FEED EFFICIENCY STUDIES IN BEEF CATTLE

by

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TABLE OF CONTENTS

INTRODUCTION

The use of production records, involving actual measurement data, was apparently used only to a very limited extent during the development of our present day breeds of beef cattle. Robert Bakewell supposedly utilized production records in conjunction with his attempts to breed more efficient strains of Shorthorn cattle in his breeding herd and some few other cattle breeders reportedly employed Bakewell's practice for the accomplishment of the same objective.

The early cattle breeders, of the British Isles, presumably disagreed in regard to who produced the fattest cattle and often contacted a disinterested person to serve as a judge on those occasions of disagreement. Undoubtedly this practice received increasing interest on behalf of cattle breeders and feeders and later led to the establishment of larger cattle exhibitions and shows. The show ring became popular and was adopted in many other countries of the world, such as the United States, where it still exists today. There is no doubt that the use of production records has not been extensively employed by purebred cattle breeders in the United States.

It is generally agreed that the selection of cattle on the basis of visual appraisal has been effective in the improvement of the suitability of cattle for current market demands. Changes due to selection and those due to environmental influences, such as modifications of production system, have been confounded, but considerable question remains in regard to the production improvement which has been accomplished as the result of selections which have been practiced.

In more recent years, research has indicated that beef cattle production characters are influenced appreciably by inheritance, and most research workers agree that feed efficiency is of primary importance to cattle producers. Reports of experimental findings indicate that gaining ability is positively correlated with feed efficiency and that gaining ability is highly heritable.

In view of the fact that direct measurements of feed efficiency necessitate the individual feeding of animals, which is quite expensive because of the equipment and labor requirements, the possibilities of indirect estimations of feed efficiency from studies of the relationships of it with other production factors has been investigated extensively in recent years.

If selection is efficient, the productive value of an individual must be determined at an early age. The performance testing of young cattle is currently being investigated for this purpose.

Because a beef animal's performance is influenced by many environmental conditions, it is important that environmental conditions be controlled, insofar as is possible, to permit the accurate comparison of production records among individuals. There are several variables which undoubtedly give rise to variation in feed efficiency. Some of these, such as initial weight, inbreeding, and gaining ability may be studied statistically.

Measurement data were taken on the cattle produced in a Beef cattle breeding project at the Kansas Agricultural Experiment Station; Manhattan, Kansas. This manuscript is a report of the study which was made to investigate the relationship of several variables with feed efficiency in beef cattle production.

A review of the literature has been made.

REVIEW OF LITERATURE

Maintenance Requirements

It is generally agreed that two components, growth and maintenance, are concerned with the utilization of feed by young animals. While it has long been recognized that some relationship exists between body size and basal metabolism, conclusive experimental findings concerning this have been established only in recent years. Trowbridge, et al., (1915) made extensive investigations concerning the maintenance requirements of cattle during feeding as influenced by such factors as age, pre-treatment, and size. Their studies also included measurements of the metabolic activity and energy requirements of cattle under different states of normal physical activity. They used the animal's surface area as a measure of relative maintenance costs, assuming that the relative surface area is a measure of relative energy needs. Among the same weight levels, maintenance requirements of cattle apparently decreased with increased age. Season was also found to be a factor in maintenance requirements, being lowest in the spring and highest in winter. Also, the heavier the animal, the greater the maintenance energy requirement per unit of surface area. They concluded that this was due to the relatively smaller surface area as well as to the heavier weight sustained.

Kleiber (1932) expressed basal metabolism as a power of body weight, concluding that basal metabolism had a closer relation to 3/4 power of body weight than to the geometric body surface of an animal. Brody (1932) studied the basal metabolism of animals varying in size from mice to elephants and reported basal metabolism was proportional to the 0.743 power of the animal's live weight. Brody, et al., (1947), in later studies of basal metabolism requirements, concluded that it tends to vary approximately with the 0.6 power of body weight instead of the 0.743 power as previously reported. The following observations were also reported by these workers: metabolism during growth is an exponential function of body weight; the greater the rapidity with which a species reaches its maturity, also the greater the rapidity with which its metabolism declines with increasing weight; and the metabolism per unit of live weight actually is a function of the size of the species and also of its state of maturity.

Kleiber (1936) believed "total energy efficiency" was a suitable characteristic for use in the breeding selection of animals for improved feed efficiency when it was defined as the amount of energy in the desired form converted by the animal in its body per unit of energy in its total food. The ability of animals to consume food, the efficiency of the animals digestion, the animal's ability for growth, differences in the amount of or level of nutrition, and the composition energy stored in the animal's body were all listed as factors affecting the efficiency of food utilization. Animals possessing higher levels of efficiency in feed conversion exhibited higher rates of production of body tissues either because they digest food more efficiently or eat more, or both. Kleiber stated:

> Basic studies in comparative physiology, particularly with regard to the relation of body size, metabolism and food utilization should be extended in order to provide reliable foundations for that other part of research which is aimed at direct practical results in the field of animal husbandry.

Most feed efficiency studies conducted with beef cattle have been made with efficiency measured in terms of "total energy efficiency" which has been generally expressed as the pounds of total digestible nutrients required per 100 pounds of live body weight gain. In some studies corrections have been made for basal metabolism on the basis of the average weight of the animals while on feeding trials. In others, pounds of feed per 100 pounds of gain have been used.

Feed Efficiency Variability

A number of workers have conducted studies to determine whether or not variations in the efficiency of feed utilization by animals of a given age and condition are of sufficient magnitude to be of economic importance to the livestock producer.

Wilson and Curtiss (1893) individually fed two steers from each of nine breeds of cattle and found that dairy breeds gained, on the average, just as rapidly and as efficiently as beef breeds. However, differences were noted in the rate and efficiency of growth between members of each pair and between the various breeds. Smith (1910) conducted two experiments which revealed a wide variation in the capacity of individual cattle to make gains. Some steers made 1/5 larger gains on the same quantity of feed than others which appeared in the same condition at the start of the feeding trials. Few live animal characteristics were found to be associated with rate of gain except the more rapid gaining steers tended to possess large middle girths at the beginning of the feeding period. Dvorachek and Semple (1931) compared the production of purebred Aberdeen-Angus cattle with Arkansas native cattle and reported that the relative economy of production of market calves produced by cows of the various breeding was variable within groups but did not necessarily favor the purebreds. The purebreds ate slightly more and gained slightly more on the average than the native cattle.

Palmer and Kennedy (1931) recognized possible limitations to early nutritional studies in which the paired feeding of rats had been conducted under the assumption that a perfect correlation existed between feed consumption and gain in body weight among populations of animals of the same sex. These authors pointed out that in order for such studies to be valid, assumptions of "equality of initial capacity to grow and develop on the basal ration" and also "equality of food utilization" had to be made. These factors were investigated by Morris, et al., (1933) who made an experimental study of inheritance as a factor influencing food utilization in the rat. Initially, crosses were made between pairs of unrelated breeding rats which had exhibited widely different levels of efficiency of food utilization. Later, "high" and "low" lines were established as the result of continuous selection for nine generations. According to the feed efficiency index used for line comparisons, the "lower" line was found to be approximately 40 percent less efficient than the "high" line. This evidence indicated that heritable factors influenced efficiency of food utilization.

Winters and McMahon (1933) pointed out that early experimental studies revealed that there were considerable differences in rate and efficiency of gain between animals of the same weight and type, although handled under identical conditions. In general, beef and dairy steers appeared equally efficient and purebred and native stock apparently possessed about the same gaining ability. Efficiency is not necessarily a measure of profit potential because type and conformation are associated with animal value. At the time these authors reported these findings, they concluded that many additional studies would be necessary prior to the justification of attempts to determine measures of feed efficiency because of the many variables which influenced that production trait.

Winters (1936) studied the breeding improvement of feed efficiency in beef cattle. The objectives of his investigations were as follows: (1) to determine if there was sufficient variation in feed efficiency to be of economical importance; (2) to determine which physical characteristics are indicative of an efficient animal; and (3) to formulate a record of performance program that would aid in the development of more economical strains of cattle. He concluded feed efficiency was economically important and that average daily gain was a satisfactory indicator of efficiency.

Knapp, et al., (1941) stated that animal husbandmen were beginning to realize the inaccuracy of show ring standards and made a general recommendation for the use of progeny testing to facilitate the breeding improvement of beef cattle in regard to the so-called economic factors, rate of gain, efficiency of gain, and carcass quality.

The effectiveness of selection for efficiency of gain in Duroc Jersey Swine was studied by Dickerson and Grimes (1946). Beginning with a common foundation in 1937, they selected for "high" and "low" lines in regard to feed efficiency. The divergence between the two lines after five years of selection was statistically significant and indicated the trait to be twenty-four percent heritable. The correlation coefficient between rate of gain and economy of gain in all cases was -.70, or larger. Dickerson and Grimes (1947) concluded this correlation coefficient to be -.78, indicating that selection based on rate of gain from weaning to market was nearly as effective for improving feed efficiency as selection for feed efficiency itself.

Craig and Chapman (1953) found considerable variation in rate of gain between five strains or lines of rats which they developed from a common commercial stock.

While a portion of this reported work pertains to animals other than beef cattle, it may be assumed that a biological application of these findings may be applied not only to beef cattle but also to other domesticated farm animals.

Plane of Nutrition and Feeding Period

The preceding evidence indicates that efficiency of feed utilization is a factor of economical importance. It also appears that appreciable variation exists between individual animals. The direct measurement of feed efficiency on the basis of individual feeding data and methods of indirect estimation by means of relationships between feed efficiency and other traits, more easily measured, have been studied by many research workers. Planes of nutrition and lengths of feeding trials necessary for the accurate measurement of variation in feed efficiency have been studied.

Brody and Proctor (1933) studied the effects of the plane of nutrition upon the utilization of feeding stuffs. They concluded that the digestibility of typical rations was quite low by beef cattle with about 28 percent of the gross ingested energy being lost in the feces. These losses increased to a limited extent, depending upon the ration, with an increase in the plane of nutrition.

Knapp and Baker (1943) stated: "that if the goal of the breeder is to develop animals to perform at their maximum, then selection for this must be based on un-limited feeding." Lush (1949) cautioned that breeding animals should be maintained under practical production environments because feeding under "forced" conditions may lead to the selection for genes which will not cause animals to respond favorably under a less favorable environment.

Black, et al., (1940) studied the performance of steers fattened under individual and group feeding conditions at different levels of nutrition and concluded that the method of feeding did not affect the gains significantly on the limited ration but favored the group feeding somewhat when on full feed. The limited fed cattle were consistently more efficient. They noted wide individual variation in the performance of steers within groups individually fed. The individual variation in rate of gain, feed efficiency, and other production traits was increased by full feeding.

Knapp, et al., (1941) reported that ultimate efficiency of gain, or rate of gain in the feed lot cannot be accurately predicted on the basis of the preweaning performance of the calf in beef cattle. They also concluded that rate of gain and efficiency of gain are not highly correlated in records of performance conducted on a time constant basis.

Knapp, et al., (1942) decided that feeding efficiency could be determined on the basis of a 168 day feeding period providing adjustments were made for initial weight. Feeding trials may be conducted on a weight constant or a time constant basis. The practical advantage of taking measurements on a time constant basis is that animals are usually weaned at same time and fed for the same period. He stated, however, that it is more desirable to take measurements on a weight constant basis because of changes in rate of growth, body conformation, and composition, etc., at various weights.

Knapp and Baker (1943) stated that if variation in growth rate of beef cattle is the primary objective, the most effective method of determining the variation between animals is by some method that will reveal the maximum growth variations. Their findings indicated that limited feeding will not effectively reveal the inherited variance in the ability of beef cattle to consume quantities of feed and to gain rapidly.

Numerous relationships have been studied between rate of gain and feed efficiency and between these two variables and other factors such as birth weight, weaning weight, initial weight, initial age, and inbreeding.

