. These were the two highest relationships observed. The height at the withers also accounted for 21 percent of the variation in leg lean and combined lean.

All other relationships were quite low. The width of rack was associated with 17 percent of the variation in combined lean and 12 percent of the variation in leg lean and shoulder lean. The width of the loin accounted for only 10 percent of the variation in loin eye area with carcass weight held constant. With the slaughter weight held constant the width of the loin accounted for 22 percent of the variation in loin eye area.

TABLE 7.

Simple correlation coefficients between live animal measurements and carcass traits and standard partial regression coefficients with carcass weight held constant.

Live Animal Measurement	Carcass Weight	Weight of Leg		Weight of Loin: Trimmed		Weight of Loin: Untrimmed		Area Loin Eye		Leg Lean		Shoulder Cross Section Lean		Combined Lean	
	r	r	b'	r	b'	r	b'	r	b'	r	b'	r	b'	r	b'
Depth of rear flank	0.41**	0.27	-0.12	0.47**	0.21	0.22	-0.04	0.20	-0.04	0.22	--	0.04	-0.06	0.18	-0.07
Width of loin	0.59**	0.53**	0.06	0.50**	0.15	0.20	-0.09	0.54*	0.32	0.34*	0.03	0.13	0.01	0.37**	0.07
Width of rack	0.63**	0.46**	-0.09	-0.14	-0.21	0.28*	-0.23	0.26	-0.15	0.13	-0.35	-0.06	-0.30	0.09	-0.41
Average width	0.64**	0.63**	0.15	-0.16	-0.27	0.35*	0.12	0.44**	0.14	0.35*	--	0.17	0.07	0.39**	0.07
Length of foreleg	0.35**	0.54**	0.24	0.28*	--	0.17	-0.12	0.29*	0.10	0.63**	0.50	0.37**	0.31	0.64**	0.50
Depth of forerib	0.21	0.36**	0.18	0.15	--	0.04	-0.05	0.27	0.16	0.34	0.24	-0.09	-0.04	0.29	0.17
Height at withers	0.30*	0.45**	0.19	0.26	0.03	0.24	0.11	0.20	0.03	0.42**	0.46	0.34*	0.30	0.59**	0.46
Circumference of gaskins	0.46**	0.46**	0.09	0.47**	0.18	0.42**	0.28	0.43**	0.21	0.37**	0.15	0.23	0.17	0.39**	0.17
Circumference of heart girth	0.75**	0.62**	--	-0.15	-0.30	0.28	-0.11	0.37**	-0.11	0.32*	-0.20	-0.04	-0.40	0.27	-0.30

* Significant at P = .05
** Significant at P = .01

C. <u>Heritability estimates of live animal and carcass measurements.</u>

The ultimate purpose of this study was to determine if there were indicators of lamb carcass desirability that could be measured in the live lamb. It has been shown that live lamb measurements can be taken with a high degree of accuracy and their relationship to the carcass has been discussed. Heritability estimates were calculated on 10 live animal measurements to help determine their usefulness as aids to selection in breeding for better lamb carcasses. Heritability estimates were also determined for 6 commonly used carcass measurements.

The heritability of a trait may be defined as the fraction of the observed variance (i.e. phenotypic variance) in a trait that is due to the genic variance for that trait in that population. In other words, heritability is based upon the supposition that related individuals will resemble each other more (be more uniform or have less variability) then non related individuals in the population. The method used to calculate the heritabilities was to multiply the correlation between paternal half sibs by 4.

For most traits there were a total of 227 lambs from 24 sires within 5 breed-year groups. The mean squares were calculated for the between sires within breed-year subgroups and for the between individuals within sires. The within sire mean square was considered an estimate of the variance within sire groups (σ^2_e). The between sire within breed-year mean square was considered an estimate of the within sire variance component (σ^2_e) plus the average number of individuals per sire group (a) times the variance component between sires (σ^2_s). Heritability was calculated as the intraclass correlation between paternal half-sibs times 4 or heritability = $\dfrac{\sigma_e^2}{\sigma_e^2 + \sigma_s^2}$ X 4. The correlation was multiplied by 4 since two offspring from the same sire only have one-fourth more of their genes in common, on the average, than do unrelated animals in a flock. The following model was used to estimate the components of variance: (Symbolism as in Ostle (1956)).

$Y_{ijkm} = \mu + b_{ij} + s_{ijk} + e_{ijkm}$

Where μ is an effect common to all observations,

b_{ij} is an effect common to all lambs born in the ith year in the jth breed, s_{ijk} is an effect common to all lambs born in the ith year in the jth breed from the kth sire, e_{ijkm} is an effect common to each individual lamb.

Thus σe^2 represents the variance within sire groups and σs^2 the variance due to sires.

Method of analysis:

Source of variation	df	M. S.	E (M.S.)
Between sires within breed-years	19	$\dfrac{\sum \dfrac{(Y_{ijk\cdot})^2}{n_{ijk}} - \sum \dfrac{(Y_{ij\cdot\cdot})^2}{n_{ij}}}{19}$	$\sigma_e^2 + \frac{227}{24}\ \sigma_s^2$
Between individuals within sires	203	$\dfrac{\sum (Y_{ijkm})^2 - \sum \dfrac{(Y_{ijk\cdot})^2}{n_{ijk}}}{203}$	σ_e^2

The heritability estimates are listed in Table 8 along with the mean squares between sires and within sires.

The heritability estimates for all body measurements of width and depth were below 0.18. Similar results were reported by Dawson et al. (1955) in cattle for width but not depth measurements and by Taneja (1958) in lamb for all body width, depth and length measurements.

TABLE 8

Mean Squares and Heritability Estimates of Live Animal and Carcass Measurements.

