

EFFECT OF PREVIOUS PLANE OF NUTRITION UPON
THE EFFICIENCY OF ENERGY UTILIZATION
BY BEEF STEERS AS MEASURED BY
RESPIRATION CALORIMETRY AND
SLAUGHTER TECHNIQUE

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CHAPTER I

INTRODUCTION

The previous plane of nutrition of beef steers has been found to influence the rate and efficiency of gain when these animals are subsequently placed on full-feed. The steers having been allowed to grow in size without much body gain will exhibit faster and more efficient gains than younger animals of comparable weight when placed on full-feed.

It appears that most restricted-fed animals can reach the same weight and size as continuously fed animals with little loss in over-all efficiency. This phenomenon of compensatory growth, which is the term used to describe the ability of an animal to recover rapidly in growth following a period of under nutrition, has been observed and measured in many studies. Osborne and Mendel (1915, 1916) first observed that growth could be continued at an accelerated rate after a long period of restriction. However, the factors responsible for this increase have not been completely explained.

The use of net energy for expressing the value of a ration for feedlot cattle has been widely employed in recent years. With the use of respiration calorimetry, a

critical measure of all losses of energy as well as energy stored in the carcass can be made. The effects of previous plane of nutrition upon efficiency of energy utilization can be studied by fractionating the gross energy of the feed into various components.

This study was designed to investigate the effects of previous plane of nutrition upon subsequent growth and energy utilization of beef steers, using respiration calorimetry, carbon-nitrogen balance, and the comparative slaughter technique.

CHAPTER II

REVIEW OF LITERATURE

Compensatory Gain

One of the first agricultural references to the subject of compensatory gain was by Waters (1908, 1909) who studied the effects of under nutrition upon beef steers. He stated that, "an animal that is below the normal size at a given age because of poor nourishment apparently had the capacity, when liberally fed, to compensate for this loss in a measure at least, by an increased rate of gain." He showed that steers fed a maintenance or submaintenance ration continued to grow in skeletal size, while the amount of fat tissue decreased, and could recover and reach normal mature height and weight during a subsequent full-feeding period. More critical work of this type followed on smaller laboratory animals. Osborne and Mendel (1915 a,b) conducted an experiment in which rats were maintained at constant weight for periods up to 500 days. When offered unrestricted food these rats grew at abnormally rapid rates and achieved their normal mature size.

These findings were supported by Eckles and Swett (1918) in experiments with dairy heifers. It had been

previously known that cattle wintered on a low plane of nutrition gain weight more rapidly on spring grass than those wintered on a high plane of nutrition. Eckles and Swett reported that with dairy heifers there was a negative relationship between wintering plane of nutrition and summer pasture gains. They concluded that the tendency to recover from the effects of a period of under nutrition is general, but that if the restriction is too severe the mature size may be permanently reduced. Black, Queensberg, and Baker (1940) wintered steers on three different planes of nutrition. They found that those wintered on a low plane made the lowest winter gains and the highest summer gains. Similar results have been reported by Joubert (1954), Heinemann and VanKeuren (1956), and Nelson and Campbell (1954). Lawrence and Pearce (1964) found that summer gain was increased 0.78 pound for each pound decrease in winter gain. The correlation coefficient between summer and winter gain was -0.9034 .

Cattle wintered on forages low in protein have been found to make greater pasture gains than those supplemented with protein. Bohman and Torell (1956) fed native mountain grass hay harvested either early or late to wintering beef calves. Those fed poorer quality late-cut hay during the winter gained more rapidly during the summer than did those fed the higher quality early-cut hay. During the following summer, as yearlings, the retarded cattle accelerated their growth rate and were as heavy as the non-restricted group,

thus, no permanent stunting occurred even when no growth took place during the winter period.

It has also been found that dairy heifers whose growth has been retarded could recover during subsequent grazing and lactation periods. Crichton and Aitken (1954) stated that "economy of food during costly winter feeding can be practiced provided there is good summer grazing." Heifers that had been retarded made a rapid recovery when given a high plane of nutrition and although the first estrous was delayed about $3\frac{1}{2}$ months, subsequent fertility and size at maturity were unaffected. Eckles and Swett (1918), however, reported that the combination of early calving and light feeding during the growing period resulted in reduced cow size at maturity.

Work at the Oklahoma station by Smithson et al. (1964) shows that body size at maturity in Herefords is not adversely affected by a low plane of nutrition the first winter.

Earlier maturing breeds of cattle were more affected by restricted growth than were late maturing breeds as reported by Joubert (1954); however, age of calving had no permanent influence on ultimate size of the animal. Differences between full-fed and restricted-fed Shorthorns tended to increase with age, but the differences between full-fed and restricted-fed Afrikaners decreased with age. Growth restriction can inflict more permanent damage to early maturing animal than to late maturing ones, as

exhibited by the low fed Shorthorns being more drastically affected by under nutrition at $4\frac{1}{2}$ years than the late maturing Afrikaners.