Birth Weight

The relationships of birth weight of calves with weaning weight, average daily gain, feed efficiency, and other factors have been studied by numerous research workers.

Knapp, et al., (1940) reported that birth weight is primarily an expression of the size, weight, age, and physiological constitution of the dam. Studies by Gregory, et al., (1950) showed that weight of dam had a significant influence on birth weight. These workers, as well as Kohli, et al., (1951) concluded that calves heavier at birth were also heavier at weaning.

Knapp, et al., (1941) found that birth weight was not highly correlated with any of the post weaning production factors, although it was significantly correlated with average daily gain during the suckling period.

Dahmen and Bogart (1952) reported that birth weight and initial age of beef calves when placed on test accounted for 40 percent of variation in gain during the test period. Of the factors studied, only birth weight had a significant effect on feed efficiency during the test. The simple correlation coefficient between birth weight and economy of gain (pounds of TDN required per 100 pounds gain) was 0.42. Eighteen percent of the variation in economy of gain was accounted for by variations in birth weight. Knapp, et al., (1941) reported that the simple correlation coefficient between birth weight and average daily gain from weaning to slaughter was .466 and that between birth weight and feed efficiency during this period was .152. Koch and Clark (1955) reported simple correlation coefficients between birth weight and the following traits: weaning weight, r = 0.40; gain from birth to weaning, r = 0.23; and gain from birth to one year of age, r = 0.07.

Woodward, et al., (1954) studied data obtained on 635 record of performance steers at the Miles City Station. The simple correlation coefficients between birth weight and other production traits were as follows: rate of gain on feeding trials, r = 0.43; feed efficiency, r = 0.12; and weaning weight, r = 0.31. All of these correlation coefficients were statistically significant.

Yao, et al., (1953) found a significant simple correlation coefficient of 0.19 between birth weight and average daily gain while on test in a study of 163 steers individually fed from a standard weight of 500 lbs. to 900 lbs. The correlation coefficient between birth weight and feed efficiency in the data on these cattle was not significant.

Dawson, et al., (1947) studied the relationships between birth weight and other production traits in beef cattle in data collected on 402 calves born as singles. In feeding studies conducted on 72 of these calves which were fed as steers, birth weight was found to be positively correlated, r = 0.28, with average daily gain. The correlation coefficient between birth weight and feed efficiency, expressed as gain per 100 pounds of TDN, was 0.07.

Nelms and Bogart (1955) in a study of 43 individually fed calves computed correlations between birth weight and uncorrected feed efficiency and between birth weight and feed efficiency corrected for maintenance requirements. These calves were fed on a weight basis, from 500 pounds to 800 pounds. For the data on steer calves, the correlation coefficient between birth weight and uncorrected feed efficiency was -0.12. The correlation coefficient between birth weight and corrected feed efficiency was -0.23. The heavier heifer calves at the time of birth made significantly more efficient post weaning gains than lighter calves as indicated by the simple correlation coefficient of -.53 between birth and corrected and uncorrected feed efficiency.

Initial Weight and/or Weaning Weight

Knapp, et al., (1941) found highly significant correlations between weaning weight and feed efficiency but a low correlation between weaning weight and average daily gain in a study of the performance of steers individually fed either from weaning to 900 pounds at Miles City, Montana, or from weaning to 800 pounds at Bozeman, Montana. Analyses were computed on a within year basis.

Patterson, et al., (1949) reported non-significant correlations between initial weight and feed lot gain in data on 814 young bulls and 104 heifers in an experimental test designed to evaluate progeny testing as an aid to the selection of beef cattle. These authors concluded that pretest environmental conditions within sire groups in comparison to those between sire groups was not important in progeny testing procedures.

Kidwell (1953) found none of the correlations between weaning weight and various periodic post weaning gains to be significant in a study of growth relations in beef cattle.

Koch and Clark (1955) found a highly significant positive correlation (r = 0.98) between weaning weight and gain from birth to weaning but a negative correlation (r = -0.28) between weaning weight and gain from weaning to one year of age in a study of 4234 calves produced at the Miles City, Montana station.

Stonaker, et al., (1952) did not find a significant correlation between weaning weight and daily gain in the feed lot. Weaning weight, however, did show a relatively high negative correlation with feed efficiency. The authors believed the heavier calves required more feed for maintenance and therefore possessed lower feed efficiency.

Stanley and McCall (1945) in a three year summary of the steer progeny from three sires which were fed from 400 pounds to 800 pounds found a significant correlation coefficient of .400 between weaning weight and average daily gain in the steers by the same sire and the correlation coefficient between these same two traits was .345, also significant, in the total population of steers.

Ruby, et al., (1948) studied the relation between initial weights and subsequent gains of weanling calves and found a correlation of .232 between initial weight and winter gain, -.144 between initial weight and summer gain and .099 between initial weight and total gain.

Knox, et al., (1951) found a correlation coefficient of 0.28 between weaning weight and gain in the feed lot in young beef calves.

Woodward, et al., (1954) in a study of 635 record of performance steers, found that weaning weight was highly significantly correlated with feed lot gain (r = 0.23) and with feed efficiency (r = -0.29).

Inbreeding

Inbreeding, as defined by Lush (1949), is the mating of animals which have a closer relationship to each other than the average relationship within the population concerned. The primary effect of inbreeding is to make pairs of genes homozygous and to lower the percentage of heterozyous correspondingly. Because this uncovers many recessive genes which would otherwise remain concealed by their dominant alleles, and because recessive genes presumably have less desirable effects than dominant genes there is usually some decrease in average individual merit when inbreeding is practiced.

Inbreeding was studied only to a limited extent in our domestic animals until recent years. Craft (1953) summarized the results of the regional swine breeding laboratory and stated that of the 100 inbred lines of swine initially established within seven breeds, about half had to be discontinued because of poor performance under inbreeding. Litter size usually showed some decline by the time average inbreeding coefficients of the individuals reached 25 to 35 percent. Growth rate had also declined in most lines at these levels of inbreeding. Economy of gain was affected less by inbreeding than were litter size and growth rate. Economy of gain seemingly improved in some lines as inbreeding increased.

Bartlett, et al., (1942) reported on studies of the influence of inbreeding on birth weight, rate of growth, and type in dairy cattle. At five months of age there were no significant differences in the three measurements, height at withers, circumference of chest, and body weight between inbred and outbred groups. At 10 months of age outbred heifers, on the average, outweighed inbred by 21 pounds. This difference was not statistically significant. At 16 and 22 months of age the two groups were similar in regard to all measurements.

Margolin and Bartlett (1945) compared the body weights of inbred dairy calves at specified ages and observed that animals possessing inbreeding coefficients up to 14 percent were equal in weight to outbred controls at all stages of development except for the eighteen-month old females which had inbreeding coefficients from five to nine percent. These inbred heifers were significantly lighter than the outbred controls. Those having inbreeding coefficients from 15 to 19 percent were heavier in body weight than other outbred controls at birth. This difference was not significant. At nine to forty-eight months of age, however, this group tended to be significantly lighter than the outbred group. The group of calves inbred 20 percent or more were equal in weight to the non inbred group from birth to 24 months of age. The authors stated that their findings were in agreement with earlier work which indicated that inbreeding may be accomplished without necessarily causing a decrease in weight or size at any stage from birth to maturity, provided the average coefficient of inbreeding does not exceed twenty percent.

The effects of inbreeding on calf weaning weights were found to be significant by Burgess, et al., (1954). Inbreeding coefficients of 25 percent for both calf and dam should be expected to decrease weaning weight about 75 pounds on the basis of his findings.

Craig and Chapman (1953) found that little, if any, loss of vigor as indicated by body weights in rats, occurred on the average as the result from inbreeding.

Age on Test

Nelms and Bogart (1955) studied the performance of a group of male calves fed from 500 to 800 pounds of individual body weight. For the male calves the correlation between initial age and birth weight was significant ($r = -0.52$); The correlation between initial age and feed efficiency (TDN required per 100 pounds of gain) was not significant ($r = 0.28$); and the correlation between initial age and feed efficiency, corrected for maintenance, was significant ($r = 0.49$). For female calves they found the correlation between initial age and birth weight was highly significant ($r = -0.58$). The correlation coefficients between initial age and uncorrected feed efficiency and feed efficiency corrected for maintenance were significant ($r = 0.42$) in both instances.

Average Daily Gain

Average daily gain has been studied by many workers in regard to its relationship with feed efficiency and other production factors. Knapp, et al., (1941) reported a correlation coefficient of 0.527 between rate of gain and feed efficiency in a study of 127 steers individually fed from the time of weaning to an individual weight of 900 pounds. Black and Knapp (1936) found a correlation coefficient of 0.88 between average daily gain and feed efficiency from weaning to slaughter. These data were obtained on seventy-two steer calves individually fed from weaning age to the time of slaughter.

Bogart and Blackwell (1950) individually fed 12 purebred bull calves from a weight of 550 pounds to 800 pounds. The calves were grouped into the six high and six low gaining groups and average daily gain and feed efficiency were calculated for each group. The fast gaining group gained on the average 2.62 pounds per day and utilized an average of 641 pounds of feed per 100 pounds of gain while the slow gaining group gained on the average 2.32 pounds per day and required 746 pounds of feed per 100 pounds of gain.

Calgon, et al., (1951) observed a high correlation between rate and economy of gain. During a three year period, calves gaining two pounds per day or more, on the average, required 266.6 pounds less feed per 100 pounds of gain than calves which gained less than 1.5 pounds per day.

Baker, et al., (1951) found a significant correlation coefficient of -0.64 between rate of gain and feed efficiency (pounds of feed required per 100 lbs. gain) in a group of 10 steer calves individually fed 222 days on a growing ration followed by a period of 77 days of feeding on a fattening ration.

Grizzle and Kincaid (1954) studied the daily body weight gains and feed consumption data collected on 121 bulls and 66 heifers which were individually fed. They reported that the linear regression of daily feed consumption on body weight accounted for a highly significant amount of the variation in the feed consumption. After adjusting the data on the basis of this finding, the differences among specified feeding periods and among animals within feeding groups were highly significant. The correlation coefficient between rate of gain and feed efficiency (based on observed feed consumption) ranged from -0.05 to 0.63. The correlation coefficients between rate of gain and feed consumption adjusted for linear regression on body weight ranged from 0.77 to 0.88. These findings indicate that rate of gain is a better measure of feed efficiency than the ratio of gain to feed consumption, unless adjustment is made for differences in body weight or constant final weights are used.

They concluded that the use of feed required per 100 pounds of gain as a measure of efficiency in feeding trials may be misleading. They believed that the younger and smaller calves tended to be more efficient because they ate less feed in comparison to those which were older and larger.

Guilbert and Gregory (1944) fed four groups of 10 steers each and found that feed efficiency measured on the basis of group averages and rate of gain were not highly correlated. The initial age and weight variation of the cattle used in the experiment may have been of appreciable but undetermined importance.

Kidwell and McCormick (1956) investigated the influence of size and type on the growth and development of cattle. They used 35 Hereford and 39 Holstein experimental steers. Seven of each group were individually fed. They observed highly significant differences in feed efficiency between the groups with the Holsteins being the most efficient. Kidwell stated that:

> Animals of a larger mature size have a longer period of essentially straight line post weaning growth and a greater rate of increase during this period than animals of a smaller mature size. At equal initial weights animals of greater mature size will increase a greater proportion of bone and muscle and a smaller proportion of fat when full fed for a constant period which does not permit both groups to reach mature weight. This results in greater economy of gain as measured by pounds of feed per 100 pounds of gain. This indicates a possible error in defining pounds of feed per pound of gain as "efficiency of food utilization" for comparative purposes unless it can be shown that the composition of the increase is identical among animals being compared.