Measurement	MS Between Sires	MS Within Sires	σs^2	Heritability estimate
1. Width of thurls	1.71	1.53	.019	0.05
2. Width of rack	0.91	1.11	-.022	-0.08
3. Width of loin	0.57	0.98	-.043	-0.18
4. Height at withers	5.93	3.10	.299	0.36
5. Depth of forerib	0.93	0.86	.007	0.03
6. Depth of rear flank	6.80	4.78	.224	0.18
7. Circumference of forearm	2.18	1.23	.100	0.31
8. Circumference of gaskin	2.07	2.10	-.003	-0.01
9. Length hock to twist	3.48	2.92	.06	0.08
10. Wool weight	0.57	1.06	-.059	-0.24
11. Area of L. dorsi	0.129	0.033	.010	0.93
12. Ether extract	0.482	0.943	-.053	-0.24
13. Fat thickness 12th rib	3.00	3.31	-.033	-0.04
14. Weight kidney knob	0.64	0.26	.040	0.53
15. Carcass length	6.96	8.74	-.188	-0.09
16. Leg area lean	2.30	0.72	.169	0.76

The estimates of heritability of body measurements in cattle have indicated heritabilities are high for certain skeletal measurements and low for fleshing measurements. In the present study the heritability estimate for height at withers, one of these skeletal measurements, was 0.36 considerably below those found in cattle. The heritability estimates of height at withers in cattle were: Schutte (1935) 0.76, Dawson et al. (1955) 0.65 and Weber (1957) 0.63. Taneja (1958) had no heritability estimate of wither height in lambs but he did report a heritability of 0.30 for forecannon length. In swine heritability estimates of leg length have also been high, as reported by King (1957) and Anderson (1954).

The circumference of the forearm was found to be lowly correlated with most carcass traits yet had a heritability estimate of 0.31. The circumference of forearm was significantly but negatively correlated with only several carcass weight measurements and was not significantly correlated to circumference of the forearm in the carcass. The circumference of the gaskins, depth of rear flank and length hock to twist all were very lowly heritable and had the lowest repeatabilities; therefore, these measurements appeared to have little value as selection indices in a breeding program.

Two of the fat measurements in the carcass, ether extract and fat thickness 12th rib, were lowly heritable but the heritability for weight of kidney knob was 0.53. The estimate for carcass length was also lowly heritable (-0.09) while several workers had reported it to be about 0.50 in swine.

Two measurements of leanness in the carcass proved to be highly heritable indicating that selection for these traits would be worthwhile. The heritability estimate for leg area lean was 0.76. The heritability estimate for area of the longissimus dorsi muscle was 0.93.

This measurement has been reported to be highly heritable in cattle and swine by numerous workers but no reports have estimated it as high as that found in the present study. The high heritability of loin eye area in lamb is encouraging for it indicates that loin eye size can be improved by selection if adequate means of estimating the loin eye in the live animal can be developed.

SUMMARY AND CONCLUSIONS

The animals used in this study were 227 lambs that were born at Michigan State University over a three year period as part of a ram progeny testing program. Live animal measurements were taken on the lambs just prior to slaughter and measurements were taken on all the carcasses.

Repeatability estimates were made on the 1959 live lamb measurements to establish some degree of confidence in their accuracy. Height at withers and circumference of heart girth were the two measurements that were most repeatable. Poorest repeatabilities were obtained for the measurement of length hock to twist and circumference of gaskins.

The relationships between live animal measurements and carcass traits were examined. Simple product moment correlations indicated that slaughter weight was the one live animal measurement that correlated most highly with the most number of carcass traits. Slaughter weight was significantly correlated not only with weight of carcass cuts but also with carcass measures of leanness and fatness.

The circumference of the heart girth appeared to be a good measure of carcass weights, either of the whole carcass or of its cuts, but a poor measure of leanness as expressed by lean area of leg, combined lean, or shoulder cross section lean. The circumference of the heart girth was significantly correlated with the area of the loin eye but when the standard partial regression was calculated the circumference of heart girth accounted for only 1 percent of the variation in loin eye area. The circumference of the heart girth was highly correlated with most measures of fat in the carcass.

The measurements on the live animal body were generally highly correlated with carcass measurements of the same area. The two leg circumference measurements are exceptions as the correlation was low between live lamb forearm and gaskin circumference and the circumference of the same areas in the carcass.

The circumference of gaskin was a measurement that was difficult to obtain with a high degree of accuracy but it was significantly correlated with the weights of the primal cuts and measures of lean in the leg.

The length of foreleg and height at withers were two live animal measurements that were correlated with each other ($r = 0.66$) and both were highly correlated with weight of the leg of lamb and leg lean area. The standard partial regressions of these two traits showed them to account for over 20 percent of the variation in leg lean area and combined carcass lean when carcass weight was held constant.

Generally the live lamb width measurements were closely associated with the weight of the corresponding area in the carcass. The average width measurement was positively correlated with leg area lean, area of loin eye, and combined lean. The live animal measurement of loin width was the measurement that correlated most highly with area of the loin eye. The standard partial regression of area of loin eye on loin width holding slaughter weight constant showed that the loin width accounted for over 20 percent of the variation in loin eye area. Width at thurls was a poor reflection of either leg weight or composition.

The depth of hind, depth of rear flank, depth of forerib, length hock to twist, and width of thurls were all live measurements that had little value in indicating either the weight of primal cuts or leanness in the carcass.

Standard partial regressions showed that none of the live animal measurements accounted for a large fraction of the variation in carcass traits when the carcass weight was held constant.

Heritability estimates of live lamb measurements, when calculated by the method of correlation between paternal half sibs, were on the whole quite low. The only heritabilities large enough to be used as aids in selection were 0.36 for height at withers and 0.31 for circumference of forearm.

Heritability estimates proved to be high for three of six carcass characters checked. The weight of the kidney knob heritability was estimated as 0.53. The leg area lean had a heritability estimate of 0.76. The estimate of heritability of area of the loin eye proved to be 0.93 in the present study.