Efficiency of Growth

Watson (1943) concluded that any period of restriction in an animal's life inevitably results in a decrease in the lifetime efficiency in the production of human food, and that rapid fattening during compensatory growth does not make up for the extended growing period.

Sheehy and Senior (1942) examined the effect of slow growth upon the over-all efficiency of weight gain in steers from 700 to 900 pounds. They showed that the amount of food saved during restriction did not equal the amount of additional food required by the restricted groups to reach equivalent weights and required 25 to 45 days longer to achieve slaughter weight. Guilbert et al. (1944) stressed the importance of continuous growth in cattle in relation to their efficiency. It was shown that calves gaining weight at one pound per day during the winter achieved 100 pounds extra growth in carcass weight for the expenditure of only 70 pounds more concentrates, compared with animals which were allowed to lose weight in the winter and were then heavily supplemented during the summer.

Others, however, have found that restricted cattle can compensate for a period of reduced growth and attain weights similar to continuously fed animals on a total

energy intake similar to unrestricted animals. Winchester (1951) fed one member of each of six pairs of identical twin beef steers and two pairs of fraternal twin steers a low calorie ration for six months or more, the other member was continuously fed a high energy ration to 1000 pounds. After the period of restriction these steers were liberally fed to 1000 pounds. The total energy required to reach 1000 pounds was similar for compensatory and control steers.

Meyer et al. (1955) found that rats restricted for 28 or 21 days and then full-fed made total gains similar to controls when given an equal total food intake, even though total time on feed was longer. Winchester and Howe (1955) concluded that young growing beef cattle between the ages of 6 and 12 months can be carried at an energy level as low as maintenance, if the nutritional needs other than those for energy are supplied, without loss later in efficiency of feed utilization. The retarded steers in this study required two to three months longer to reach slaughter weight, but the total feed required to reach a given weight was increased only slightly by the 6 months period of low energy allowance. In a subsequent study designed to determine the effect of growth retardation on calves weaned at 3 to 4 months of age, Winchester and Ellis (1956) fed one member of each of ten pairs of twin calves a low energy allowance for 3 to 4 months, then switched to a high energy ration and full-fed them until they reached a low prime grade or were 82 weeks of age. The feed required to

produce an animal of a given size and weight was not increased over continuously full-fed co-twins.

Meyer and Clawson (1964) used identical treatments for both rats and sheep. They fed 20%, 36%, 52%, 64%, 84%, and 100% of a full feed for 21 days (rats) or 42 days (sheep). At the end of the restricted period one-third of the animals were fed ad libitum until the same amount of total feed was consumed as full-fed controls received during the previous period, and one-third were fed ad libitum until they attained a body weight equivalent to that attained by continuously full-fed controls during the first period. They found that restricted, full-fed rats and sheep did not reach the same body weight as controls on the same total energy intake, but final body energy was the same for restricted, full-fed sheep as for continuously full-fed controls indicating that the restricted, full-fed sheep were as efficient over-all.

Meyer et al. (1965) found that the lowest total net energy requirement to reach a similar final empty body energy at slaughter was for steers given a high energy intake after weaning, compared to those restricted for 172 days on a low or medium energy intake and then full-fed a high energy ration. However, steers given a fattening ration following a low, medium or liberal intake did not differ significantly in total NE requirements, even though varying lengths of time were required to reach equal final empty body energy. Improvement in partial efficiency of

feed utilization and feed capacity were shown to be responsible for this compensatory growth.

Meyer and Clawson (1964) found that in rats and sheep the total and partial efficiency of energy utilization (daily energy gain/daily gross energy intake, or daily energy gain/daily gross energy available for growth, respectively) was increased during full-feeding following a period of restriction. In a later study Meyer et al. (1965) also obtained similar results with steers.

Fox (1970) reported that restricted and then full-fed steers required more time to reach 1000 pounds, but total energy and protein required to reach the same final body energy and protein composition is similar for continuously full-fed and restricted, full-fed steers. There were no differences between compensatory and control steers fed to 1000 pounds in ME required per 100 pounds gain or ME required per 100 Mcal retained, although there was a trend for a higher ME requirement per 100 Mcal retained for compensatory steers fed to this weight.

Fox et al. (1972) reported that compensatory steers made a greater proportion of the protein gain during the first part of the full-feeding period and a greater portion of the fat gain during the last part of the full-feeding period, when compared to continuously full-fed controls. However, there were no differences between compensatory and control steers in final body composition at 454 kg. Total protein intake required by compensatory steers to

reach final weight was less than that required by continuously full-fed controls. Compensatory steers made up for the period of retarded growth and equaled controls in total protein efficiency by the time they reached 364 kilograms. Compensatory steers had higher NE_m and NE_g values and utilized energy more efficiently during the full-feeding period than steers continuously full-fed. These results show that the NE_m and NE_g values of the ration and the efficiency with which dietary protein is utilized is not independent of the previous nutritional treatment of the cattle.

