FACTORS AFFECTING BEEF CARCASS TRAITS

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INTRODUCTION

According to a report by the Foreign Agricultural Service, 49 percent of the meat consumed in the world in 1959 and 1960, excluding Communist China, was beef and veal; 42 percent was pork; and 8.5 percent was lamb, mutton, and goat. Although the United States is the largest meat producer, it is ranked fifth in per capita consumption of meat. Total meat consumption per person in the United States during this two year period was approximately 160 pounds. Nearly 55 percent of this was beef and veal. The U.S.D.A Agricultural Marketing Service has indicated that the total meat consumption in 1961 is expected to be around 165 pounds. Most of this gain in consumption will likely be in beef.

Comsumer preference studies have shown that the meat buyer placed more importance on quality of beef than on price. They considered color of the lean and fat and freedom of excessive fat to be the most important factors in purchasing fresh beef.

Studies conducted on eating preferences showed that consumers consistently favored steaks from younger carcasses. Panel members, having a preference for these steaks, indicated that tenderness was the main factor; those members who preferred steaks from older beef indicated a stronger preference for flavor and juiciness.

In order to produce beef which is more acceptable to the consumer, the producer must determine what can be done to improve carcass composition and quality. First of all, he needs to know the heritabilities of those traits which affect carcass composition and quality. If the heritability estimates for these traits are relatively high, improvement through selection can be obtained. Direct selection for carcass traits is not possible; therefore, selection must be based either on progeny tests or on indicators in the live animal which are highly associated with carcass composition and quality.

The purposes of this study were to estimate heritabilities of important live animal and carcass traits, to predict carcass composition by the use of various live animal and carcass measurements, and to determine the importance of some factors which influence tenderness of beef.

REVIEW OF LITERATURE

Beef Carcass Evaluation

With increased emphasis on the meat type animal, beef carcass evaluation has recently become very important. Although various cuts, muscles, and measurements have been suggested as indicators of carcass composition, these data have been collected on diverse sources of material. Cattle in these experiments have usually varied widely in weight, grade, and age.

In order to evaluate the carcass composition of lean, fat, and bone, the complete carcass must be physically separated. This requires considerable time and labor and is a very expensive procedure. Due to these difficulties, research data depicting the relationship between carcass measurements and composition are limited.

Loin eye area has been used extensively by swine and beef research workers as an index of muscling. Kline and Hazel (1955) and Price _et al_. (1957) reported a relatively low relationship between loin eye area and total muscling of the entire pork carcass. Cole _et al_. (1960) studied the relationships between loin eye area and separable components of the beef carcass and separable lean of the various wholesale cuts. Even though the data included 81 steers, 9 heifers, and 9 cows which represented grades from choice to utility, the loin eye area accounted for only 5 to 30 percent of the variation in separable lean of either the carcass or of a particular wholesale cut. Carcass weight accounted for 27 percent of the variation in loin eye area. Similar results of the influence of carcass weight on loin eye area were reported by Knapp _et al_. (1946), Woodward _et al_. (1954), Butler (1957), and Magee _et al_. (1958). Goll _et al_. (1961) indicated when carcass grade was held constant, the partial correlations between carcass measurements or percentage of major wholesale cuts and loin eye area differed slightly from the simple correlations.

Lush (1926) reported dressing percentage and percent fat in the lean of the wholesale rib were indicators of animal fatness. Hopper (1944) and Hankins and Howe (1946) supported these findings when they reported high correlations between the percentage of separable lean, fat, and bone of the 9-10-11th rib section and the percentage of separable lean, fat, and bone of the carcass. Cole _et al_. (1960) also reported that the 9-10-11th rib lean separation accounted for 60 percent of the variation in total carcass separable lean. Crown and Damon (1960) obtained correlations between separable lean, fat, and bone of the 9-10-11th rib section and that of the total carcass of .94, .98, and .73, respectively. Orme (1959) suggested that the best estimates of the weight of lean in the carcass were the separable round, chuck, or foreshank. Correlation coefficients between the separable round, chuck, and foreshank with total separable carcass lean were .95, .93, and .81, respectively.

As long ago as 1893, Wilson and Curtiss reported detailed carcass cutout on nine dairy and beef breeds. Although numbers were small, the differences in the yield of high priced cuts between the beef and dairy breeds were small.

Stonaker *et al.* (1952) and Butler *et al.* (1956) compared various types of beef cattle. No differences in percentage of high priced cuts were found between the conventional and comprest types or between Herefords and Brahman X Hereford crossbreds.

Pierce (1957) selected 459 carcasses ranging in grade from prime through canner. Finish influenced the yield of most wholesale and retail cuts considerably more than did conformation. Higher grades and greater depth of fat were associated with higher wholesale yields of short loin, rib, flank, brisket, plate, and hindquarter, but with lower yields of round, loin end, chuck, and foreshank. This is in agreement with conclusions reached by Butler (1957) and Goll *et al.* (1961a).

Murphey *et al.* (1960) used 450 beef carcasses and 300 live cattle to develop a method for predicting the yield of retail cuts from beef carcasses and live cattle. The most useful estimating equation for predicting the percentage of boneless retail cuts from the round, loin, rib, and chuck was obtained through the combination of fat thickness, carcass weight, percent kidney fat, and loin eye area.

Live Animal Evaluation

In an attempt to predict the carcass components, various live animal measurements have been evaluated. Johnson (1940), Johansson and Hildeman (1954), and Kidwell (1955) found circumference measurements of the heart girth and flanks to be correlated with live animal weight.

Lush (1928), Wanderstock and Salsbury (1946), Stonaker *et al*. (1952), Johansson and Hildeman (1954), Woodward *et al*. (1954), and Kidwell (1955) reported skeletal measurements of length of leg and body to be highly correlated with final weight. Black *et al*. (1938) indicated that depth of chest and width of loin were indicative of the amount of finish. Black *et al*. (1938), Cook *et al*. (1951), Yao *et al*. (1953), Green (1954), and Brown *et al*. (1956) have shown width measurements of round and shoulder to be associated with leanness. Weseli *et al*. (1958) observed that circumference of forearm was positively correlated with loin eye area and circumference of cannon. Bone scores were associated with loin eye area, although no relationship was noticed with fat thickness. Orme (1959) reported relatively high correlations between various body circumference measurements and loin eye area, but they approached zero when effects of live weight were removed. The circumference of foreshank was found to account for 16 percent of the variation existing in carcass separable lean. Live weight and various live animal measurements were highly associated with the weight of wholesale cuts (Green, 1945; Green et al., 1955; Kidwell et al., 1959; Orme et al., 1959; and Ternan et al., 1959). Live weight was the simplest predictor of the weight of wholesale cuts. Other measurements, such as width of shoulder, loin, and thighs, were associated with the weight of wholesale cuts. Negative correlations were found between round measurements and percentage of round.

Although reports were conflicting when live steer grades were associated with carcass leanness, Yao et al. (1953), Weseli et al. (1958), and Ternan et al. (1959) indicated that live steer grades were positively associated with carcass grades. Wheat and Holland (1960) reported highly significant correlations between slaughter grade and carcass grade before ribbing (.38), but these correlations dropped to .22 after ribbing.

Woodward et al. (1954) noted that average daily gain was positively correlated with area of rib eye, but this association was zero when final weight was held constant. Later, Woodward et al. (1959) reported that correlations between production characters and carcass traits were not high enough to have much predictive value.

Limited heritability estimates of live animal and carcass measurements have been reported by Knapp and Nordskog (1946), Knapp et al. (1950), Dawson et al. (1955), and Shelby et al. (1955). The range of heritability estimates is shown in Table I. The heritability estimates of skeletal measurements, final weight, dressing percentage, and slaughter grade were high. However, the heritability estimates of width measurements were low. The standard errors of these heritability estimates were large.

Carcass Quality

Tenderness of a steak is influenced by many factors. The literature reveals that breed, sire, sex, age, muscle, cooking method, and finish are some of the factors that influence the eating qualities of meat. There are reports that tenderness is influenced by heredity. Cover _et al_. (1957) reported heritability estimates ranging from .74 to 1.02 for shear value. These data were based on nine sire groups. Florida workers (Carpenter _et al_., 1961) stated that steaks and roasts from animals of part Brahman breeding were less tender than those of Shorthorn breeding. Yao and Hiner (1953) reported heritability estimates of .30 for organoleptic score and .77 for shear value. These data included 298 beef and dual purpose Shorthorn steers. Alsmeyer _et al_. (1959) reported that the heritability estimate for shear value was .49. This estimate was computed from an intra-breed, intra-class correlation and was based on 16 sires. Kieffer _et al_. (1958) reported differences in tenderness among seven Angus sire groups. The heritability estimate for shear value was .92.

TABLE I

HERITABILITY ESTIMATES FOR BEEF CATTLE CHARACTERISTICS REPORTED IN LITERATURE

Characteristic	No. of Estimates	Range of Estimates (%)	References[1]
Live Animal Traits			
Slaughter Grade	4	42-63	1, 2, 3, 4
Wither Height	1	65	3
Flank Height	1	5	3
Loin Width	1	5	3
Shoulder Width	1	0	3
Hip Width	1	0	3
Chest Depth	1	40	3
Cannon Circumference	1	34	3
Feed-Lot Gain	4	60-86	1, 2, 3, 4
Dressing Percentage	2	50-73	3, 4
Final Weight	4	84-92	1, 2, 3, 4
Carcass Traits			
Carcass Grade	4	16-84	1, 2, 3, 4
Thickness of Fat	1	38	4
Loin Eye Area	3	68-73	1, 2, 4
Color of Loin Eye	1	31	4

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[1]
1. Knapp and Nordskog (1946)
2. Knapp *et al.* (1950)
3. Dawson *et al.* (1955)
4. Shelby *et al.* (1955)

Many workers (Cline et al., 1932; Brady, 1937; Hiner and Hankins, 1950; and Hiner et al., 1955) have shown that as animal age increases, tenderness tends to decrease. They reported that cow meat was less tender than that from either heifers or steers.

Several investigators have observed differences in the tenderness of steaks from the same muscle. Ramsbottom et al. (1945) indicated that the shear values for longissimus dorsi muscle were somewhat higher at the anterior end (10.7 ± 1.4) than at the middle (8.3 ± .9) or posterior end (8.3 ± .8). Blakeslee and Miller (1948) and Paul and Bratzler (1955), however, found the anterior steaks from the longissimus dorsi muscle to be more tender than the posterior steaks.

Treatment has been confounded with side in most tenderness experiments; therefore, little information is available as to whether or not side differences may exist. Hankins and Hiner (1940) analyzed four Shorthorn steer carcasses and found no appreciable difference in tenderness between sides. In contrast, Bray et al. (1942) studied six Hereford steers weighing about 700 pounds and found that the right side was significantly more tender than the left side. The greatest source of variation in their study existed among the cores taken from the longissimus dorsi muscle.

Cooking method is another source of variation in meat tenderness. Various methods of cookery have been utilized depending upon the cut. Ramsbottom and Strandine (1948) utilized three U.S. Good heifer carcasses for the comparison of deep fat cooked and raw beef. Thirty-five of the 50 muscles sampled yielded higher shear values for cooked than for raw beef. The mean shear value for cooked longissimus dorsi muscle was 8.3 pounds. The comparable value for raw beef was 3.8 pounds. The longissimus dorsi muscle became less tender when heated quickly to 170°F. Doty et al. (1951) studied 48 beef carcasses and found no close relationship between shear strength of uncooked meat and tenderness scores of cooked meat. Doty and Satchell (1951) also noted that the shear values of all longissimus dorsi samples were increased by cooking.

Visser et al. (1960) studied the effect of deep fat cooking and oven roasting on muscles from six U.S. Good carcasses. Heat penetration curves for roasts cooked in deep fat were steeper and shorter than those for oven roasts. At a given temperature the heat conductivity of liquid fat was about six times that of air. Although the temperature of the fat was less than the oven temperature, the heat was transferred into the meat more rapidly in fat than in air. When roasts were cooked to the same internal temperature, oven cooked roasts required approximately two to three times as long to reach the desired end-point as those cooked in fat. When the meat was cooked to 85°C., cooking losses were similar for both cooking methods.

After cooking the roasts stood at room temperature until the maximum internal temperature was obtained. The internal temperature of deep fat cooked roasts rose five to six degrees, whereas the interior temperature of the oven cooked roasts did not rise. Average tenderness scores indicated that deep fat cooked roasts were less tender than oven cooked roasts.

Cover (1943) studied the effect of rates of heat penetration on tenderness of beef roasts. The roasts cooked at 80°C. had consistently lower shear values than those cooked at 125°C.

Harrison (1943) noted that roasts cooked in air were more tender than those cooked in steam. Tenderness scores for deep fat cooked and water cooked roasts were not significantly different.

Various workers have associated the quantity and distribution of fat with tenderness of meat. Husaini _et_ _al_. (1950) studied 10 Hereford and 10 Holstein steers which represented wide variations in market grade. They noted that the correlations between carcass grade or marbling score and tenderness scores were small but positive. There was no relationship between tenderness score and moisture or total protein. Kropf and Graf (1959) evaluated 334 steer, heifer, and cow carcasses ranging in grade from choice to commercial. Carcass grade exerted a highly significant effect upon taste panel and shear values. Similar results were reported by Wanderstock and Miller (1948), Paul and Bratzler (1955), and Wierbicki _et_ _al_. (1956). Since these results were obtained on experimental animals which varied widely in age and carcass grade, age could have had a greater effect on these correlations than carcass grade.

Cover et al. (1956) obtained juiciness scores, tenderness scores, and shear values for 38 animals. The correlations between ether extract in the loin eye and juiciness score, tenderness score, and shear value were .51, .34, and -.33, respectively. The correlations between the fat in the carcass and these latter variables were .48, .24, and -.24, respectively. When Cover et al. (1958) plotted the tenderness rating of 203 carcasses against carcass grade, a wide scattering of tenderness ratings was found for different animals within a grade. This revealed that some of the lower grades of meat had tenderness scores as high as those from higher grades.

Wilson et al. (1955), using a biopsy technique on eight commercial grade steers, noted that, as animals fattened during the feeding trial, the shear values were reduced. However, Woodward et al. (1959) conducted a study with 210 Hereford steers and stated that tenderness was not closely related to either slaughter or carcass grade.

Using 502 animals, Alsmeyer et al. (1959) reported that shear values were small and negatively correlated with outside finish, carcass conformation, and carcass grade. Age at time of slaughter accounted for 8.1 percent of the variability in tenderness, whereas marbling accounted for 6.9 percent. The variation due to breed of sire and sires within breed suggested that these factors were more important than marbling and age.

Although the basic causes of differences in beef tenderness are not fully understood, reports state that sire, muscle, cooking technique, and age are sources of variation.