The area of the loin eye was a carcass trait upon which genetic improvement might be possible if a consistently accurate measure of this trait can be found in the live animal. A correlation of 0.54 was found between body loin width and area of the loin eye in 94 lambs in 1959 but because this estimate did not agree with the 1957-1958 results ($r = 0.26$) no meaningful conclusions can be made.

The leg lean area was highly heritable and correlated significantly with slaughter weight ($r = 0.59$), length of foreleg, ($r = 0.63$) and height at withers ($r = 0.59$). The standard partial regression showed that length of foreleg accounted for one fourth of the variation in leg lean area when carcass weight was held constant.

BIBLIOGRAPHY

Anderson, D. E. 1954. Genetic relations between carcass characteristics, rate and economy of gain in swine. Iowa State Coll. J. Sci. 29:362.

Bailey, C. M., A. L. Pope and A. B. Chapman. 1961. Predicting loin eye area in lambs from weanling traits and carcass measurements. J. An. Sci. 20:302.

Barton, R. A. and A. H. Kirton. 1958. The leg and loin as indices of the composition of New Zealand lamb and mutton carcasses. New Zealand J. of Agri. Research 1:783.

Barton, W. M. 1938. The relationship of certain body measurements to weight in beef cattle. Mich. State College M. S. Thesis.

Botkin, M. P., M. Stanley and C. O. Schoonover. 1959. Relationship between live lamb measurements and meatiness. J. An. Sci. 18:1165. (Abs.).

Branaman, G. A. 1939. Some factors in lamb production associated with size and type in mutton sheep. Univ. of Ill. Ph. D. Thesis.

Buiatti, P. G. 1954. Ereditabilita e correlazione fra peso vivo e altezza al garrese in vitelle de razza chianina. (The heritability of live weight and height at withers and correlation between them in Chiana heifers.) Riv. Zootec., 27:59. An. Breed. Abst. 22:914.

Butler, O. D. 1957. The relation of conformation to carcass traits. J. An. Sci. 16:227.

Campbell, D., H. H. Stonaker and A. L. Esplin. 1959. The use of ultrasonics to estimate the size of the longissimus dorsi muscle in sheep. J. An. Sci. 18:1483. (Abs.).

Clark, R. T. 1954. Heritability of beef carcass characteristics. Proc. Seventh Ann. Reciprocal Meat Conf. 7:206.

Cole, J. W., L. E. Orme and C. M. Kincaid. 1960. Relationship of loin eye, separable lean of various beef cuts and carcass measurements to total carcass lean in beef. J. An. Sci. 19:89.

Cook, A. C., M. L. Kohli and W. M. Dawson. 1951. Relationship of five body measurements to slaughter grade, carcass grade and dressing percentage in Milking Shorthorn steers. J. An. Sci. 10:386.

Crown, R. M. and R. A. Damon Jr. 1960. The value of the 12th rib cut for measuring beef carcass yields and meat quality. J. An. Sci. 19:109.

Dawson, W. M. 1952. Heritability of growth, beef characteristics and body measurements in Milking Shorthorn steers. Genetics 37:575 (Abs.).

Dawson, W. M., R. L. Hiner and L. L. Madsen. 1955a. Evaluating beef and dual purpose cattle by the proportion of weight carried on the front and hind legs. J. An. Sci. 14:1179. (Abs.).

Dawson, W. M., T. S. Yao and A. C. Cook. 1955b. Heritability of growth, beef characters and body measurements in milking shorthorn steers. J. An. Sci. 14:208.

DePape, J. G. and J. A. Whatley Jr. 1956. Live hog probes at various sites, weights and ages as indicators of carcass merit. J. An. Sci. 15:1029.

Fredeen, H. T. 1953. Genetic aspects of Canadian bacon production. Can. Dept. Agri. Publication No. 889.

Green, W. W. 1954. Relationships of measurements of live animals to weights of grouped significant wholesale cuts and dressing percent in beef steers. J. An. Sci. 13:61.

Givens, C. S. Jr., R. C. Carter and J. A. Gaines. 1960. Selection for weanling traits in spring lamb. J. An. Sci. 19:134.

Hammond, J. 1932. Growth and Development of Mutton Qualities in the Sheep. Edinburgh.

Harrington, G. 1958. Pig Carcass Evaluation. Commonwealth Agri. Bureaux, Farmham Royal, Bucks, England.

Hazel, L. N. and E. A. Kline. 1952. Mechanical measurement of fatness and carcass value on live hogs. J. An. Sci. 11:313.

Hazel, L. N. and E. A. Kline. 1959. Ultrasonic measurement of fatness in swine. J. An. Sci. 18:815.

Hazel, L. N. and C. E. Terrill. 1946a. Heritability of weanling traits in range Columbia, Corriedale and Torghee lambs. J. An. Sci. 5:371.

Hazel, L. N. and C. E. Terrill. 1946b. Heritability of type and condition in range Rambouillet lambs as evaluated by scoring. J. An. Sci. 5:55.

Henneman, H. A. 1942. The relationship of rate of growth in lambs to body measurements and carcass value. Michigan State College M. S. Thesis.

Hetzer, H. O., O. G. Hankins, J. King and J. H. Zeller. 1950. Relationship between certain body measurements and carcass characteristics in swine. J. An. Sci. 9:37.

Hetzer, H. O., J. H. Zeller and O. G. Hankins. 1956. Carcass yields as related to live hog probes at various weights and locations. J. An. Sci. 15:257.

Holland, L. A. and L. N. Hazel. 1958. Relationship of live measurements and carcass characteristics of swine. J. An. Sci. 17:825.

Hundley, W. S. and R. C. Carter. 1956. Heritability of growth rate and market grade in mutton lambs. J. An. Sci. 15:1226. (Abs.).

Joubert, D. M. 1959. The influence of age on the body conformation and carcass composition of cattle. South African J. of Sci. 55:139.

Katada, A. and I. Takada. 1959. (The relationship of body type to economic characters of Corriedale fat wether lamb in Japan.) Jap. J. Zootich. Sci. 29:49. An. Brud. Abst. 27:260.