Wilson and Osbourn (1960) stated that a restricted and a re-alimentated animal is no less efficient (in terms of weight gain and food conversion) than a continuously grown animal, providing it does not lose weight and is allowed to express its increased appetite during re-alimentation by ad libitum feeding. Fox et al. (1972), also stated that their data suggested that during recovery, compensatory cattle may require a higher protein:energy ratio to realize the maximum compensatory growth early in the recovery period.

Composition of Gain and Final Body Composition

Sheehy and Senior (1942) concluded that restricted, full-fed animals compensate for the period of restriction and reach the same final weight as continuously fed animals due to more protein and less fat in the gain during

recovery, and therefore less energy per unit of weight gain and have a lower final body energy content. Meyer et al. (1965) found that steers given a high energy intake immediately after weaning and continued to a low choice finish have the lightest body weight, empty body weight and carcass weight but make equal energy gain and have a higher carcass fat, lower carcass protein and a smaller rib eye. The highest fat content of empty body weight gain was in steers given the high energy intake immediately after weaning or the low energy intake for 172 days followed by a high energy intake.

Meyer, Lueker, and Smith (1956), however, reported that there was a greater proportion of fat at slaughter in the bodies of rats restricted in total food intake for 28 days and then full-fed than in continuously fed controls. Meyer and Clawson (1964) found that during recovery, both rats and sheep had a higher percent fat and lower percent protein in the empty body weight gain.

Most workers, however, have found little difference in total body composition between restricted, full-fed and continuously full-fed animals, and none on a fat-free basis. Winchester and Howe (1955) and Winchester and Ellis (1956) found no difference in final carcass composition between restricted, full-fed and continuously full-fed steers. Similar results were reported by Fox et al. (1972). Lawrence (1964b) reported that a longer period of time was required for previously restricted steers to

reach 1000 pounds than continuously fed controls, there was little difference in dissectable muscle, fat, and bone but there was a tendency for full-fed steers to have a higher percent of fat.

Effect of Feed Intake

Quinby (1948) studied the food and water economy of the young rat during chronic starvation and recovery and found that food intake during recovery was increased, resulting in an increased over-all food efficiency due to a larger proportion of the food intake being used for growth during the period of full-feeding. Meyer et al. (1965) reported that steers previously restricted for 172 days on a low energy intake consumed more feed relative to body size during subsequent full-feeding than did those previously fed a medium to high energy intake, but had an increase in energy utilization independent of feed intake. However, Meyer and Clawson (1964), found that the feed intake per unit of metabolic weight was similar for restricted, full-fed and continuously full-fed rats and sheep and concluded that feed intake was not a factor in compensatory growth in their study.

Effect on Basal Metabolism and Nutrient Utilization

The profound effect of under nourishment on basal metabolism (per unit of surface area) has long been known and was first reported by Chittenden (1904). Kaunitz,

Slanetz and Johnson (1957) found that the food intake required for maintenance of a constant weight of rats was reduced 30% when body weight was held constant for four to six weeks. Quinby (1948) found that rats were able to maintain a constant body weight on decreasing amounts of food as the period of restriction increased. He attributed this ability to an increase in digestibility. Forbes, Swift and Black (1938) fed rats for maintenance and growth and compared these to fasted rats to determine the efficiency of diet utilization at various planes of nutrition. Rats fed at a low level of energy intake utilized the food more efficiently with time. Metabolizable energy values were unaffected, however, but net energy values varied during maintenance and growth, indicating that digestibility was not a factor. Ritzman and Benedict (1924) also found no differences in digestibility of protein or energy with submaintenance, maintenance or fattening levels when they studied the effect of varying feed levels on the physiological economy of steers. Three groups of steers were fed a submaintenance level and one group was fed at maintenance for four and one-half months, then were full-fed either pasture or a high or low protein grain ration for two months. Metabolizability of the energy varied with the plane of nutrition. Similar results have been reported by Meyer (1964), Blaxter (1951), and Sheehy and Senior (1942).

Lee et al. (1962) suggested that caloric-restriction

adaptation involves a lower average turnover of fat as a result of cyclic variations in lipogenesis. This cyclic variation in lipogenesis may be a result of the pattern of food ingestion, a pattern characterized by periods of eating and fasting. This study was conducted with ad libitum fed control animals characterized as "nibblers" and restricted fed animals, which were fed only sufficient food to maintain a constant body weight, fed every second day.