Chambers, et al., (1956) reported intra sire correlation coefficients between rate of gain of calves and pounds of feed required per 100 pounds of gain of -0.52 for the first year and -0.66 for the second year of the experiment. Upon adjusting for differences in the average feed lot weights of the calves, these two traits were even more highly correlated (r = -.78 for the first year and -.83 for the second year). These data in this study included a total of 74 bulls, which were individually fed 154 days following common weaning date.

Knapp and Baker (1944) reported a correlation coefficient of 0.49 between rate of gain and gross efficiency in a study which included 66 steers individually fed ad libitum 273 days after weaning. The use of the method for correcting feed efficiency as described by Titus, et al., (1934) raised this corresponding correlation coefficient to 0.83. In these data daily gain varied from 1.42 to 2.48 pounds and initial weight varied from 298 to 492 pounds.

Kohli, et al., (1951) reported analyses of data collected on Milking Shorthorn steers produced in record of performance experiments between 1932 and 1949 at the Beltsville, Maryland Research Center. Although a total of 157 steers were included in the study, the data on 62 of these were also analyzed separately because this particular group of steers was managed different from the others. For the data on the entire 157 steers the correlation coefficient between average daily gain and feed efficiency was 0.70. For the data on the group of 62 steers this correlation coefficient was 0.77. Both correlation coefficients were significant.

Roubicek, et al., (1951) analyzed data obtained on 46 steer progeny of two Hereford and two Shorthorn sires and 35 heifer progeny from the same sires. They observed highly significant correlation coefficients between rate of gain and feed efficiency in the data on both sexes of calves.

In a report on a three-year summary of an experiment conducted to determine whether or not significant differences exist between groups of calves sired by different bulls in regard to feed efficiency, Stanley and McCall (1945) observed a significant correlation coefficient of .779 between average daily gain and feed efficiency (TDN required per 100 pounds gain). The steers were fed from a standard individual initial weight of 400 pounds to 800 pounds. Each steer was fed individually.

Stonaker, et al., (1952) reported correlation coefficients of .436 and .527 between average daily gain and feed efficiency in data obtained on 24 comprest and 63 conventional Hereford steers. Although the comprest steers gained 20 percent less per day, on the average, they consumed approximately 20 percent less feed per day in comparison with the conventional steers. The major size differences prevailing in the Hereford breed were apparently not associated with feed efficiency. Rate of gain, total gain, and total feed consumed were appreciably different between the two types of cattle studied. They found no significant relationship between the average daily pre weaning and post weaning gains of the steers studied.

Woodward and Clark (1950) studied the repeatability of the performance of the progeny of several Hereford sires and found that the relationship between rate of gain and feed efficiency was similar for all sire progeny groups of calves used in the experiment.

Yeo, et al., (1953) reported a highly significant correlation coefficient (r = 0.84) between average daily gain and feed efficiency in a study of the data on 101 beef and 62 Milking Shorthorn steers which were fed on a weight constant basis (500 to 900 pounds).

Woodward, et al., (1942) concluded that large type Hereford steers gained faster and used less feed per 100 pounds of gain in comparison with small type steers when fed on a comparable time constant basis.

Stonaker, et al., (1952) found no correlation between daily pre weaning and post weaning gains in beef steers.

Winters and McMahon (1933) in studies of the feed efficiency variation in steers, found a correlation coefficient of 0.34 between average daily gain and feed efficiency.

Nelms and Bogart (1955) studied the factors affecting the feed efficiency of 45 calves fed individually. For the data on the male calves, rate of gain was highly significantly correlated (r = -0.81) with uncorrected feed efficiency and significantly correlated (r = -0.56) with corrected efficiency. For the data on the females, these respective correlation coefficients were -0.63 and -0.35.

Pierce, et al., (1954) conducted an experiment which included a total of 46 Hereford bull, steer and heifer calves. These calves were individually fed during a period of three years. The correlation coefficient between rate of gain and feed efficiency was highly significant (r = -0.82).

The regression coefficient for feed efficiency on rate of gain was -232.8, indicating that for each one pound increase in average daily gain there was a corresponding decrease of 232.8 pounds of TDN required for each 100 pounds gain in live weight.

Pierce, et al., (1954) analyzed the data on 100 grade steers and 60 grade heifers which were fed in groups of 10 during a period of three years. Rate of gain was significantly affected by all of the four variables studied, birth weight, suckling gain, initial weight, and initial age. Approximately 29 percent (r = .537) of the total variance in rate of gain was accounted for by these four factors.

MacDonald and Bogart (1955) in a study which included data on 42 beef calves, reported a correlation coefficient of 0.68 between rate and feed efficiency for the male calves and 0.87 for the female calves. All calves were stall fed ad libitum and from an individual initial weight of 500 pounds to 800 pounds.

Woodward, et al., (1954) analyzed the data on 635 calves fed individually and found a significant correlation coefficient

(0.47) between rate of gain and feed efficiency.

Heritability

Many heritability estimates have been computed for the various beef cattle production factors considered in this study.

Warwick and Cartwright (1955) analyzed the production data obtained on 853 beef calves in which two breeds were represented. Initial age and weight did not have a significant influence on subsequent gain in the feed lot. Rate of gain appeared to be from 33 to 51 percent heritable.

Knapp and Nordskog (1946) computed heritabilities on the basis of intra-sire correlations and reported the following values for the various production traits in beef cattle: birth weight, 23 percent; weaning weight, 12 percent; total feed lot gain, 99 percent; and feed efficiency, 75 percent.

Kohli, et al., (1952) computed heritability estimates from paternal half-sib correlations on production data obtained on cattle fed on a weight constant basis. The heritability value of average daily gain was 63.6 percent and that for feed efficiency was 25.6 percent.

Knapp and Clark (1950) revised their previous estimates of the heritability of beef cattle production traits. By methods of computation on the basis of half-sib correlations, the following heritability estimates were obtained: birth weight, 53 percent; weaning weight, 28 percent; and total gain, 65 percent.

Dawson, et al., (1955) estimated the heritability of several production traits in Milking Shorthorn steers. The heritability estimates for average daily gain was 18.8 percent; that for feed efficiency, 3.2 percent; and that for birth weight, 50.6 percent.

Complex Studies on Feed Efficiency

Nelms and Bogart (1955) in detailed studies of feed efficiency on data obtained on 43 male and female calves which had been fed individually, computed the partial regression coefficient for feed efficiency on (a) birth weight, (b) initial age, and (c) gain on test. Analyses were made on a within line and within sex basis. The following partial regression coefficients were obtained:

	TDN per 100 lb. gain	
	Actual	Corrected
Birth weight	-1.68 ± 1.62	-1.63 ± 1.50
Initial age	0.40 ± 0.41	0.42 ± 0.39
Gains on test	-124.06 ±35.91	-64.63 ±38.13

The biological implications suggested in reference to these partial regression coefficients were as follows:

1. For each 10-pound increase in birth weight, there was a reduction in the TDN required per 100 pounds of gain which was equal to 16 pounds when feed efficiency was corrected

for maintenance and equal to 17 pounds when no maintenance corrections were made.

2. For each 10-day increase in initial age, there was an increase of 4.2 pounds in TDN required per 100 pounds of gain when feed efficiency was corrected for maintenance. The partial regression coefficient for feed efficiency on initial age was not significant when feed efficiency was uncorrected.

3. For each one pound increase in average daily gain there was a reduction of 124 pounds of TDN required per 100 pounds of gain on the basis of uncorrected feed efficiency. The corresponding reduction in TDN was equal to 65 pounds when feed efficiency was corrected for maintenance.

Multiple correlation analyses indicated that approximately 90 percent of the observed variation in feed efficiency was accounted for by variations in the three independent variables, birth weight, initial weight, and total gain.

Dahmen and Bogart (1952) in a study of the factors affecting gains in beef cattle, analyzed the data obtained on 74 beef calves which were individually fed. Male and female calves differed significantly in regard to rate of gain and feed efficiency. The multiple regression correlation value of all four variables, (birth weight, suckling rate of gain, initial age, and weaning score) on economy of gain was 0.551557. Only the two variables, birth weight and initial age, had a significant effect on rate of gain. The multiple correlation coefficient (R) of rate of gain with birth weight and initial age was 0.6311. Forty percent of the variation in rate of gain could be accounted for by variations in birth weight and initial age.

The partial regression coefficient of rate of gain on birth weight was 0.01, indicating that for each deviation of 1.0 pound in birth weight there was an associated deviation of 0.01 pound in average daily feed lot gain. The partial regression coefficient of average daily gain on initial age was 0.0046, indicating that for each 10-day deviation in initial age there was an associated deviation of 0.05 pounds in average daily feed lot gain.

Of the partial regressions of feed efficiency on the variables (birth weight, suckling rate of gain, initial age, and weaning score) only birth weight was significantly different from zero. This particular partial regression coefficient of -2.096 indicated that for each one pound increase in birth weight above the mean, two pounds less TDN were required on the average per 100 pounds of feed lot gain. The correlation coefficient of feed efficiency with birth weight was 0.4219. Eighteen percent of the variation in feed efficiency was accounted for by variations in birth weight.

Pierce, et al., (1954) analyzed data collected on 19 bulls, 18 heifers, and 9 grade steers, all of which were fed individually over a period of three years. Feed efficiency, as used in the study, was a measure of the pounds of TDN required per pound of gain. Analyses were computed on a within sex within year basis.

Four independent variables, birth weight, suckling gain, initial weight, and initial age were considered. Partial regression coefficients indicated that only birth weight and initial age had a significant effect upon average daily feed lot gains. The multiple correlation of all four of the variables, with average daily gain was equal to .530. After the removal of the two variables, suckling gain and initial weight, the regression coefficient for rate of gain on birth weight was 0.013, indicating that for each increase of one pound in birth weight there was an average increase in average daily gain of 0.013 pound. The regression coefficient of .00438 for average daily gain on initial age indicated that for every 10 days deviation from the mean in initial age there was likewise a deviation equal to .043 pound in average daily gain. The older calves tended to gain faster. The multiple correlation coefficient for birth weight and initial age on rate of gain was .511, indicating that these two variables accounted for 26 percent of the variation in average daily gain during the feeding period.

The correlation coefficient of average daily gain with feed efficiency was -0.82. The regression coefficient for feed efficiency on rate of gain was -232.8, indicating that for every one pound increase in average daily gain there was a corresponding decrease of 232.8 pounds of TDN required per 100 pounds gain in live weight.

Magee (1956) analyzed data obtained on approximately 12 Herefords and 4 Angus bulls fed each year over a five-year period in record of performance tests. Feed efficiency ranged from 650 to 1005 pounds of feed required per 100 pounds gain. Analyses were computed on a within breed, within year basis. The multiple correlation coefficient between feed efficiency and the three variables, average daily gain, initial weight and initial age was 0.86. Initial age did not have a significant effect on feed efficiency after all the variation due to initial weight and average daily gain was accounted for.

MATERIALS AND METHODS

Materials

The data used in this study were obtained on the purebred Shorthorn cattle maintained for experimental purposes in the State Project No. 286, "The Improvement of Beef Cattle Through Breeding Methods", at the Kansas Agricultural Experiment Station, Manhattan, Kansas. These investigations are a part of the North Central Regional Project NC-1, "The Improvement of Beef Cattle Through Breeding Methods."

An inbreeding program was initiated in the Kansas State College Shorthorn herd in 1949 for the development of one inbred line designated as the Wernacre Premier line. A second line, the Mercury line, was established by the introduction of a bull into the herd in 1950. Inbreeding was initiated in the Mercury line in 1952. The foundation sires for these two lines were College Premier 29th, 2368167, and Gregg Farm's Hoarfrost, 2492499, respectively. Both lines have been closed to outside breeding since their establishment.