Kieffer, N. M., R. L. Hendrickson, D. Chambers and D. F. Stephens. 1958. The influence of sire upon some carcass characteristics of Angus steers and heifers. J. An. Sci. 17:1137. (Abs.).

Kidwell, J. F. 1955. A study of the relation between body conformation and carcass quality in fat calves. J. An. Sci. 14:233.

King, J. W. B. 1957. The heritability of carcass traits in British bacon pigs. Proc. Brit. Soc. An. Prod. 49:69.

Knapp, Bradford Jr., W. H. Black and P. V. Phillips. 1939. A study of the accuracy of scoring certain characteristics in beef cattle. Amer. Soc. An. Prod. Proc. 122.

Knapp, B. Jr. and A. W. Nordskog. 1946. Heritability of live animal scores, grades and certain characteristics in beef cattle. J. An. Sci. 5:194.

Knapp, B. Jr. and R. T. Clark. 1950. Revised estimates of heritability of economic characteristics in beef cattle. J. An. Sci. 9:582.

Knight, A. D., W. C. Foote and J. A. Bennett. 1959. Some relationships of live animal and carcass measurements to carcass characteristics and breed type differences in lamb. J. An. Sci. 18:1167 (Abs.).

Ljungdahl, W. A. 1942. Significant factors in the determination of carcass quality in lamb. Michigan State College M. S. Thesis.

Lush, J. L. 1928. Changes in body measurements of steers during intensive fattening. Texas Agr. Exp. Sta. Bull. 385.

Lush, J. L. 1932. The relation of body shape of feeder steers to rate of gain, to dressing percentage and to value of dressed carcasses. Tex. Agr. Exp. Sta. Bull. 471.

Matthews, D. J. 1959. Relationship of live lamb measurements to carcass characteristics as affected by different breeding systems. Dissertation Abst. 20:828.

Matthews, D. J., R. A. Merkel, J. D. Wheat and R. F. Cox. 1959. Relationship of objective measurements of the longissimus dorsi muscle in live lambs to carcass muscling characteristics. J. An. Sci. 18:1480. (Abs.).

Matthews, D. J., R. A. Merkel, J. D. Wheat and R. F. Cox. 1960. A technique for measuring the cross-sectional axes of the longissimus dorsi muscle and fat depth in lambs. J. An. Sci. 19:803.

McMeekan, C. C. 1941. Growth and development in the pig, with special reference to carcass quality. IV. The use of sample joints and of carcass measurements as indices of the composition of the bacon pig. J. Agr. Sci. 31:1.

Orme, L. E. 1958. Methods for estimating carcass characteristics in beef. Michigan State University Ph. D. Thesis.

Orme, L. E., A. M. Pearson, W. T. Magee and L. J. Bratzler. 1959. Relationship of live animal measurements to various carcass measurements in beef. J. An. Sci. 18:991.

Orme, L. E., J. W. Cole, C. M. Kincaid and R. J. Cooper. 1960. Predicting total carcass lean in mature beef from weights of certain entire muscles. J. An. Sci. 19:726.

Ostle, B. 1956. Statistics in Research. Iowa State College Press, Ames, Iowa.

Palsson, H. 1939. Meat qualities in sheep with special reference to Scottish breeds and crosses. J. Agr. Sci. 29:544.

Palsson, H. and J. B. Verges. 1952. Effects of plane of nutrition on growth and development of carcass quality in lambs. J. Agr. Sci. 42:1.

Pearson, A. M., J. F. Price, J. A. Hoefer, L. J. Bratzler and W. T. Magee. 1957. A comparison of the live probe and lean meter for predicting various carcass measurements of swine. J. An. Sci. 16:481.

Pearson, A. M., L. J. Bratzler and W. T. Magee. 1958. Some simple cut indices for predicting carcass traits of swine. II. Supplemental measures of leanness. J. An. Sci. 17:27.

Phillips, R. W. and W. M. Dawson. 1936. A study of methods for obtaining measurements of swine. Amer. Soc. An. Prod. p. 93.

Phillips, R. W. and J. A. Stoehr. 1945. The accuracy of measurements and weights of sheep. J. An. Sci. 4:311.

Price, J. F. 1960. The use of ultrasound in meat animal evaluation. Michigan State University Ph. D. Thesis.

Robison, O. W., A. B. Chapman and H. L. Self. 1960. Swine selection indexes including live animal measurements as indicators of carcass merit. J. An. Sci. 19:1024.

Robison, O. W., J. H. Cooksey, A. B. Chapman and H. L. Self. 1960. Estimation of carcass merit of swine from live animal measurements. J. An. Sci. 19:1013.

Saffle, R. L., L. E. Orme, D. D. Sutton, D. E. Ullrey and A. M. Pearson. 1958. A comparison of urinary and blood serum creatinine with live probe measures of leanness for live swine. J. An. Sci. 17:480.

Schutte, D. L. 1935. Factors affecting the growth of range cattle in semi arid regions. Ondestepoort J. Vet. Sci. 5:535.

Shelby, C. E., R. T. Clark and R. R. Woodward. 1955. The heritability of some economic characteristics of beef cattle. J. An. Sci. 14:372.

Smith, H. G., C. S. Hobbs, E. J. Warwick and W. M. Whitaker. 1950. The accuracy and repeatability of live animal and photographic measurements in beef cattle. J. An. Sci. 9:839.

Stouffer, J. R., D. E. Hogue, D. H. Marden and G. H. Wellington. 1958. Some relationships between live animal measurements and carcass characteristics of lamb. J. An. Sci. 17:1151. (Abs.).

Stouffer, J. R., M. V. Wallentine and G. H. Wellington. 1959. Ultrasonic measurement of fat thickness and loin eye area in live cattle and hogs. J. An. Sci. 18:1183. (Abs.).

Tallis, G. M., E. M. Klosterman and V. R. Cahill. 1959. Body measurements in relation to beef type and certain carcass characteristics. J. An. Sci. 18:108.

