RELATION OF RATE OF GAIN TO FEED EFFICIENCY IN BEEF CATTLE

by

ROBERT LEIGHTON BLACKWELL

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APPROVED:

[redacted]

Professor of Animal Husbandry

In Charge of Major

[redacted]

Head of Department of Animal Husbandry

[redacted]

Chairman of School Graduate Committee

[redacted]

Dean of Graduate School

Date thesis is presented 7/31/50

Typed by Maurine Kimel

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INTRODUCTION

Domestic animals are important to man primarily because of their ability to convert the energy in vegetable matter into a more beneficial form. A beef animal is produced for the meat yield of its carcass which is the end product of physiological processes involving energy conversion. Therefore, the efficiency with which these processes take place are of paramount concern in the selection of beef cattle for breeding purposes. Numerous studies show conclusively that these conversion processes proceed at widely different levels of efficiency within most groups of meat animals. Fortunately, at least a portion of these variations in efficiency are under genetic influences thus justifying selection for efficiency in a constructive breeding program. The exploitation of these genetic differences is difficult because their mode of inheritance is complex. Futhermore, they are obscured by many existing environmental conditions which are constantly fluctuating and causing changes throughout the entire life of the individual.

To attain maximum progress in improvement through selection it is essential that the phenotype of each character under consideration be measured directly, with a minimum of error. Moreover, this phenotypic expression must be highly indicative of breeding value or genotype if rapid improvement is to be made. For characters whose mode of inheritance is simple and whose expression is affected but little by environmental conditions, this requisite is generally satisfied. However, the situation in our domestic animals is more complex with respect to some of the more important productive characters. Rarely are any phenotypic attributes of these forms of production highly correlated with their genotypes. Therefore, the breeding value of an animal for these purposes must be estimated by a phenotypic criterion which is inherently inefficient. The expression of milk, egg and wool production can be measured directly and with a minimum of error allowing for a more accurate prediction of breeding value of an individual. Subsequent selection for breeding purposes can be made on the basis of such a prediction with considerable confidence.

The relative breeding values of animals for efficient meat production is more difficult to predict because an accurate measurement of that characteristic cannot be obtained except by carefully conducted slaughter tests or animal calorimetry, neither method being widely adapted in the selection of breeding stock. To enhance the accuracy of predicting genetic constitution of beef cattle for efficiency, one must find a criterion which maintains a close relationship to efficient feed converting ability, and at the same time, one which exhibits the quality of being easily measurable without the need of sacrificing the animal. One such criterion which meets the latter requirement is rate of gain because it can be computed easily and with considerable accuracy over a given period of time in the early part of the animal's life.

Mathematically, there must be a positive correlation between gain per day and gain per unit of feed consumed because gain is a common numerator in both terms. Under certain conditions, this correlation could be so low that selection for efficiency based on rate of gain might yield little or no results.

The present study is concerned with some of the factors affecting rate and efficiency of gain and the conditions under which cattle selected for high rate of gain in the early growth period will also be those superior in ability to convert feed into beef.

REVIEW OF LITERATURE

The importance of the various aspects of growth and development is indicated by the vast quantity of literature on this subject concerning both laboratory and farm animals. Although the present review is primarily concerned with the factors affecting rate of growth and efficiency of food utilization in beef cattle, frequent reference will be made to results obtained from studies of other types of animals. Since this is not a nutritional study, suffice it to say that the chemical composition and biological value of the ration fed an animal no doubt equals or exceeds any single environmental factor in importance.

Both Brody (4, p.1) and Wright (64, pp.93-94) consider growth and its efficiency complex to involve innumerable genetic, physiological and environmental factors. Therefore, difficulty arises when one studies these factors separately because of the existing close relationships and interactions. However, for sake of order, the literature will be reviewed under the following broad categories: effect of age and size on rate and economy of gain; growth of the calf in relation to milking ability of the cow; sex influence and genetic factors directly affecting growth and food utilization; relation of beef type and conformation to rate and economy of gain; and the problem of improving the efficiency of beef cattle.

Effect of Age and Size on Rate and Economy of Gain

The age and size factors are of considerable importance in cattle feeding because of their physiological effects upon production of body substance. According to Brody (4, p.49), the increase in size of a given animal associated with increasing age would be expected to raise the energy cost of maintenance, and to reduce correspondingly the total efficiency of growth unless this increase in maintenance is compensated for by an increase in growth rate. In the case of different species, such as cattle compared with chickens, there is such compensation and nearly the same efficiency of growth at equivalent physiologic ages. The increase in size associated with increasing age in the same animal is not compensated for by increased growth rate however, and consequently the result is decreased efficiency of growth with increasing age or weight.

Gross energetic efficiency of meat production (4, p.55) declines rapidly with increasing age. Lambert, et al, (39, p.240) state that efficiency of food utilization is a function of live weight, and the ability of an animal to convert feed into gain in live weight is dependent upon at least two factors; namely, initial efficiency and rate of decline in efficiency. Hankins and Titus (18, pp.451-452) illustrate graphically the relationships between feed efficiency and live weight during growth, and between feed efficiency and age. The first is a straight line, decreasing as weight increases, and while the latter is a sigmoid curve which decreases with increased age.

During the growth of most mammals, the curve of total metabolism plotted against weight shows a peak or break (4, p.449). Prior to this peak the rate of metabolism tends to be directly proportional to simple weight and thereafter to the 0.6 power of weight, or roughly to surface area. It is suggested that the position of the metabolic peak is not due to one cause, but is the resultant of many factors: to puberty, to weaning, to change in growth, but particularly to stabilization of the neuro-endocrine-homeothermic system. Basal energy metabolism of mature animals varies approximately with the 0.73 power of body weight.

Snell (57, pp.6-7) found that age was one of the most important factors controlling gain per unit of live weight, but it had little effect on the ability of a range steer to digest feed. The rate of gain per 1000 pounds live weight declined with age because the younger steers tended to use their feed for growth, while the older steers tended to fatten. The younger steers consumed more feed per unit weight and required less feed per 100 pounds of gain. Gramlich and Thalman (12, p.34) observed that two-year-old cattle made greater daily gains the first 100 days of feeding, calves during the last 100 days, while yearlings gained uniformly throughout the 175-day feeding period. Two-year-old cattle gained more rapidly and required more feed per 100 pounds of gain than yearling cattle, and the latter likewise made greater gains with a higher feed requirement per 100 pounds of gain than did the calves. These characteristic gains and feed requirements associated with age were true for both steers and heifers. Jones, Lush and Jones (22, p.6) noted that older steers gained more per animal but less per 1000 pounds of live weight. Younger steers made cheaper gains, but the older steers were fatter at the end of the feeding period.

Growth of the Calf in Relation to Milking Ability of the Cow

The suckling period is a critical time in the life of most mammals because the main source of nourishment for the young is that supplied by the mammary secretion of the mother. Gaines (11, p.24) demonstrated the energy yield of milk increased with the weight of the dairy cow in a linear manner. Brody (4, p.855) suggests that since feed is converted into milk by the body, the quantity of such conversion, other conditions being equal, should increase with size of body. It is true, however, that some large cows yield no more, and often less, than some small ones; but this is because the lactational drive of the large cow is inferior to that of the small one. Therefore, dairy cows produce more milk than beef cows of the same size because of genetic differences in lactating ability.

Knapp, et al, (28, pp.11-12) and Knox and Koger (35, p.1) report that the heaviest calves at weaning are those from cows at the age when maximum mature size is reached. Sawyer, Li, and Bogart (51) found that the largest cows of the same age wean the heaviest calves. Sawyer, Bogart, and Oloufa (50, p.514) reported that two-year-old cows weaned calves that were considerably lighter than mature cows. In these instances milk producing capacity is considered the fundamental influence affecting the weaning weight of the calves, since Knapp and Black (29, p.253) had shown earlier that amount of milk consumed was the greatest factor influencing rate of gain in calves during the suckling period.

After the influence of age of dam had been removed, Koger and

Knox (38, p.465) found the permanent difference in cows amounted to 51 per cent of the remaining in the weaning weights of range calves. Significant differences have been found by Lasley and Bogart (40) in the ability of beef bulls to sire heifers that wean heavy calves.

A study by Knapp and Black (29, p.254) brought out the fact that when selection of breeding animals was made during the suckling period, the calves selected were usually those that made the greatest gain and those from cows giving the most milk and scoring the poorest for beef characteristics. Dickerson's analysis (8, p.492) strongly indicated that there is a tendency for poor suckling ability in swine to be caused by the same genes responsible for rapid fat deposition and low feed requirements. Davis and Willet (7, p.642) found no apparent correlation of rapidity of growth from birth to two years of age with milk and fat production for the first lactation or for lifetime averages. Thus there may be a negative, and perhaps an antagonistic, association between high milk production and compact type in beef cattle.

Sex Influence and Genetic Factors Directly Affecting Growth and Food Utilization

The physiological aspects of most growth and food conversion phenomena are under the control of the endocrine system which is dominated by the pituitary gland. This system has certain restrictions placed on it and appears to be under direct genetic influence. Sex also has been shown to account for a large portion of the differences in growth and efficiency displayed by animals possessing similar breeding and existing under the same environment.

Palmer, et al, (49, p.23) working with two inbred strains of rats—one selected for high and the other for low efficiency of food utilization—were able to demonstrate marked strain differences after a few generations of selection. Within strains, the males were more efficient than the females; however, the carcasses of female rats contained a higher percentage of ether extract and a lower percentage of protein than did carcasses from the males. Individual and strain differences in digestibility were not large. Discrepancies in quantity of food consumed accounted for a part of the difference in efficiency between strains, but when animals representing the two strains were compelled to consume equal quantities of the same ration, the rate of growth and the efficiency of food utilization were still in favor of the high efficiency strain. Increased heat loss of metabolism during growth was proportionately higher in the less efficient strain. Morris, Palmer and Kennedy (47, p.53) stated that the maintenance cost was probably the largest item involved in the efficiency of food utilization by these rats.