The cows in both lines have been pasture bred for spring calf production. The calves were not creep-fed during the suckling period. The calves produced in 1950 were weaned at approximately 196 days of age and placed on individual feeding trials for 196 days following a three-week post weaning feed lot adjustment period. The calf weaning age and feed trial period were shortened to 182 days in 1951 and subsequent years to facilitate the feeding and breeding management of the herd.

All calves were individually fed and records of periodic weight gain and feed consumption were maintained. The calves were tied to individual feeders twice a day for two hour periods. The calves were grouped according to sex into three lots. Approximately one-half of the bull calves were castrated each year immediately after weaning. The bull calves which were scored the highest on type were fed as bulls and replacement sires in the breeding herd were selected from these.

The ration used for the feed trials consisted of cracked yellow corn, chopped alfalfa hay, and soybean oil meal. The amount of concentrates was increased gradually during the early part of the feeding period. The alfalfa hay was chopped fine enough so that "sifting" or "sorting" by individual calves was avoided for the most part. Some calves bloated occasionally during the feed trials.

The ration for the various phases of the feed trials was as follows:

(a) 1st & 2nd week -- 20# chopped alfalfa hay and 5# cracked corn.

(b) 3rd week -- 20# chopped alfalfa hay and 10# cracked corn.

(c) 4th week -- 20# chopped alfalfa hay and 15# cracked corn.

(d) 5th week -- 20# chopped alfalfa hay and 20# cracked corn.

(e) 6th & 7th week -- 20# chopped alfalfa hay, 25# cracked corn, and 3# soy bean oil meal. (full-feed ration for heifers).

(f) 8th & 9th week -- 15# chopped alfalfa hay, 25# cracked corn, and 3# soy bean oil meal.

(g) 10th week -- 15# chopped alfalfa hay, 30# cracked corn, and 3# soy bean oil meal.

(h) 11th & 12th week -- 15# chopped alfalfa hay, 40# cracked corn, and 3# soy bean oil meal.

(i) 13th week -- 15# chopped alfalfa hay, 45# cracked corn, and 3# soy bean oil meal. (full-feed ration for bulls and steers).

The ration was mixed and placed in individual sacks in accordance with the preceding specified quantities. The feed was recorded on individual records each time a sack of feed was emptied into a calf's feeder. Feed was provided so that it was available to all calves during the time they were tied to their feeders.

Table 1 is a summary which indicates the number of calves which were individually fed each year during the period from 1950 to 1955 inclusive. Data on the 1956 calves were not complete at the time these analyses were made.

The four variables considered in this study were initial weight, inbreeding, average daily gain, and pounds of total digestible nutrients required per 100 pounds of live body weight gain.

The initial weight of the calves used in this study was the weight of the calves at the beginning of the feed trials. The calves were consistently weighed after being held off feed approximately twelve hours. Initial weight is designated as the X_1 variable in the following analyses. Since the calves were placed on feed trials approximately two weeks after weaning, the initial weight was comparable to the weaning weight.

Inbreeding of the calves was the actual coefficient of inbreeding expressed as the percent of inbreeding. This variable is designated as X_2 in the analyses. Inbreeding coefficients were calculated according to Wright (1923) and were recorded during the progress of the experiment by the use of genetic co-variance charts which were maintained on both of the inbred lines.

The average daily gains of the calves were computed by

Table 1. Number of Shorthorn calves fed individually according to line, sex, year, and sire.

Wernacre Premier Line Year	Sire	Number	Mercury Line Year	Sire	Number
		(a) Heifers			
1950	College Premier 29	9	--	--	--
1951	College Premier 29	6	1951	Gregg Farms Hoarfrost	10
1952	College Premier 29	3	1952	Gregg Farms Hoarfrost	5
1952	KSC Premier 11	4	--	--	--
1953	College Premier 29	5	1953	Gregg Farms Hoarfrost	5
				KSC Mercury	1
1954	--	--	1954	Gregg Farms Hoarfrost	1
				KSC Mercury	6
1955	KSC Premier 11	6	1955	KSC Mercury 4	9
	KSC Premier 14	1			
	Totals	33			37
	Grand total				70
		(b) Bulls			
1950	College Premier 29	7	1950	--	--
1951	College Premier 29	3	1951	Gregg Farms Hoarfrost	1
1952	College Premier 29	2	1952	Gregg Farms Hoarfrost	4
1953	KSC Premier 11	1	1953	Gregg Farms Hoarfrost	2
				KSC Mercury	2
1954	--	--	1954	Gregg Farms Hoarfrost	2
				KSC Mercury	1
1955	KSC Premier 11	1	1955	KSC Mercury 4	4
	Totals	14			16
	Grand total				30
		(c) Steers			
1950	College Premier 29	6	--	--	--
1951	College Premier 29	2	1951	Gregg Farms Hoarfrost	2
1952	College Premier 29	2	1952	Gregg Farms Hoarfrost	1
	KSC Premier 11	1			
1953	College Premier 29	3	1953	Gregg Farms Hoarfrost	3
1954	College Premier 29	2	1954	Gregg Farms Hoarfrost	1
	KSC Premier 11	2		KSC Mercury	2
1955	KSC Premier 14	1	1955	KSC Mercury 4	4
	Totals	19			14
	Grand total				33

dividing the total feed trial gain by the total number of days the calves were fed. Average daily gain is the X_3 variable in the analyses.

Feed efficiency, the Y variable in the analyses, is the average number of pounds of total digestible nutrients (TDN) that a calf utilized for a live body weight gain of 100 pounds during a feed trial. No corrections for maintenance were made. Feeds were not analyzed. Total digestible nutrients intakes were estimated by the use of Morrison's (1949) tables of average composition of feeding stuffs.

Methods

The data were analyzed for the determination of the means and standard deviations of the variables considered, simple correlations between all four of the variables, multiple correlations of the three independent variables (initial weight, inbreeding, and average daily gain) with the dependent variable (feed efficiency), partial and standard partial regression coefficients of feed efficiency on the three independent variables, and analyses of variance as described by Snedecor (1946 and 1956). Sex, line, and year effects were treated by computing all analyses on a within sex, within year, and within line basis. Analyses were not made on a within sire basis because of the very limited number of sire comparisons existing within a line within any one year. All results are presented on a within sex basis.

RESULTS

Presentation of Data

The data used on the 70 heifers, 30 bulls, and 33 steers are presented in Tables 2, 3, 4, and 5. These are summarized on a within line, within year, within sex basis. Data for each of the variables appear in these tables and year averages for both lines combined as well as total averages for totals are included.

The standard deviations for all variables are presented in Table 6.

Analyses of variance were computed as a part of the multiple correlation studies. These are presented on a within sex basis in Table 7.

Summaries of the initial weight (X_1) data, presented in Table 2, indicate that calves of the Wernacre Premier line were heavier on the average than those of the Mercury line. Analyses of variance revealed that this difference was significant only in the case of the steers as indicated in Table 7. Since the general analyses were computed on a within line basis, consideration was not given to studies of the difference in initial weight between lines.

The standard deviations of initial weight (X_1) presented in Table 6 show that considerable variation existed in the experimental animals in regard to this variable. This afforded an excellent opportunity to study the effect of initial weight

Table 2. Average initial weights (X_1) of calves expressed in pounds of live body weight at the start of feed trials for both the Wernacre Premier (WP) and Mercury (M) lines. ($\bar{x}_1$ - average initial weights; n - number of individuals)

Lines		Year 1950	1951	1952	1953	1954	1955	Total
(a) Heifers								
WP	$\bar{x}_1$	418.13	435.00	375.14	349.20	--	370.71	391.58
	n	8	6	7	5	0	7	33
M	$\bar{x}_1$	--	369.30	369.00	370.83	317.14	348.78	354.65
	n	0	10	5	6	7	9	37
Total	$\bar{x}_1$	418.13	393.94	372.58	361.00	317.14	358.38	372.06
	n	8	16	12	11	7	16	70
(b) Bulls								
WP	$\bar{x}_1$	492.86	537.67	499.50	297.00	--	486.00	488.93
	n	7	3	2	1	0	1	14
M	$\bar{x}_1$	--	537.00	424.75	348.50	387.67	428.00	406.56
	n	0	1	4	4	3	4	16
Total	$\bar{x}_1$	492.86	537.50	449.67	338.20	387.67	439.60	445.00
	n	7	4	6	5	3	5	30
(c) Steers								
WP	$\bar{x}_1$	437.50	544.00	384.67	446.00	424.00	345.00	434.00
	n	6	2	3	3	4	1	19
M	$\bar{x}_1$	--	432.50	360.00	424.33	375.33	354.00	385.29
	n	0	2	1	3	3	5	14
Total	$\bar{x}_1$	437.50	488.25	378.50	435.17	403.14	352.50	413.33
	n	6	4	4	6	7	6	33

Table 3. Average coefficients of inbreeding (X_2) of calves expressed as percent of inbreeding for both the Wernacre Premier (WP) and Mercury (M) lines. ($\bar{x}_2$ - average coefficient of inbreeding; n - number of individuals).

Lines		Year 1950	1951	1952	1953	1954	1955	Total
				(a) Heifers				
WP	$\bar{x}_2$	13.13	11.83	20.86	10.40	--	20.00	15.58
	n	8	6	7	5	0	7	33
M	$\bar{x}_2$	--	0.0	0.0	2.33	7.29	11.56	4.57
	n	0	10	5	6	7	9	37
Total	$\bar{x}_2$	13.13	4.44	12.17	6.00	7.29	15.25	9.76
	n	8	16	12	11	7	16	70
				(b) Bulls				
WP	$\bar{x}_2$	9.86	12.33	11.00	25.00	--	32.00	13.21
	n	7	3	2	1	0	1	14
M	$\bar{x}_2$	--	0.0	0.0	6.75	8.33	9.50	5.63
	n	0	1	4	4	3	4	16
Total	$\bar{x}_2$	9.86	9.25	3.67	10.40	8.33	14.00	9.17
	n	7	4	6	5	3	5	30
				(c) Steers				
WP	$\bar{x}_2$	7.17	11.00	11.67	13.00	19.75	15.00	12.26
	n	6	2	3	3	4	1	19
M	$\bar{x}_2$	--	0.0	0.0	0.0	5.67	13.40	6.00
	n	0	2	1	3	3	5	14
Total	$\bar{x}_2$	7.17	5.50	8.75	6.50	13.71	13.67	9.61
	n	6	4	4	6	7	6	33

Table 4. Average daily gains (X_3) of calves expressed in pounds for both the Wernacre Premier (WP) and Mercury (M) lines. ($\bar{x}_3$ - average daily gains; n - number of individuals)

Lines		1950	1951	1952	1953	1954	1955	Total
				Year				
				(a) Heifers				
WP	$\bar{x}_3$	1.6838	1.7267	1.6900	1.6180	--	1.5200	1.6482
	n	8	6	7	5	0	7	33
M	$\bar{x}_3$	--	1.5340	1.4260	1.7567	1.7471	1.5422	1.5978
	n	0	10	5	6	7	9	37
Total	$\bar{x}_3$	1.6338	1.6063	1.5800	1.6936	1.7471	1.5325	1.6216
	n	8	16	12	11	7	16	70
				(b) Bulls				
WP	$\bar{x}_3$	2.5343	2.3667	2.9450	2.4200	--	2.1800	2.5236
	n	7	3	2	1	0	1	14
M	$\bar{x}_3$	--	2.4500	2.5050	2.2525	2.5067	2.4175	2.4169
	n	0	1	4	4	3	4	16
Total	$\bar{x}_3$	2.5343	2.3875	2.6517	2.2860	2.5067	2.3700	2.4667
	n	7	4	6	5	3	5	30
				(c) Steers				
WP	$\bar{x}_3$	2.1467	1.7400	2.1567	2.1433	2.2475	1.9100	2.1137
	n	6	2	3	3	4	1	19
M	$\bar{x}_3$	--	2.1750	2.1800	2.2533	2.1833	1.9880	2.1271
	n	0	2	1	3	3	5	14
Total	$\bar{x}_3$	2.1467	1.9575	2.1625	2.1983	2.2200	1.9750	2.1194
	n	6	4	4	6	7	6	33