Taneja, G. C. 1958. Heritabilities of body length, depth, width, fore cannon length, fold score, and mutton score in Australian Merino Sheep. J. Genetics 56:103.

Terrill, C. E. 1958. Fifty years of progress in sheep breeding. J. An. Sci. 17:944.

Terrill, C. E. and L. N. Hazel. 1943. Heritability of yearling fleece and body traits of range Rambouillet ewes. J. An. Sci. 2:358. (Abs.).

Wanderstock, J. J. and G. W. Salisbury. 1946. The relation of certain objective measurements to weights of beef cattle. J. An. Sci. 5:264.

Weber, F. 1957. Die Statistischen und genetischen Grundlagen von kor permessungen am Rind. (The statistical and genetical bases of body measurements in cattle). Z. Tierz. Zucht Biol. 69:225. An. Breed. Abst. 25:1811.

Whatley, J. A. and F. D. Enfield. 1957. Heritability of carcass length, carcass backfat thickness and loin lean area in swine. J. An. Sci. 16:1066. (Abs.).

White, F. E. and W. W. Green. 1952. Relationships of measurements of live animals to weights of wholesale cuts of beef. J. An. Sci. 11:370.

Yao, T. S., W. M. Dawson and A. C. Cook. 1953. Relationships between meat production characters and body measurements in beef and Milking Shorthorn steers. J. An. Sci. 12:775.

Young, L. G. 1960. Production factors and carcass characteristics of fattening calves influenced by rate of gain feeding. Michigan State University Ph. D. Thesis.

APPENDIX TABLE 1

1959 DATA

Simple Correlation Coefficients Between Live Lamb Measurements and Carcass Traits.

	Age	Wool wt.	Sl. wt.	Depth hind	Depth to rear flank	Width thurls	Width loin	Width rack	Average width
Mean	196.8	4.6	88.8	10.9	30.2	25.7	14.7	21.5	20.6
Standard deviation	27.4	1.1	4.2	1.0	1.1	1.2	1.0	1.0	0.7
Quality grade	+.054	+.036	+.190	+.061	-.079	-.180	+.145	+.222	+.066
Hot carcass weight	+.613	+.363	+.861	+.250	+.428	+.135	+.573	+.610	+.628
Shoulder lean	+.227	+.242	+.156	+.181	+.036	+.236	+.133	-.056	+.169
Cross section fat	+.001	+.106	+.211	-.008	+.147	-.172	+.057	+.372	+.102
Longissimus dorsi depth	+.333	+.081	+.357	+.095	+.119	+.114	+.444	+.209	+.372
Longissimus dorsi width	+.238	+.212	+.162	+.108	+.058	-.167	+.200	+.100	+.030
Fat thickness 12th rib	+.128	+.131	+.299	-.159	+.243	-.107	+.276	+.387	+.249
Weight leg	+.532	+.163	+.798	+.175	+.269	+.285	+.525	+.458	+.625
Weight loin untrimmed	+.330	+.354	+.325	+.030	+.221	+.225	+.196	+.280	+.347
Weight loin trimmed	+.597	+.524	+.554	+.097	+.471	-.114	+.499	+.288	+.285
Weight kidney knob	+.416	+.372	+.515	+.137	+.510	+.238	+.442	+.450	+.280
Combined fat	+.323	+.256	+.500	+.067	+.451	-.235	+.387	+.581	+.317
Ruffle fat	+.264	+.088	+.364	+.077	+.201	+.104	+.269	+.299	+.341
Caul fat	+.368	+.215	+.437	+.130	+.425	-.144	+.435	+.388	+.301
Combined lean	+.538	+.393	+.530	+.256	+.178	+.312	+.374	+.093	+.388
Length of tibia	-.041	+.004	-.114	-.123	-.193	-.140	-.071	-.174	-.187
Weight forecannon	+.191	+.078	+.158	+.073	-.217	+.344	-.071	-.054	+.147
Length forecannon	+.145	+.061	+.088	+.261	-.082	+.143	-.090	-.177	-.035
Weight of fore	+.547	+.257	+.217	+.304	+.199	+.534	+.621	+.621	+.652
Weight of hind	+.537	+.329	+.809	+.242	+.460	+.044	+.535	+.563	+.537
Length of loin	+.281	+.358	+.028	+.003	+.262	-.022	+.184	-.165	-.018
Ether extract fat 12th rib	+.060	-.037	-.225	+.159	-.141	-.203	-.027	-.086	-.161

APPENDIX TABLE 1 (CONTINUED)