Except for a brief early period in the growth of the Albino rat, females tend to grow at a slower rate and attain a smaller adult size than males similarly maintained, according to Mendell and Cannon (46, p.780). Kellerman (23, p.331) reported that male rats made uniformly better use of their food than females. Slonaker (55, pp.316-317) found normal rats of each sex were more active, consumed more food, and had less energy available for growth and metabolism than gonadectomized animals. Growth of the different groups was correlated with the amount of available energy.

In the growing chicken, Hess and Jull (19, p.38) found differences in feed efficiency between individuals that could not be explained on the basis of body weight, rate of gain, or time. There were significant differences between the slope of the line in the regression of efficiency on live weight for progeny of different sires. Males were slightly more efficient than females in utilizing feed, and differences between sexes, although not marked at low weights, progressively increased in favor of the males. This was taken to indicate either a lower maintenance requirement for males or a more rapid decrease in efficiency for females. Faster growing individuals utilized their feed more efficiently than slow-growing individuals.

Weight differences between Leghorns and Rocks at 24 weeks-of-age were shown by Asmundsen and Lerner (1, p.352) to be due to differential growth rate up to 16 weeks, and for the purpose of studying genetic differences in rate of growth, the period from two to eight weeks-of-age was considered by them to be most suitable.

Dickerson and Gowen (9, pp.497-498), studying a strain of mice carrying the "yellow" gene, observed that the yellow mice of both sexes exceeded their black litter mates greatly in gains but only moderately in feed consumption. The extra gain was entirely fatty tissue. The evidence indicated that the "yellow" gene in mice reduced food requirement per unit of gain and produced obesity, primarily by increasing food intake and by reducing energy expended for activity. Similarly, Dickerson (8, p.492) discovered that the genetic differences in rate of gain in pigs resulted more largely from fat deposition than from bone and muscle growth. Here, also, a combination of less activity and larger appetites were considered responsible for the hereditary association of lower food requirements with more rapid gains and greater fat deposition.

Comstock, Winters and Cummings (6, p.127) found in certain lines of swine that barrows grew faster than gilts; therefore, it became necessary to consider sex as a factor in making progeny comparisons.

As early as 1920, Hammond (16, p.256) reported that steers were heavier than heifers at 22 months-of-age, and further that this sex difference increased with age. Lush, et al, (45, p.33), Schutte (52, p.582), Knapp, et al, (28, pp.11-12), and Koger and Knox (37, pp. 18-19) reported that steer calves were heavier at weaning than heifers.

Schutte (52, p.582) found that as maturity approached, steers exceeded heifers in all body measurements except those of the pelvis region. An analysis by Black and Knapp (3, p.106), also, indicated that a significant amount of the variation in the gain in weight between sexes of Shorthorn calves from 140 days to one year-of-age could be attributed to increased skeletal growth as indicated by height at withers.

Trowbridge and Moffett (59, p.23) reported that steer calves full fed for 182 days gained more than heifers of similar quality, type, and age that were fed the same way. Daily feed consumption was about equal for the heifers and the steers; therefore, the heifers required more feed than the steers to produce a unit of gain.

Relation of Beef Type and Conformation to Rate and Economy of Gain

In general, type in beef cattle denotes the gross interrelationship of length, width and height of the body; whereas, conformation refers to the relationship of the size and shape of the various parts to each other. Scores are subjective values indicating the degree of perfection with which type and conformation are blended in an animal compared to an ideal. It has long been the belief that type and conformation are closely associated with performance, and consequently, that show-ring merit of beef cattle is synonymous with production. If this were true, strains of animals which would produce as desired could be developed by selecting for the proper external characteristics.

Gregory (13, pp.246-247) reached the conclusion that conformation in cattle is primarily the result of the interaction of growth factors affecting muscle diameter and growth factors affecting linear skeletal development. His study indicated that some of the genetic agencies which control muscle diameter are different in nature and possibly independent of those which control linear sketal development. General conformation of an animal, according to Gregory, may be expressed as the ratio between the round measurement and height at withers. Such a muscle-skeletal index of the breeds of beef cattle studied was practically constant from birth to maturity. This postulation is contrary to the findings of Hultz (20, pp.93-94) who observed that beef calves frequently change type during the period from six to twelve months-of-age.

Eckles and Swett (10, p.54) concluded that it was impossible to represent the growth of an animal by a single term. They recommended the use of increase in height at withers and gain in weight to measure growth. The growth impulse was found by them and others to be decidedly stronger in the skeleton than in the fleshy parts of the body. Schutte (52, p.582) found the source of variance in wither height to be approximately three-fourths genetic and one-fourth environmental. Lush (42, p.56) showed that steers increased much more in width during fattening than they did in length or depth of body, with changes in height and head measurements being affected least of all. Severson and Gerlaugh (53, pp.389-390) reported similar findings. Therefore, it seems that wither height is the best measurement of skeletal growth in cattle.

Correlations between measurements of feeder steers and subsequent gains were reported by Lush (44, p.29) to be low. Form and function were not sufficiently related to enable one to predict future performance of individual steers accurately. Stanley and McCall (58, p.51) and Knapp, et al, (27, p.19) found that the appearance of feeder calves was not a reliable indication of capacity for growth or efficiency in the feed lot.

No relation between live animal measurements and muscle-bone ratio was found by Hankins, Knapp and Phillips (17, pp.48-49) nor was there a relationship between the muscle-bone ratio and efficiency of gain. Correlations between carcass measurements and the muscle-bone ratio were too small to be of value in predicting the proportions of muscle to bone within types of cattle.

Conflicting results have been reported by Hultz and Wheeler (21, p.147) and Knox and Koger (36, p.366) with respect to feed-lot performance of Hereford steers of different types. The former found that low-set, two-year-old steers gained slightly faster and more economically during a 156-day feeding period than the intermediate or rangy type. Knox and Koger, on the other hand, found that steers classified as rangy weighed more when they were put on feed and made more rapid gains than the compact steers. In both studies the medium type steers were intermediate in performance. Knox and Koger state that when gain was expressed in per cent of initial weight there was a slight but non-significant advantage for the compact steers. The fact that some compact steers gained very rapidly indicated that some strains of compact cattle may be superior to others in this respect. It seems unlikely, therefore, that type alone is responsible for the reported differences. Hultz (20, pp.93-94) found that very rangy calves made more rapid gains than did very low-set calves. These findings differ from those secured when older cattle were studies by Hultz and Wheeler.

Woodward, Clark and Cummings (63, p.15), in summarizing a four-year feeding study in which groups of large and small type steer calves were compared, found that the large type calves averaged heavier into the feed lot and made somewhat faster gains. The large type steers consumed more feed, and in all but one year, required slightly less feed to produce 100 pounds of gain. It is conceivable that the factors operating here are the same or similar to those reported by Black and Knapp (3, p.106). They found that differences in skeletal growth between types of Shorthorn calves explained the variation in gains from 140 days to one year-of-age.

Washburn, et al, (60, pp.131-132) found no appreciable difference between compact and conventional type Shorthorn steers with respect to feed capacity per unit of body weight or in digestibility of nutrients. Conventional type animals exhibited greater ability to utilize digested dry matter during growth. A rapid decline in efficiency was observed for both types when the animals changed from the growth to the fattening phase of development. Animals of each type reached the same level at the time the animals were judged finished. Although it required seventy days longer to finish the conventional type steers, they gained more per day in both the growing and the fattening period than the compact steers.

Knapp, Black and Phillips (30, p.124) studied the accuracy of scoring certain characteristics in beef cattle. The conclusion was reached that scoring as a technique for evaluating differences in animals is subject to considerable error and is probably of very doubtful value when differences between animals are small. An impressive finding reported by Lush (43, p.880) brought out the fact that the large amounts of variation in gain and also in final value of experimental animals was not foreseen by trained men who spent much time in close study of such animals. He stated that perhaps the major factors which determine feed-lot performance and final value are not closely associated with visible differences in the animal.

With respect to the relative effects of genetic and environmental factors on certain live animal scores, grades, and carcass characteristics, Knapp and Nordskog (33, p.198) obtained heritability figures by intra-sire correlations as follows: score at weaning, 53 per cent; slaughter grade, 63 per cent; carcass grade, 84 per cent; dressing percentage, 1 per cent; and area of the eye muscle, 69 per cent.

The Problem of Improving the Efficiency of Beef Cattle

Problems involved in breeding for increased efficiency of feed utilization have been the subject of much thought and study. As a consequence, several procedures for measuring performance have been proposed. Sheets (54, p.42) suggested a plan that combines carcass grade and efficiency of food utilization. The latter is measured as pounds of cold dressed carcass per 100 pounds of total digestible nutrients consumed throughout life. Winters (61, p.127) proposed that beef animals be evaluated on the basis of conformation score and rate of gain to one year-of-age. Later, Black and Knapp (2, pp.74-75) emphasized economy of gain in the feed lot combined with slaughter grade as the best appraisal of performance.

Clark, et al, (5, pp.10-12) compared performance of steer progeny of several Hereford bulls, and because of the great sire differences, they advocated the use of progeny test in evaluating beef bulls. Stanley and McCall (58, p.51) found differences between sire groups of calves in the amount of gain made in the feed lot. Knapp, et al, (27, p.19) showed that inherited differences between the progeny of various sires existed in weaning weights, daily gain in the feed lot, and weights of heifers at 18 and 30 months-of-age. They found that neither the efficiency of gain nor the rate of gain after weaning could be accurately predicted from the rate of gain during the suckling period.

Knapp and Nordskog (32, p. 69) reported the following estimates of heritability for some of the important productive characteristics in beef cattle: weaning weight, 30 per cent; final weight, 94 per cent; daily gain, 46 per cent; and efficiency of gain, 48 per cent. Although these estimates are considered high, it appears that considerable improvement might be made by selection for these characteristics.