Table 5. Average total digestible nutrients (Y) expressed in pounds, required by the calves per 100 pounds of live body weight gain for both the Wernacre Premier (WP) and Mercury (M) lines. ($\bar{y}$ - average total digestible nutrients; n - number of individuals)

Lines		1950	1951	1952	1953	1954	1955	Total
		Year						
(a) Heifers								
WP	$\bar{y}$	616.38	632.33	508.86	477.80	--	480.43	546.64
	n	8	6	7	5	0	7	33
M	$\bar{y}$	--	614.80	549.80	491.33	477.00	503.44	532.84
	n	0	10	5	6	7	9	37
Total	$\bar{y}$	616.38	621.38	525.92	485.18	477.00	493.38	539.34
	n	8	16	12	11	7	16	70
(b) Bulls								
WP	$\bar{y}$	502.43	571.67	438.00	397.00	--	475.00	498.57
	n	7	3	2	1	0	1	14
M	$\bar{y}$	--	559.00	404.50	408.50	407.67	430.25	422.19
	n	0	1	4	4	3	4	16
Total	$\bar{y}$	502.43	568.50	415.67	406.20	407.67	439.20	457.83
	n	7	4	6	5	3	5	30
(c) Steers								
WP	$\bar{y}$	575.50	746.00	456.67	480.33	488.00	505.00	537.53
	n	6	2	3	3	4	1	19
M	$\bar{y}$	--	561.50	472.00	468.00	487.33	451.60	419.93
	n	0	2	1	3	3	5	14
Total	$\bar{y}$	575.50	653.75	460.50	474.17	487.71	460.50	513.09
	n	6	4	4	6	7	6	33

Table 6. Standard deviations of initial weight, coefficient of inbreeding, average daily gain, and feed efficiency, within sexes and within lines within years and within sexes.

Variants	Standard Deviations: Within Sex	Mean ± standard deviation	Within sex, within lines and within years
1. Initial weight (X_1) expressed in pounds			
(a) Heifers	57	315 - 429	50
(b) Bulls	82	368 - 527	58
(c) Steers	56	357 - 470	35
2. Coefficient of inbreeding (X_2) expressed in percent			
(a) Heifers	9	1 - 19	5
(b) Bulls	9	0 - 18	7
(c) Steers	7	2 - 17	4
3. Average daily gain (X_3) expressed in pounds			
(a) Heifers	0.23	1.39 - 1.85	0.22
(b) Bulls	0.31	2.16 - 2.77	0.31
(c) Steers	0.21	1.91 - 2.32	0.19
4. Feed efficiency (Y) expressed in pounds /100# gain			
(a) Heifers	88	452 - 627	67
(b) Bulls	73	385 - 531	53
(c) Steers	97	416 - 611	75

Table 7. Analyses of variance of initial weight (X_1), coefficient of inbreeding (X_2), average daily gain (X_3), and feed efficiency (Y) for (a) heifers, (b) bulls and (c) steers.

Source of variance	d f	X_1 Initial weight	X_2 Coefficients of inbreeding	X_3 Average daily gain	Y Feed efficiency
		Mean Squares			
		(a) Heifers			
Between years	5	10,018	259	.07	50,117**
Between lines w/i years	4	4,867.	563**	.10..	2,157
Within lines w/i years	60	2,524	29	.05	4,499
		(b) Bulls			
Between years	5	23,485*	62	.0954	19,239**
Between lines w/i years	4	3,066	237**	.0827	831
Within lines w/i years	20	3,347	52	.0977	2,786
		(c) Steers			
Between years	5	11,320	76	.0700	28,753..
Between lines w/i years	5	3,544*	163**	.0440	7,364
Within lines w/i years	22	1,252	20	.0356	5,602

** - Significant at 1% level
* - Significant at 5% level
.. - Significant at 10% level
. - Significant at 25% level

upon feed efficiency.

Data relative to the inbreeding of the calves used in the study are presented in Table 3. The average coefficients of inbreeding are appreciably higher in the Wernacre Premier than the Mercury line for all years. This is due to the fact that inbreeding was initiated first in the Wernacre Premier line. The analyses of variance shown in Table 7 indicate that the differences in inbreeding between the two lines within years are highly significant. Although the calves were not highly inbred, there was considerable variation in the coefficients of inbreeding as shown in Table 6.

Data pertaining to the average daily gains of calves are shown in Table 4. Considerable variation existed among individuals within sexes and likewise the sexes differ markedly. Part of the difference between the heifers compared to the bulls and steers is due to the difference in the rations used. The means, as shown in Table 4, indicate that the bulls gained more rapidly on the average than the steers. No attempt was made to evaluate sex differences in gaining ability in this study. Analyses of variance presented in Table 7 indicate that the between years and between line within year sources of variation were not significant in the data used in this study.

The feed efficiency data are summarized in Table 5 which shows that considerable variation existed between years whereas the variation between lines within years was comparatively small as indicated in Table 6. Analyses of variance which are presented in Table 7 indicate that the variation in feed efficiencies between years was highly significant in the data for both heifers and bulls. This was not the case in the data for the steers. The standard deviations in Table 6 show that considerable individual variation existed among the calves of all three sexes.

Analyses of Data

As previously mentioned, this study was made to evaluate the effects of three independent variables, initial weight, inbreeding, and average daily gain, upon the dependent variable, feed efficiency. There are undoubtedly other independent variables which are sources of variation in feed efficiency, however these were not considered in this study. A graphic portrayal of the probable sources of variation in feed efficiency are shown in Fig. 1.

A graphic portrayal of the sources of variation in feed efficiency considered in this study and the relationships among these independent variables is presented in Fig. 2.

The statistical analyses were computed within sexes and within years. The computations in the analyses were as follows:

(a) Simple correlations

(1) $r\ x_1\ y$

(2) $r\ x_2\ y$

(3) $r\ x_3\ y$

(4) $r\ x_1\ x_2$

(5) $r\ x_1\ x_3$

(6) $r\ x_2\ x_3$

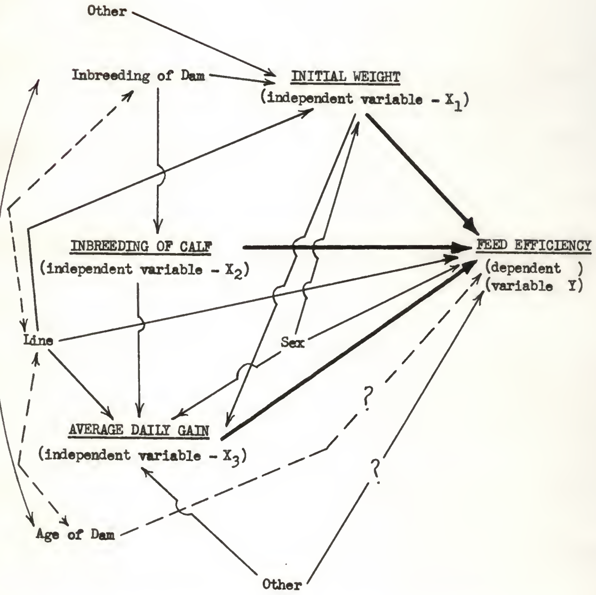

Fig. 1. A graphic portrayal of the probable sources of variation in feed efficiency.

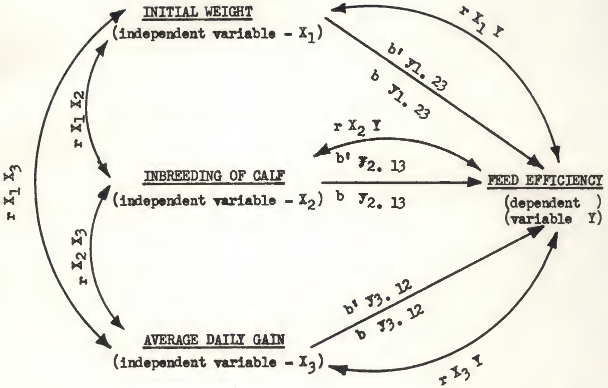

Fig. 2. A graphic portrayal of the sources of variation in feed efficiency considered in this study and the relationships among these independent variables.

(b) Standard Partial Regressions

(1) $b'y$ 1.23

(2) $b'y$ 2.13

(3) $b'y$ 3.12

(c) Partial Regressions

(1) by 1.23

(2) by 2.13

(3) by 3.12

(d) Multiple correlation (R) for all three of the independent variables (X_1, X_2 and X_3) with the dependent variable (Y).

The simple correlation coefficients, standard partial regression coefficients, partial regression coefficients, and multiple correlation coefficients were tested for significance and 95 percent confidence intervals were computed for the partial regression coefficients.

Analyses of Data on the Heifers

The simple correlation coefficients among the independent variables and between each of these and feed efficiency are presented in Table 8. The highly significant negative correlation between the coefficient of inbreeding and initial weight indicated that inbreeding decreased initial weight significantly in these data. Since weaning weight was approximately the same as initial weight, inbreeding probably had a comparable effect on weaning weight although this was not included in this study.

Many of the dams of the more highly inbred calves included in these data were at least slightly inbred. In the event that inbreeding of dams is related to maternal ability in cows, the effects of the inbreeding of the dams is probably confounded with the effects of the inbreeding of the calves in this study.

Table 8. Simple correlation coefficients among the independent variables and between each of the independent variables and the dependent variable in the data on the heifers. All computations were made on a within year within line basis.

Variable	Initial weight	Inbreeding of calf	Average daily gain	Feed efficiency
	X_1	X_2	X_3	Y
X_1	--	-.36**	-.04	.37**
X_2		--	.08	-.12
X_3			--	-.34**

**Significant at the 1% level of probability; d.f. = 60.

The highly significant positive correlation between initial weight and feed efficiency indicated that the higher the initial weight, the greater the amount of TDN required per 100 pounds of live weight body gain.

The highly significant negative correlation between average daily gain and feed efficiency indicated that the more rapidly the calves gained, the smaller the amount of TDN required per 100 pounds of live weight body gain.

The simple correlation coefficients between initial weight and average daily gain, inbreeding of calf and average daily gain, and inbreeding of calf and feed efficiency were all non-significant.

The standard partial regression coefficients of feed efficiency on the independent variables are presented in Table 9. These permitted observations of the comparative value of each of the independent variables for the prediction of feed efficiency. Initial weight and average daily gain both contributed to the knowledge of feed efficiency whereas inbreeding appeared to add very limited information in these data.

The partial regression coefficients of feed efficiency on the three independent variables and their respective confidence intervals at the 95 percent level of probability are presented in Table 10. These partial regression coefficients were used in the multiple regression equation $Y = 512.6360 + .4930 X_1 + .4767 X_2 - 99.4805 X_3$.

Table 9. Standard partial regression coefficients of the dependent variable on the three independent variables in the data on the heifers. All computations were made on a within year within line basis.

Independent variables	Standard partial regression coefficients
Initial weight	.3793**
Coefficients of inbreeding	.0375
Average daily gain	-.3303**

**Significant at the 1% level of probability; d.f. = 60.

Table 10. Partial regression coefficients of the dependent variable on the three independent variables in the data on the heifers. All computations were made on a within year within line basis.

Independent variables	Partial regression coefficients	95% Confidence intervals
Initial weight	.4930**	0.1662 to 0.8197
Coefficients of inbreeding	.4767	-2.5877 to 3.5211
Average daily gain	-99.4805**	-178.5759 to - 30.3853

**Significant at the 1% level of probability; d.f. = 60.

The following biological implications were justifiable in reference to the respective partial regression coefficients:

(1). For each two pounds increase in initial weight, on the average, an additional one pound of TDN was required for each 100 pounds of live weight gain while on a feeding trial.