MATERIALS AND METHODS

The data reported in this study were collected from 176 Angus calves dropped during the 1957, 1958, and 1959 spring calving seasons in the Federal Reformatory herd and fed at the Fort Reno Livestock Research Station near El Reno, Oklahoma. The cattle evaluated in this study were sired by 24 different Angus bulls. These bulls were mated to unrelated groups of cows which were comparable in ages, weights, and records of prior production. Sixteen of the sire groups were by bulls from Line 1 of Project 670. These bulls were closely related (half-sibs or better) and are designated by three digit numbers in all tables.

Calves were dropped from February through May and were creep fed while nursing their dams until they were weaned in early October.

The distribution of feed-lot data of the 176 calves is given by sire and sex in Tables IIa and IIb. Sire progeny were approximately the same average age. In 1957 and 1958 calves were self fed in sire groups of four to six per lot, while in 1959 they were self fed in two large lots, each containing 30 steers with equal numbers of calves by each sire in each lot. A complete mixed ration containing 350 lbs. ground whole ear corn, 200 lbs. cottonseed hulls, 100 lbs. chopped alfalfa hay, 100 lbs. whole oats, 100 lbs.

TABLE IIa

FEED-LOT DATA OF 23 SIRE PROGENY GROUPS OF STEERS

			Feed-Lot Data		
Year	Sire	No.	A. D. G. (lbs.)	Sl. Age (days)	Final Wt. (lbs.)
1957	2	6	2.10	396	865
	7	6	2.30	358	839
	15	6	1.89	398	815
	17	6	2.32	362	885
	005	4	2.46	379	919
	114	7	2.21	403	920
	264	10	2.38	392	970
Mean			2.23	385	894
St. Dev.			.25	21	78
1958	6	5	2.25	399	883
	7	5	2.21	392	881
	115	5	2.20	392	934
	155	5	2.04	404	882
	175	5	2.06	387	828
	185	4	2.23	366	829
Mean			2.16	391	874
St. Dev.			.17	17	61
1959	6	5	2.59	397	935
	21	7	2.23	389	826
	046	6	2.25	390	829
	066	3	2.41	390	835
	096	6	2.53	389	906
	196	7	2.52	382	957
	264	7	2.62	376	925
	406	4	2.25	398	824
	426	8	2.62	380	911
	436	6	2.53	380	928
Mean			2.46	386	890
St. Dev.			.24	16	78

TABLE IIb

FEED-LOT DATA OF NINE SIRE PROGENY GROUPS OF HEIFERS

			Feed-Lot Data		
Year	Sire	No.	A. D. G. (lbs.)	Sl. Age (days)	Final Wt. (lbs.)
1957	005	6	2.13	366	787
	114	5	1.98	404	813
	264	4	2.16	395	906
Mean			2.08	386	828
St. Dev.			.15	24	70
1958	6	4	2.15	383	811
	005	5	1.79	367	750
	115	5	1.81	394	836
	155	5	1.85	381	783
	175	5	1.81	397	792
	185	4	1.90	400	826
Mean			1.88	386	794
St. Dev.			.27	19	61

wheat bran, 100 lbs. cottonseed oil meal, and 50 lbs. blackstrap molasses was fed. At the termination of the test, which lasted for approximately 171 days, a final weight was obtained following a 20 hour shrink. From this final shrunk weight, average daily gain and dressing percentage were calculated. Measurements and scores were taken in triplicate for the 1958 and 1959 calves and the averages were used in the analyses. The distribution of live animal measurements and scores is presented in Tables IIIa and IIIb.

The cattle were slaughtered at Oklahoma City and the carcasses were weighed, graded, measured, and separated into the various wholesale cuts 48 hours after slaughter. The carcasses were scored to the nearest one-third of a grade for conformation, marbling, and carcass grade. The length and circumference of forearm were taken. The loin eye area, fat thickness, and fat area were obtained at the 12th rib on the right side of all carcasses. Fat thickness and fat area were determined by methods reported by Malkus _et_ _al_. (1961). The carcass measurements and scores are summarized by year, sire, and sex in Tables IVa and IVb.

Weights of the wholesale cuts were obtained from both sides of each carcass. In 1957 the chuck and shank were left together whereas they were separated in 1958 and 1959. The round was weighed with the rump on and was cut the same each year. Tables Va and Vb summarize the carcass cutout by year, sire, and sex.

TABLE IIIa

LIVE ANIMAL MEASUREMENTS AND SCORES OF 16 SIRE PROGENY GROUPS OF STEERS

			Measurements[1]									Scores[2]		
Year	Sire	No.	Wither Height	Chest Depth	Shoulder Width	Loin Width	Thigh Width	Rump Ln.	Forearm Ln.	Forearm Circ.	Can. Circ.	Muscle	Gr.	Bone
1958	6	5	43.3	25.8	19.2	13.2	18.9	17.7	10.8	13.6	6.9	11.4	10.2	11.2
	7	5	43.0	25.3	19.6	12.9	19.4	17.6	10.5	14.3	7.0	12.2	11.0	12.2
	115	5	44.3	25.0	19.4	13.1	19.4	18.0	11.2	14.3	7.1	12.2	10.8	12.8
	155	5	43.2	25.0	18.7	12.7	18.1	17.7	10.7	13.6	6.9	11.4	10.6	10.8
	175	5	42.7	24.7	18.4	12.6	17.7	17.5	10.4	12.9	6.6	11.6	10.0	10.8
	185	4	42.3	24.1	18.5	12.8	18.4	17.3	10.8	13.6	6.8	10.5	10.0	9.5
Mean			43.2	25.0	19.0	12.9	18.6	17.6	10.7	13.7	6.9	11.6	10.4	11.2
St. Dev.			1.0	.7	.8	.5	.9	.6	.4	.6	.2	1.2	.7	1.6
1959	6	5	43.3	25.9	19.3	13.2	18.9	17.7	10.8	13.6	6.9	12.0	11.6	11.2
	21	7	42.3	24.5	18.9	12.9	17.7	17.8	10.6	13.7	6.7	10.8	10.3	9.1
	046	6	41.8	24.5	19.1	13.3	18.5	17.3	10.9	13.5	6.8	11.5	10.7	9.5
	066	3	42.6	24.9	19.5	12.7	18.3	17.8	10.9	13.2	6.7	10.7	10.0	10.0
	096	6	43.5	25.6	18.8	12.9	18.7	18.2	11.1	14.0	7.0	11.7	11.0	10.7
	196	7	42.7	25.3	19.9	13.0	18.9	18.2	11.2	13.8	6.8	12.3	11.1	10.6
	264	7	43.9	25.5	19.5	13.4	19.0	18.2	11.5	13.8	6.9	11.0	10.3	9.6
	406	4	41.9	24.3	19.4	12.9	18.4	17.3	10.8	13.5	6.6	12.2	11.7	9.7
	426	8	43.2	25.6	19.4	13.0	18.8	18.4	11.1	13.9	7.1	11.0	10.2	10.7
	436	6	44.1	25.1	19.6	13.2	18.8	18.1	11.3	14.0	7.0	11.8	10.8	11.2
Mean			43.0	25.1	19.3	13.0	18.6	18.0	11.0	13.8	6.9	11.4	10.7	10.2
St. Dev.			1.4	.8	.7	.5	.8	.6	.4	.4	.3	1.3	1.2	1.4

[1] Inches

[2] Scores: Choice+, 12; Choice, 11; Choice-, 10; Good+, 9.

TABLE IIIb

LIVE ANIMAL MEASUREMENTS AND SCORES OF SIX-SIRE PROGENY GROUPS OF HEIFERS

			Measurements[1]									Scores[2]		
			Wither	Chest	Shoulder	Loin	Thigh	Rump	Forearm		Can.			
Year	Sire	No.	Height	Depth	Width	Width	Width	Ln.	Ln.	Circ.	Circ.	Muscle	Gr.	Bone
1958	6	4	40.9	24.5	18.6	13.3	18.0	17.3	10.1	13.2	6.5	13.0	12.0	12.0
	005	5	40.2	23.5	18.0	12.9	17.5	17.0	10.1	13.0	6.2	11.4	10.4	10.4
	115	5	43.1	24.1	17.8	11.6	18.8	16.9	10.2	13.6	6.7	12.8	11.4	11.6
	155	5	42.3	23.7	18.0	12.4	17.8	17.1	10.3	13.2	6.3	11.2	10.2	10.2
	175	5	41.0	23.6	17.8	12.6	17.8	16.9	10.2	13.4	6.2	11.6	11.0	10.4
	185	4	41.1	23.9	18.4	13.3	17.9	17.3	10.1	13.1	6.4	13.0	11.8	11.8
Mean			41.4	23.8	18.0	12.6	17.9	17.0	10.1	13.1	6.4	12.1	11.1	11.0
St. Dev.			1.4	.6	1.0	1.2	.7	.5	.4	.6	.4	1.3	1.0	1.1

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[1] Inches

[2] Scores: Choice+, 12; Choice, 11; Choice-, 10; Good+, 9 .

TABLE IVa

CARCASS MEASUREMENTS AND SCORES OF 23 SIRE PROGENY GROUPS OF STEERS

			Chilled				Measurements[2]			
			Wt.	Yield	Scores[1]		Loin	Fat	Forearm	
Year	Sire	No.	(lbs.)	(%)	Conf.	Gr.	Area	Thick.	Ln.	Circ.
1957	2	6	532	61.5	10.8	9.8	10.6	.79		
	7	6	514	61.2	11.3	9.6	10.7	.80		
	15	6	490	60.2	10.0	9.7	10.4	.69		
	17	6	529	59.8	11.6	9.2	11.0	.75		
	005	4	560	60.9	12.0	10.2	10.9	.72		
	114	7	563	61.2	11.4	10.0	11.5	.85		
	264	10	593	61.4	11.6	11.2	11.6	.90		
Mean			546	61.0	11.2	10.0	11.0	.80		
St. Dev.			52	1.3	1.2	1.0	1.0	.14		
1958	6	5	558	63.2	9.8	9.8	10.8	.84	10.8	12.8
	7	5	570	64.7	11.8	10.0	11.7	.95	10.3	13.2
	115	5	617	66.1	11.6	11.0	12.0	.91	10.8	12.8
	155	5	566	64.1	10.8	10.2	10.9	.85	10.6	13.6
	175	5	521	62.9	10.2	11.4	10.4	1.13	10.4	12.2
	185	4	527	63.6	10.7	9.8	11.4	.73	10.3	12.3
Mean			560	64.0	10.8	10.4	11.2	.90	10.6	13.0
St. Dev.			46	1.4	1.0	1.0	.8	.17	.4	.8
1959	6	5	594	63.5	11.2	10.4	9.8	.98	10.6	13.3
	21	7	537	64.8	11.7	11.8	10.3	.91	10.2	12.8
	046	6	521	62.8	11.2	11.7	9.8	.96	10.0	13.0
	066	3	536	64.2	11.7	12.3	10.6	.84	10.2	12.9
	096	6	573	63.2	10.8	10.8	10.1	.91	10.5	13.0
	196	7	601	62.8	11.4	10.4	11.7	.89	10.5	13.3
	264	7	592	64.0	10.8	11.1	11.1	.96	10.6	13.4
	406	4	532	64.6	11.0	11.0	9.3	.91	10.1	12.8
	426	8	586	64.3	10.9	10.6	10.8	.84	10.5	13.2
	436	6	586	63.1	11.3	10.2	11.8	.82	10.7	13.5
Mean			569	63.9	11.2	11.0	10.6	.90	10.4	13.1
St. Dev.			52	1.4	1.0	1.1	1.1	.17	.4	.4

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[1] Scores: Choice+, 12; Choice, 11; Choice-, 10; Good+, 9.

[2] Loin Area in Sq. In.; Other Traits in Inches.

TABLE IVb

CARCASS MEASUREMENTS AND SCORES OF NINE SIRE PROGENY GROUPS OF HEIFERS

			Chilled		Scores[1]		Measurements[2]			
			Wt.	Yield			Loin	Fat	Forearm	
Year	Sire	No.	(lbs.)	(%)	Conf.	Gr.	Area	Thick.	Ln.	Circ.
1957	005	6	477	60.7	8.8	9.5	10.0	.70		
	114	5	491	60.4	10.0	10.0	10.3	.84		
	264	4	562	62.2	10.0	11.0	11.8	.80		
Mean			504	60.9	9.5	10.1	10.6	.78		
St. Dev.			48	1.2	1.1	1.2	1.0	.14		
1958	6	4	519	63.9	10.4	9.6	11.2	.82	10.1	12.5
	005	5	488	65.1	10.0	10.0	9.6	.89	10.0	12.0
	115	5	545	65.2	10.8	10.0	11.1	.78	10.4	13.0
	155	5	504	64.4	10.2	8.6	10.5	.99	10.6	12.2
	175	5	506	63.9	9.4	9.0	9.8	1.09	10.0	12.6
	185	4	525	63.6	10.7	10.8	10.4	1.01	9.8	12.4
Mean			514	64.3	10.2	9.6	10.4	.94	10.2	12.4
St. Dev.			43	1.4	1.4	1.2	1.2	.16	.4	.6

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[1] Scores: Choice+, 12; Choice, 11; Choice-, 10; Good+, 9.

[2] Loin Area in Sq. In.; Other Traits in Inches

TABLE Va

YIELDS OF MAJOR WHOLESALE CUTS FROM 23 SIRE PROGENY GROUPS OF STEERS

			Percent Cold Carcass Weight				
Year	Sire	No.	Round	Chuck	Loin	Rib	W.S.C.[1]
1957[2]	2	6	21.4	28.1	17.5	9.4	76.4
	7	6	22.6	28.0	17.2	9.2	77.0
	15	6	21.5	29.0	17.5	9.1	77.2
	17	6	22.2	27.7	18.0	9.5	77.3
	005	4	22.2	28.6	17.4	9.2	77.4
	114	7	22.0	28.6	17.8	9.4	77.8
	264	10	22.1	28.3	17.2	9.1	76.7
Mean			22.0	28.2	17.4	9.2	76.9
St. Dev.			.8	.8	.4	.4	1.0
1958	6	5	20.6	25.3	17.2	9.8	72.9
	7	5	22.5	24.6	17.8	9.8	74.6
	115	5	21.1	25.2	17.1	9.6	73.0
	155	5	21.3	25.0	16.8	9.8	72.9
	175	5	21.0	24.8	17.2	10.6	73.6
	185	4	22.0	25.5	17.3	9.6	74.4
Mean			21.6	25.1	17.1	9.8	73.8
St. Dev.			.8	.6	.5	.4	1.0
1959	6	5	21.6	24.9	17.0	10.0	73.5
	21	7	22.0	25.1	17.9	10.8	75.7
	046	6	22.4	25.4	17.6	10.4	75.8
	066	3	21.6	25.6	17.6	10.0	74.8
	096	6	21.8	25.4	17.7	10.3	75.4
	196	7	22.1	25.3	17.4	10.4	75.1
	264	7	21.9	25.6	17.5	10.1	75.1
	406	4	22.1	25.4	17.3	10.4	75.3
	426	8	22.2	25.5	16.9	10.2	74.7
	436	6	22.2	26.4	17.6	10.2	76.6
Mean			22.0	25.4	17.4	10.2	75.2
St. Dev.			.7	.6	.6	.5	1.2

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[1] Sum of Four Major Cuts, Namely: Round, Chuck, Loin, and Rib.