Guilbert and Gregory (14, p.152) observed that two lots of steers having the same rate of gain differed significantly in economy of gain while two other groups having the same efficiency differed significantly in rate of gain. From this they concluded that absolute rate of gain was not a satisfactory index of economy of gain in groups differing in potential size and earliness of maturity; but rather, that rate of gain in relation to metabolic size was more closely associated with efficiency of food utilization.

When initial and final weights varied widely, the correlation between rate and efficiency of gain obtained by Knapp and Baker (26, pp.222-223) was 0.49. After the data were corrected to constant initial and final weights the correlation was 0.83. A correlation between rate and efficiency, they state, is reduced in a time constant population and is applicable only to animals of the same size. Knapp, et al (27, p.19) obtained a correlation of 0.527 between daily gain and efficiency of gain in the feed lot; and even though this is a spurious type correlation, they considered it a useful relationship provided time, feed and gain are kept variable.

From the standpoint of total feed requirement for a unit of production, Guilbert, et al, (15, p.34) found that greatest efficiency was obtained from a high plane of nutrition with which there is continuous growth and development. Knapp and Baker (25, p.326) found ad libitum feeding to be the best method by which genetic growth differences could be determined. Variations in ability to use unlimited quantities of feed were masked when sire groups were fed somewhat alike.

According to Kleiber (24, p.251), the rate of production of body substance in growing animals depends not only on the stimulus for growth but also on the level of available energy. With two animals having the same growth stimulus, the one with the higher level of available energy will have the higher rate of production of body substance because it either eats more or digests better. The power of digestion does not seem to be greatly different among similar animals, but their appetites vary considerably. With the same growth stimulus, therefore, the bigger eater will be the better feed utilizer because of the resultant higher available energy level.

A feeding period long enough to indicate differences between progeny groups was found to be 168 days, provided the data were adjusted for initial weight, Knapp, et al, (34, p.292). If the method of least squares were used to determine the regression of efficiency on mean weight, at least five or six 28-day periods were needed to determine the slope of the regression. Knapp and Clark (31, p.180) found that genetic influences increased as the feeding period progressed. Genetic causes accounted for 84 per cent of the variation in gain during the last one-third of a 252-day feeding period; whereas, only 10 per cent of the variation during the first one-third of the feeding period was due to genetic causes.

Winters and Peters (62, pp.168-169) saw that certain steers exhibited marked differences in appetites and in gains, neither of which were in proportion to their weight or degree of fatness at the time the feeding trial began. The heaviest steer and the heaviest eater did not always make the largest gains. Certain steers near the average in feed consumption showed marked differences in gains. In some cases, gains made were not in proportion to the nutrients provided nor to the nutrients available above estimated needs for maintenance.

Investigators generally agree that one of the major problems in beef cattle production is improvement in efficiency. It appears that the attainment of a relatively large size is more closely associated with efficiency of feed conversion than is type or appearance. The various studies indicate that less emphasis should be placed on appearance in selecting breeding stock, and that focus should be placed on the productive characters. Substantial genetic variations exist in these characters, indicating that considerable permanent improvement can be made by proper selection and a sound mating system. Early environment supplied by the dam during the suckling period is of sufficient importance in the overall efficiency complex to warrant increased attention.

MATERIALS AND METHODS

The data used in this study are from 35 beef calves individually fed at the Oregon Agricultural Experiment Station on the Western Regional Beef Cattle Improvement Project. The calves were purebred Hereford and Aberdeen Angus bulls and heifers, grade Hereford heifers and steers, and grade Shorthorn steers. All were born during the spring and summer of 1949 and were fed the following winter and spring.

Some of the calves that went on feed early in the winter were confined in small individual stalls while they were eating and at night, but were allowed to run together in a large pen during the day. Later, new barn facilities became available so that the calves could be kept in groups of six and tied at mangers at feeding time. Feeding was done twice daily at uniform times and the calves remained tied for approximately seven hours each day. The mangers were so constructed that each calf had access only to the feed weighed out to it. Water was supplied at all times in automatic drinking cups installed along the manger. Wood shavings were used for bedding rather than straw to insure that nothing would be eaten other than the ration. Bulls and heifers were fed separately.

The roughage fed was high quality alfalfa hay, chopped to facilitate weighing and to avoid waste. The concentrate mixture (see Appendix, Table III) consisted largely of rolled barley, ground oats, and dried beet pulp. Several sources of protein were included. The plan was to feed the concentrate mixture and hay in an average ratio of 1:2

during the growing period from 500 to 800 pounds. At weights between 500 and 600 pounds the ratio was 1:3; from 600 to 700 pounds it was 1:2; and at weights above 700 pounds equal quantities of grain and hay were fed. The amount of grain fed was governed by the quantity of hay consumed. Hay was fed slightly in excess of consumption in order for calves to show the ability to utilize large quantities of roughage. Small quantities of hay were refused making the overall grain-hay ratio somewhat narrower than 1:2.

Live weights were taken at 14-day intervals between 10:00 and 11:00 a.m. Hay that had been refused was weighed, and the amount subtracted from the total quantity fed during the 14-day period. The data were summarized on individual record forms for each period and included initial weight, final weight, and total grain and hay consumed.

The calves were scored and measured at weights of 500 and 800 pounds. Scoring was done by three or more animal husbandmen, and the average of these scores for each calf was considered as the official score. Body measurements used in this study are height at withers, heart girth, paunce girth, and round measurement divided by height at withers. The latter is the muscle-skeletal index as described by Gregory (13, p.226).

Feed efficiency as used in this study is gain in live weight per pound of digestible nutrients consumed. Digestible nutrients were computed from Morrison's tables of average composition of feeding stuffs (48, pp.1086-1131).

The statistical methods used were analysis of variance and covariance, regression, and correlation as outlined by Snedecor (54, pp.103-168, 214-339). The five per cent significance level is used throughout in the statistical analysis. The regression of feed efficiency on live weight was calculated for each calf by a method similar to that presented by Hankins and Titus (18, pp.465-467). Likewise, the regression of rate of gain on live weight was calculated for each calf. The constants, "a" and "b", of the linear regression equation $\bar{Y} = a + bX$ appear in the Appendix, Table II. These constants were used to compute the feed efficiency and rate of gain for each calf at 650 pounds and at 325 days of age.

RESULTS

Comparison of a Constant Gain in Weight of 250 Pounds in the Feed Lot with a Time Constant Feeding Period as Methods for Determining Efficient Feed Utilizers

The problem of choosing a basis on which to make comparisons in feed utilization by beef cattle has been a point for much discussion. The relative merit of a time constant feeding period and a constant gain in weight were compared by using data from the same bull calves with initial weights of 550 pounds. The data were then selected in two ways: 1. The gain in weight and total digestible nutrients consumed during a feeding period of 100 days were determined. 2. The number of days and quantity of total digestible nutrients required to gain 250 pounds were determined.

The data are given in Table 1 and Table 2 and are presented graphically in Figure 1 and Figure 2, respectively. The correlation obtained between time in days and total digestible nutrients required to gain 250 pounds was .587. This is a significant correlation, whereas, a non-significant correlation was obtained between gain in weight and total digestible nutrients consumed during a 100-day period.

Since these two sets of data were obtained from the same calves having the same initial weight, the only difference between them is time, feed and gain in weight. When only time was held constant, the correlation between gains and feed consumed lacked significance. When time and feed were variable with gain in weight held constant, the correlation between time and feed was significant.

Apparently, when time is held constant in a feeding operation there is a tendency to penalize the faster growing individuals when compared on an efficiency basis. It will be shown later that size of animal has a marked effect on efficiency; therefore, the faster growing calf will reach a lower level of efficiency by the end of the feeding period than will the slower growing calf because he is larger at that time. Although the faster gaining calf may be more efficient at the same weight than the slower gaining calf, the difference may not be apparent when final weights are not the same.

Table 1

Gain in Weight, Total Digestible Nutrients Consumed, Rate of Gain and Feed Efficiency for Bull Calves with an Initial Weight of 550 Pounds and Fed for 100 Days

	Gains in Lbs.	T. D. N. Consumed	Rate of Gain	Feed Efficiency
	231	1014	2.31	.228
	247	1055	2.47	.234
	240	1013	2.40	.237
	237	1069	2.37	.222
	242	980	2.42	.247
	273	1046	2.73	.261
	270	1125	2.70	.240
	286	1078	2.86	.265
	246	910	2.46	.270
	257	804	2.57	.320
	250	776	2.50	.322
	210	840	2.10	.250
Mean	249.1	975.8	2.49	.258

Table 2

Time in Days, Total Digestible Nutrients, Rate of Gain, and Feed Efficiency for Bull Calves with an Initial Weight of 550 Pounds and a Gain of 250 Pounds

	Time in Days	T. D. N. Consumed	Rate of Gain	Feed Efficiency
	113	1210	2.21	.207
	111	1067	2.25	.234
	103	1055	2.42	.237
	105	1136	2.38	.220
	102	1009	2.45	.248
	92	923	2.72	.271
	91	1003	2.74	.249
	92	998	2.72	.251
	102	942	2.45	.265
	98	888	2.55	.282
	99	826	2.53	.303
	112	1013	2.23	.246
Mean	101.6	1005.8	2.47	.251