(2). For each one-tenth pound increase in average daily gain, on the average, ten pounds less TDN were required per 100 pounds gain of live body weight.

(3). For each two percent increase in coefficient of inbreeding, on the average, one additional pound of TDN was required per 100 pounds of live weight body gain.

The multiple correlation value (R) for all three of the independent variables with feed efficiency was .4966, which was highly significant. Twenty-five percent of the variation in feed efficiency in the data for the heifers could be accounted for by the three variables, initial weight, coefficients of inbreeding, and average daily gain. Initial weight accounted for 14 percent of the variance, average daily gain, 11 percent, and inbreeding coefficient, less than one percent. Both initial weight and average daily gain accounted for a highly significant amount of the variation in feed efficiency whereas that which was accounted for by coefficient of inbreeding, was not significant.

Analyses of Data on the Bulls

The simple correlation coefficients among the independent variables and between each of these and feed efficiency are presented in Table 11. The highly significant negative correlation between average daily gain and feed efficiency indicated that the more rapid gaining bulls made the most economical gains.

The highly significant negative correlation between the coefficients of inbreeding and initial weight indicated that inbreeding decreased initial weight significantly.

The simple correlation coefficients between initial weight and average daily gain, initial weight and feed efficiency, inbreeding coefficients and average daily gain, and inbreeding and feed efficiency were all nonsignificant. A relatively high positive correlation was found between initial weight and average daily gain which was an indication of a trend of relationship between these two variables. The correlation coefficient between initial weight and feed efficiency was positive and indicative

Table 11. Simple correlation coefficients among the independent variables and between each of the independent variables and the dependent variable in the data on the bulls. All computations were made on a within year within line basis.

Variables	Initial weight	Inbreeding of calf	Average daily gain	Feed efficiency
	X_1	X_2	X_3	Y
X_1	--	-.55**	.38	.29
X_2		--	-.14	-.27
X_3			--	-.58**

**Significant at the 1% level of probability; d.f. = 20.

of the same trend of relationship between these two variables as was found in the data on the heifers.

The correlation coefficient between inbreeding coefficients and feed efficiency was negative as in the case of the data on the heifers; however, it was nonsignificant in both sets of data.

It should be noted that the degrees of freedom are appreciably smaller for the data on the bulls in comparison to those for the data on the heifers. This difference introduces considerable change in regard to sampling errors in evaluations of the two sets of analyses.

The standard partial regression coefficients of feed efficiency on the independent variables are presented in Table 12. These permitted observations of the comparative value of each of the independent variables for the prediction of feed efficiency.

Table 12. Standard partial regression coefficients of the dependent variable on the three independent variables in the data on the heifers. All computations were made on a within year within line basis.

Independent variables	Standard partial regression coefficients
Initial weight	.460038
Coefficients of inbreeding	-.095879
Average daily gain	-.584269**

**Significant at the 1% level of probability; d.f. = 20.

Initial weight and average daily gain both appeared to contribute to the knowledge of feed efficiency whereas inbreeding seemed to add no information in these data. Only the standard partial regression coefficient of feed efficiency on avera e daily gain was statistically significant. The partial regression coefficients of feed efficiency on the three independent variables and their respective confidence intervals at the 95 percent level of probability are presented in Table 13. These partial regression coefficients were used in the multiple regression equation, $Y = 509.50 + .4197 X_1 \quad -.7048 X_2 \quad -98.6458 X_3$

The following biological implications were justifiable in reference to the respective partial regression coefficients:

(1). For each pound increase in initial weight, on the average, an additional four-tenths pound of TDN was required for each 100 pounds of live weight gain while on a feeding trial.

(2). For each one-tenth pound increase in average daily gain, on the average, ten pounds less TDN was required per 100

Table 13. Partial regression coefficients of the dependent variables on the three independent variables in the data on the bulls. All computations were made on a within year within line basis.

Independent variables	Partial regression coefficients	95% Confidence intervals
Initial weight	.4197	-.0339 to .8733
Coefficients of inbreeding	-.7048	-4.1263 to 2.7166
Average daily gain	-98.6458**	-169.5299 to -27.7617

**Significant at the 1% level of probability; d.f. = 20.

pounds of live weight body gain.

(3). For each ten percent increase in coefficient of inbreeding, on the average, seven pounds less of TDN were required for each 100 pounds of live weight body gain.

The multiple correlation value (R) for all three of the variables with feed efficiency was .6264, which was highly significant. Thirty-nine percent of the variation in feed efficiency in the data for the bulls could be accounted for by the three variables, initial weight, coefficient of inbreeding, and average daily gain. Initial weight accounted for 16 percent of the variance, average daily gain, 23 percent, and inbreeding coefficient, less than one percent. Average daily gain accounted for a highly significant amount of the variation in feed efficiency whereas those which were accounted for by initial weight and coefficients of inbreeding were not significant.

Analyses of Data on the Steers

The simple correlation coefficients among the independent variables and between each of these and feed efficiency are presented in Table 14. None of these correlations were significant. Although these were not significant, the higher values were at least comparable to the significant correlation coefficients in the data on the heifers and bulls. The more highly inbred steers tended, however not significantly, to have lower initial weights. Likewise, the more highly inbred steers tended to make more efficient gains and higher average daily gains while on feeding trials. The data on the steers, as that for the bulls, was limited in regard to numbers of individuals.

Table 14. Simple correlation coefficients among the independent variables and the dependent variable in the data on the steers. All computations were made on a within year within line basis.*

Variables	Initial weight	Inbreeding of calf	Average daily gain	Feed efficiency
	X_1	X_2	X_3	Y
X_1		-.16	.05	.39
X_2		---	.25	-.29
X_3			--	-.28

*d.f. = 22.

The standard partial regression coefficients of feed efficiency on the independent variables are presented in Table 15. These permitted observations of the comparative value of each

Table 15. Standard partial regression coefficients of the dependent variable on the three independent variables in the data on the bulls. All computations were made on a within year within line basis.*

Independent variables	Standard partial regression coefficients
Initial weight	.381588
Coefficient of inbreeding	-.154888
Average daily gain	-.280897

*d.f. = 22.

of the independent variables for the prediction of feed efficiency. Initial weight appeared to contribute the most toward a knowledge of feed efficiency and was followed by average daily gain with the coefficients of inbreeding being of least importance. The preceding statement makes reference to the general trend as none of standard partial regression coefficients was statistically significant.

The partial regression coefficients and their 95 confidence intervals are presented in Table 16. These were used in the multiple regression equation $Y = 440.30 + .8071 X_1 -2.5807 X_2 -111.5012 X_3$. The following biological implications may be made in reference to the respective partial regression coefficients:

(1). For each one pound increase in initial weight, on the average, an additional eight-tenths pound of TDN was required for each 100 pounds of live weight gain while on a feeding

Table 16. Partial regression coefficients of the dependent variable on the three independent variables in the data on the bulls. All computations were made on a within year within line basis.*

Independent variables	Partial regression coefficients	95% Confidence intervals
Initial weight	0.8071	-0.0479 to 1.6620
Coefficients of inbreeding	-2.5807	-9.2090 to 4.0477
Average daily gain	-111.5012	-274.8859 to 51.8834

*d.f. = 22.

trial.

(2). For one-tenth pound increase in average daily gain, on the average, eleven pounds less TDN were required per 100 pounds of live weight body gain.

(3). For each one percent increase in coefficient of inbreeding, on the average, two and six-tenths pounds less TDN were required per 100 pounds of live weight body gain.

The multiple correlation value (R) for all three of the independent variables with feed efficiency was .5285 which was highly significant. Twenty-eight percent of the variation in feed efficiency among the data on the steers could be accounted for by the three variables, initial weight, coefficients of inbreeding, and average daily gain. Initial weight accounted for 16 percent of the variation in feed efficiency, average daily gain, ten percent, and coefficients of inbreeding, two percent. None of these were significant.

CONCLUSIONS

In conclusion it may be stated that the findings of this study reveal the existence of pronounced individual variability of the beef cattle production traits of animals maintained under similar environmental conditions. The relationships among the independent variables studied (initial weight, inbreeding of calf, and average daily gain) and the relationships of these with the dependent variable (feed efficiency) have been investigated by other research workers.

The simple correlations found in this study between average daily gain and feed efficiency (heifers, -0.34**; bulls, -0.58**; and steers, -0.28) indicate that the more rapid gaining individuals are the most efficient, as has been reported by many workers. Why the correlations computed in these data are not as high as many others which have been reported cannot be explained. It is believed that adjustment for linear regression of initial weight on average daily gain or on feed efficiency might increase the relationship between rate of gain and feed efficiency in these data. Chambers, et al., (1956) reported that the correlation coefficient between rate of gain and feed efficiency increased from -0.52 to -0.78 in one instance and from -0.66 to -0.83 in another upon adjusting for the average feed lot weight. Grizzle and Kincaid (1954) also reported an increase in the correlation coefficient between these two factors from 0.77 to 0.88 after adjustment for linear regression on body weight. Nelms and Bogart (1955), however, reported a decrease in this correlation coefficient from -0.81** to -0.56* upon correcting for maintenance requirements on the basis of body weight in beef calves.

Few studies have been made of beef cattle production data collected on a weight constant basis because of the natural complications of the necessary experimental design and the method of management is not characteristic of practical production. It does tend to eliminate initial weight as an important variable but may introduce complications due to initial age. If future studies substantiate the importance of initial weight as indicated in these findings, adjustment for initial weight will be necessary in order to justify the use of rate of gain for the prediction of feed efficiency.

The relationship between initial weight and feed efficiency in this study, although significant only in the data on the heifers, indicates that the calves heavier in initial weight at the start of a feeding trial also required on the average, more TDN per 100 pounds live weight gain as indicated by the correlation coefficients (heifers, 0.37**; bulls, 0.29; and steers, 0.39). This should be expected on the basis of a knowledge of maintenance requirements as presented in the review of literature.

The initial weight appeared to have little consistent relation with rate of gain on test. The correlation coefficients between initial weight and average daily gain were -0.04 for the heifers, 0.38 for the bulls, and 0.05 for the steers.

Although an individual calf's efficiency of feed conversion decreased as initial weight increased, its ability to gain was not significantly affected within the limits of variability in the initial weights included in the data used.

Inbreeding, a factor not extensively studied to date in beef cattle, was not found to be significantly correlated with either average daily gain or with feed efficiency in any of the analyses. However, inbreeding was found to be significantly negatively correlated with initial weight in two of three analyses (heifers, -0.36**; steers, -0.55**; and bulls, -0.16). Since weaning weight was approximately the same as initial weight, inbreeding probably has a comparable effect on weaning weight. Most of the dams of calves possessing considerable inbreeding were themselves inbred. If inbreeding of dam affects maternal ability, this effect was confounded with the inbreeding of the calves used in this study.

Inbreeding apparently had no relationship whatsoever with average daily gain. The correlation coefficients were 0.08 for the heifers, -0.14 for the bulls, and 0.25 for the steers.

Inbreeding was found to be consistently, although not significantly, negatively correlated with feed efficiency (heifers, -0.12; bulls -0.27; and steers, -0.29). The more highly inbred calves tended to be the most efficient. This tends to be in agreement with some of the findings in swine reviewed by Craft (1953). Because inbreeding was negatively correlated with initial weight and initial weight was negatively correlated with feed efficiency, the more highly inbred calves may have tended to be the more efficient because inbreeding tended to suppress initial weight.