[2] Chuck Was Weighed with the Shank in 1957.

TABLE Vb

YIELDS OF MAJOR WHOLESALE CUTS FROM NINE SIRE PROGENY GROUPS OF HEIFERS

			Percent Cold Carcass Weight				
Year	Sire	No.	Round	Chuck	Loin	Rib	W.S.C.[1]
1957[2]	005	6	21.8	27.7	17.5	9.6	76.6
	114	5	21.3	26.9	17.8	9.8	75.8
	264	4	21.5	26.8	17.8	9.8	75.9
Mean			21.5	27.2	17.7	9.6	76.1
St. Dev.			.6	.7	.6	.4	1.1
1958	6	4	21.6	23.4	17.3	9.6	71.9
	005	5	21.3	24.7	17.4	10.0	73.4
	115	5	21.6	24.7	17.5	9.5	73.3
	155	5	21.4	25.2	17.4	10.0	74.0
	175	5	21.5	24.2	17.4	10.3	73.4
	185	4	21.1	23.4	18.1	10.0	72.6
Mean			21.4	24.5	17.5	9.9	73.4
St. Dev.			.6	.8	.5	.4	1.4

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[1] Sum of Four Major Cuts, Namely: Round, Chuck, Loin, and Rib.

[2] Chuck Was Weighed with the Shank in 1957.

The wholesale ribs from both sides of each carcass were used for detailed studies of tenderness, chemical composition, and tissue separation. During the first two years of this study, the 9-10-11th rib sections from both sides of each carcass were separated into fat, lean, and bone; in the third year only the 10-11th rib sections were used for this purpose. The rib sections were cut according to procedures recommended by Hankins and Howe (1946). The longissimus dorsi muscle from the 9-10-11th rib sections was sampled for chemical determination of moisture, protein, ash, and ether extract. Duplicate analyses were run on each side of each carcass. The data for carcass composition by sire progeny groups is presented in Tables VIa and VIb.

In 1957 the 12th rib steaks from both sides of the carcasses were broiled for the tenderness shear study. In the succeeding year the 8th and 12th rib steaks were broiled on the right side and deep fat cooked on the left side; in 1959 the 8th, 9th, and 12th rib steaks from both sides were deep fat fried. In 1957 a trained taste panel scored the eighth rib steaks for tenderness, flavor, juiciness, and number of chews required before swallowing. The higher scores indicated superiority in the first three traits evaluated. In 1958 only the number of chews and tenderness scores were obtained on the seventh rib steaks by a trained taste panel. Tables VIIa and VIIb summarize the distribution of these carcass quality traits.

Although all steaks were removed from 0°F. storage and warmed to a constant temperature (48°F.) during a 48 hour

TABLE VIa

PHYSICAL AND CHEMICAL COMPOSITION OF 9-10-11th RIB SECTION FROM 23 SIRE PROGENY GROUPS OF STEERS

			Physical Comp. (%)			Chemical Comp. (%)			
Year	Sire	No.	Lean	Fat	Bone	Protein	Fat	Water	Ash
1957	2	6	44.8	42.0	13.1	20.7	6.9	70.6	1.12
	7	6	45.7	41.1	13.2	21.2	5.4	71.3	1.07
	15	6	47.8	39.0	13.3	21.1	6.0	71.0	1.10
	17	6	46.0	40.9	13.2	21.2	5.3	71.7	1.03
	005	4	47.4	38.7	14.0	20.9	7.3	70.7	1.10
	114	7	44.6	42.5	12.8	21.2	6.2	70.8	1.11
	264	10	45.7	41.5	12.8	20.9	8.1	69.4	1.01
Mean			45.8	41.0	13.2	21.0	6.6	70.6	1.09
St. Dev.			2.7	3.1	1.0	.6	1.9	1.4	.10
1958	6	5	45.7	43.2	11.9	20.8	6.4	70.3	1.04
	7	5	47.0	40.6	12.4	20.9	5.2	72.2	1.04
	115	5	46.3	41.0	11.6	20.9	7.1	68.7	1.04
	155	5	45.8	42.6	11.6	21.0	5.2	71.1	1.06
	175	5	43.8	45.0	11.3	20.6	8.0	69.2	1.00
	185	4	48.7	39.2	12.1	21.3	4.8	70.9	1.10
Mean			46.1	42.1	11.8	20.9	6.2	70.4	1.04
St. Dev.			2.4	3.0	.9	.4	1.5	1.8	.06
1959[1]	6	5	40.3	47.2	12.5	21.3	5.2	71.8	1.02
	21	7	42.0	46.7	11.3	20.3	7.3	70.6	1.06
	046	6	42.8	45.1	12.0	21.0	6.2	71.0	1.02
	066	3	44.2	43.7	12.1	20.6	7.8	70.8	1.02
	096	6	44.2	46.5	12.5	21.4	5.2	72.0	1.04
	196	7	42.7	46.1	11.2	21.5	5.3	71.2	1.02
	264	7	44.6	44.1	11.5	21.0	6.3	71.0	1.02
	406	4	42.0	47.0	11.0	21.0	6.0	71.5	.87
	426	8	43.1	44.5	12.4	20.7	7.1	70.6	1.02
	436	6	45.4	42.4	12.2	21.0	5.1	71.5	1.04
Mean			43.2	45.3	11.8	21.0	6.2	71.2	1.05
St. Dev.			3.4	4.1	1.0	.6	1.8	1.4	.04

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[1] 1959 Data Was Collected on the 10-11th Rib Section.

TABLE VI-b

PHYSICAL AND CHEMICAL COMPOSITION OF 9-10-11th RIB SECTION FROM NINE SIRE PROGENY GROUPS OF HEIFERS

			Physical Comp. (%)			Chemical Comp. (%)			
Year	Sire	No.	Lean	Fat	Bone	Protein	Fat	Water	Ash
1957	005	6	46.2	40.0	13.8	21.5	6.1	70.4	1.12
	114	5	44.8	43.1	12.1	20.7	7.1	69.9	1.06
	264	4	44.3	43.7	12.0	20.6	7.6	70.0	1.09
Mean			45.2	42.0	12.8	21.1	6.7	70.2	1.08
St. Dev.			2.4	3.0	5.0	.8	1.5	1.2	.04
1958	6	4	45.1	43.5	11.4	21.5	6.6	69.8	1.16
	005	5	45.1	44.4	10.6	20.9	6.7	70.2	1.12
	115	5	47.6	40.3	12.2	20.8	6.4	70.8	1.06
	155	5	44.4	44.1	11.5	20.5	8.0	69.7	1.02
	175	5	42.6	46.4	11.0	20.8	7.3	69.8	1.00
	185	4	42.5	46.3	11.2	20.8	8.4	68.9	1.02
Mean			44.6	44.0	11.3	20.8	7.2	69.8	1.06
St. Dev.			3.6	3.9	.8	.4	1.3	1.1	.12

TABLE VIIa

SOME TRAITS ASSOCIATED WITH CARCASS QUALITY OF 23 SIRE PROGENY GROUPS OF STEERS

			Ave. Shear Value (lbs.)			Taste Panel Scores[1]			
Year	Sire	No.	12th	8th	9th	No. Chews	Tend.	Flavor	Juic.
1957	2	6	12.5			29.8	7.12	7.02	7.16
	7	6	13.0			29.0	7.20	7.10	7.20
	15	6	11.5			27.6	7.15	7.10	7.28
	17	6	13.6			27.1	7.63	7.20	7.30
	005	4	13.0			27.8	7.65	7.45	7.50
	114	7	16.0			29.6	7.02	7.18	7.10
	264	10	12.4			26.6	7.83	7.40	7.69
Mean			13.1			28.1	7.39	7.21	7.34
St. Dev.			2.4			3.8	.72	.39	.51
1958	6	5	13.9	16.3		23.7	6.20		
	7	5	13.5	16.8		25.8	6.00		
	115	5	13.8	16.6		23.8	6.32		
	155	5	14.0	16.0		23.4	6.08		
	175	5	14.2	14.4		20.8	6.90		
	185	4	15.4	16.2		24.5	6.08		
Mean			14.1	16.0		23.6	6.26		
St. Dev.			2.0	1.6		2.2	.56		
1959	6	5	17.7	19.4	19.9				
	21	7	20.8	21.6	21.4				
	046	6	19.8	20.7	22.1				
	066	3	16.9	17.2	19.2				
	096	6	21.6	20.2	21.0				
	196	7	15.6	16.4	18.2				
	264	7	17.2	17.2	17.3				
	406	4	17.1	18.0	19.0				
	426	8	18.5	16.2	16.8				
	436	6	16.0	17.2	17.7				
Mean			18.2	18.4	19.2				
St. Dev.			3.4	3.4	3.0				

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[1] Tenderness, Flavor, and Juiciness Scores Rise with Increased Desirability.

TABLE VIIb

SOME TRAITS ASSOCIATED WITH CARCASS QUALITY OF NINE SIRE PROGENY GROUPS OF HEIFERS

			Ave. Shear Value (lbs.)			Taste Panel Scores[1]			
Year	Sire	No.	12th	8th	9th	No. Chews	Tend.	Flavor	Juic.
1957	005	6	12.0			26.4	7.56	7.26	7.62
	114	5	14.4			27.6	7.40	7.36	7.34
	264	4	12.7			27.8	7.70	7.31	7.52
Mean			13.0			27.1	7.54	7.30	7.50
St. Dev.			2.2			4.1	.76	.46	.54
1958	6	4	13.4	15.9		24.4	6.08		
	005	5	12.2	14.8		23.7	6.14		
	115	5	14.7	17.3		24.7	6.24		
	155	5	12.9	15.4		23.8	6.54		
	175	5	15.2	18.0		24.7	5.90		
	185	4	12.6	15.4		22.7	6.78		
Mean			13.6	16.2		24.0	6.26		
St. Dev.			1.8	2.2		1.8	.52		

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[1] Tenderness, Flavor, and Juiciness Scores Rise with Increased Desirability.

period prior to cooking, the cooking technique was changed during the course of the experiment. In 1957 the 12th rib steaks from both sides of the carcass were broiled and tenderness was estimated by the use of the Warner-Bratzler shearing device. The two inch thick rib steaks were browned on one side until the internal temperature reached 90°F. and then turned and broiled to an interior temperature of 155°F. Two one inch cores, with three shears per core, were analyzed per steak. Although in 1958 the steaks on the left side were deep fat fried, the broiling technique of the steaks on the right side was the same as in 1957.

Since there appeared to be great variation between steak doneness by deep fat cookery, this technique was still further modified in 1959. Individual baskets were made so that four rib steaks could be cooked simultaneously. These wire baskets were constructed so that thermometers could be inserted and kept in the center of each steak. Four steaks were removed from a 34°F. cooler just prior to cooking and were inserted individually into the baskets which were numbered by cooking position in the frier. Steaks were placed into the fat simultaneously and cooked for approximately 20 minutes or until the thermometers in the steaks would register an internal temperature of 150°F. The steaks were then removed from the deep fat frier and placed on plates in the same order as the frier cooking positions. They were then sheared in the same order; therefore, position of frier and sequence of shearing were confounded.

The center of each core was scored for doneness. A score of one was rare and four was considered well done.

Instead of obtaining taste panel evaluation in 1959, the seventh rib steaks were sheared without cooking. Each steak was thawed to a uniform temperature of 34°F. The uncooked steaks were sheared in the same cooler where they had been thawed.

Simple correlations, means, and standard deviations were calculated on the I.B.M. 650 by the use of the Beaton Correlation Routine. The output from this program was used to compute the multiple regression equations, betas $\left[b_{YX_1 \cdot X_2 \ldots X_n}\left(\frac{\sigma_{X_1}}{\sigma_Y}\right)\right]$, and standard errors of the betas with the Granet Multiple Regression Routine. Through the use of the Beaton Package Deck Routine, intra-year multiple correlation ($R_{Y \cdot X_1 X_2 \ldots X_n}$) and partial regression ($b_{YX_1 \cdot X_2 X_3 \ldots X_n}$) coefficients were computed by pooling the within year corrected sums of squares and cross products and inverting this matrix.

By the use of the Granet Correlation Routine, the intra-year simple correlation matrix was computed from the pooled sums of squares and cross products matrix. By inverting the correlation matrix, which has the dependent variable as the left hand member, it was possible to use the element a_{11} of the inverted correlation matrix (A) and calculate the multiple correlation coefficient (R) and the standard error of the estimate. The formula for the multiple R is

$\sqrt{1-\frac{1}{a_{11}}}$. The standard error of the estimate is $\sqrt{\left(\frac{N}{N-M}\right)\left(\frac{\sigma_i^2}{a_{11}}\right)}$ where σ_i^2 is the variance for the dependent variable, N is the total number of observations, and M is the total number of variables.

In order to find the major independent variables affecting the dependent variable, a "t" test was applied to the standard partial regression coefficients.

To facilitate the computation of the intra-year, intra-sex, paternal half-sib heritability estimates, the Pulley Hierarchical Analysis of Variance Program was used to calculate the variance components. The Doolittle Method was used to hold carcass weight constant for estimating heritability of loin eye area. Standard errors of these paternal half-sib heritability estimates were calculated according to the method described by Hazel and Terrill (1945).

In order to compute the sources of variation in tenderness, it was necessary to find the expected mean squares. The three rules suggested by Schultz (1955) were followed to find the expected mean squares of the mixed effect model with cross and hierarchical classification (Appendix A). The number of animals per sire and number of observations required to sample animals were computed according to procedures outlined by Cochran and Cox (1957).

RESULTS AND DISCUSSION

This section is reported in three parts. In the first part, heritabilities for certain live animal and carcass traits were estimated. In the second section, the various live animal and carcass measurements were used to predict carcass composition. In the third part, some factors which affect the tenderness of beef were investigated.

Heritability Estimates

In order to plan a selection program, some indication of the heritabilities of the traits to be improved is needed. Table VIII gives the heritability estimates of various live animal and carcass traits. The estimates were based on paternal half-sib, intra-class correlations involving 176 animals by 24 sires. These estimates are in the range of those reported by others which were shown in Table I.

Growth and size measurements, such as average daily gain and slaughter weight, yielded very high intra-class correlations between paternal half-sibs (.25 and .22, respectively). These high intra-class correlations can be explained by examining the distribution of the data as shown in Tables IIa and IIb. The range between sire progeny groups of steers for average daily gain was from 1.89 to 2.62 pounds. Slaughter weight varied from 815 to 970 pounds.