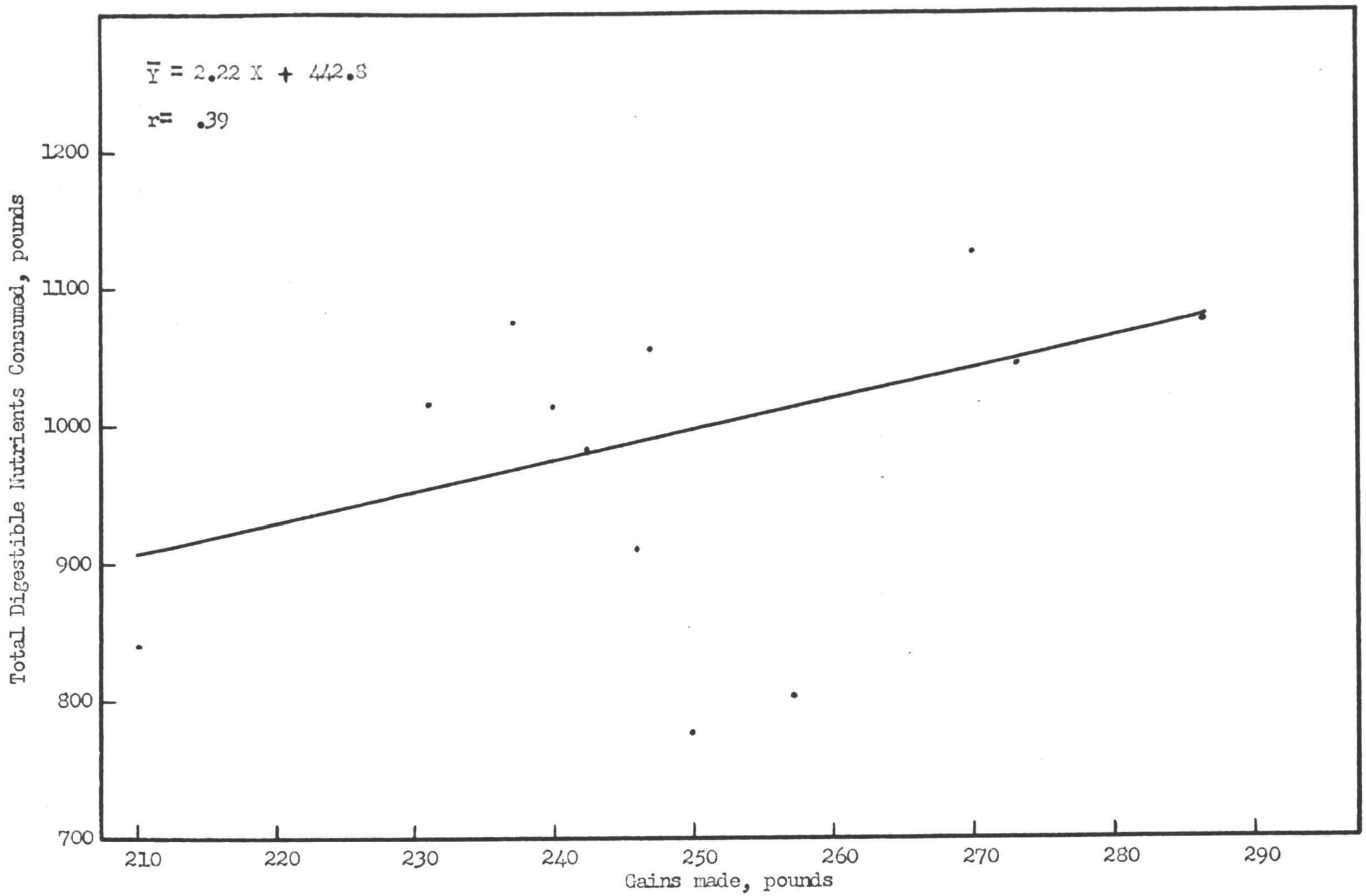

Figure 1. Correlation between total digestible nutrients consumed and gains made during 100 days of feeding for bull calves having an initial weight of 550 pounds.

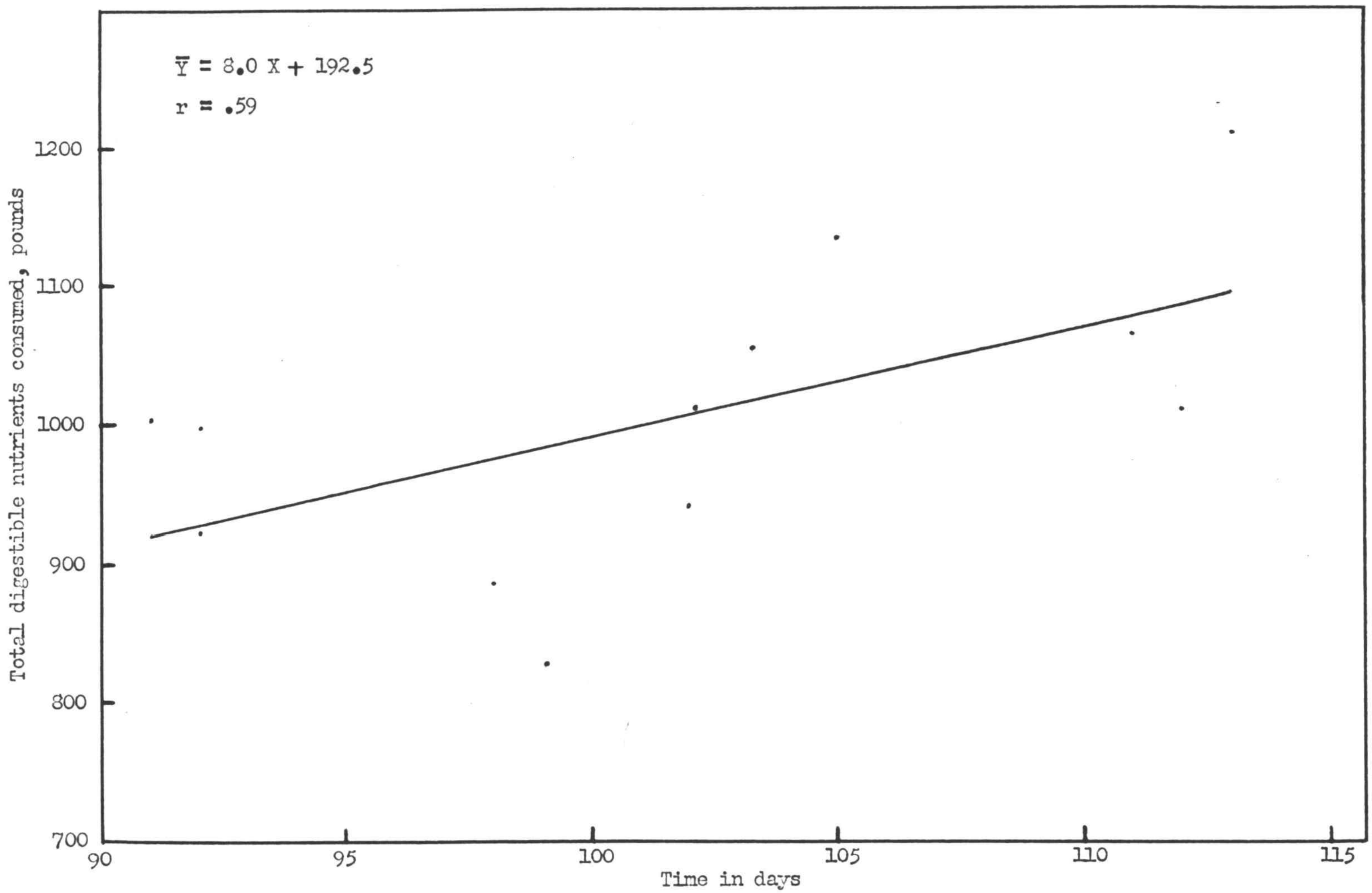

Figure 2. Correlation between total digestible nutrients consumed and time required to gain 250 pounds for bulls with initial weight of 550 pounds.

Rate of Gain and Feed Efficiency of Calves During the Feeding Period Following Weaning

Significant differences between sexes were found both in daily gain and in feed efficiency for bull, steer, and heifer calves (Table 3). The within-sex regression coefficient obtained was .0818 with a confidence interval of .0405 to .1231. The regression coefficient was found to be significantly different from zero. This is interpreted as meaning that after the effect of sex had been removed, an increase in feed efficiency of .0405 to .1231 for each pound increase in daily gain could be expected. Assuming an efficiency of .250 for a given rate of gain, 400 pounds of total digestible nutrients would be required per 100 pounds of gain; whereas, only 268 to 344 pounds of total digestible nutrients would be required for each 100 pounds of gain when the daily gain was increased one pound. Such an increase in daily gain would result in a saving of 56 to 132 pounds of total digestible nutrients per 100 pounds of gain.

The correlation coefficient obtained between rate of gain and feed efficiency was .594. This correlation agrees closely with that reported by Knapp, et al, (27, p.19), in which they obtained a correlation of .527 between rate and efficiency of gains in the feed lot.

Rate of Gain and Feed Efficiency of Calves at 325 Days of Age

A phase of the present study is to determine the effect of sex at a constant age on rate of gain and feed efficiency. Data from fifteen bull and twelve heifer calves were used in this analysis. From the

Table 3

Summary of Analysis of Variance and Covariance of Rate of Gain and Feed Efficiency for Bull, Steer and Heifer Calves During the Feeding Period Following Weaning

Source of Variance	D/F	Sum of Squares and Products: Rate of Gain	Sum of Squares and Products: Cross Products	Sum of Squares and Products: Feed Efficiency	Mean Square: Rate of Gain	Mean Square: Feed Efficiency	Regression Coefficient b	Correlation Coefficient r
Total	33	3.11024	.16615	.03599				
Between Sexes	2	1.89648	.06681	.01298	.94824*	.00649*		
Within Sexes	31	1.21376	.09934	.02301	.03915	.00074	.0818	.594*

* Significant

Table 4

Summary of Analysis of Variance and Covariance of Rate of Gain and Feed Efficiency for Bull and Heifer Calves at 325 Days of Age

Source of Variance	D/F	Sum of Squares and Products: Rate of Gain	Sum of Squares and Products: Cross Products	Sum of Squares and Products: Feed Efficiency	Mean Square: Rate of Gain	Mean Square: Feed Efficiency	Regression Coefficient b	Correlation Coefficient r
Total	26	7.45263	.14735	.02233				
Between Sexes	1	5.03827	.08056	.00129	5.03827*	.00129		
Within Sexes	25	2.41436	.06679	.02104	.09657	.00084	.02766	.296

* Significant

original data it was possible to obtain the weight of the calves at 325 days of age. By using these weights and the individual linear regression constants given in the Appendix (Table II) the daily gain and feed efficiency was computed for each calf at this constant age. The mean weight for bulls was approximately 723 pounds while the heifers averaged approximately 565 pounds. A significant difference in daily gains was found between bulls and heifers, but there was no significant difference in their feed efficiency at this age (Table 4). These two facts are illustrated in Figures 3 and 4. The analysis of variance of the weights at 325 days of age showed significant sex differences (Table 5).