The highly significant multiple correlation values of initial weight, inbreeding coefficients, and average daily gain with feed efficiency (.4966 for the heifers; .6264 for the steers; and .5285 for the bulls) indicate that the three independent variables account for 25, 39, and 28 percent, of the variation in feed efficiency among the heifers, bulls, and steers, respectively, in this study. Because of the larger sample size in the case of the data on the heifers, the findings from the analyses of that set of data are likely more nearly representative of the true relationships between the variables under consideration. In the case of the data on the heifers a multiple correlation value of .50 was found between the independent variables (initial weight, inbreeding of calf, and average daily gain) and feed efficiency, thus accounting for 25 percent of the feed efficiency variation. Initial weight accounted for slightly more than one-half of this variation and average daily gain somewhat less. Inbreeding at the levels existing in these data appeared to account for very little, if any, of the variation in feed efficiency.

While none of the complex studies reviewed in the literature involved identically the same variables, reference to these investigations may be made for comparison.

Magee (1956) studied the effects of average daily gain, initial weight, and initial age on feed efficiency and reported a multiple correlation value (R) of .86. Initial age was found to be nonsignificant. His findings are similar to those of this study in regard to the influences of initial weight and average daily gain upon feed efficiency. The multiple correlation value was however much higher than that obtained in this study.

Pierce, et al., (1954) in a multiple correlation study of birth weight, suckling gain, initial age, and initial weight with average daily gain, found that birth weight and initial age added significantly to the variation in gaining ability. The multiple correlation value of the four variables with average daily gain was .53. Upon removal of the two nonsignificant variables, suckling gain and initial weight, R = .511. Twenty-six percent of the variation in average daily gain was accounted for by birth weight and initial age.

Nelms and Bogart (1955) in a multiple correlation study involving birth weight, initial age, and gain on test, found a very high multiple correlation value (R = .99). The three independent variables accounted for approximately 90 percent of the variation in feed efficiency.

Dahmen and Bogart (1952) studied the effects of birth weight, suckling rate of gain, initial age and weaning score on economy of gain and reported a multiple correlation value of these variables with feed efficiency of .55.

SUMMARY

The purpose of this study was to investigate the possibility of estimating feed efficiency indirectly by means of its relationship with other production factors. The other production factors considered in this study were initial weight, inbreeding of calf, and average daily gain. A total of 133 purebred Shorthorn calves produced during the period 1950 through 1955 inclusive were individually fed for 196 days in 1950 and 182 days in the following years following a short post weaning adjustment period. Data collected on 70 heifers, 30 bulls, and 33 steers were used in the analyses. These data are presented in the appendix tables.

The data collected on these animals were analyzed for the simple correlations between all four variables, multiple correlations of the three independent variables (initial weight, inbreeding of calf, and average daily gain) on the dependent variable (feed efficiency), partial and standard partial regression coefficients for feed efficiency on the three independent variables, and analyses of variance. All analyses were computed on a within sex, within line, within year basis and the results were so presented.

Multiple correlations of the independent variables on feed efficiency were highly significant in all three analyses and accounted for 25, 39, and 28 percent, respectively, of the variation in feed efficiency among the data on the heifers, bulls,

and steers used in the study. Initial weight accounted for approximately one-half and average daily gain also for about one-half of the variation in feed efficiency. Inbreeding, at the levels included in this study, appeared to account for very little, if any, of the variation in feed efficiency.

Average daily gain was negatively correlated with feed efficiency. The more rapid gaining animals required, on the average, less TDN per 100 pounds gain in live weight gain.

Initial weight was positively correlated with feed efficiency. The heavier calves at the start of the feeding trials, on the average, required more TDN per 100 pounds of live weight gain than the lighter calves.

Inbreeding was negatively correlated with initial weight. The higher the inbreeding, the lower the initial weight on the average. Due to the close relationship between initial weight and weaning weight, the same relationship probably existed between inbreeding and weaning weight.

Other relationships between the variables were not statistically significant or consistent in the analyses.

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APPENDIX

Table 17. Data collected on the 1950 Shorthorn calves, Sire College Premier 29th.

	Calf	Fx^1	Dam	Fx^2	Initial weight	Final weight	Total gain	Days fed	Ave. daily gain	Total TDN per 100 lbs. gain
Variables under study		X_2			X_1				X_3	Y
Heifers:	01	16	45	00	475	825	350	196	1.79	663
	03	00	C163	00	475	850	375	196	1.91	550
	013	19	61	00	340	690	350	196	1.79	526
	021	16	801	00	360	650	290	196	1.48	579
	029	17	505	00	440	760	320	196	1.63	653
	031	13	355	00	420	725	305	196	1.56	590
	039	16	435	00	410	720	310	196	1.58	575
	041	8	513	00	425	765	340	196	1.73	795
Total:		105		00	3345	5985	2640		13.47	4931
Average:		13		00	418	748	330		1.68	616
Bulls:	0050	6	825	00	480	920	440	196	2.24	523
	05	13	024	00	495	915	420	196	2.45	538
	07	19	53	00	475	960	485	196	2.47	504
	023	3	529	00	490	980	490	196	2.50	481
	033	14	715	00	530	1145	615	196	3.14	514
	035	00	124	00	535	1020	485	196	2.47	516
	037	14	357	00	445	930	485	196	2.47	441
Total:		69		00	3450	6870	3420		17.74	3517
Average:		10		00	493	981	489		2.53	502

Table 17 (concl.)

	Calf	Fx^1	Dam	Fx^2	Initial weight	Final weight	Total gain	Days fed	Ave. daily gain	Total TDN per 100 lbs. gain
Variables under study:		X_2			X_1				X_3	Y
Steers:	09	7	729	00	455	880	425	196	2.17	573
	011	8	714	00	465	875	410	196	2.09	613
	015	13	615	00	425	865	440	196	2.24	513
	019	8	739	00	375	825	450	196	2.30	570
	025	0	103	00	480	865	385	196	1.96	646
	027	7	605	00	425	840	415	196	2.12	538
Total:		43		00	2625	5150	2525		12.88	3453
Average:		7		00	438	858	421		2.15	576

1. Fx^1, coefficient of inbreeding of calf.
2. Fx^2, coefficient of inbreeding of dam.

Table 18. Data collected on the 1951 Shorthorn calves, Sire College Premier 29th.

Variables under study	Calf	Fx X_2	Dam	Fx	Initial weight X_1	Final weight	Total gain	Days fed	Ave. daily gain X_3	Total TDN per 100 lbs. gain Y
Heifers:	11	-	527	-	553	856	303	182	1.66	618
	123	14	357	-	434	736	302	182	1.66	664
	19	13	427	-	485	856	371	182	2.04	605
	135	8	513	-	416	683	267	182	1.71	683
	137	17	505	-	384	714	330	182	1.69	739
	143	19	61	-	338	619	281	182	1.60	485
Total:		71		-	2610	4464	1854		10.36	3794
Average:		12		-	435	744	309		1.73	632
Bulls:	121	7	02	-	637	1117	480	182	2.64	558
	133	16	45	-	534	904	370	182	2.03	594
	13	14	339	-	442	884	442	182	2.43	563
Total:		37		-	1613	2905	1292		7.10	1715
Average:		12		-	538	968	431		2.37	572
Steers:	15	3	938	3	533	824	291	182	1.60	827
	17	19	701	0	555	897	342	182	1.88	665
Total:		22		3	1088	1721	633		3.48	1492
Average		11		2	544	861	317		1.74	746

Table 19. Data collected on the 1951 Shorthorn calves, Sire Gregg Farms Hoarfrost.

	Calf	Fx	Dam	Fx	Initial weight	Final weight	Total gain	Days fed	Ave. daily gain	Total TDN per 100 lbs. gain
Variables under study		X_2			X_1				X_3	Y
Heifers:	111	-	83	-	375	725	350	182	1.92	561
	115	-	733	-	393	657	264	182	1.45	638
	103	-	729	-	471	758	287	182	1.58	770
	127	-	825	-	381	647	266	182	1.46	663
	117	-	529	-	454	765	311	182	1.71	585
	107	-	815	-	330	574	244	182	1.34	538
	105	-	81	-	280	550	270	182	1.48	531
	129	-	827	6	353	610	257	182	1.41	650
	139	-	163	-	361	589	228	182	1.25	592
	131	-	833	-	295	611	316	182	1.74	620
Total:		-		6	3693	6486	2793		15.34	6148
Average:				1	369	649	279		1.53	615
Bulls:	109	-	605	-	537	982	445	182	2.45	559
Total: same										
Average: same										
Steers:	113	-	739	-	440	862	422	182	2.32	615
	101	-	813	-	425	794	369	182	2.03	508
Total:		-		-	865	1656	791		4.35	1123
Average:		-		-	433	828	396		2.18	562

Table 20. Data collected on the 1952 Shorthorn calves, Sire College Premier 29th.

Variables under study	Calf	Fx X_2	Dam	Fx	Initial weight X_1	Final weight	Total gain	Days fed	Ave. daily gain X_3	Total TDN per 100 lbs. gain Y
Heifers:	27	17	505	-	367	565	198	182	1.09	523
	29	16	45	-	398	656	258	182	1.42	680
	227	19	701	-	410	682	272	182	1.49	515
Total:		52		-	1175	1903	728		4.00	1718
Average:		17		-	392	634	243		1.33	573
Bulls:	219	8	513	-	469	1024	555	182	3.05	435
	215	14	715	-	530	1047	517	182	2.84	441
Total:		22		-	999	2071	1072		5.89	876
Average:		11		-	500	1036	536		2.95	438
Steers:	229	14	357	-	403	820	417	182	2.29	456
	239	13	355	-	380	722	342	182	1.88	593
Total:		27		-	783	1542	759		4.17	959
Average:		14		-	392	771	380		2.09	480

Table 21. Data collected on the 1952 Shorthorn calves, Sire KSC Premier 11.

	Calf	Fx	Dam	Fx	Initial weight	Final weight	Total gain	Days fed	Ave. Daily gain	Total TDN per 100 lbs. gain
Variables under study		X_2			X_1				X_3	Y
Heifers:	247	25	039	16	406	782	376	182	2.07	453
	253	21	041	8	346	727	381	182	2.09	480
	249	24	031	16	361	687	326	182	1.79	451
	251	24	029	17	338	681	343	182	1.88	460
Total:		94		57	1451	2877	1426		7.83	1844
Average:		24		14	363	719	357		1.96	461
Steers:	255	8	733	-	371	790	419	182	2.30	411
Total:	same									
Average:	same									

Table 22. Data collected on the 1952 Shorthorn calves, Sire Gregg Farms Hoarfrost.

	Calf	Fx	Dam	Fx	Initial weight	Final weight	Total gain	Days fed	Ave. daily gain	Total TDN per 100 lbs. gain
Variables under study		X_2			X_1				X_3	Y
Heifers:	235	-	99	-	378	629	251	182	1.38	550
	231	-	02	-	401	618	217	182	1.19	499
	23	-	809	-	376	579	203	182	1.12	594
	221	-	833	-	360	678	318	182	1.75	565
	225	-	729	-	330	638	308	182	1.69	541
Total:		-		-	1845	3142	1297		7.13	2749
Average:		-		-	369	628	259		1.43	550
Bulls:	25	-	83	-	400	801	401	182	2.20	396
	217	-	124	-	448	969	521	182	2.86	378
	211	-	938	3	411	824	413	182	2.27	403
	213	-	527	-	440	930	490	182	2.69	441
Total:		-		3	1699	3524	1825		10.02	1618
Average:		-		1	425	881	456		2.51	405
Steers:	233	-	827	6	360	757	397	182	2.18	472
Total:	same									
Average:	same									

Table 23. Data collected on the 1953 Shorthorn calves, Sire College Premier 29th.