	Age	Wool wt.	Sl. wt.	Depth hind	Depth to rear flank	Width thurls	Width loin	Width rack	Average width
Leg cross section- total area	+.594	+.432	+.592	+.214	+.244	+.232	+.339	+.160	+.358
Shoulder cross section	+.299	+.433	+.501	+.204	+.234	+.115	+.289	+.396	+.382
Leg distal tibia to twist	+.160	-.046	+.145	+.177	-.078	+.036	+.025	-.087	-.011
Leg twist to widest lean	-.188	+.036	-.215	-.116	-.041	-.079	+.056	+.025	-.001
Leg width of lean at twist	+.464	+.302	+.554	+.126	+.067	+.294	+.241	+.162	+.341
Leg width of widest lean	+.616	+.476	+.745	+.006	+.328	+.294	+.554	+.297	+.559
Leg twist to widest lean - Leg distal tibia to twist	-.214	+.034	-.256	-.133	-.040	-.084	+.030	+.020	-.020
Percent hind	+.294	+.265	+.336	+.078	+.479	-.160	+.301	+.084	+.085
Combined lean - age	-.815	-.511	-.390	+.199	-.538	+.202	-.408	-.319	-.211
Ether extract of loin eye	+.131	+.033	-.069	+.039	-.041	-.297	+.185	+.192	+.016
Final grade	+.006	-.021	+.235	-.121	-.042	-.185	+.296	+.404	+.228
Carcass length	+.418	+.553	+.383	+.067	+.331	+.097	+.275	+.040	+.196
Width gigot	+.501	+.238	+.714	+.055	+.204	+.420	+.445	+.317	+.601
Depth thorax	-.014	-.141	+.332	+.313	-.080	+.296	+.116	+.125	+.292
Length crutch to break joint	+.174	+.046	+.055	+.050	+.040	-.007	+.112	-.026	+.057
Circumference leg	+.158	-.041	+.396	+.114	-.071	+.373	+.290	+.069	+.400
Circumference forearm	-.373	-.182	-.533	-.181	-.499	+.192	-.387	-.282	-.213
Leg area lean	+.576	+.428	+.587	+.202	+.220	+.246	+.340	+.135	+.354
Leg cross section fat	+.178	+.066	+.090	+.145	+.320	-.194	+.038	+.273	+.029
Leg cross section bone	+.045	-.053	-.044	-.094	-.218	+.227	-.116	-.068	+.060
Weight rack	+.671	+.396	+.609	+.058	+.409	+.016	+.543	+.489	+.484
Carcass cutting weight	+.590	+.320	+.851	+.223	+.411	+.130	+.594	+.631	+.645
Conformation grade	+.129	+.202	+.339	-.075	-.120	+.182	+.233	+.292	+.350
Fat thickness sirloin	+.377	+.063	+.473	+.037	+.313	-.067	+.398	+.603	+.430
Percent water	+.091	+.000	+.248	+.044	+.143	+.066	+.061	-.252	-.574
Area longissimus dorsi	+.418	+.135	+.393	+.112	+.192	+.123	+.540	+.256	+.438

APPENDIX TABLE 1 (CONTINUED)

	Length hock to twist	Depth rear flank	Length of fore-leg	Depth of fore-rib	Height at withers	Cir. of gaskin	Cir. of fore-arm	Cir. of heart girth	Carcass weight
Mean	16.2	23.3	36.5	27.4	55.8	22.1	18.5	82.0	
Standard deviation	2.7	1.3	1.4	0.8	1.8	1.1	1.1	2.4	
Quality grade	-.020	-.193	-.156	-.069	-.241	-.007	+.012	+.186	+.257
Hot carcass weight	-.158	+.023	+.391	+.224	+.325	+.465	-.158	+.726	--
Shoulder lean	-.014	+.039	+.365	-.092	+.336	+.229	+.084	-.037	+.217
Cross section fat	-.070	-.010	-.304	-.045	-.262	-.065	-.157	+.227	+.203
Longissimus dorsi depth	-.032	+.044	+.204	+.180	+.155	+.283	-.083	+.424	+.532
Longissimus dorsi width	+.173	+.151	+.188	+.318	+.189	+.294	-.023	+.210	+.230
Fat thick. 12th rib	+.121	-.003	-.163	+.039	-.263	+.246	-.170	+.430	+.334
Weight leg	-.081	-.141	+.542	+.360	+.450	+.465	+.174	+.620	+.860
Weight loin untrimmed	+.528	+.068	+.173	+.044	+.241	+.419	-.244	+.276	+.454
Weight loin trimmed	-.066	+.316	+.278	+.152	+.260	+.473	-.417	+.367	+.714
Weight kidney knob	-.338	+.299	+.094	-.076	+.128	+.307	-.534	+.519	+.674
Combined fat	-.253	+.104	-.137	-.063	-.120	+.242	-.392	+.565	+.606
Ruffle fat	+.031	-.075	+.234	+.058	+.288	+.325	-.157	+.458	+.440
Caul fat	-.300	+.083	+.121	+.051	+.205	+.541	-.275	+.526	+.534
Combined lean	+.038	-.023	+.637	+.293	+.587	+.395	+.082	+.272	+.556
Length of tibia	+.075	+.039	+.259	+.055	+.338	+.127	+.222	-.224	+.000
Weight forecannon	+.312	-.083	+.676	+.383	+.618	+.004	+.326	-.180	+.039
Length forecannon	+.110	+.056	+.538	+.351	+.500	+.054	+.002	+.001	+.114
Weight of fore	-.068	-.044	+.316	+.254	+.308	+.373	-.118	+.728	+.944
Weight of hind	-.196	+.007	+.360	+.184	+.301	+.452	-.160	+.670	+.938
Length of loin	+.003	+.088	+.145	+.098	+.226	+.305	-.130	-.145	+.033
Ether extract-fat 12th rib	-.303	-.041	-.004	-.232	+.023	-.010	-.114	-.164	-.095
Leg cross section-total carcass	+.070	-.042	+.616	+.337	+.589	+.385	-.015	+.321	+.565
Shoulder cross section	-.093	+.010	+.117	-.110	+.079	+.203	-.085	+.262	+.550
Leg distal tibia to twist	+.227	-.050	+.522	+.430	+.573	+.049	+.188	-.011	-.014

APPENDIX TABLE 1 (CONTINUED)