Table 5

Summary of the Analysis of Variance of Live Weights of Bull and Heifer Calves at 325 Days of Age

Source of Variation	Sum of Squares	D/F	Mean Square
Total	311603.41	26	
Between Sexes	165445.00	1	165445.00*
Within Sexes	145258.41	25	5850.33

*significant

The size difference between bull and heifer calves at this age account for a part of the similarity in efficiency as well as for a part of the difference in rate of gain. As live weight increased during the growth period feed efficiency declined and rate of gain increased (Figures 3 and 4). Therefore, it cannot be said that either rate of gain or feed efficiency is a constant attribute of growing

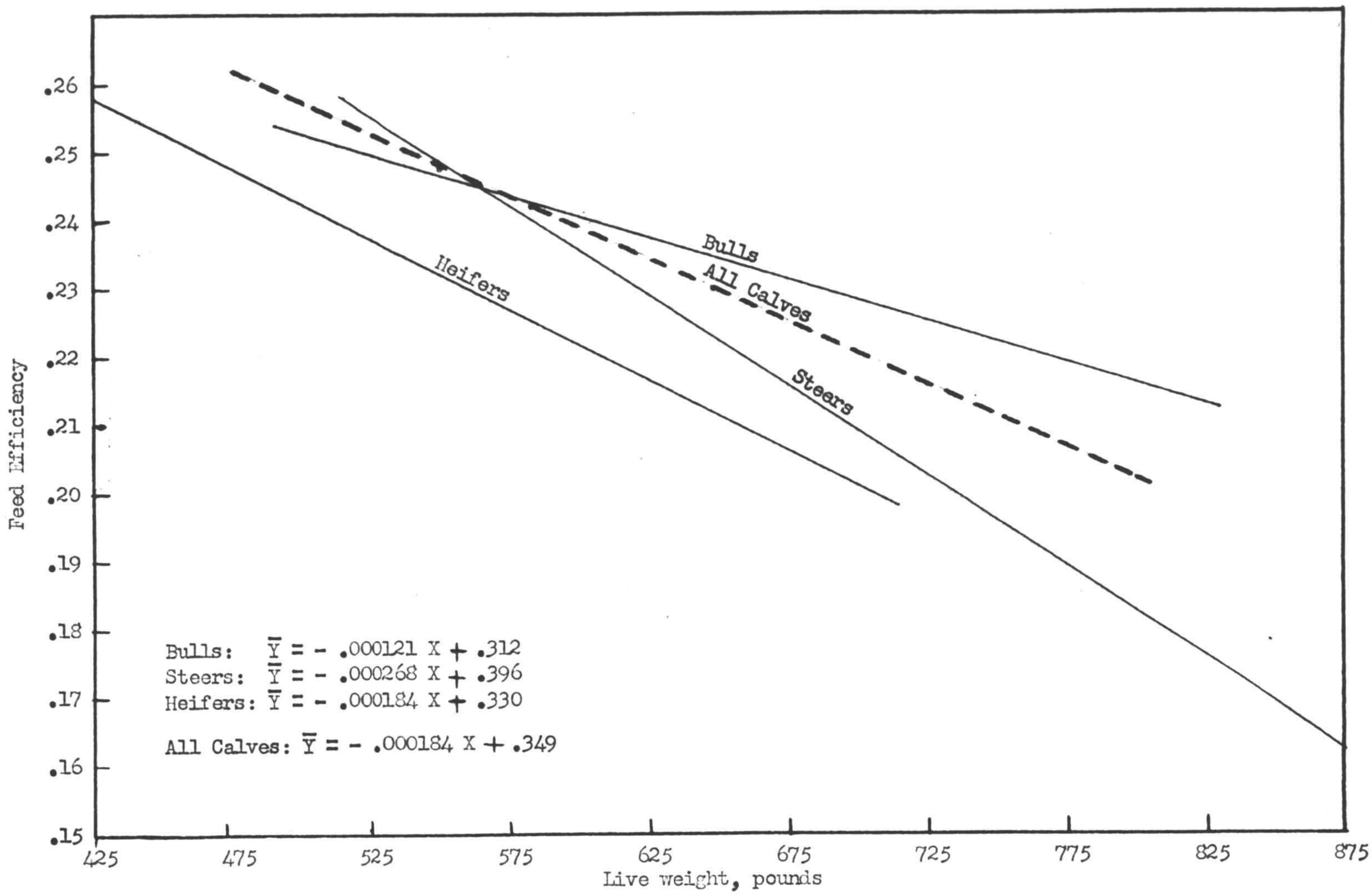

Figure 3. The regression of feed efficiency on live weight for bull, steer, and heifer calves.

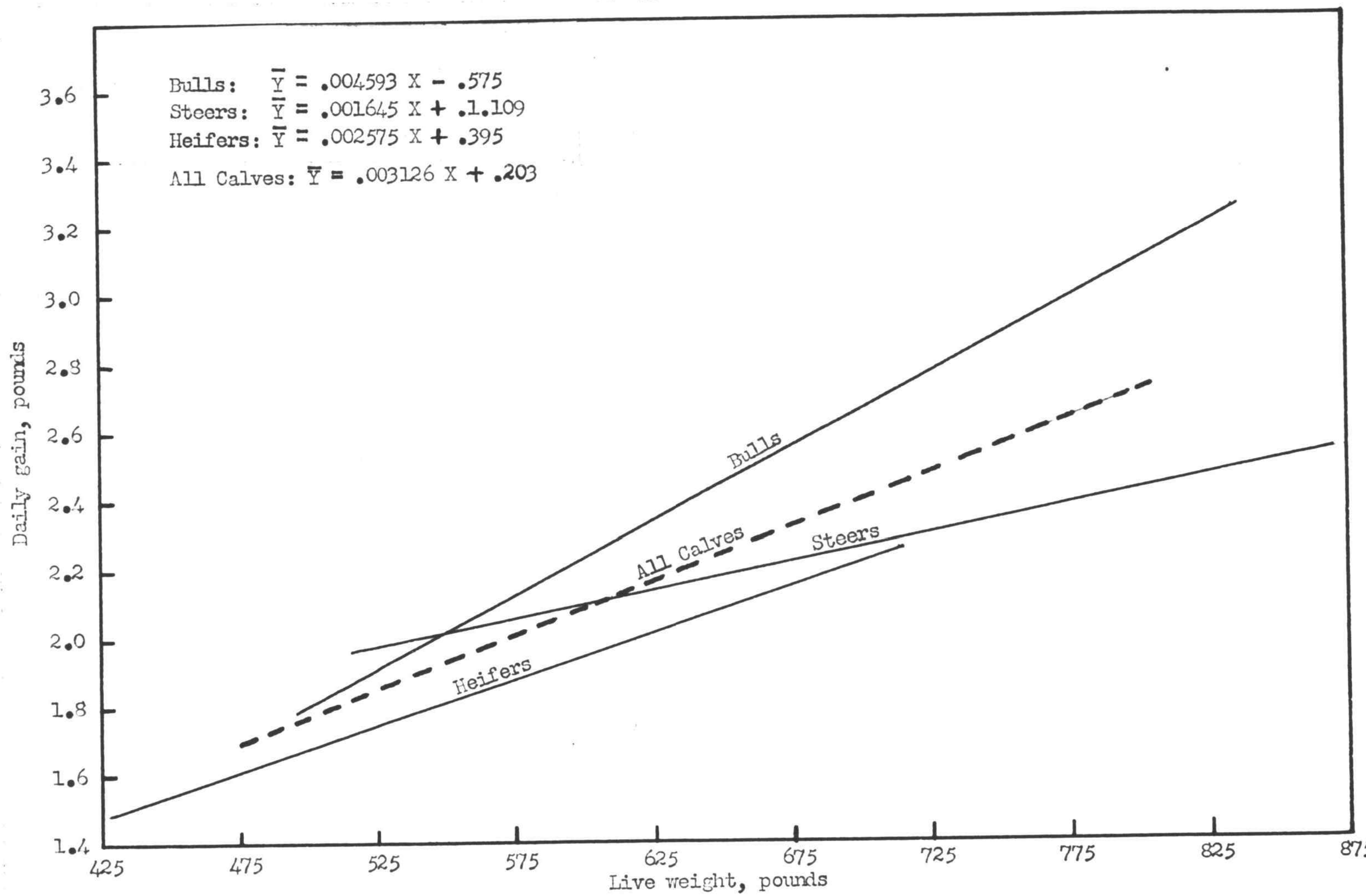

Figure 4. The regression of daily gain on live weight for bull, steer, and heifer calves.

beef calves.

Neither the within-sex regression coefficient of feed efficiency on rate of gain nor the correlation between these two measurements were significant when studied at a constant age. The low correlation obtained may be explained by the fact that heifers and bulls of the same age differed markedly in weight and rate of gain but not in feed efficiency.

Rate of Gain and Feed Efficiency at a Constant Weight

An analysis was made to determine the relation between rate of gain and feed efficiency at the constant live weight of 650 pounds, and to determine the effect of sex on these two measurements. Data from fifteen bull, six steer and nine heifer calves were used in this analysis. The rate of gain and feed efficiency was computed for each calf at 650 pounds live weight by using the linear regression constants given in the Appendix (Table II).