TABLE VIII

INTRA-YEAR, INTRA-SEX HERITABILITY ESTIMATES OF LIVE ANIMAL AND CARCASS TRAITS BASED ON PATERNAL HALF-SIB INTRA-CLASS CORRELATIONS

Economic Characteristics	Heritability (%)	Standard Error (%)
Live Animal Traits		
Slaughter Weight	100	32
Average Daily Gain	88	32
Dressing Percentage	74	30
Slaughter Grade	49	26
Carcass Traits		
Carcass Weight	96	32
Carcass Grade	78	30
Fat Thickness Over Loin Eye	38	26
Carcass Conformation	29	23
Live Weight Basis		
Percent Round	46	26
Percent Chuck	60	28
Percent Loin	46	26
Percent Rib	30	24
Percent Major Wholesale Cuts	56	28
Percent in Rib Section		
Lean	30	24
Fat	31	24
Bone	41	25
Loin Eye Area		
Unadjusted for Carcass Weight	108	32
Carcass Weight Constant	76	30
Tenderness Shear Value	68	28

This variation among sire progeny groups would tend to give high heritability estimates of average daily gain and those traits associated with weight.

Dressing percentage and carcass grade yielded high heritability estimates of .74 and .78, respectively. The distribution tables in the Materials and Methods section show that those bulls which sired slow gaining calves also sired earlier maturing and fatter calves at time of slaughter. The greatest range among sire progeny groups within any year for dressing percentage was about three percent. Carcass grade varied about a full grade among sire progeny groups. This variability could partially explain the high heritabilities obtained in this study.

Percentage of lean, fat, and bone in the rib sections gave moderate heritability estimates with relatively large standard errors (.30 ± .24, .31 ± .31, and .41 ± .25, respectively). The heritability estimates for percentages of major wholesale cuts, round, chuck, loin, and rib were moderate to high (.56, .46, .60, .46, and .30, respectively).

The heritability estimate for loin eye area, uncorrected for carcass weight, was 1.08 with a standard error of .32. Since nearly 25 percent of the variation in loin eye area was associated with carcass weight (Appendix B, Tables XXIX and XXX), the heritability of loin eye area was calculated holding carcass weight constant. This yielded a heritability estimate and a standard error of .76 ± .30 which is comparable to estimates reported in the literature.

Summary of Heritability Estimates

Heritability estimates were based on paternal half-sib, intra-class correlations involving 176 animals from 24 sires. Heritability estimates for live animal traits of slaughter weight, average daily gain, and dressing percentage were 1.00, .88, and .74, respectively. Percentages of round, chuck, loin, rib, and major wholesale cuts gave moderate to high heritabilities (.46, .60, .46, .30, and .56, respectively). Percent lean, fat, and bone in the rib section yielded moderate heritabilities of .30, .31, and .41, respectively. Loin eye area, adjusted for carcass weight, gave a heritability estimate and standard error of .76 ± .30.

Carcass and live animal measurements in this study had relatively high heritabilities which indicated that progress could be expected from selection.

Prediction of Carcass Composition

Since the heritability estimates for percentages of round, major wholesale cuts, lean in the rib section, and fat in the rib section are moderate to high, selection could be effective in this population. However, selection would have to be based upon a progeny or a sib test because the information on carcass composition requires the slaughter of the individual.

If live animal or carcass measurements could be used to predict carcass composition, the beef producer could place more emphasis on these measurements in his selection program because they may be more readily obtained.

Since complete physical separation of the whole carcass into lean, fat, and bone is expensive and time consuming, it was not done in this study. A review of the literature revealed that percent round and composition of the 9-10-11th rib section are indicators of carcass composition (Hankins and Howe, 1946; Orme, 1959; Cole et al., 1960; and Crown and Damon, 1960). The four major wholesale cuts (round, chuck, loin, and rib) are of greatest economic importance, since they comprise about 75 percent of the carcass weight and about 90 percent of the value of the carcass. Therefore, the best indicators of carcass composition in these data were percent lean in the rib section, percent fat in the rib section, percent round, and percent major wholesale cuts.

Phenotypic Correlations Between Live Animal and Carcass Traits:

Intra-year simple correlations were obtained between various live animal measurements and indicators of carcass composition. The simple correlations between various live animal measurements in this study were in general agreement with those reported in the literature. Skeletal measurements, such as length of rump, height of withers, and depth of chest, were significantly correlated with slaughter weight (.69, .64, and .76, respectively) as shown in Table XXIII of Appendix B.

Average daily gain was positively associated with width of thighs (.52), circumference of forearm (.45), length of rump (.47), and length of forearm (.56). These relationships indicated that animals with greater skeletal size and muscle development had higher average daily gains and heavier slaughter weights.

Simple correlations(Appendix B, Table XXIV) indicated that live animal measurements were not significantly associated with percent major wholesale cuts and were of little predictive value in this study. Nevertheless, steers which were heavier, deeper in their chest, and higher in grade yielded a lower percentage of the four major wholesale cuts.

Skeletal measurements of the live animal, such as length of rump, depth of chest, and length of forearm, were more closely associated with percent fat (.13, .24, and -.19, respectively) and percent lean (-.20, -.26, and .20, respectively) than were width measurements (Appendix B, Table XXIV). Slower gaining steers which were wider across their loin and deeper in their chest had a greater percentage of fat in the rib section. Black <u>et al</u>. (1938) also found depth of chest and width of loin to be indicators of body finish.

Percent round on a live weight basis was positively associated with circumference of forearm (.36), width of shoulder (.20), and width of thigh (.20) but negatively related to depth of chest (-.18). Percent round was not significantly correlated with average daily gain (.06).

Intra-year simple correlations were also obtained between various carcass measurements and carcass composition. Loin eye area was significantly correlated with percent major wholesale cuts (.29), percent round (.29), percent lean in the rib section (.48), and percent fat in the rib section (-.44) as shown in Table XXV of Appendix B. This is in general agreement with Cole _et al_. (1960) who reported a coefficient of determination of .19 between loin eye area and total separable lean in the carcass.

Both fat thickness and fat area over the loin eye were negatively associated with percent lean in the rib section (-.50). Although the correlation between percent round and fat area (-.22) was smaller than with fat thickness (-.31), percent fat in the rib section was more closely associated with fat area (.62) than fat thickness (.55) over the loin eye. Carcass conformation score was significantly correlated with percent major wholesale cuts (.29) and percent round (.35), while carcass grade was significantly correlated with percent lean (-.30) and percent fat (.32) in the rib section. Circumference of carcass forearm was associated with percent round (.31) but not significantly correlated with the other dependent variables (percent major wholesale cuts, percent lean in the rib section, and percent fat in the rib section). The most important carcass measurements influencing percent round were loin eye area, conformation score, circumference of forearm, and fat thickness over the loin eye.

Intra-year simple correlations between various carcass measurements are shown in Table XXVI of Appendix B. Carcass grade was negatively related to loin eye area (-.16), length of forearm (-.28), circumference of forearm (-.20), and carcass weight (-.22) but positively associated with fat thickness (.21) and fat area (.20) over the loin eye. These associations indicated that lower grading carcasses, which had a high ratio of loin eye area to fat thickness over the loin eye, yielded a greater percentage of lean.

Intra-year simple correlations between carcass and live animal measurements are presented in Table XXVII of Appendix B. Slaughter and carcass grades were not significantly correlated (.01). Similar results have been reported by Wheat and Holland (1960). Muscle score of the live animal was positively associated with loin area (.19) and carcass conformation (.43). Interestingly, all live animal scores and measurements were significantly correlated with circumference of carcass forearm.

Visual live animal scores for slaughter grade and muscling were not highly associated with any of the four major wholesale cuts on a carcass weight basis (Appendix B, Table XXVIII). However, carcass conformation was positively correlated with percent round (.18) and percent loin (.29), while carcass grade was positively correlated with percent rib (.25). Percent fat in the rib section was negatively correlated with percent round (-.45) and percent chuck (-.27) but positively associated with percentages of loin (.02), rib (.26), flank (.34), plate (.12), and brisket (.18) as shown in Table XXVIII of Appendix B. Even though these correlations were small, one can conclude that as an animal fattens, a greater proportion of fat is deposited in the rib, loin, flank, plate, and brisket than in the round and chuck.

In support of these observations, Butler (1957), Pierce (1957), and Goll <u>et al</u>. (1960a) stated that higher carcass grades were associated with larger yields of loin, rib, flank, plate, and brisket.

All 133 steers in this study were combined to obtain the intra-year phenotypic correlations found in Table XXIX of Appendix B. Some of the live animal and carcass measurements were not obtained in 1957 and 1958; therefore, they were not included in these tables.

Loin eye area accounted for 9 to 16 percent of the variation in the dependent variables and was probably the best over-all indicator of carcass composition. Fat thickness over the loin eye explained nearly 25 percent of the variation in percent fat or lean in the rib section. Carcass and slaughter grades were significantly correlated with percent major wholesale cuts (.27) and percent round (.12) on a live weight basis.

All 43 heifers were combined to obtain the intra-year correlations found in Table XXX, Appendix B. Results were comparable to the findingsobtained from the data for the steers. The heifers were lighter in weight but yielded a higher percentage of loin and rib. Carcass weight was not significantly correlated with any of the dependent variables.

Prediction Equations of Carcass Composition:

Prediction equations were computed using those variables which were more easily obtained and more highly associated with carcass composition. Indicators of carcass composition were regressed on those live animal and carcass measurements which were of economic importance. Regression equations for the prediction of percentages of major wholesale cuts, of lean in the rib section, of fat in the rib section, and of round are shown in Table IX. These equations were calculated using data from the 133 steers while Table X shows similar equations using data from the heifers.

In the first multiple regression equation, percent major wholesale cuts were regressed on seven independent variables. The equation implies that when all independent variables were held constant except slaughter grade (X_1), the higher grading steers yielded a lower percentage of the four major wholesale cuts. Similarly, steers with greater average daily gains (X_2) produced a larger percentage of the four major wholesale cuts. Identical reasoning may be applied to the other partial regression coefficients.

The seven variables --slaughter grade (X_1), average daily gain (X_2), loin eye area (C_1), carcass grade (C_2), carcass conformation (C_3), fat thickness (C_4), and carcass weight (C_5) --accounted for 16 percent of the variance in percentage of major wholesale cuts. When an intra-year multiple correlation (R) was calculated using all carcass and live animal measurements, 38 percent of the total variation in percentage of major wholesale cuts was explained (Table XXXI, Appendix B). Since R^2 was very small, percent major wholesale cuts were not accurately predicted by these

TABLE IX

MULTIPLE REGRESSION EQUATIONS FOR ESTIMATING VARIOUS DEPENDENT VARIABLES ($\hat{Y}_i$) FROM 133 STEERS

No.	Estimating Equation[1]	R^2	Standard Error of Estimate
1	$\hat{Y}_1 = 41.0 - .29X_1 + .24X_2 + .06C_1 + .19C_2 + .32C_3 - .15C_4 + .01C_5$	.16	1.24
2	$\hat{Y}_2 = 53.0 - .37X_1 \underline{\qquad} + 1.54C_1 - .63C_2 \underline{\qquad} - 4.80C_4 \underline{\qquad}$	.50	2.39
3	$\hat{Y}_3 = 28.0 + .56X_1 - .32X_2 - 1.54C_1 + .92C_2 \underline{\qquad} + 7.85C_4 \underline{\qquad}$	.54	2.82
4	$\hat{Y}_4 = 15.9 - .12X_1 - .38X_2 + .20C_1 - .06C_2 + .16C_3 - .72C_4 \underline{\qquad}$	.24	.66

[1] $\hat{Y}_1$ = Predicted % Wholesale Cuts on Live Weight Basis

$\hat{Y}_2$ = Predicted % Lean in the Rib Section

$\hat{Y}_3$ = Predicted % Fat in the Rib Section

$\hat{Y}_4$ = Predicted % Round on Live Weight Basis

X_1 = Slaughter Grade

X_2 = Average Daily Gain

C_1 = Loin Area

C_2 = Carcass Grade

C_3 = Carcass Conformation

C_4 = Fat Thickness Over the Loin Eye

C_5 = Carcass Weight

TABLE X

MULTIPLE REGRESSION EQUATIONS FOR ESTIMATING VARIOUS DEPENDENT VARIABLES ($\hat{Y}_i$) FROM 43 HEIFERS

No.	Estimating Equation[1]	R^2	Standard Error of Estimate
1	$\hat{Y}_1 = 45.6 - .42X_1 - 2.02X_2 + .03C_1 + .04C_2 + .32C_3 + 2.54C_4 + .01C_5$	.38	1.06
2	$\hat{Y}_2 = 51.2 - .89X_1 \underline{\qquad\quad} + 1.00C_1 - .26C_2 \underline{\qquad\quad} - 6.14C_4 \underline{\qquad\quad}$	.50	1.98
3	$\hat{Y}_3 = 33.9 + 1.38X_1 - .97X_2 - 1.05C_1 + .22C_2 \underline{\qquad\quad} + 8.14C_4 \underline{\qquad\quad}$	.58	2.31
4	$\hat{Y}_4 = 16.1 - .40X_1 + .56X_2 + .17C_1 + .10C_2 + .08C_3 - .46C_4 \underline{\qquad\quad}$	.40 ?	.58 ?

[1] $\hat{Y}_1$ = Predicted % Wholesale Cuts on Live Weight Basis

$\hat{Y}_2$ = Predicted % Lean in the Rib Section

$\hat{Y}_3$ = Predicted % Fat in the Rib Section

$\hat{Y}_4$ = Predicted % Round on Live Weight Basis

X_1 = Slaughter Grade

X_2 = Average Daily Gain

C_1 = Loin Area

C_2 = Carcass Grade

C_3 = Carcass Conformation

C_4 = Fat Thickness Over the Loin Eye

C_5 = Carcass Weight

independent variables. Other measurements not obtained in this study could possibly improve this prediction. Since weight of the wholesale cut is the combination of lean, fat, and bone, differences in leanness were masked. If trimmed wholesale cutout had been obtained, greater differences among animals and sire progeny groups would probably have resulted.

Equation 2 in Table IX estimated percent lean in the rib section. The combination of slaughter grade (X_1), loin eye area (C_1), carcass grade (C_2), fat thickness over the loin eye (C_4), and carcass weight (C_5) accounted for 50 percent of the variation in percent lean. The addition of wholesale cutout, average daily gain, and carcass conformation did not appreciably change the multiple correlation as shown in Appendix B, Table XXXII.

Since average daily gain was negatively correlated with percent fat (-.10) but not associated with percent lean (.01) in the rib section, average daily gain was added as an independent variable to predict percent fat in the rib section (equation 3, Table IX). This combination of variables accounted for 54 percent of the variability in percent fat. The maximum R^2 obtained was .58 (Table XXXII, Appendix B). Even though a greater proportion of the total variation was explained in the prediction of percent fat in the rib section, the standard error for percent fat (2.82) was larger than for percent lean (2.39) in the rib section.