Variables under study	Calf	Fx X_2	Dam	Fx	Initial weight X_1	Final weight	Total gain	Days fed	Ave. daily gain X_3	Total TDN per 100 lbs. gain Y
Heifers:	333	8	733	-	335	591	256	182	1.41	504
	37	14	715	-	318	650	332	182	1.82	426
	31	16	45	-	393	675	282	182	1.55	489
	35	14	715	-	393	713	320	182	1.76	487
	335	0	C163	-	307	590	283	182	1.55	483
Total:		52		-	1746	3219	1473		-8.09	2389
Average:		10		-	349	644	295		1.62	478
Steers:	39	14	357	-	450	857	407	182	2.24	456
	33	17	505	-	470	815	345	182	1.90	498
	307	8	513	-	418	835	417	182	2.29	487
Total:		39		-	1338	2507	1169		6.43	1441
Average:		13		-	446	836	390		2.14	480

Table 24. Data collected on the 1953 Shorthorn calves, Sire KSC Premier 11.

	Calf	Fx	Dam	Fx	Initial weight	Final weight	Total gain	Days fed	Ave. daily gain	Total TDN per 100 lbs. gain
Variables under study:		X_2			X_1				X_3	Y
Bulls:	337	25	039	16	297	737	440	182	2.42	397
Total:	same									
Average:	same									

Table 25. Data collected on the 1953 Shorthorn calves, Sire Gregg Farms Hoarfrost.

Variables under study	Calf	Fx X_2	Dam	Fx	Initial weight X_1	Final weight	Total gain	Days fed	Ave. daily gain X_3	Total TDN per 100 lbs. gain Y
Heifers:	325	-	739	-	344	669	325	182	1.79	404
	309	-	605	-	356	650	294	182	1.62	488
	313	-	527	-	435	770	335	182	1.84	537
	315	-	99	-	405	733	328	182	1.80	557
	317	-	729	-	380	720	340	182	1.87	495
Total:		-		-	1920	3542	1622		8.92	2481
Average:		-		-	384	708	324		1.78	496
Bulls:	319	-	02	-	425	895	470	182	2.58	405
	311	-	938	3	435	802	367	182	2.01	548
Total:		-		3	860	1697	837		4.59	953
Average:		-		2	430	849	419		2.30	477
Steers:	305	-	717	-	426	849	423	182	2.32	461
	301	-	83	-	421	810	389	182	2.14	486
	303	-	809	-	426	845	419	182	2.30	457
Total:		-		-	1273	2504	1231		6.76	1404
Average:		-		-	424	835	410		2.25	468

Table 26. Data collected on the 1953 Shorthorn calves, Sire KSC Mercury.

	Calf	Fx	Dam	Fx	Initial weight	Final weight	Total gain	Days fed	Ave. daily gain	Total TDN per 100 lbs. gain
Variables under study:		X_2			X_1				X_3	Y
Heifers:	323	14	111	-	305	600	295	182	1.62	467
Total:	same									
Average:	same									
Bulls:	327	14	129	-	230	535	305	182	1.68	427
	329	13	107	-	304	703	399	182	2.74	254
Total:		27		-	534	1238	704		4.42	681
Average:		14		-	267	619	352		2.21	341

Table 27. Data collected on the 1954 Shorthorn calves, Sire College Premier 29.

	Calf	Fx	Dam	Fx	Initial weight	Final weight	Total gain	Days fed	Ave. daily gain	Total TDN per 100 lbs. gain
Variables under study		X_2			X_1				X_3	Y
Steers:	47	17	505	-	416	805	389	182	2.14	497
	405	14	715	-	449	857	408	182	2.24	490
Total:		31		-	865	1662	797		4.38	987
Average:		16		-	433	831	399		2.19	494

Table 28. Data collected on the 1954 Shorthorn calves, Sire KSC Premier 11.

	Calf	Fx	Dam	Fx	Initial weight	Final weight	Total gain	Days fed	Ave. daily gain	Total TDN per 100 lbs. gain
Variables under study:		X_2			X_1				X_3	Y
Steers:	403	24	01	16	388	835	447	182	2.46	454
	43	24	029	17	443	835	392	182	2.15	511
Total:		48		33	831	1670	839		4.61	965
Average:		24		17	416	835	420		2.31	483

Table 29. Data collected on the 1954 Shorthorn calves, Sire Gregg Farms Hoarfrost.

	Calf	Fx	Dam	Fx	Initial weight	Final weight	Total gain	Days fed	Ave. daily gain	Total TDN per 100 lbs. gain
Variables under study		X_2			X_1				X_3	Y
Heifers:	45	-	813	-	435	777	342	182	1.88	433
Total:	same									
Average:	same									
Bulls:	49	-	529	-	413	917	504	182	2.77	433
	409	-	733	-	400	858	458	182	2.52	391
Total:		-		-	813	1775	962		5.29	824
Average:		-		-	407	888	481		2.65	412
Steers:	407	-	527	-	424	830	406	182	2.23	503
Total:	same									
Average:	same									

Table 30. Data collected on the 1954 Shorthorn calves, Sire KSC Mercury.

	Calf	Fx	Dam	Fx	Initial weight	Final weight	Total gain	Days fed	Ave. daily gain	Total TDN per 100 lbs. gain
Variables under study		X_2			X_1				X_3	Y
Heifers:	417	14	235	-	313	620	307	182	1.69	430
	415	3	99	-	314	650	336	182	1.85	463
	411	13	127	-	350	673	323	182	1.77	539
	427	8	717	-	285	605	320	182	1.76	516
	425	13	231	-	255	557	302	182	1.66	455
	423	-	163	-	268	563	295	182	1.62	503
Total:		51		-	1785	3668	1883		10.35	2906
Average:		8		-	298	611	314		1.73	484
Bulls:	421	25	605	-	350	755	405	182	2.23	399
Total:	same									
Average:	same									
Steers:	419	4	83	-	361	709	348	182	1.91	507
	413	13	23	-	341	780	439	182	2.41	452
Total:		17		-	702	1489	787		4.32	959
Average:		9		-	351	745	394		2.16	480

Table 31. Data collected on the 1955 Shorthorn calves, Sire KSC Premier 11.

	Calf	Fx	Dam	Fx	Initial weight	Final weight	Total gain	Days fed	Ave. daily gain	Total TDN per 100 lbs. gain
Variables under study		X_2			X_1				X_3	Y
Heifers:	507	24	01	16	425	710	285	182	1.57	510
	509	15	357	0	395	655	260	182	1.43	443
	515	15	505	0	425	670	245	182	1.35	510
	519	15	45	0	360	626	266	182	1.46	534
	523	24	029	17	330	605	275	182	1.51	481
	527	21	041	8	340	663	323	182	1.77	430
Total:		114		41	2275	3929	1654		9.09	2908
Average:		19		7	379	655	276		1.52	485
Bulls:	525	32	715	-	486	882	396	182	2.18	475
Total:	same									
Average:	same									

Table 32. Data collected on the 1955 Shorthorn calves, Sire KSC Premier 14.

	Calf	Fx	Dam	Fx	Initial weight	Final weight	Total gain	Days fed	Ave. daily gain	Total TDN per 100 lbs. gain
Variables under study		X_2			X_1				X_3	Y
Heifers:	537	26	251	24	320	602	282	182	1.55	455
Total:	same									
Average:	same									
Steers:	547	15	241	3	345	693	348	182	1.91	505
Total:	same									
Average:	same									

Table 33. Data collected on the 1955 Shorthorn calves, Sire KSC Mercury 4th.

Variables under study	Calf	Fx X_2	Dam	Fx	Initial weight X_1	Final weight	Total gain	Days fed	Ave. daily gain X_3	Total TDN per 100 lbs. gain Y
Heifers:	511	4	733	-	372	622	250	182	1.37	581
	513	3	729	-	420	603	183	182	1.01	560
	521	14	115	-	365	590	225	182	1.24	557
	539	8	99	-	325	698	373	182	2.05	348
	541	13	127	-	340	681	341	182	1.87	483
	543	25	83	-	300	585	285	182	1.57	486
	545	4	605	-	290	615	325	182	1.79	411
	551	17	235	-	375	635	260	182	1.43	587
	553	16	23	-	352	634	282	182	1.55	518
Total:		104		-	3139	5663	2524		13.88	4531
Average:		12		-	349	629	280		1.54	503
Bulls:	501	6	813	-	500	945	445	182	2.45	400
	503	14	317	-	410	855	445	182	2.45	438
	533	4	527	-	402	800	398	182	2.19	460
	531	14	309	-	400	870	470	182	2.58	423
Total:		38		-	1712	3470	1758		9.67	1721
Average:		10		-	428	868	440		2.42	430

Table 33 (concl.)

	Calf	Fx	Dam	Fx	Initial weight	Final weight	Total gain	Days fed	Ave. daily gain	Total TDN per 100 lbs. gain
Variables under study		X_2			X_1				X_3	Y
Steers:	505	14	313	-	445	850	405	182	2.23	629
	517	13	221	-	350	692	342	182	1.88	462
	529	13	529	-	350	740	390	182	2.14	236
	535	14	325	-	300	600	300	182	1.65	515
	555	13	231	-	325	696	371	182	2.04	416
Total:		67		-	1770	3578	1808		9.94	2258
Average:		13		-	354	716	362		1.99	452

FEED EFFICIENCY STUDIES IN BEEF CATTLE

by

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B. S., Kansas State College
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AN ABSTRACT OF A THESIS

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Production records have been used only to a very limited extent in the development of our present day breeds of beef cattle. Considerable question remains in regard to the production improvement which has been accomplished as the result of selections which have been practiced on the basis of visual appraisal. In recent years research has indicated that beef cattle production characters are influenced appreciably by inheritance, and most research workers agree that feed efficiency is of primary importance to cattle producers. In view of the fact that direct measurements of feed efficiency necessitate the individual feeding of animals, which is quite expensive because of the labor and equipment requirements, the possibilities of indirect estimations of feed efficiency from studies of the relationships of it with other production factors has been investigated extensively in recent years.

The purpose of this study was to investigate the possibility of estimating feed efficiency indirectly by means of its relationship with other production factors. The other production factors considered in this study were initial weight, inbreeding of calf, and average daily gain. A total of 133 purebred Shorthorn calves produced during the period 1950 through 1955 inclusive were individually fed for 196 days in 1950 and 182 days in the following years following a short post weaning adjustment period. Data collected on 70 heifers, 30 bulls, and 33 steers were used in the analyses. These data were obtained on the purebred Shorthorn cattle maintained for experimental purposes in the

State Project No. 286, "The Improvement of Beef Cattle Through Breeding Methods," at the Kansas Agricultural Experiment Station, Manhattan, Kansas. Two inbred lines have been developed in this herd. The cows of both lines are pasture bred for spring calf production. The calves were not creep-fed during the suckling period.

The data collected on these animals were analyzed for the simple correlations between all four variables, multiple correlations of the three independent variables (initial weight, inbreeding of calf, and average daily gain) on the dependent variable (feed efficiency), partial and standard partial regression coefficients for feed efficiency on the three independent variables, and analyses of variance. All analyses were computed on a within sex, within line, within year basis and the results were so presented.

Multiple correlations of the independent variables on feed efficiency were highly significant in all three analyses and accounted for 25, 39, and 28 percent, respectively, of the variation in feed efficiency among the data on the heifers, bulls, and steers used in the study. Initial weight accounted for approximately one-half and average daily gain also for about one-half of the variation in feed efficiency. Inbreeding, at the levels included in this study, appeared to account for very little, if any, of the variation in feed efficiency.

Average daily gain was negatively correlated with feed efficiency. The more rapid gaining animals required, on the average, less TDN per 100 pounds of live weight gain.

Initial weight was positively correlated with feed efficiency. The heavier calves at the start of the feeding trials, on the average, required more TDN per 100 pounds of live weight gain than the lighter calves.

Inbreeding was negatively correlated with initial weight. The higher the inbreeding, the lower the initial weight on the average. Due to the close relationship between initial weight and weaning weight, the same relationship probably existed between inbreeding and weaning weight.

Other relationships between the variables were not statistically significant or consistent in the three analyses.