At this weight the difference between the sexes was found to be significant for both rate of gain and feed efficiency (Table 6). The bull calves excelled the steers and the heifers in both rate and efficiency while the steers were intermediate in their ability to grow rapidly and efficiently. The within-sex regression coefficient obtained was .0598 with a confidence interval of .0268 to .0938. This regression coefficient was found to be significantly different from zero. Here again, if an efficiency of .250 is assumed for a given rate of gain, an increase of one pound in rate of gain would reduce the feed requirement so that only 291 to 373 pounds of total digestible nutrients would be required per 100 pounds of gain rather than 400 pounds. This is a saving of 27 to 109 pounds of total digestible nutrients per 100 pounds of gain.

Since the heifers were older than the bulls at 650 pounds, there is probably a considerable difference in their physiological activity. Heifers are nearer the level at which growth is being reduced because of approaching maturity; and consequently, the feed consumed by them has a higher maintenance requirement placed upon it than does the feed eaten by bulls of the same weight. This would reduce the nutrients available for increase in body size of the heifers.

<u>Rate of Gain from Birth to Weaning Compared to Rate of Gain on Feed</u>

The effect of size at a constant age on rate of gain has been mentioned previously. It was found that sex differences in rate of gain at 325 days of age were due largely to unequal size. There still existed a significant difference in daily gain between the sexes when comparisons were made at a constant size. Observations of the calves while they were on feed and their size and age at weaning indicated that the individuals which were larger in relation to age at weaning might be those that made the slowest gains on feed following weaning. The rate of gain from birth to weaning was compared with the rate of gain on feed after weaning using data from fifteen bull and nine heifer calves raised in the same environment.

Significant sex differences both in daily gains from birth to

Table 6

Summary of Analysis of Variance and Covariance of Rate of Gain and Feed Efficiency for Bull, Steer and Heifer Calves at 650 Pounds Live Weight

Source of Variance	D/F	Sum of Squares and Products: Rate of Gain	Sum of Squares and Products: Cross Products	Sum of Squares and Products: Feed Efficiency	Mean Square: Rate of Gain	Mean Square: Feed Efficiency	Regression Coefficient b	Correlation Coefficient r
Total	29	2.29487	.17330	.02726				
Between Sexes	2	.49115	.06535	.00875	.24558*	.00438*		
Within Sexes	27	1.80372	.10795	.01851	.06680	.00069	.0598	.591*

* Significant

Table 7

Summary of Analysis of Variance and Covariance of Rate of Gain from Birth to Weaning and Rate of Gain on Feed for Bull and Heifer Calves

Source of Variance	D/F	Sum of Squares and Products: Rate of Gain, B-W[1]	Sum of Squares and Products: Cross Products	Sum of Squares and Products: Rate of Gain on Feed	Mean Square: Rate of Gain, B-W[1]	Mean Square: Rate of Gain on Feed	Regression Coefficient b	Correlation Coefficient r
Total	23	2.89580	.70112	2.34440				
Between Sexes	1	.89900	1.11299	1.14584	.89900*	1.14584*		
Within Sexes	22	1.99680	- .41187	1.19866	.09080	.05448	- .2062	- .266

1. Birth to Weaning
* Significant

weaning and in rate of gain during the feeding period following weaning were found (Table 7). Bull calves made more rapid gains before and after weaning than did the heifers. These cummulative differences in daily gains during these two growth periods account for much of the existing sex differences in size at 325 days of age. There was a slight, but non-significant, negative trend in the regression of rate of gain following weaning on the rate of gain from birth to weaning after the effect of sex had been removed.

Body Measurements and Scores

A study was made of certain body measurements and the conformation score taken at 500 pounds live weight in relation to rate of gain, feed efficiency, and measurements and conformation score taken at 800 pounds. The correlation and regression coefficients obtained are presented in Table 8. This analysis indicates that few of the measurements are of importance in predicting performance in the feed lot.

A significant, negative correlation was found between paunch circumference and feed efficiency. It is probable that the calves with the greatest measurement in this region are fatter due to a higher feed intake before weaning, and it may be that the fatter calves at weaning are those which gain the slowest while on feed after weaning.

Conformation score at 500 pounds was negatively correlated with rate of gain and feed efficiency, but was positively correlated with conformation score at 800 pounds.

The more desirable calves from the standpoint of type and conformation apparently were the ones that made the slowest gains and had the poorest efficiency. The calves that were scored the highest at a weight of 500 pounds were also those that received the highest score at a weight of 800 pounds.

The relative size of the various body parts as indicated by measurements were not constant because the measurements taken at 500 pounds and at 800 pounds were not correlated.

Table 8

Correlations Between Body Measurements, Conformation Score, Rate of Gain, and Feed Efficiency

Items Correlated	Correlation Coefficient	Regression Coefficient
Wither height at 500 pounds:		
Age in days at 500 pounds	.313	.0126
Wither height at 800 pounds	.217	.1890
Feed efficiency from 500 to 800 pounds	.158	.0043
Rate of gain from 500 to 800 pounds	.410	.1210
Muscle-skeletal index at 500 pounds:		
Muscle-skeletal index at 800 pounds	.111	.1947
Feed efficiency from 500 to 800 pounds	-.060	-.0006
Rate of gain from 500 to 800 pounds	-.065	-.0059
Age at 500 pounds	.132	.0173
Paunch circumference at 500 pounds:		
Feed efficiency from 500 to 800 pounds	-.519*	-.0052
Rate of gain from 500 to 800 pounds	-.156	-.0021
Score at 500 pounds live weight with:		
Feed efficiency from 500 to 800 pounds	-.617*	-.0051
Rate of gain from 500 to 800 pounds	-.597*	-.0551
Score at 800 pounds	.587	.6160
Age at 500 pounds	.079	.0102
Heart girth at 500 pounds:		
Feed efficiency from 500 to 800 pounds	.226	.0043
Rate of gain from 500 to 800 pounds	.132	.0250

* Significant

DISCUSSION

The analysis of the individual feeding data from beef calves has given encouraging results with respect to the use of rate of gain as a criterion for selecting the more efficient cattle during the growing period. Limitations on the use of this method have been shown to exist so that certain conditions must be satisfied before it can be employed satisfactorily either experimentally or commercially. The factors which required consideration in making comparisons between groups of animals are sex, initial size, age, length of the feeding period and the amount of gain made during the feeding period.

It was found that the sex, size and age of the calf had marked effects on growth and feed efficiency. Sex differences in these two measurements at the same age were chiefly due to size differences. However, when comparisons were made at the same size there still existed significant differences which were believed to be due to physiological factors affecting maintenance requirements peculiar to the sex of the calf.

The results of the comparison of equal length of feeding period with equal gain in weight from a constant size show the latter to be superior in supplying reliable data as a basis for comparing either individual animals or groups of animals. This method eliminates the differences in size so that the analysis of such data will require simpler methods. Unfortunately, the very nature of beef calves is such that error in collecting data at constant weights may frequently be made. The huge capacity of the alimentary tract causes great fluctuation in weight from time to time, and is due to "fill". Recommendations made by various workers for eliminating a great part of this fluctuation are shrinking, weighing at constant times during the day, and multiple weighings at the beginning and end of the feeding period. These practices are no doubt useful.

An additional method used in this present study for eliminating fluctuations in weight due to "fill" was the regression of rate of gain and feed efficiency on mean live weight for several consecutive two-week feeding periods. This enables one to compute, with considerable accuracy, the rate of gain or feed efficiency at any given weight within the range of the data. The accuracy of this method would depend upon the magnitude of the standard error of the regression coefficient and the length of the total feeding period.

The selection of cattle for breeding purposes on the basis of feed converting ability during the growth period will probably continue to require a feeding period of greater length than desired commercially. Uncontrollable factors which induce errors into the data such as "fill" can partially be overcome by longer feeding periods. Since various workers in the field have shown that genetic variation accounts for a considerable portion of the total variation in this important economic factor, it is mandatory, therefore, that data selected to be used for making genetic comparisons be as devoid of the environmental effects as possible. Extremely short feeding periods or a small gain in weight are much more likely to give misleading results. A feeding period of 168 days was recommended by Knapp, et al, (34, p. 292) to determine differences between progeny groups having the same initial weight. The findings in the present study indicate that more information is obtained by feeding for a constant gain in weight. Perhaps if this practice were adopted, a smaller gain in weight that would be expected in a 168-day feeding period would give equally good results.

A phase of the present study was concerned with the relation of rates of gain during two segments of the growth curve, namely, from birth to weaning and immediately following weaning to approximately one year of age. The rate of growth during these two periods were not found to be significantly correlated. This finding corresponds to that of Knapp, et al, (27, p.19) wherein no correlation was found between growth rates during these two periods. Lerner and Asmundson (41, p.249) found that decreased early growth rate within breeds of chickens led to a compensatory growth in later stages. There was a similar trend in the data analyzed in this study, but it lacked significance.

The variability in size at the constant age of 325 days indicated that selection at approximately one year of age based on rate of gain up to that time would give valid results. This would incorporate rate of growth during both early periods and combine milk producing ability of the dam and individual ability to grow rapidly during the entire time. Winters and McMahon (61, p.27) suggested that selection be made at this time.

Scores, measurements, and appearance have been proven to have little value in predicting feed-lot performance of beef cattle, Lush (43, p.880; 44, p.29). The rangy type of cattle appear to be the ones that made the greatest gains in the feed lot, Knox and Koger (36, p.336) and Hultz (20, p.93-94). Similar results were also found in the present study. It is likely that the rangy cattle were also the larger cattle when they went into the feed lot in the studies just cited. This might explain differences in the feed lot when they were compared with more compact cattle. Size differences in the case of the present study could not be a factor because scores and measurements were taken at the same weights.

The variability of the scores and measurements obtained at constant weights in the cattle studied was extremely small. On the other hand, there existed considerable variability in the performance factors studied. It is probable that the factors controlling beef type and conformation are different from those controlling growth and the efficiency complex. As long as it seems feasible to combine both groups of factors in the same groups of animals, two bases for selection must be established. This would require the use of selection indices based upon the heritability of the various factors involved.