The prediction of percent round on a live weight basis for steers is shown in equation 4 of Table IX. A combination of the six most important independent variables -- slaughter grade (X_1), average daily gain (X_2), loin eye area (C_1), carcass grade (C_2), carcass conformation (C_3), and fat thickness over the loin eye (C_4)-- accounted for 24 percent of the variance in percent round. This was only a small proportion of the total variance; however, the standard error of this estimate (.66) was small compared to the other dependent variables. When wholesale cutout was included in the multiple correlation with the above six independent variables, the multiple R increased to .86 (Table XXXIII, Appendix B). Although this is a sizeable increase over the suggested estimating equation in Table IX, the procurement of wholesale cutout would also give percent round.

The multiple regression equations using data for the 43 heifers are shown in Table X. Results obtained from the heifers were comparable to those from the steers. Those variables important for steers were also important in the prediction of the dependent variables for heifers. In general, the partial regression coefficients were similar; however, carcass weight was of lesser importance while average daily gain was a more important variable for heifers than steers. The multiple correlation coefficients were larger and the standard errors of the estimates were smaller for heifers than for steers.

A combination of a small number of independent variables which are easily and economically obtained and will explain most of the variation in the dependent variable is ideal. The equations in Tables IX and X are a step in that direction. In these data the phenotypic variation among animals was small because the animals were similar in breeding and they were self fed the same growing ration for a constant period of time prior to slaughter. This may partially explain the small multiple correlation coefficients obtained from these data.

The regression of the percentage of major untrimmed wholesale cuts (round, chuck, loin, and rib) on other live animal and carcass measurements are presented in Table XI. Equation 1 accounted for only 18 percent of the variation in percent wholesale cuts. This combination of wither height (X_2), depth of chest (X_3), circumference of forearm (X_4), slaughter weight (X_5), loin eye area (C_1), and carcass conformation (C_2) illustrates that these measurements had little predictive value. Equation 2 is similar to equation 1 in Table IX with the substitution of fat area for fat thickness over the loin eye. By this substitution, five percent more of the total variance was explained. The removal of both fat thickness and fat area over the loin eye from the estimating equation reduced R^2 to .16 as shown in equation 3.

The cutability index suggested by Murphey <u>et al</u>. (1960) is based upon variables similar to those in equation 5. The

TABLE XI

MULTIPLE REGRESSION EQUATIONS FOR ESTIMATING PERCENT MAJOR WHOLESALE CUTS ON LIVE WEIGHT BASIS FROM 88 STEERS

No.	Estimating Equation[1]	R^2	Standard Error of Estimate
1	$\hat{Y} = 33.6 + .24X_2 + .02X_3 + .08X_4 - .01X_5 + .25C_1 + .43C_2$	.18	1.28
2	$\hat{Y} = 42.3 - .36X_1 + .26X_6 + .17C_1 + .46C_2 \underline{\qquad} + .34C_4$	.21	1.25
3	$\hat{Y} = 43.1 - .26X_1 + .31X_6 + .14C_1 + .47C_2 - .06C_3 \underline{\qquad}$	.16	1.28
4	$\hat{Y} = 44.0 - .38X_1 + .34X_6 \underline{\qquad} + .50C_2 \underline{\qquad} + .32C_4$	.19	1.26
5	$\hat{Y} = 39.6 + .36X_6 + .19C_1 + .36C_2 - .63C_3 + .17C_5 + .00C_6$	.14	1.30

[1] $\hat{Y}$ = Predicted % Major Wholesale Cuts

X_1 = Slaughter Grade

X_2 = Wither Height

X_3 = Chest Depth

X_4 = Forearm Circumference

X_5 = Slaughter Weight

X_6 = Average Daily Gain

C_1 = Loin Area

C_2 = Carcass Conformation

C_3 = Fat Thickness Over Loin Eye

C_4 = Fat Area Over Loin Eye

C_5 = Carcass Grade

C_6 = % Kidney Knob on a Carcass Weight Basis

R^2 obtained in this study (.14) is considerably smaller than that reported by the above workers. This disagreement may be partially explained by the greater uniformity of the experimental animals in these data. Percentage of untrimmed wholesale cuts was the dependent variable in this study whereas percentage of boneless retail cuts from the round, chuck, loin, and rib was the dependent variable in their study.

The prediction of percent fat or lean in the rib section by various combinations of live animal and carcass measurements is shown in Table XII. A comparison of equations 1 and 2 indicates that fat area explained four percent more of the variation in percent lean in the rib section than did fat thickness over the loin eye. The removal of fat thickness from the prediction equation did not effect the R^2 appreciably (equation 3). By the addition of muscle score on the live animal to equation 2 in Table IX ($R^2 = .50$), the R^2 increased to .60 in equation 2 in Table XII. The use of muscle score in the prediction of percent lean in the rib section would merit consideration.

Through the use of the four independent variables of slaughter grade (X_2), average daily gain (X_3), fat area over the loin eye (C_4), and carcass weight (C_5), 50 percent of the variation in percent fat in the rib section was explained. Both carcass weight and average daily gain were important variables in the prediction of the composition of the rib section. This does not agree with the report of Woodward _et al_. (1959) who found that production characters had little predictive value for carcass traits.

TABLE XII

MULTIPLE REGRESSION EQUATIONS FOR ESTIMATING PERCENT LEAN AND FAT IN THE RIB SECTION FROM 88 STEERS

No.	Estimating Equation[1]	R^2	Standard Error of Estimate
1	$\hat{Y}_1 = 55.3 + .68X_1 - 1.04X_2 + 1.65C_1 - .78C_2 \underline{\qquad\quad} - 1.12C_4 - .02C_5$	.64	2.14
2	$\hat{Y}_1 = 58.4 + .88X_1 - 1.35X_2 + 1.61C_1 - .96C_2 - 2.76C_3 \underline{\qquad\quad} - .02C_5$	.60	2.25
3	$\hat{Y}_1 = 57.7 + .90X_1 - 1.44X_2 + 1.74C_1 - 1.05C_2 \underline{\qquad\quad}\ \underline{\qquad\quad} - .02C_5$	.59	2.28
4	$\hat{Y}_2 = 27.2 + .94X_3 + .94X_2 \underline{\qquad\quad}\ \underline{\qquad\quad}\ \underline{\qquad\quad} + 3.08C_4 - .02C_5$	.49	2.98

[1] $\hat{Y}_1$ = Predicted % Lean in Rib Section

$\hat{Y}_2$ = Predicted % Fat in Rib Section

X_1 = Muscle Score

X_2 = Slaughter Grade

X_3 = Average Daily Gain

C_1 = Loin Area

C_2 = Carcass Grade

C_3 = Fat Thickness Over the Loin Eye

C_4 = Fat Area Over the Loin Eye

C_5 = Carcass Weight

The prediction of percent round based on live animal and carcass weights of various combinations is shown in Table XIII. Equations 1 and 3 indicate that live animal measurements predict percent round more effectively on a live weight basis; carcass measurements predict percent round on a carcass weight basis more accurately (equations 4 and 5). The partial regression coefficients indicated that circumference of forearm is one of the most important variables in the prediction of percent round. Carcass conformation was more closely associated with percent round than was carcass grade. These equations implied that faster gaining animals with larger forearms, with higher conformation scores, and with less fat covering yielded a higher percentage of round.

Summary of Prediction of Carcass Composition

Most linear live animal measurements had little value for predicting carcass composition. Measurements of loin width and chest depth were positively associated with the fatness of the animal. Circumference of forearm was the best live animal measurement for indicating leanness in the carcass.

No large differences in wholesale cutout were noted between animals of sire progeny groups. The fatter, slower gaining animals had a higher percentage of flank, brisket, plate, untrimmed rib, and untrimmed loin.

A combination of loin eye area and fat thickness or fat area were useful for predicting carcass components. By

TABLE XIII

MULTIPLE REGRESSION EQUATIONS FOR ESTIMATING PERCENT ROUND BASED ON LIVE WEIGHTS AND CARCASS WEIGHTS OF 88 STEERS

No.	Estimating Equations[1]	R^2	Standard Error of Estimate
1	$\hat{Y}_1 = 13.4 + .06X_1 - .12X_2 - .02X_3 - .30X_4 + .06X_5 + .61X_6$ \underline{\qquad}	.31	.46
2	$\hat{Y}_1 = 13.7 + .06X_1 - .13X_2$ \underline{\qquad} $- .30X_4$ \underline{\qquad} $+ .61X_6 + .08X_7$	.31	.45
3	$\hat{Y}_2 = 19.1 + .15X_1 - .18X_2 - .16X_3 - .20X_4 + .24X_5 + .81X_6$ \underline{\qquad}	.28	.46
4	$\hat{Y}_1 = 11.5 + .03C_1 + .03C_2 + .14C_3 - .04C_4 + .16C_5 - .80C_6 - .02C_7$	.28	.47
5	$\hat{Y}_2 = 20.3 - .08C_1 - .04C_2 + .12C_3 - .01C_4 + .38C_5 - 1.28C_6 - .17C_7$	.32	.44

[1] $\hat{Y}_1$ = Predicted % Round on Live Weight Basis
$\hat{Y}_2$ = Predicted % Round on Carcass Weight Basis
X_1 = Muscle Score
X_2 = Slaughter Grade
X_3 = Loin Width
X_4 = Chest Depth
X_5 = Forearm Length
X_6 = Forearm Circumference
X_7 = Average Daily Gain
C_1 = Loin Area
C_2 = Carcass Grade
C_3 = Carcass Conformation
C_4 = Carcass Forearm Length
C_5 = Carcass Forearm Circumference
C_6 = Fat Thickness Over the Loin Eye
C_7 = Fat Area Over the Loin Eye

using these carcass measurements along with subjective scores for muscling and slaughter grade of live animals, 25 to 50 percent of the variability of the dependent variables was explained.

Visual live animal scores were easier to obtain and had greater predictive value than most linear live animal measurements. Subjective scores of carcass grade and conformation explained nearly 10 percent of the variation in carcass fat and lean.

Average daily gain accounted for about five percent of the variation in percent fat in the rib section. The data in this study indicated that faster gaining animals of this age produced leaner carcasses.

The multiple regression equations indicated it was possible to combine visual scores, carcass measurements, and production characters to 16 to 54 percent of the variation in the dependent variables.

Sources of Variation in Tenderness

Tenderness is one of the most important factors influencing consumer acceptance of beef. Previous research has shown that animal age, breeding, location of muscle, method of cooking, and degree of finish affect tenderness of beef. The purpose of this investigation was to study the sources of variation in the tenderness of rib steaks from animals which were of approximately the same age and breeding and which were within a narrow range of grades following uniform feeding tests.

A mixed effect model with cross and nested classification was used in these data. The expected mean squares were obtained by following the three rules suggested by Schultz (1955) given in Appendix A. The appropriate variance ratios (F) and components of variance are shown in the expected mean squares presented in Table XV.

The 1959 data were balanced with five animals per sire. An analysis of variance for tenderness (determined from shear technique) was computed (Table XIV). A highly significant difference was found for shear value among animals within sire. A large portion of the explainable variation in tenderness was due to animals, as shown in Table XV. Similar results were also noted in the other years (Appendix B, Tables XXXIV through XXXVII). Since many of the first order interactions with animals were significant, some of this variation is also found in the animal-to-animal variation and probably biases this estimate.

Although the "F" tests revealed no statistically significant differences between position of the rib steaks, location of steak explained from 10 to 28 percent of the total variation in tenderness. The average shear values indicated that the 12th rib steaks were more tender (18.2 lbs.) than either the eighth (18.4 lbs.) or ninth (19.2 lbs.) rib steaks. Bray _et_ _al_. (1942), Ramsbottom _et_ _al_. (1945), Blakeslee and Miller (1948), and Paul and Bratzler (1955) also indicated an end-to-end variation in the tenderness of the _longissimus dorsi_ muscle.

TABLE XIV

ANALYSIS OF VARIANCE OF SHEAR VALUES FROM EIGHT SIRE GROUPS OF FIVE STEERS EACH (1959)

Source		D.F.	M.S.	"F" Test[1]
Sire	a	7	172.20	2.12
Animal in Sire	b(a)	32	81.01	28.72***
Side	C	1	1194.17	51.16***
Rib	D	2	35.26	1.34
Core	E	1	310.25	25.15**
	aC	7	4.47	1.58
	aD	14	21.32	7.56**
	aE	7	8.44	2.99**
	CD	2	18.38	7.11**
	CE	1	20.95	5.14
	DE	2	37.48	19.62**
	Cb(a)	32	21.68	7.68**
	Db(a)	64	7.68	2.72**
	Eb(a)	32	6.70	2.38**
	aCD	14	2.58	
	aCE	7	4.07	
	aDE	14	1.91	
	CDE	2	5.10	
	CDb(a)	64	8.66	
	CEb(a)	32	4.82	
	DEb(a)	64	4.62	
	aCDE	14	2.68	
	CDEb(a)	64	2.82	

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[1] ** Significance at $P < .01$
*** Significance at $P < .001$

Refer to Table XV for Appropriate Variance Ratios.

TABLE XV

SOURCES OF VARIATION OF SHEAR VALUES FROM EIGHT SIRE GROUPS OF FIVE STEERS EACH (1959)

Description		Expected Mean Square	Variance Component	Percent Variation
Sire	a	$\sigma_e^2 + 12\sigma_{b(a)}^2 + 60\sigma_a^2$	1.52	4.50
Animal in Sire	b(a)	$\sigma_e^2 + 12\sigma_{b(a)}^2$	6.52	19.30
Side	C	$\sigma_e^2 + 6K_{Cb(a)}^2 + 30K_{aC}^2 + 240K_C^2$	4.88	14.46
Rib	D	$\sigma_e^2 + 4K_{Db(a)}^2 + 20K_{aD}^2 + 160K_D^2$	5.67	16.80
Core	E	$\sigma_e^2 + 6K_{Eb(a)}^2 + 30K_{aE}^2 + 240K_E^2$	1.24	3.68
	aC	$\sigma_e^2 + 30K_{aC}^2$	.06	.16
	aD	$\sigma_e^2 + 20K_{aD}^2$	.92	2.74
	aE	$\sigma_e^2 + 30K_{aE}^2$	.18	.56
	CD	$\sigma_e^2 + 2K_{CDb(a)}^2 + 10K_{aCD}^2 + 80K_{CD}^2$	.19	.58
	CE	$\sigma_e^2 + 3K_{CEb(a)}^2 + 15K_{aCE}^2 + 120K_{CE}^2$	.14	.42
	DE	$\sigma_e^2 + 2K_{DEb(a)}^2 + 10K_{aDE}^2 + 80K_{DE}^2$	.44	1.32
	Cb(a)	$\sigma_e^2 + 6K_{Cb(a)}^2$	3.14	9.32

TABLE XV (Cont'd).