	Length hock to twist	Depth rear flank	Length of fore-leg	Depth of fore-rib	Height at withers	Cir. of gaskin	Cir. of fore-arm	Cir. of heart girth	Carcass weight
Leg twist to widest lean	-.263	+.020	-.193	-.234	-.396	-.231	-.218	-.025	-.194
Leg width of lean at twist	+.177	-.051	+.553	+.385	+.435	+.440	+.346	+.262	
Leg width of widest lean	+.113	-.034	+.534	+.328	+.358	+.602	+.151	+.465	+.522
Leg twist to widest lean-leg distal tibia to twist	-.277	+.025	-.307	-.303	-.486	-.226	-.224	-.030	+.752
Percent hind	+.260	+.030	+.252	-.023	+.177	+.415	-.169	+.195	+.386
Combined lean-age	+.004	-.263	-.163	-.122	-.192	-.457	+.250	-.254	-.398
Ether extract of loin eye	-.201	-.024	-.109	-.223	-.105	+.139	-.254	+.125	+.162
Final grade	-.142	-.206	-.258	-.083	-.286	+.004	-.029	+.358	+.352
Carcass length	+.072	+.142	+.354	+.180	+.283	+.208	-.219	-.016	+.290
Width gigot	+.037	-.106	+.561	+.347	+.368	+.456	+.087	+.452	+.724
Depth thorax	+.172	-.109	+.394	+.459	+.387	-.229	+.102	+.376	+.306
Length crutch to break joint	+.175	-.177	+.449	+.261	+.371	+.072	+.148	-.050	-.040
Cir. leg	+.012	-.485	+.512	+.196	+.264	+.123	+.350	+.173	+.322
Cir. forearm	+.176	-.084	-.241	+.026	-.165	-.382	+.246	-.441	-.575
Leg area lean	+.071	-.023	+.629	+.344	+.589	+.368	-.010	+.320	+.559
Leg cross section fat	-.093	-.118	-.221	-.110	-.105	+.120	-.154	+.063	+.084
Leg cross section bone	+.232	-.212	+.329	+.137	+.329	+.155	+.329	-.113	-.028
Weight rack	-.058	+.218	+.250	+.127	+.279	+.488	-.430	+.553	+.813
Car. cutting weight	-.174	+.001	+.349	+.213	+.302	+.460	-.132	+.751	+.993
Conformation grade	+.015	+.459	+.163	+.031	-.135	+.171	+.384	+.266	+.335
Fat thick. sirloin	-.274	-.233	-.074	-.090	-.095	+.450	-.083	+.669	+.591
Percent water	+.149	+.224	+.246	+.246	+.234	+.162	-.075	-.134	+.096
Area l. dorsi	-.088	-.022	+.290	+.271	+.198	+.428	+.046	+.368	+.574

APPENDIX TABLE 2

1957 and 1958 DATA

Simple Correlation Coefficients Between Live Lamb and Carcass Traits

	Age	Weight off	Sl. weight	Width thurls	Width loin	Width rack	Length hock to twist	Depth rear flank	Depth forerib
Mean	161.7	97.3	89.4	24.0	13.9	21.3	16.5	23.6	27.3
Standard deviation	19.7	6.1	6.4	1.3	1.1	1.2	2.2	3.0	1.2
Quality grade	+.045	+.394	+.559	+.174	+.536	+.411	+.222	+.398	+.600
Specific gravity rack	+.362	+.398	+.244	+.271	+.074	+.086	+.115	+.178	+.354
Wt. hot carcass	+.171	+.756	+.854	+.289	+.625	+.675	-.066	+.211	+.410
Shoulder lean	-.039	-.407	+.530	+.223	+.500	+.392	-.098	+.279	+.520
Shoulder fat	+.226	+.237	+.385	+.173	+.376	+.378	-.170	+.205	+.303
Depth l. dorsi	+.169	-.106	-.146	+.101	+.107	+.065	+.023	-.192	-.180
Width l. dorsi	-.004	+.146	-.141	+.320	+.152	+.064	+.119	-.093	+.187
Fat 12th rib	+.297	+.162	+.261	-.029	+.348	+.375	-.133	+.005	-.109
Weight leg	+.110	+.735	+.809	+.332	+.578	+.567	-.046	+.202	+.429
Weight untrimmed loin	+.281	+.505	+.599	+.225	+.567	+.550	-.055	+.217	+.266
Weight trimmed loin	+.248	+.594	+.694	+.290	+.619	+.554	-.123	+.200	+.368
Wt. kidney knob	+.229	+.175	+.234	+.088	+.309	+.351	+.029	+.199	+.038
Combined fat	+.274	+.294	+.440	+.171	+.507	+.456	-.205	+.176	+.333
Ruffle fat	-.050	+.228	+.164	-.054	+.153	+.058	+.107	+.107	+.137
Caul fat	+.333	+.110	+.197	-.000	+.274	+.334	-.174	+.076	+.085
Sp. gravity l. dorsi	-.532	+.103	-.081	+.173	-.269	-.178	+.167	+.054	+.159
Combined lean	-.000	+.568	+.664	+.374	+.526	+.475	-.024	+.072	+.442
Ether extract of loin eye	+.108	+.083	+.166	-.007	+.251	+.275	-.234	+.308	+.228
Final grade	-.036	+.098	+.166	-.000	+.292	+.392	-.224	+.013	+.025
Carcass length	-.002	+.699	+.693	+.223	+.307	+.358	+.161	+.212	+.411
Width gigot	+.127	+.687	+.725	+.298	+.418	+.462	-.026	+.098	+.257
Depth thorax	+.109	+.517	+.578	+.337	+.268	+.322	+.186	-.023	+.484

APPENDIX TABLE 2 (CONTINUED)

	Age	Weight off	Sl. weight	Width thurls	Width loin	Width rack	Length hock to twist	Depth rear flank	Depth forerib
Length crutch to break joint	-.072	+.352	+.226	+.211	-.122	-.057	+.492	-.104	+.121
Cir. leg	-.153	+.578	+.552	+.330	+.230	+.266	+.121	-.006	+.349
Cir. forearm	-.101	+.485	+.463	+.280	+.234	+.226	+.332	+.025	+.241
Leg area lean	+.060	+.587	+.627	+.439	+.387	+.395	+.045	-.169	+.322
Leg area fat	+.291	+.185	+.236	+.202	+.300	+.218	-.096	+.120	+.220
Leg area bone	-.123	-.272	-.452	-.118	-.569	-.471	+.271	-.051	-.602
Weight rack	+.180	+.475	+.497	+.106	+.504	+.464	+.046	+.030	+.123
Car. cutting weight	+.225	+.798	+.864	+.300	+.603	+.703	-.063	+.141	+.463
Conformation grade	+.079	+.344	+.527	+.164	+.500	+.466	-.282	+.359	+.658
Fat thickness sirloin	+.209	+.169	+.281	+.100	+.494	+.379	-.176	+.053	+.434
Percent water	-.035	+.021	+.137	+.006	-.008	-.077	-.130	+.106	+.338
Area l. dorsi	+.236	+.167	+.192	+.291	+.257	+.247	+.083	-.075	+.048