SUMMARY AND CONCLUSIONS

1. When beef calves were fed to gain a given amount of weight, there was a significant correlation between time and feed required to make the gain.

2. When the calves were fed for a given period of time, the correlation of gains made with feed consumed lacked significance.

3. It appears that testing animals for feed efficiency is more accurate when they are fed to make a given amount of gain rather than for a given period of time.

4. When length of feeding period, amount of gains made, and total feed consumed varied, there was a significant correlation between rate of gain and feed efficiency. Bulls gained faster and were more efficient than steers or heifers; the latter made the slowest gain and had the lowest efficiency.

5. At an age of 325 days, bulls were larger and gained faster than heifers, but there was no difference in their feed efficiency. Rate and efficiency were not correlated at this age.

6. At a constant weight of 650 pounds, bulls gained faster and were more efficient than heifers. Heifers were much older than bulls at this weight.

7. Rate of gain and feed efficiency were highly correlated at a constant weight of 650 pounds.

8. Gains before weaning were not related to gains made during the feeding period following weaning. Apparently gains made prior to weaning are largely influenced by the milk supply of the dam while

gains following weaning are influenced to a greater extent by genetic growth tendencies.

9. Bull calves gain faster before and after weaning than heifers; consequently, they reach a much heavier weight at approximately one year of age.

10. Although most of the live-animal scores and measurements studied showed little relationship to rate of gain and feed efficiency, paunch circumference at 500 pounds live weight was negatively correlated with gains made between the weights of 500 and 800 pounds.

11. Conformation score at 500 pounds live weight was negatively correlated with both gains and efficiency during the feeding period.

12. Conformation score at 500 pounds was highly correlated with conformation score at 800 pounds, indicating that appraisal of animals for this trait at weaning is fairly reliable.

13. Beef calves apparently change in body shape and in the relationships of parts because ratios of measurements taken at 500 pounds were not related to ratios of the same measurements taken at 800 pounds.

LITERATURE CITED

1. Asmundsen, V. S. and I. Michael Lerner. Inheritance of rate of growth in domestic fowl. III. Comparative rates of growth of Leghorn and Rocks. Poultry Science 13:348-352. 1934.

2. Black, W. H. and Bradford Knapp, Jr. A method of measuring performance in beef cattle. Proceedings of the American Society of Animal Production, 29th annual meeting. 72-77. December 1936.

3. Black, W. H. and Bradford Knapp, Jr. The influence of type and sex on the body measurements of Shorthorn calves. Proceedings of the American Society of Animal Production, 30th annual meeting. 101-106. December 1937.

4. Brody, Samuel. Bioenergetics and growth with special reference to the efficiency complex in domestic animals. New York, Reinhold, 1945. 1023p.

5. Clark, R. T., et al. Performance testing of beef cattle. Montana Agricultural Experiment Station Bulletin 417. 1-12. September 1943.

6. Comstock, R. E., L. M. Winters, and John N. Cummings. The effect of sex on the development of the pig. III. Differences in growth rate between gilts and barrows by lines of breeding. Journal of Animal Science 3:120-128. 1944.

7. Davis, H. P. and E. L. Willett. Relation between rate of growth and fat production. Journal of Dairy Science 21:637-642. 1938.

8. Dickerson, G. E. Composition of hog carcasses as influenced by heritable differences in rate and economy of gain. Iowa Agricultural Experiment Station Research Bulletin 354. 492-524. October 1947.

9. Dickerson, G. E. and J. W. Gowen. Hereditary obesity and efficient food utilization in mice. Science 105:496-498. 1947.

10. Eckels, C. H. and W. W. Swett. Some factors influencing the rate of growth and size of dairy heifers at maturity. University of Missouri Agricultural Experiment Station Research Bulletin 31. 1-56. 1918.

11. Gaines, W. L. Size of cow and efficiency of milk production. Journal of Dairy Science 14:14-24. 1931.

12. Gramlich, H. J. and R. R. Thalman. Sex and age factors in cattle feeding. Nebraska Agricultural Experiment Station Bulletin 252. 1-55. October 1930.

13. Gregory, P. W. The nature of size factors in domestic breeds of cattle. Genetics 18:221-249. 1933.

14. Guilbert, H. R. and P. W. Gregory. Feed utilization test with cattle. Journal of Animal Science 3:141-153. 1944.

15. Guilbert, H. R., et al. The importance of continuous growth in beef cattle. California Agricultural Experiment Station Bulletin 688. 1-35. September 1944.

16. Hammond, John. On the relative growth and development of various breeds and crosses of cattle. Journal of Agricultural Science 10:233-289. 1920.

17. Hankins, O. G., Bradford Knapp, Jr. and Ralph W. Phillips. The muscle-bone ratio as an index of merit in beef and dual-purpose cattle. Journal of Animal Science 2:42-49. 1943.

18. Hankins, O. G. and Harry W. Titus. Growth, fattening and meat production. Food and Life, Year Book in Agriculture. Washington. United States Government Printing Office, 1939. 1165p.

19. Hess, Carl W. and Morley A. Jull. A study of inheritance of feed utilization efficiency in the growing domestic fowl. Poultry Science 27:24-39. 1948.

20. Hultz, Fred S. Type in beef calves. Wyoming Agricultural Experiment Station Bulletin 153. 71-94. 1927.

21. Hultz, Fred S. and S. S. Wheeler. Type in two-year-old steers. Wyoming Agricultural Experiment Station Bulletin 155. 127-147. 1927.

22. Jones, J. M., J. L. Lush and J. H. Jones. I. Fattening steers on cottonseed meal and cottonseed hulls with and without corn. II. The influence of age on fattening steers. Texas Agricultural Experiment Station Bulletin 309. 1-31. June 1923.

23. Kellermann, J. H. The effect of intermittent starvation on calcification, food utilization, and tissue composition. Onderstepoort Journal of Veterinary Science and Animal Industry 12:321-332. 1939.

24. Kleiber, Max. Problems involved in breeding for efficiency of food utilization. Proceedings of the American Society of Animal Production, 29th annual meeting. 247-258. December 1936.

25. Knapp, Bradford, Jr. and A. L. Baker. Limited versus full-feeding in record of performance tests for beef cattle. Journal of Animal Science 2:321-327. 1943.

26. Knapp, Bradford, Jr. and A. L. Baker. Correlation between rate and efficiency of gain in steers. Journal of Animal Science 3:219-223. 1944.

27. Knapp, Bradford, Jr., et al. Record of performance in Hereford cattle. Montana Agricultural Experiment Station Bulletin 397. 1-30. December 1941.

28. Knapp, Bradford, Jr., et al. Growth and production factors in range cattle. Montana Agricultural Experiment Station Bulletin 400. 1-13. March 1942.

29. Knapp, Bradford, Jr. and W.H. Black. Factors influencing rate of gain of beef calves during the suckling period. Journal of Agricultural Research 63:249-254. 1941

30. Knapp, Bradford, Jr., W. H. Black and R. W. Phillips. A study of the accuracy of scoring certain characters in beef cattle. Proceedings of the American Society of Animal Production, 32nd annual meeting. 122-124. December 1939.

31. Knapp, Bradford, Jr. and R. T. Clark. Genetic and environmental correlations between growth rates of beef cattle at different ages. Journal of Animal Science 6:175-181. 1947.

32. Knapp, Bradford, Jr. and Arne W. Nordskog. Heritability of growth and efficiency in beef cattle. Journal of Animal Science 5:62-70. 1946.

33. Knapp, Bradford, Jr. and Arne W. Nordskog. Heritability of live animal scores, grades and certain carcass characteristics in beef cattle. Journal of Animal Science 5:194-199. 1946.

34. Knapp, Bradford, Jr., et al. Length of feeding period and number of animals required to measure economy of gain in progeny tests of beef bulls. Journal of Animal Science 1:283-292. 1942.

35. Knox, J. H. and Marvin Koger. The effect of age on the weight and production of range cows. New Mexico Agricultural Experiment Station Press Bulletin 1004. 1-5. June 1945.

36. Knox, J. H. and Marvin Koger. A comparison of gains and carcasses produced by three types of feeder steers. Journal of Animal Science 5:331-337. 1946.

37. Koger, Marvin and J. H. Knox. The effect of sex on weaning weight of range calves. Journal of Animal Science 4:15-19. 1945.

38. Koger, Marvin and J. H. Knox. The repeatability of the yearly production of range cows. Journal of Animal Scince 6:461-466. 1947.

39. Lambert, W. V., et al. The role of nutrition in genetic research. Proceedings of the American Society of Animal Production, 29th annual meeting. 236-243. December 1936.

40. Lasley, John F. and Ralph Bogart. Tenative title of paper being prepared for publication, "The effect of sire of cows on weaning weights of their calves". Correspondence with the authors at Oregon State College.

41. Lerner, I. Michael, and V. S. Asmundson. Genetic growth constants in domestic fowl. Poultry Science 17:286-294. 1938.

42. Lush, Jay L. Changes in body measurements of steers during intensive fattening. Texas Agricultural Experiment Station Bulletin 385. 1-59. September 1928.

43. Lush, Jay L. Predicting gains in feeder cattle and pigs. Journal of Agricultural Research 42:853-881. 1931.

44. Lush, Jay L. The relation of body shape of feeder steers to rate of gain, to dressing percent, and to value of dressed carcass. Texas Agricultural Experiment Station Bulletin 471. 1-30. December 1932.

45. Lush, J. L., et al. Normal growth of range cattle. Texas Agricultural Experiment Station Bulletin 409. 1-34. March 1930.

46. Mendell, L. B. and H. C. Cannon. The relation of rate of growth to diet. Journal of Biological Chemistry 75:779-787. 1927.