SOURCES OF VARIATION OF SHEAR VALUES FROM EIGHT SIRE GROUPS OF FIVE STEERS EACH (1959)

Description	Expected Mean Square	Variance Component	Percent Variation
Db(a)	$\sigma_e^2 + 4K_{Db(a)}^2$	1.22	3.60
Eb(a)	$\sigma_e^2 + 6K_{Eb(a)}^2$	.64	1.92
aCD	$\sigma_e^2 + 2K_{CDb(a)}^2 + 10K_{aCD}^2$	-.60	20.62
aCE	$\sigma_e^2 + 3K_{CEb(a)}^2 + 15K_{aCE}^2$	-.05	
aDE	$\sigma_e^2 + 2K_{DEb(a)}^2 + 10K_{aDE}^2$	.27	
CDE	$\sigma_e^2 + 5K_{aCDE}^2 + 40K_{CDE}^2$	.06	
CDb(a)	$\sigma_e^2 + 2K_{CDb(a)}^2$	2.92	
CEb(a)	$\sigma_e^2 + 3K_{CEb(a)}^2$	.66	
DEb(a)	$\sigma_e^2 + 2K_{DEb(a)}^2$	.90	
aCDE	$\sigma_e^2 + 5K_{aCDE}^2$	-.02	
CDEb(a)	σ_e^2	2.82	

A highly significant difference was found between sides. The average shear value for rib steaks from the right side was 17.0 pounds, and for the left side it was 20.1 pounds. Although the right side usually had more tender shear values than the left side, this difference was not consistent for all animals, and a side x animal-in-sire interaction existed. The significance of this interaction in the data from 1957 and 1958 could not be detected since cooking technique and side were confounded in the 1958 data and the 1957 data included only one steak from each side. Bray *et al.* (1942) also showed that the right side was significantly more tender than the left side; however, the greatest source of variation in their study was that which existed among cores from the steaks.

Core was not the major source of variation in this study but it did account for between 3 and 12 percent of the total variation and was significant at the one percent level in most replications. The dorsal core (one nearest the vertebra) sheared more tender than the lateral core.

The pooled third and fourth order interactions along with sampling error accounted for nearly 20 percent of the total variation in tenderness. Most of the first order interactions were significant in the 1959 data (Table XIV); however, these interactions were not consistently significant in the 1957 and 1958 data shown in Tables XXXIV through XXXVII of Appendix B.

An analysis of variance was run using only the dorsal or the lateral core (Tables XVa and XVb). Although side differences and side x animal interaction were still significant, some of the interactions with rib were no longer significant and an increase in the error term was observed. Differences among steaks measured by the dorsal core were not significant, whereas steaks were significantly different when they were measured by the lateral core.

Even though differences in shear value among sires were not significant, nearly 20 percent of the variation among animals was due to sires (Tables XV, XVa, and XVb). The heritability estimates and standard errors of the estimates of tenderness were based on an average shear value of each animal included within each sire (Table XVI). As the number of sires increased from 10 to 17 and the number of animals increased from 59 to 116, the standard errors of the estimates decreased. The standard errors also decreased when the number of sires were increased from 17 to 24 and the number of animals increased from 116 to 176.

When using data for 17 sires, the heritability estimates of tenderness based on the average of two cores per steak from both sides for the 12th and the 8th rib steaks were practically the same (.62 and .64, respectively). A heritability estimate of .69 was obtained when the average shear values for the 8th and 12th rib steaks were used. Using data for 10 sires, the heritability estimates for the 8th, 9th, and 12th rib steaks were .74, .96, and .89,

TABLE XVa

ANALYSIS OF VARIANCE OF SHEAR VALUES FROM EIGHT SIRE GROUPS OF FIVE STEERS EACH (1959)[1]

Source		D. F.	M.S.	"F" Test[2]	Variance Component	Percent Variation
Sire	a	7	70.08	2.10	1.16	6.34
Animal in Sire	b(a)	32	35.15	7.06***	5.02	27.45
Side	C	1	449.36	47.70***	3.66	20.02
Rib	D	2	4.16		- .10	- .54
	aC	7	3.78		- .08	- .43
	aD	14	10.64	2.14*	.56	3.06
	CD	2	6.78	1.36	.04	.22
	Cb(a)	32	10.62	2.13**	1.88	10.28
	Db(a)	64	7.24	1.45	1.13	6.18
	CDb(a)	64	4.98		4.98	27.24

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[1] Average of Three Shears on Dorsal Core.

[2] * Significance at $P < .05$
** Significance at $P < .01$
*** Significance at $P < .001$

TABLE XVb

ANALYSIS OF VARIANCE OF SHEAR VALUES FROM EIGHT SIRE GROUPS OF FIVE STEERS EACH (1959)[1]

Source		D.F.	M.S.	"F" Test[2]	Variance Component	Percent Variation
Sire	a	7	106.56	2.02	1.80	6.70
Animal in Sire	b(a)	32	52.56	8.70***	7.75	28.83
Side	C	1	765.77	46.02***	6.24	23.21
Rib	D	2	68.58	5.90**	.71	2.64
	aC	7	4.76		- .08	- .30
	aD	14	12.59	2.08*	.66	2.45
	CD	2	16.69	2.76	.26	.96
	Cb(a)	32	17.92	2.97**	3.96	14.73
	Db(a)	64	5.06		- .49	- 1.82
	CDb(a)	64	6.04		6.04	22.46

[1] Average of Three Shears on Lateral Core.

[2] Significance as Shown in Table XVa .

TABLE XVI

INTRA-YEAR, INTRA-SEX HERITABILITY ESTIMATES OF SHEAR VALUES BASED ON PATERNAL HALF-SIB INTRA-CLASS CORRELATIONS[1]

Rib Steak	No. of Sires	Heritability (%)	Standard Error (%)
12th	24	68	28
12th	17	62	35
12th	10	89	54
8th	17	64	35
8th	10	74	48
9th	10	96	55
Combination			
12th and 8th	17	69	36
12th and 8th	10	90	54
12th, 8th, and 9th	10	94	54
12th dorsal[2]	24	54	27
12th lateral[2]	24	64	28

[1] Average of Three Shears on Two Cores from Both Sides.

[2] Average of Three Shears on One Core from Both Sides.

respectively, which compared with .90 when the average shear values of the 8th and 12th rib steaks were used. The average values of all three rib steaks yielded a heritability estimate of .94. From these estimates it appears that an increase from two to four or six rib steaks per animal did not change the heritability estimates appreciably. This occurrence may be explained by the steak x animal interaction.

When a heritability estimate was computed using average shear value of the dorsal core on both sides for the 12th rib steak, a marked decrease was noted in the estimate (.54) as compared with the average of both cores (.68). The reduction using only the lateral core (.64) was not as great as the dorsal core. This implies that one core was not as effective in measuring tenderness as the combination of two cores on a steak.

Based on these data, tenderness appears to be a highly heritable trait. Similar heritability estimates have been obtained by Yao and Hiner (1953), Cover et al. (1957), Kieffer et al. (1958), Alsmeyer et al. (1959), and Carpenter et al. (1961).

The number of replications required to measure a certain mean difference in shear values between sires or animals, using the method described by Cochran and Cox (1957), is shown in Table XVII. In order to detect a 3.5 pound mean difference in shear force between sires at the five percent level of significance, 20 animals per sire would be required assuming that animals are measured by six steaks each. Four

TABLE XVII

NUMBER OF REPLICATIONS REQUIRED PER FACTOR TO MEASURE TENDERNESS WITH EXPECTED MEAN DIFFERENCES AT A FIVE PERCENT LEVEL OF SIGNIFICANCE[1]

Factor	Number of Replications	Expected Mean Difference
Sire	(animal)	
	3	20.8
	4	13.3
	6	8.8
	8	7.0
	10	6.0
	15	4.6
	20	3.9
Animal	(steaks)	
	1	25.9
	4	4.6
	6	3.0
	8	2.4

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[1] Formula: $\delta = \sqrt{\frac{2\sigma^2}{r}} \left[t_{.05\ (r-1)} \right]$

δ = Expected Mean Difference

σ^2 = Variance of Animals or Steaks Assuming Each Steak Provided Data from the Dorsal Core Only

r = Number of Replications

to six steaks per animal would be needed to detect the same mean difference between animals at the same level of probability assuming each steak provided data from the dorsal core. Both estimates tend to give unreasonable answers. Since the animal-to-animal variation is very large, this estimate of 20 animals is probably an overestimate. Rib-to-rib variation using only the dorsal core was very small and probably is an underestimate of the number of steaks required to measure animals.

Since the main source of variation in tenderness was among animals, studies of the data were conducted to identify factors which influenced shear force. Intra-year, intra-sex, simple correlations between the average shear value of various steaks and the chemical composition of the loin eye muscle are shown in Table XVIII. Correlations were higher between adjoining steaks on the same side than between the corresponding steaks on opposite sides. The correlation between shear values for the eighth rib steaks on the right and left sides was .64 while the correlation between the eighth and ninth rib steaks on the left side was .87. One might expect this to be true because adjoining steaks might have more similarity in composition and histological structure than corresponding steaks on opposite sides.

Cover _et al._ (1958) reported little association between ether extract and shear force value within the same grade. The correlations in this study were also near zero when the average chemical analysis from both sides was associated

TABLE XVIII

SIMPLE CORRELATIONS BETWEEN AVERAGE SHEAR VALUES OF VARIOUS STEAKS AND CHEMICAL COMPOSITION OF LEAN

	Intra-Year, Intra-Sex Simple Correlations						Over-all	
	12 Left	12 Right	8 Left	8 Right	9 Left	9 Right	Left	Right
No. of Steaks	176	176	116	116	59	59	351	351
Shear Value								
12th Left			+.65		+.64			
12th Right	+.58			+.62		+.54		
8th Left					+.87			
8th Right			+.64			+.78		
9th Left								
9th Right					+.52			
Chemical Comp.								
Left H_20	-.09		-.04		+.33		-.02	
Right H_20		+.06		+.12		+.16		.13
Left Ash	+.14		+.12		+.07		.10	
Right Ash		+.10		+.05		+.10		.04
Left Ether Extract	-.18		-.19		-.36		-.22	
Right Ether Extract		-.04		+.01		+.08		.01
Left Protein	-.05		-.01		+.30		.02	
Right Protein		+.04		+.11		+.12		.13

$r > .10$; Significance at $P < .05$ Where d.f. = 350

$r > .14$; Significance at $P < .01$ Where d.f. = 350 with shear values. However, correlations were noted when the analysis was made on a within side basis (Table XVIII). An over-all analysis using 352 steaks showed that shear values were more closely associated with ether extract and ash on the left side (-.22 and .10, respectively) than on the right side (.01 and .04, respectively). Shear values were more highly correlated with moisture and protein on the right side (.13) than on the left side (-.02 and .02, respectively). Although no difference was noticed between the average moisture and average protein content on the left and right side, there was .22 percent more ether extract on the right side and .04 percent more ash on the left side (Table XIX).

The simple correlations between chemical composition of the loin eye muscle and shear values within a side were small. These relationships and differences in chemical analyses were not great enough to explain the significant side difference noted in this study.

Cooking method is another source of variation in meat tenderness. Although side was confounded with cooking technique in the 1958 data, the mean shear value for all deep fat cooked steaks from the left side was 15.6 pounds while the broiled steaks from the right side averaged 14.4 pounds. A comparison of the deep fat cooking and broiling methods showed that the coefficients of variation differed only .50 percent. This is in agreement with Harrison (1943) and Visser et al. (1960) who reported deep fat cooked steaks were slightly less tender than oven cooked steaks.

TABLE XIX

INTRA-YEAR, INTRA-SEX SIMPLE CORRELATIONS BETWEEN CHEMICAL ANALYSES OF LEAN ON THE RIGHT AND LEFT SIDE WITH THEIR MEANS AND STANDARD DEVIATIONS

	Moisture		Ash		Ether Extract		Protein	
	Left	Right	Left	Right	Left	Right	Left	Right
Moisture								
Right	.22							
Ash								
Left	-.91							
Right		.29	.01					
Ether Extract								
Left	-.38		.08					
Right		-.79		-.25	.60			
Protein								
Left	.82		-.78		-.47			
Right		.31		.09		-.58	.34	
Mean	70.5	70.5	1.10	1.06	6.36	6.58	20.9	20.9
St. Dev.	4.1	1.6	.44	.08	1.93	2.00	1.0	.6

$r > .14$; Significance at $P < .05$ (d.f. = 172)

$r > .19$; Significance at $P < .01$ (d.f. = 172)

To give an indication of the uniformity of doneness of the steaks, each core was given a color score and then compared with the shear value. The resulting correlations were small and inconsistent (Table XX). This indicates either that doneness as indicated by color was not associated with tenderness or that differences in color were not adequately scored.

Another indication of cooking variability was obtained by comparing shear values for cooked and uncooked steaks (Table XXI). The simple correlations between shear values for uncooked and cooked steaks were much smaller than the correlations between cooked steaks from the same side, as shown in Table XVIII. Doty _et al_. (1951) also showed no close relationship between tenderness values of cooked and uncooked steaks. Although this association in our data was small, the coefficient of variation indicated less variation between uncooked steaks than between cooked steaks. This suggests that cooking increased the variability of tenderness within animals.

Summary of Sources of Variation in Tenderness

Detailed tenderness studies were conducted on 176 animals of approximately the same age and grade. Results indicated that animals, ribs, and sides were the main sources of variation. Cores and sires each accounted for between 3 and 12 percent of the total variation.

TABLE XX

SIMPLE CORRELATIONS BETWEEN THE AVERAGE SHEAR VALUES OF STEAKS AND DONENESS COLOR FROM 59 STEER CARCASSES

Shear Value[1]	Doneness Color Score[2]					
	12 left	12 right	8 left	8 right	9 left	9 right
12 left	.20	.01	-.06	.00	.04	-.10
12 right	.10	.06	.10	-.08	-.06	.10
8 left	.05	-.04	.02	.10	-.06	-.05
8 right	.30	-.12	.08	.12	.06	-.16
9 left	.08	-.06	.10	.16	.02	.01
9 right	.17	-.14	-.06	.06	.13	.00

[1] Shear Value (Pounds Per Square Inch)

[2] Doneness Color Score: Rare - 1, Medium Rare - 2, Medium - 3, Well Done - 4.

$r > .26$; Significance at $P < .05$ (d.f. = 58)

$r > .34$; Significance at $P < .01$ (d.f. = 58)

TABLE XXI

SIMPLE CORRELATIONS BETWEEN THE AVERAGE SHEAR VALUES OF COOKED STEAKS AND UNCOOKED STEAKS WITH MEANS AND STANDARD DEVIATIONS OF COOKED AND UNCOOKED STEAKS FROM 59 STEER CARCASSES[1]

Uncooked Steaks	Cooked Steaks						Mean	St. Dev.
	12 left	12 right	8 left	8 right	9 left	9 right		
7 left	.18	.22	.21	.02	.25	-.04	19.1	3.5
7 right	.15	.28	.20	.05	.29	.02	19.6	3.5
Mean	19.6	16.8	19.8	17.0	21.0	17.2		
St. Dev.	4.3	3.2	3.9	3.5	3.8	3.0		

[1] Level of Significance is Shown in Table XX.