APPENDIX TABLE 2 (CONTINUED)

	Height Withers	Cir. Gaskin	Cir. Forearm
Mean	57.7	23.5	18.7
Standard deviation	1.9	1.4	1.0
Quality grade	+.139	+.031	-.079
Specific gravity rack	+.269	-.182	-.115
Wt. hot carcass	+.218	+.110	+.160
Shoulder lean	+.210	+.040	+.071
Shoulder fat	-.078	-.020	-.071
Depth l. dorsi	-.119	-.129	+.206
Width l. dorsi	+.282	+.041	+.253
Fat 12th rib	-.272	+.153	+.090
Weight leg	+.277	+.083	+.164
Weight untrimmed loin	-.081	+.090	+.036
Weight trimmed loin	-.006	+.070	+.057
Wt. kidney knob	-.190	-.009	-.053
Combined fat	-.130	-.054	-.049
Ruffle fat	+.178	-.010	-.053
Caul fat	-.270	+.235	+.038
Sp. gravity l. dorsi	+.212	-.084	-.113
Combined lean	+.401	+.035	+.207
Ether extract of loin eye	-.231	+.266	-.227
Final grade	-.328	+.071	+.017
Carcass length	+.433	-.014	+.160
Width gigot	+.211	-.067	+.211
Depth thorax	+.432	+.060	+.070
Length crutch to break joint	+.618	-.019	+.086
Cir. leg	+.405	+.054	+.176
Cir. forearm	+.385	+.072	+.268
Leg area lean	+.443	+.008	+.245
Leg area fat	-.010	+.118	+.030

APPENDIX TABLE 2 (CONTINUED)

	Height withers	Cir. gaskin	Cir. forearm
Leg area bone	-.044	-.081	+.110
Weight rack	+.066	-.074	+.124
Car. cutting weight	+.178	+.098	+.145
Conformation grade	+.048	+.083	-.052
Fat thickness sirloin	-.124	+.188	-.085
Percent water	+.249	+.042	+.116
Area l. dorsi	+.084	-.117	+.385

APPENDIX TABLE 3

1959 DATA

Simple Correlation Coefficients Between Various Live Lamb Measurements

	Age	Wool weight	Sl. wt.	Depth hind	Depth to flank	Width thurls	Width loin	Width rack	Average width
Cir. heart girth	+.356	+.025	+.614	+.285	+.324	+.087	+.507	+.684	+.608
Cir. forearm	-.143	-.176	-.040	-.162	-.240	+.194	-.009	-.086	+.074
Cir. gaskin	+.515	+.334	+.382	-.100	+.317	+.013	+.436	+.305	+.364
Ht. at withers	+.466	+.149	+.319	+.198	+.073	+.102	+.177	+.042	+.164
Depth of forerib	+.234	+.014	+.268	+.106	-.021	+.147	+.383	-.006	+.247
Length of foreleg	+.431	+.303	+.452	+.095	+.095	+.239	+.253	+.065	+.293
Depth rear flank	+.160	+.267	-.024	-.057	+.276	-.242	-.084	-.120	-.241
Length hock to twist	-.008	+.079	-.118	-.216	-.324	+.268	-.155	-.129	+.002
Average width	+.441	+.088	+.615	+.104	+.227	+.622	+.695	+.660	
Width rack	+.399	+.069	+.555	+.297	+.340	+.012	+.403		
Width loin	+.488	+.157	+.518	-.041	+.311	+.069			
Width thurls	+.072	+.006	+.188	-.016	-.117				
Depth to flank	+.452	+.259	+.542	+.256					
Depth hind	+.011	-.027	+.307						
Slaughter weight	+.570	+.350							
Wool weight	+.522								

APPENDIX TABLE 3 (CONTINUED)

	Length hock to twist	Depth rear flank	Length of fore-leg	Depth of fore-rib	Height at withers	Cir. of gaskin	Cir. of fore-arm
Cir. heart girth	-.195	-.077	+.146	+.292	+.138	+.235	-.164
Cir. forearm	+.113	-.420	+.240	+.083	+.099	+.053	
Cir. gaskin	+.037	-.017	+.323	-.019	+.242		
Ht. at withers	+.248	+.154	+.657	+.368			
Depth of forerib	+.242	-.045	+.424				
Length of foreleg	+.170	-.009					
Depth rear flank	-.003						

APPENDIX TABLE 4

1957-1958 DATA

Simple Correlation Coefficients Between Various Live Lamb Measurements

	Age	Wt. off test	Sl. wt.	Width thurls	Width loin	Width rack	Length hock to twist	Depth rear flank	Depth forerib
Cir. forearm	-.060	+.223	+.214	+.232	+.130	+.029	+.252	-.066	-.055
Cir. gaskin	+.168	-.023	+.082	+.111	+.024	+.017	+.170	+.018	+.235
Height withers	-.134	+.462	+.430	+.335	+.105	+.010	+.393	-.049	+.262
Depth forerib	+.124	+.441	+.532	+.310	+.515	+.431	-.166	+.385	
Depth rear flank	-.013	+.155	+.183	+.005	+.069	-.015	-.134		
Length hock to twist	-.232	+.124	+.024	+.146	-.172	-.069			
Width rack	+.323	+.544	+.659	+.250	+.495				
Width loin	+.309	+.382	+.508	+.280					
Width thurls	+.115	+.382	+.421						
Slaughter weight	+.212	+.911							
Wt. off test	+.015								

APPENDIX TABLE 4 (CONTINUED)

	Ht. withers	Cir. gaskin
Cir. forearms	+.207	+.039
Cir. gaskin	+.035	