47. Morris, H. P., L. S. Palmer, and Cornelia Kennedy. Fundamental food requirements for the growth of the rat. VII. An experimental study of inheritance as a factor influencing food utilization in the rat. University of Minnesota Agricultural Experiment Station Technical Bulletin 92. 1-55. February 1933.

48. Morrison, Frank B. Feeds and feeding, a handbook for the student and stockman, 21st edition. Ithaca, Morrison Publishing Co. 1948. 1207p.

49. Palmer, Leroy S., et al. Genetic differences in the biochemistry and physiology influencing food utilization for growth in rats. University of Minnesota Agricultural Experiment Station Technical Bulletin 176. 1-54. June 1946.

50. Sawyer, W. A., Ralph Bogart and Mohamed M. Oloufa. Weaning weight of calves as related to age of dam, sex and color. Journal of Animal Science 7:513-514. 1948. (ABSTRACT).

51. Sawyer, W. A., J. C. R. Li and Ralph Bogart. The relative influence of age of dam, birth weight, the size of dam on weaning weight of calves. Paper read at the annual meeting of the Western Section of the American Society of Animal Production. Pullman, Washington. June 27-28, 1949.

52. Schutte, D. J. Factors affecting the growth of range cattle in semiarid regions. Onderstepoort Journal of Veterinary Science and Animal Industry 5:535-617. 1935.

53. Severson, B. O. and Paul Gerlaugh. A statistical study of body weights, gains, and measurements of steers during the fattening period. Journal of Agricultural Research 11:383-394. 1917.

54. Sheets, E. W. Evaluating beef cattle performance for register of merit. Proceedings of the American Society of Animal Production, 26th annual meeting. 41-47. January 1933.

55. Slonaker, James Rollin. The affect of the excision of different sexual organs on the development, growth and longevity of the albino rat. American Journal of Physiology 93:307-317. 1930.

56. Snedecor, George W. Statistical methods. 4th edition. Ames, Iowa State College Press, 1946. 485p.

57. Snell, M. G. The utilization of feed by range steers of different ages. New Mexico Agricultural Experiment Station Bulletin 140. 1-7. 1923.

58. Stanley, E. B. and Ralph McCall. A study of performance in Hereford cattle. I. Progeny testing of Hereford sires. II. Type as an indicator of performance. University of Arizona Agricultural Experiment Station Technical Bulletin 109. 35-53. September 1945.

59. Trowbridge, E. A. and H. C. Moffett. Yearling heifers and steers for beef production. University of Missouri Agricultural Experiment Station Bulletin 314. 1-24. July 1932.

60. Washburn, L. E., et al. Nutrient utilization by "compact" and conventional type Shorthorn steers. Journal of Animal Science 7:127-134. 1948.

61. Winters, Laurence M. and Harry McMahon. Efficiency variation in steers, a proposed record of performance. University of Minnesota Agricultural Experiment Station Technical Bulletin 94. 1-28. December 1933.

62. Winters, L. M. and W. H. Peters. Individual feeding in steer experimentation. Proceedings of the American Society of Animal Production, 24th annual meeting. 167-171. 1931.

63. Woodward, R. R., R. T. Clark and J. N. Cummings. Studies on large and small type Hereford Cattle. Montana Agricultural Experiment Station Bulletin 401. 1-18. February 1942.

64. Wright, Sewall. Physiological aspects of genetics. Annual Review of Physiology 7:75-106. 1945.

APPENDIX

Table I

Individual growth and feed lot performance data for calves by breed and sex

Calf number	Breed	Initial age in days	Initial weight in lbs.	Final weight in lbs.	Daily gain: Birth to weaning in lbs.	Daily gain: On feed in lbs.	T. D. N. consumed in lbs.
Bulls							
86	Hereford	221	526	815	2.04	2.29	1106
84	Hereford	233	546	875	2.00	2.61	1246
64	Hereford	245	498	800	1.78	2.69	1032
85	Hereford	171	480	860	2.34	2.09	1462
24	Hereford	172	500	905	2.42	2.23	1584
29	Hereford	279	470	802	1.38	2.63	1118
87	Hereford	231	440	705	1.56	2.10	1035
117	Angus	225	522	845	2.06	2.56	1272
106	Angus	180	480	862	2.24	2.34	1606
113	Angus	245	498	805	1.77	2.74	1146
116	Angus	229	475	850	1.82	2.44	1544
118	Angus	264	495	783	1.61	2.28	1250
115	Angus	192	485	813	2.19	2.14	1494
114	Angus	195	485	825	2.13	2.21	1464
105	Angus	211	510	875	2.09	2.37	1584
Steers							
21	Shorthorn	---	520	916	----	2.43	2012
22	Shorthorn	---	660	985	----	1.99	2036
23	Shorthorn	---	580	915	----	2.06	1802
24	Shorthorn	---	550	905	----	2.18	1960
25	Shorthorn	---	480	902	----	2.59	1934
416	Hereford	233	390	836	----	2.12	1940
428	Hereford	230	380	810	----	2.28	1747
Heifers							
413	Hereford	227	330	691	----	1.61	1672
415	Hereford	237	350	780	----	1.92	1767
437	Hereford	227	350	775	----	1.90	1832
63	Hereford	237	485	804	1.73	1.90	1389
22	Hereford	281	460	708	1.31	1.96	1034
20	Hereford	219	405	675	1.42	2.14	879
70	Hereford	279	420	648	1.18	1.80	988
83	Hereford	213	420	670	1.58	1.98	1204
110	Angus	236	518	810	1.93	1.83	1564
111	Angus	250	445	641	1.62	1.55	981
112	Angus	276	395	625	1.24	1.83	1043
109	Angus	214	505	800	2.05	1.84	1464

Table II. Constants for the Regression of Feed Efficiency on Mean Live Weight and the Regression of Rate of Gain on Mean Live Weight with Respective Efficiency and Rate of Gain Computed for Each Calf at 650 Pounds and Weight at 325 Days.

Calf Number	Breed	Regression constants for efficiency on live weight "a"	Regression constants for efficiency on live weight "b"	Computed efficiency At 650 pounds live weight	Computed efficiency At age of 325 days	Regression constants for rate of gain on live weight "a"	Regression constants for rate of gain on live weight "b"	Computed daily gain At 650 pounds live weight	Computed daily gain At age of 325 days	Weight at age of 325 days
Bulls										
86	Hereford	.4291	-.000253	.266	.225	0.632	.002584	2.31	2.62	770
84	Hereford	.4796	-.000303	.283	.253	-1.381	.005796	2.39	2.95	747
64	Hereford	.4494	-.000209	.315	.303	0.711	.003093	2.72	2.89	701
85	Hereford	.0149	.000383	.264	.308	-2.878	.007955	2.29	3.21	765
24	Hereford	.1336	.000151	.222	.256	-1.548	.005708	2.16	3.08	810
29	Hereford	.1729	.000181	.291	.271	-2.856	.008921	2.94	2.01	546
87	Hereford	.2697	-.000024	.254	.255	-0.123	.004090	2.54	2.40	618
117	Angus	.6148	-.000516	.279	.215	-0.095	.003986	2.50	2.99	774
106	Angus	.2802	-.000077	.231	.217	0.643	.002533	2.29	2.71	817
113	Angus	.8330	-.000840	.287	.236	2.079	.001017	2.74	2.80	711
116	Angus	.3230	-.000121	.244	.241	-0.392	.004457	2.51	2.62	676
118	Angus	.6613	-.000663	.230	.235	4.039	.002688	2.29	2.30	648
115	Angus	.4055	-.000277	.225	.193	-0.661	.004439	2.22	2.74	766
114	Angus	.3184	-.000126	.237	.214	-0.685	.004896	2.50	2.99	751
105	Angus	.2450	-.000028	.227	.224	-1.444	.005750	2.29	2.83	743
Steers										
21	Shorthorn	.4693	-.000364	.233	----	1.703	.001044	2.38	----	----
22	Shorthorn	.5620	-.000478	----	----	2.867	-.001016	----	----	----
23	Shorthorn	.1819	.000132	.268	----	-1.118	.004488	1.80	----	----
24	Shorthorn	.4038	-.000301	.208	----	2.385	-.000339	2.17	----	----
25	Shorthorn	.3222	-.000147	.227	----	0.956	.002436	2.54	----	----
416	Hereford	.2641	-.000052	.230	.236	0.075	.003481	2.34	1.98	548
428	Hereford	.5885	-.000549	.232	.272	2.214	.000028	2.23	2.23	579
Heifers										
413	Hereford	.4141	-.000375	.170	.234	1.116	.001011	1.77	1.60	480
415	Hereford	.3197	-.000143	.227	.249	-0.065	.003612	2.28	1.84	492
437	Hereford	.2819	-.000098	.218	.242	-0.045	.003519	2.24	1.73	505
63	Hereford	.2664	-.000065	.224	.227	-1.733	.005839	2.06	1.83	610
22	Hereford	.2051	.000036	.229	.224	-0.882	.004989	2.36	1.77	532
20	Hereford	.3529	-.000155	.252	.257	-0.128	.004303	2.67	2.54	620
70	Hereford	.2931	-.000116	----	.236	0.184	.003233	2.29	1.77	490
83	Hereford	.2838	-.000066	.241	.265	-0.162	.004019	2.45	2.39	635
110	Angus	.4693	-.000399	.210	.206	1.822	-.000145	1.92	1.92	660
111	Angus	.6008	-.000718	----	.192	2.950	-.002446	1.36	1.56	570
112	Angus	.3871	-.000324	----	.231	1.424	.001023	2.09	1.92	483
109	Angus	.2983	-.000158	.196	.187	3.045	-.002026	1.73	1.61	707

Table III

The concentrate mixture used in the experimental feeding

Feed stuff	Percentage of mixture
Rolled barley	60.0
Oats	20.0
Dried beet pulp	10.0
Wheat bran	5.0
Soybean meal	2.5
Linseed meal	1.0
Dried skim milk	0.5
Bone meal	0.5
Salt	0.45
Irridiated yeast	0.05