End-to-end variability existed in the longissimus dorsi muscle. The average shear value of two cores on both sides indicated that the 12th rib steaks were more tender than either the eighth or ninth rib steaks. Cores taken from the dorsal position across all steaks yielded lower shear values than those taken from the lateral position.

Highly significant differences were found between sides. The left side generally sheared higher values than the right side; however, a side x animal interaction existed indicating that some animals had lower shear values on the left side. The within side analysis showed that ether extract was negatively correlated with shear force on the left side, while no association between these variables was found on the right side. These correlations were too small to explain the side differences in tenderness.

Cooking of steaks increased their variability in tenderness. The coefficient of variation differed only .50 percent between broiling and deep fat cooking. The mean shear value for deep fat cooked steaks was higher than for the broiled steaks when side and method were confounded. Although no close relationship was shown between shear values obtained from cooked and uncooked steaks, less variation occurred between uncooked steaks than between cooked steaks.

Although sire differences were not significant, heritability estimates for tenderness ranged from .62 to .69 when the average of two cores were obtained on each steak. With the increase from two to four or six steaks per animal, the heritability estimates did not change appreciably which was explained by a rib x animal interaction. When the average of the dorsal core on both sides was used, the heritability estimate decreased to .54. This indicated that one core on a steak was not as effective in measuring tenderness as the combination of two cores.

SUMMARY

The data used in the study were collected over a three year period on 43 heifers and 133 steers sired by 24 Angus bulls. The animals were self fed the same growing ration to an average animal age of 386 ± 24 days and to an average choice grade. Live animal measurements, carcass measurements, wholesale cutout, and physical rib separation into lean, fat, and bone were obtained. Prediction equations were calculated for percent major wholesale cuts on a live weight basis, percent round on a carcass and live weight basis, and percent lean and fat in the rib section. Tenderness shear values were collected on 702 steaks. Analysis of variance was conducted to determine the main sources of variation. Shear values on cooked steaks were correlated with chemical analyses, doneness score, and shear values of uncooked steaks.

Heritability estimates were obtained from intra-year, intra-sex, paternal half-sib, intra-class correlations. These estimates included the following: slaughter weight, 1.00 ± .32; average daily gain, .88 ± .32; dressing percentage, .74 ± .30; carcass grade, .78 ± .30; area of loin eye per unit carcass weight, .76 ± .30; fat thickness at 12th rib, .38 ± .26; percentage of major wholesale cuts, .56 ± .28; percentage of round on live weight basis, .46 ± .26;

percent lean in the rib section, .30 ± .24; percent fat in the rib section, .31 ± .24; and tenderness of the rib steaks as measured by shear force, .68 ± .28.

The multiple regression study revealed that most linear live animal measurements had little value in predicting carcass components. However, circumference of forearm was the best indicator of muscling while loin width and chest depth were associated with fatness of the animal. Carcass grade, conformation score, loin eye area, and fat thickness over the loin eye could predict the carcass components as effectively as complete untrimmed wholesale cutout. Average daily gain and slaughter weight were important variables in the prediction of carcass composition.

Analyses of variance indicated that animals, sides, and ribs were the main sources of variation in tenderness. End-to-end variability existed in the *longissimus dorsi* muscle. Shear values indicated that the 12th rib steaks were more tender than the eighth and ninth rib steaks. Shear values of dorsal cores were lower than shear values of the lateral cores. Although a side x animal-in-sire interaction existed, the left side generally sheared higher values than the right side.

Cooking increased the variability in tenderness; however, little association was found between shear values of cooked steaks and doneness color scores or of shear values obtained on uncooked steaks.

Although variation in tenderness existed, the average tenderness values for these youthful cattle were in a range which should be highly acceptable to the consumer.

The results of this study indicate the opportunity to select effectively for certain economically important traits like growth rate and slaughter weight on an individual basis. If progeny or sib tests can be conducted, it appears that one could select effectively also for changes in carcass composition and for tenderness. No major antagonistic relationships were noted between carcass characteristics and traits of productive efficiency.

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APPENDIX A

Method for Determining Expectations of Mean Squares in Analysis of Variance

A mixed effect model with cross and nested classification was used in these data. The expected mean squares were obtained by following the three rules suggested by Schultz (1955).

Rule 1. Decide for each variate (nested or cross) whether it is to be regarded as fixed or random and assign it a letter (small letters for random, capital letters for fixed) to be used both as a designating symbol and as a coefficient indicating the number of such individuals. List the sources of variation in the analysis of variance, completely identifying each source by means of the selected symbols.

Rule 2. List in the expectation of each mean square the component due directly to that particular source. Completely identify the component by using as subscripts all of the symbols necessary to completely identify or describe the source; in which case all of the remaining symbols become coefficients of the component. List as other components in the expectation of a particular mean square all other components whose identifying subscripts contain all of the symbols necessary to completely describe the source of the mean square under consideration. It is helpful if the order of the subscripts is such that the first symbols following σ^2 describe the origin of the variation while the remainder (enclosed in parentheses) indicate the position in the hierarchy at which the component arises.

Rule 3. To determine which components should be deleted in a mixed model consider each component in the following manner. Among the subscripts of the components under consideration ignore or delete from consideration those one or more subscript symbols which are necessary to describe the source of variation in which the component is listed. If any one of the remaining subscripts specifies a fixed effect, delete the component from the expectation.

Bennett and Franklin's (1954) procedure for obtaining the expected values of mean squares in partially hierarchical models is shown in Table XXII. The procedure is to construct a two-way table, columns corresponding to the indices used in the model i, j, k, l, v, rows corresponding to the terms of

TABLE XXII

METHOD USED TO COMPUTE VARIANCE COMPONENTS

	(r, R)	(t, T)	(u, U)	(w, W)	(n, N)	Components
	i	j	k	l	v	
a_i	1 - r/R	t	u	w	n	tuwn
$b(a)_{j(i)}$	1	1-t/T	u	w	n	uwn
C_k	r	t	1-u/U	w	n	rtwn
D_l	r	t	u	1-w/W	n	rtun
E_v	r	t	u	w	1-n/N	rtuw
aC_{ik}	1-r/R	t	1-u/U	w	n	twn
aD_{il}	1-r/R	t	u	1-w/W	n	tun
aE_{iv}	1-r/R	t	u	w	1-n/N	tuw
CD_{kl}	r	t	1-u/U	1-w/W	n	rtn
CE_{kv}	r	t	1-u/U	w	1-n/N	rtw
DE_{lv}	r	t	u	1-w/W	1-n/N	rtu
$Cb(a)_{kj(i)}$	1	1-t/T	1-u/U	w	n	wn
$Db(a)_{lj(i)}$	1	1-t/T	u	1-w/W	n	un
$Eb(a)_{vj(i)}$	1	1-t/T	u	w	1-n/N	uw
aCD_{ikl}	1-r/R	t	1-u/U	1-w/W	n	tn
aCE_{ikv}	1-r/R	t	1-u/U	w	1-n/N	tw
aDE_{ilv}	1-r/R	t	u	1-w/W	1-n/N	tu
CDE_{klv}	r	t	1-u/U	1-w/W	1-n/N	rt
$CDb(a)_{klj(i)}$	1	1-t/T	1-u/U	1-w/W	n	n
$CEb(a)_{kvj(i)}$	1	1-t/T	1-u/U	w	1-n/N	w
$DEb(a)_{lvj(i)}$	1	1-t/T	u	1-w/W	1-n/N	u
$aCDE_{iklv}$	1-r/R	t	1-u/U	1-w/W	1-n/N	t
$CDEb(a)_{klvj(i)}$	1	1	1	1	1	1

the model. The numbers of elements in the sample and in the population are entered in parentheses (r,R), (t,T), etc.

For those columns whose indices are not in the suffix for the term defining that row, the number of elements in the sample is entered. For example, the j, k, l, and v indices do not appear in the suffix to a_i; hence t, u, w, and n are entered in the corresponding columns opposite a_i.

Next, if any term is an unrestricted variable, one is entered in the vacant cells. In this case, $CDEb(a)_{Klvj(i)}$ is the only unrestricted random variable.

If any term contains a suffix inside parentheses, one is also entered in the column corresponding to the index inside the parentheses. In this example, $b(a)_{j(i)}$ has i inside the parentheses; therefore one goes in the i column opposite $b(a)_{j(i)}$.

Finally, wherever a cell is still empty, enter (1-c/C) where c and C are the number of elements in the sample and in the population.

For any mean square, the expectation will include all terms that include in their suffix the indices that are in the suffix of that mean square. This will yield the same result as Rule 2. The coefficient for each component of variance making up the expectation of the mean square is the product of the entries in all columns whose indices are not in the suffix of the variance component.

In this model, CDE were fixed effects; thus the sample contained the entire population, therefore (1-u/U) = (1-w/W) =

$(1-n/N) = 0$. On the other hand, sires and animals were random or were samples from infinite populations; consequently $(1-r/R) = (1-t/T) = 1$.

Legend of Table XXII

a = sires

b(a) = animals in sires

C = sides

D = ribs

E = cores

r = number of sires in the sample of the population (R)

t = number of animals in the sample of the population (T)

u = number of sides in the sample of the population (U)

w = number of ribs in the sample of the population (W)

n = number of cores in the sample of the population (N)

APPENDIX B

TABLE XXIII

INTRA-YEAR PHENOTYPIC CORRELATIONS BETWEEN VARIOUS LIVE ANIMAL MEASUREMENTS[1] FROM 88 STEERS

		(X_2)	(X_3)	(X_4)	(X_5)	(X_6)	(X_7)	(X_8)	(X_9)	(X_{10})	(X_{11})	(X_{12})
Muscle Score	(X_1)	.81	.52	.24	.50	.02	-.06	.22	-.16	.48	.34	.08
Sl. Grade	(X_2)		.40	.20	.39	.02	-.12	.24	-.14	.42	.34	.00
Should. Width	(X_3)			.51	.69	.30	.08	.39	.08	.46	.56	.40
Loin Width	(X_4)				.46	.42	.33	.46	.24	.38	.56	.36
Thigh Width	(X_5)					.34	.24	.47	.32	.60	.61	.52
Rump Ln.	(X_6)						.60	.59	.40	.44	.69	.47
Wither Height	(X_7)							.58	.52	.36	.64	.33
Chest Depth	(X_8)								.31	.50	.76	.44
Forearm Ln.	(X_9)									.32	.46	.56
Forearm Circ.	(X_{10})										.67	.45
Final Wt.	(X_{11})											.57
A. D. G.	(X_{12})											

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[1] All Scores and Grades are Based on: Prime -, 13; Choice+, 12; Choice, 11; Choice-, 10; Good+, 9.

$r > .21$; Significance at $P < .05$ (d.f. = 85)
$r > .28$; Significance at $P < .01$ (d.f. = 85)

TABLE XXIV

INTRA-YEAR PHENOTYPIC CORRELATIONS BETWEEN VARIOUS DEPENDENT VARIABLES (%) AND LIVE ANIMAL MEASUREMENTS FROM 88 STEERS

	Dependent Variables (%)				
	Live Wt. Basis				Car. Wt. Basis
Live Animal	Lean	Fat	WSC	Round	Round
Muscle Score	-.10	.17	-.01	.14	.10
Sl. Grade	-.32	.38	-.13	.00	-.05
Should. Width	-.01	-.07	.17	.20	.02
Loin Width	-.11	.06	.04	-.02	-.18
Thigh Width	.00	-.02	-.01	.20	.12
Rump Ln.	-.20	.13	.02	-.02	-.10
Wither Height	-.12	.09	.06	.00	-.10
Chest Depth	-.26	.24	-.10	-.18	-.18
Forearm Ln.	.20	-.19	-.02	.04	.01
Forearm Circ.	.04	-.04	.08	.36	.28
Final Wt.	-.12	.06	-.10	.00	-.09
A. D. G.	.10	-.23	-.06	.01	.06

$r > .21$; Significance at $P < .05$ (d.f. = 85)

$r > .28$; Significance at $P < .01$ (d.f. = 85)

TABLE XXV

INTRA-YEAR PHENOTYPIC CORRELATIONS BETWEEN VARIOUS DEPENDENT VARIABLES AND CARCASS MEASUREMENTS FROM 88 STEERS

	Percent			Loin			Forearm		Fat		Car.
	Round	Lean	Fat	Area	Grade	Conf.	Ln.	Circ.	Thick.	Area	Wt.
%WSC (Live)	.52	.10	.00	.29	.04	.29	-.02	.06	-.08	.08	.06
% Round (Live)		.35	-.33	.29	-.17	.35	.02	.31	-.31	-.22	.10
% Lean (Rib)			-.85	.48	-.30	.02	.02	-.02	-.50	-.50	-.12
% Fat (Rib)				-.44	.32	.00	-.07	-.01	.55	.62	.09

$r > .21$; Significance at $P < .05$ (d.f. = 85)

$r > .28$; Significance at $P < .01$ (d.f. = 85)

TABLE XXVI

INTRA-YEAR PHENOTYPIC CORRELATIONS BETWEEN VARIOUS CARCASS MEASUREMENTS FROM 88 STEERS

		(C_2)	(C_3)	(C_4)	(C_5)	(C_6)	(C_7)	(C_8)
Loin Area	(C_1)	-.16	.18	.23	.35	-.26	-.03	.47
Grade	(C_2)		.06	-.28	-.20	.21	.20	-.22
Conf.	(C_3)			-.26	.35	.03	.09	.14
Forearm Ln.	(C_4)				.31	-.12	.00	.59
Forearm Circ.	(C_5)					-.04	.08	.60
Fat Thick.	(C_6)						.72	.17
Fat Area	(C_7)							.32
Carcass Wt.	(C_8)							

$r > .21$; Significance at $P < .05$ (d.f. = 85)

$r > .28$; Significance at $P < .01$ (d.f. = 85)

TABLE XXVII

INTRA-YEAR PHENOTYPIC CORRELATIONS BETWEEN CARCASS AND LIVE ANIMAL MEASUREMENTS FROM 88 STEERS

	Carcass Measurements							
	Loin			Forearm		Fat		
Live Animal	Area	Gr.	Conf.	Ln.	Circ.	Thick.	Area	Car. Wt.
Muscle Score	.19	.10	.43	-.13	.38	.14	.20	.34
Sl. Grade	-.01	.01	.34	-.08	.30	.26	.33	.34
Should. Width	.44	.02	.33	.10	.40	.15	.23	.60
Loin Width	.39	.06	.04	.26	.33	.17	.22	.57
Thigh Width	.34	-.07	.33	.20	.44	.12	.14	.61
Rump Ln.	.26	-.12	.00	.58	.38	.06	.15	.68
Wither Height	.22	-.10	-.12	.75	.33	.08	.18	.65
Chest Depth	.12	-.06	-.04	.51	.36	.26	.28	.70
Forearm Ln.	.26	-.28	-.16	.62	.21	-.06	-.10	.44
Forearm Circ.	.33	-.18	.41	.32	.58	.00	.07	.67
Final Wt.	.40	-.24	.06	.62	.58	.14	.27	.96
A.D.G.	.30	-.27	.10	.40	.33	-.04	-.06	.52

r > .21 ; Significance at $P < .05$ (d.f. = 85)
r > .28 ; Significance at $P < .01$ (d.f. = 85)

TABLE XXVIII

INTRA-YEAR PHENOTYPIC CORRELATIONS BETWEEN PERCENT WHOLESALE CUTS AND CARCASS AND LIVE ANIMAL MEASUREMENTS FROM 88 STEERS

Measurements	Percent Wholesale Cuts (Carcass Weight Basis)							
	Round	Chuck	Loin	Rib	Kid. Knob	Flank	Plate	Brisket
Live Animal								
Muscle Score	.10	-.10	-.06	-.13	-.14	.28	.02	.14
Sl. Grade	-.05	-.20	-.08	-.13	-.09	.39	.12	.20
A. D. G.	.06	.19	-.36	-.38	-.12	-.20	.16	.01
Carcass								
% WSC	.17	.28	.24	.19	-.25	-.20	-.28	-.12
% Lean	.41	.26	.04	-.16	.04	-.38	-.11	-.19
% Fat	-.45	-.27	.02	.26	-.11	.34	.12	.18
Loin Area	.10	.38	-.04	-.10	-.03	-.20	-.02	-.18
Grade	-.20	-.14	.03	.25	-.02	.20	-.07	-.08
Conf.	.18	-.02	.29	-.05	-.24	.16	.20	-.06
Fat Thick.	-.44	-.32	-.02	.13	-.03	.30	.20	.06
Fat Area	-.45	-.20	.05	.22	-.12	.32	.28	.09

r > .21 ; Significance at $P < .05$ (d.f. = 85)

r > .28 ; Significance at $P < .01$ (d.f. = 85)

TABLE XXIX

INTRA-YEAR PHENOTYPIC CORRELATIONS BETWEEN VARIOUS DEPENDENT VARIABLES (Y_i) AND CARCASS (C_i) AND LIVE ANIMAL MEASUREMENTS (X_i) FROM 133 STEERS

		(Y_1)	(Y_2)	(Y_3)	(Y_4)	(C_1)	(C_2)	(C_3)	(C_4)	(C_5)	(X_1)
% WSC[1]	(Y_1)										
% Lean[2]	(Y_2)	.07									
% Fat[2]	(Y_3)	.01	-.88								
% Round[1]	(Y_4)	.66	.17	-.12							
Loin Area	(C_1)	.30	.36	-.32	.40						
Car. Grade	(C_2)	.04	-.27	.30	.01	-.02					
Car. Conf.	(C_3)	.27	.00	.02	.12	.20	.07				
Fat Thick.	(C_4)	-.06	-.52	.58	-.16	-.18	.25	.10			
Car. Wt.	(C_5)	.18	-.14	.12	.29	.52	-.01	.29	.24		
Sl. Grade	(X_1)	-.08	-.27	.32	-.15	.08	.02	.42	.29	.38	
A.D.G.	(X_2)	.04	.01	-.10	.03	.34	-.06	.27	.06	.58	.14

[1] Live Weight Basis.

[2] In the Rib Section.

$r > .18$; Significance at $P < .05$ (d.f. = 130)

$r > .22$; Significance at $P < .01$ (d.f. = 130)

TABLE XXX

INTRA-YEAR PHENOTYPIC CORRELATIONS BETWEEN VARIOUS DEPENDENT VARIABLES (Y_i) AND CARCASS (C_i) AND LIVE ANIMAL MEASUREMENTS (X_i) FROM 43 HEIFERS

		(Y_1)	(Y_2)	(Y_3)	(Y_4)	(C_1)	(C_2)	(C_3)	(C_4)	(C_5)	(X_1)
% WSC[1]	(Y_1)										
% Lean[2]	(Y_2)	-.08									
% Fat[2]	(Y_3)	.15	-.96								
% Round[1]	(Y_4)	.46	.38	-.38							
Loin Area	(C_1)	.07	.28	-.22	.11						
Car. Grade	(C_2)	.08	-.26	.30	-.04	.21					
Car. Conf.	(C_3)	.20	.08	-.07	-.14	.39	.48				
Fat Thick.	(C_4)	.23	-.54	.53	-.14	-.22	.10	-.08			
Car. Wt.	(C_5)	.04	.04	-.04	.08	.52	.04	.30	-.04		
Sl. Grade	(X_1)	-.18	-.36	.41	-.34	.37	.50	.42	.10	.42	
A. D. G.	(X_2)	-.21	-.02	-.02	-.08	.12	.01	.08	-.03	.48	.24

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[1] Live Weight Basis.

[2] In the Rib Section.

$r > .30$; Significance at $P < .05$ (d.f. = 40)

$r > .39$; Significance at $P < .01$ (d.f. = 40)

TABLE XXXI

INTRA-YEAR PARTIAL REGRESSION COEFFICIENTS AND MULTIPLE CORRELATION COEFFICIENTS (R) FOR VARIOUS COMBINATIONS OF VARIABLES INFLUENCING PERCENTAGE OF FOUR MAJOR WHOLESALE CUTS ON A LIVE WEIGHT BASIS

	From 88 Steers					133 Steers	
Combinations	I	II	III	IV	V	VI	VII
Live Animal							
Muscle	.20						
Grade	-.28		-.36	-.31	-.39	-.24	-.33
Should. Width	.32						
Loin Width	-.01						
Thigh Width	-.22						
Rump Ln.	.13						
Wither Height	.06	.31					
Chest Depth	.30	.15					
Forearm Ln.	.00						
Forearm Circ.	.34	.22					
Final Wt.	-.05	-.01					
A. D. G.	.38		-1.01	-1.07	-.53	-1.36	-1.08
Carcass							
Loin Area	.10	.47	.35	.36		.16	.24
Grade	-.05					.02	.02
Conformation	.12	.32	.42	.42	.48	.26	.38
Forearm Ln.	.42						
Forearm Circ.	-.02						
Fat Thick.	-1.26			.27		.59	-.09
Fat Area	.24		.23		.23		
Wt.	.06					.01	.01
% Round						.37	
% Chuck						.40	
% Loin						.24	
% Rib.						.48	
% Kid. Knob						-.45	
R	.75	.52	.50	.48	.42	.62	.46
R^2	.56	.27	.25	.23	.18	.38	.21

TABLE XXXII

INTRA-YEAR PARTIAL REGRESSION COEFFICIENTS AND MULTIPLE CORRELATION COEFFICIENTS (R) FOR VARIOUS COMBINATIONS OF VARIABLES INFLUENCING PERCENTAGE OF LEAN AND FAT IN THE RIB SECTION

	Percent Lean in the Rib			Percent Fat in the Rib		
Combinations	I[1]	II[2]	III[2]	IV[1]	V[2]	VI[2]
Live Animal						
Muscle	.62			- .07		
Grade	-1.38	- .39	- .32	1.34	.62	.52
Should. Width	.24			-1.40		
Loin Width	- .44			.38		
Thigh Width	- .02			.24		
Rump Ln.	-1.24			1.47		
Wither Height	- .36			.14		
Chest Depth	- .17			.82		
Forearm Ln.	1.21			- .12		
Forearm Circ.	1.03			- .78		
Final Wt.	.01			- .04		
A. D. G.	-1.35	- .03		- .34	-1.91	-2.74
Carcass						
Loin Area	1.46	1.40	1.32	-1.31	-1.32	-1.18
Grade	- .58	- .40	- .51	.57	.48	.62
Conformation	.16	.21		- .30	- .28	
Forearm Ln.	.80			-1.05		
Forearm Circ.	- .66			.59		
Fat Thick.	- .38	-3.88	-5.64	- .66	5.82	8.12
Fat Area	- .81			1.96		
Wt.	- .02	- .02	- .02	.05		.01
% Round		.66			- .80	
% Chuck		.09			- .08	
% Loin		- .18			.36	
% Rib		-1.08			1.66	
% Kid. Knob		.41			- .83	
R	.82	.71	.60	.86	.76	.70
R^2	.65	.51	.44	.73	.58	.49

[1] From 88 Steers

[2] From 133 Steers

TABLE XXXIII

INTRA-YEAR PARTIAL REGRESSION COEFFICIENTS AND MULTIPLE CORRELATION COEFFICIENTS (R) FOR VARIOUS COMBINATIONS OF PERCENT ROUND ON A LIVE WEIGHT AND CARCASS WEIGHT BASIS

	From 88 Steers (Live Wt. Basis)						
Combinations	I	II	III	IV	V	VI[1]	VII[2]
Live Animal							
Muscle	.06	.12	.10				.11
Grade	-.12	-.19	-.19			-.08	-.20
Should. Width	.11						.18
Loin Width	-.09	.01					-.18
Thigh Width	.09						.14
Rump Ln.	-.02						-.04
Wither Height	.00						.01
Chest Depth	-.11	-.22	-.27				-.17
Forearm Ln.	-.09	-.03					-.16
Forearm Circ.	.47	.64	.66				.73
Final Wt.	-.01						.00
A. D. G.	-.20		-.29		- .32	-.64	-.34
Carcass							
Loin Area	-.02			.07		.08	-.01
Grade	-.06	-.08		-.04		-.01	-.09
Conformation	-.01			.15	.14	.10	-.01
Forearm Ln.	.31			.04			.48
Forearm Circ.	.16			.16	.16		.26
Fat Thick.	-.38			-.52	-1.00	-.23	-.52
Fat Area	-.06			-.05			-.12
Wt.	.01						-.01
% Round							
% Chuck						.55	
% Loin						-.06	
% Rib						-.07	
% Kid. Knob						-.11	
R	.78	.60	.59	.54	.52	.86	.73
R^2	.61	.36	.35	.29	.28	.76	.53

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[1] From 133 Steers

[2] From 88 Steers; Carcass Weight Basis.

TABLE XXXIV

ANALYSIS OF VARIANCE OF SHEAR VALUES FROM FOUR STEERS/SIRE IN 1958

Source		D.F.	M.S.	"F" Test[1]	Variance Component	Percent Variation
Sire	a	5	6.74	.27	.55	-3.62
Animal in Sire	b(a)	18	24.65	7.85***	2.68	17.38
Side	C	1	176.33	37.61***	1.78	11.56
Rib	D	1	178.25	8.19*	1.63	10.54
Core	E	1	46.21	27.86***	.46	3.00
	aC	5	3.17	1.01	.00	.01
	aD	5	14.67	4.67*	.72	4.66
	aE	5	1.56	.50	-.09	-.64
	CD	1	28.37	4.62*	.46	2.99
	CE	1	6.98	3.18	.10	.64
	DE	1	4.33	6.96*	.07	.50
	Cb(a)	18	4.65	1.48	.37	2.44
	Db(a)	18	10.23	3.26*	1.77	11.46
	Eb(a)	18	3.23	1.03	.02	.16
	aCD	5	6.14		-.31	40.11
	aCE	5	2.19		-.06	
	aDE	5	.62		-.70	
	CDE	1	.80		-.09	
	CDb(a)	18	8.65		2.75	
	CEb(a)	18	2.68		-.22	
	DEb(a)	18	6.21		1.54	
	aCDE	5	3.04		-.02	
	CDEb(a)	18	3.14		3.14	

[1] * Significance at $P < .05$
***Significance at $P < .001$

TABLE XXXV

ANALYSIS OF VARIANCE OF SHEAR VALUES FROM FOUR HEIFERS/SIRE IN 1958

Source		D.F.	M.S.	"F" Test[1]	Variance Component	Percent Variation
Sire	a	5	28.98	1.24	.18	1.22
Animal in Sire	b(a)	18	23.20	11.35***	2.64	17.90
Side	C	1	17.89		-.06	-.46
Rib	D	1	406.59	221.80***	4.22	28.54
Core	E	1	3.15		-.05	-.34
	aC	5	19.12	9.36***	1.06	7.22
	aD	5	1.76		-.01	-.12
	aE	5	1.58		-.02	-.19
	CD	1	36.04	4.22	.57	3.88
	CE	1	.56		.00	.00
	DE	1	20.80	2.84	.28	1.90
	Cb(a)	18	7.34	3.60**	1.32	8.98
	Db(a)	18	2.10	1.03	.02	.12
	Eb(a)	18	3.33	1.62	.32	2.18
	aCD	5	8.54		.67	29.15
	aCE	5	.62		-.24	
	aDE	5	7.31		.51	
	CDE	1	3.81		.10	
	CDb(a)	18	3.14		.55	
	CEb(a)	18	2.60		.28	
	DEb(a)	18	3.20		.58	
	aCDE	5	1.29		-.18	
	CDEb(a)	18	2.04		2.04	

[1] * Significance at $P < .05$.

** Significance at $P < .01$.

*** Significance at $P < .001$.

TABLE XXXVI

ANALYSIS OF VARIANCE OF SHEAR VALUES FROM FIVE STEERS/SIRE IN 1957

Source		D. F.	M. S.	"F" Test[1]	Variance Component	Percent Variation
Sire	a	5	68.73	3.53*	2.05	12.92
Animal in Sire	b(a)	30	19.45	4.66***	3.82	24.04
Side	C	1	.11		-.40	-2.56
Core	E	1	154.79	10.01***	1.94	12.18
	aC	5	28.83	6.90*	2.05	12.93
	aE	5	15.22	3.64*	.92	5.79
	CE	1	20.94	2.77	.37	2.34
	Cb(a)	30	4.73	1.13	.28	1.74
	Eb(a)	30	4.41	1.06	.12	.77
	aCE	5	7.56		.56	29.82
	CEb(a)	30	4.18		4.18	

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[1] * Significance at P < .05
***Significance at P < .001

TABLE XXXVII

ANALYSIS OF VARIANCE OF SHEAR VALUES FROM FOUR HEIFERS/SIRE IN 1957

Source		D. F.	M. S.	"F" Test[1]	Variance Component	Percent Variation
Sire	a	2	18.16		-.12	-1.26
Animal in Sire	b(a)	9	21.50	4.41*	5.38	54.41
Side	C	1	29.61	25.36***	1.28	12.98
Core	E	1	33.50	3.86	1.03	10.47
	aC	2	1.24		-.45	-4.60
	aE	2	10.16	2.08	.66	6.68
	CE	1	.02		-.20	1.98
	Cb(a)	9	2.46		-1.20	-12.18
	Eb(a)	9	3.38		-.74	-7.55
	aCE	2	2.38		-.62	43.03
	CEb(a)	9	4.88		4.88	

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[1] * Significance at $P < .05$.
***Significance at $P < .001$.

VITA

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Doctor of Philosophy

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