Horst, Mendel and Benedict (1934) studied the influence of previous diet, growth and age on the basal metabolism of the rat. They held rats at a constant body weight for 42 days, then placed them on full feed. Basal heat production per square meter of body surface was reduced to 28% below controls after 31 to 34 days of restricted feeding. When placed on full feed, these rats had basal heat production values that were 9 to 11% higher by the seventh to tenth day and 15 to 33% higher by the 18th day than at the end of restriction, and were constant with controls thereafter. They concluded that the lowered maintenance requirement of previously restricted animals may be due to a lower basal metabolism. Meyer, Lueker, and Smith (1956) concluded that the extension of this lower maintenance requirement induced by the low level of feeding during restriction into the full feeding period is part of the reason for the compensatory response of animals. Wilson and Osbourn (1960) also reached a similar conclusion.

Meyer and Clawson (1964), however, concluded that the

maintenance requirements were not influenced by under nutrition in their study with rats and sheep. They decided that past interpretation may not have been correct because of a carry-over influence of heat increment from digesting materials in the gastrointestinal tract on basal heat production. Blaxter and Wool (1951), however, found that basal heat production declined over four days of fasting in six-day-old bull calves, and the decline in metabolic rate was greater than the decline in body weight. They observed that this decline in basal metabolism may be due to a decrease in activity during restriction, as activity decreased markedly during fasting and low levels of feeding. Ritzman and Benedict (1924) reached a similar conclusion when they stated, "steers previously on a submaintenance level fattened with greater economy because they wasted less had less body movement."

Perhaps the postulation presented by Maynard and Loosli (1969) can add to the explanation of the physiological changes which occur during restriction and recovery. They stated that in stunting, cells may be depleted yet remain in outline, capable of being filled in later without complete rebuilding. The rapid increase in weight which follows retardation may be to a considerable extent a replacement of lost fat, and this process may take place more rapidly than true growth. The actual suppression of growth may be less than the weight measures indicate. Cellular development may proceed in important ways and yet

not be reflected in any increase in weight.

Howarth and Baldwin (1971) noted that rates of protein synthesis and accumulation during recovery were similar to normal, showing that a compensatory acceleration in growth of the protein component of muscle did not occur. This supports the contention that the compensatory acceleration in body growth is not attributable to protein in skeletal muscle but rather is caused by growth of internal organs or adipose tissue as proposed by Wilson and Osbourn (1960).

Respiration Calorimetry

The "law of Hess," or the "law of constant sums" formulated by G. H. Hess, a German chemist, in 1840 states that the total amount of heat produced or consumed when a chemical system changes from an initial state to a final state is independent of the way in which this change is brought about. To establish Hess' equation as correct for the living animal, one must measure the chemical energy of the food, excreta and built-up or broken-down body substance, and the heat produced by the animal (Kleiber, 1935). This can be determined by either direct or indirect respiration calorimetry.

Direct calorimetry is based on the principle that heat evolved is employed to increase the temperature of a surrounding medium to yield an estimate of the animal's heat production. This involves measurements of actual heat losses due to radiation, conduction, convection, and

moisture vaporization of heat produced, when food is oxidized by the animal. This measurement involves quite extensive instrumentation. Indirect calorimetry is based on the fact that oxygen consumption and carbon dioxide production are closely related with heat production (Brody, 1945). This method comprises the measurement of the oxygen consumed by the animal, the carbon dioxide and methane it produces with an apparatus for collecting respiratory gases and the nitrogen it excretes in its urine, and the computation from these the heat produced. Both methods have shown similar results (Blaxter, 1962).

Respiration apparatus, (apparatus capable of measuring gaseous exchange of animals) as the instruments are termed that are used in indirect calorimetry, are of two main types -- open circuit and closed circuit. In the open circuit apparatus, outdoor air is passed through the chamber of the instrument and the changes in its oxygen, methane and carbon dioxide content as well as volume of air are measured. In the closed circuit system, air is recirculated continuously through the chambers after passing through absorbents which remove carbon dioxide and water vapor. A fall in pressure in the whole apparatus occurs as a result of the absorption of oxygen by the animal, and oxygen is admitted to the system in proportion to this fall in pressure. Almost all the respiration apparatus in current use for large animals are of the open circuit type (Blaxter, 1962).

The best known respiration calorimeter for animals was built in 1899 by Atwater and Rosa (Kleiber, 1961). With this apparatus, it was demonstrated that heat production and work of human beings is derived from the chemical energy of katabolized material (food or body substance), as predicted by the "law of conservation of energy." Later similar respiration calorimeters were built for small animals by Williams (1912) and for large animals by Armsby in 1904 (Braman, 1933); Mitchell (1932); Kleiber (1935); and Blaxter, et al. (1954). The largest and most modern energy metabolism laboratory in the U.S.A. currently is operated by the U.S.D.A. at Beltsville, Maryland (Flatt, et al., 1958).

Armsby (1913) compared theoretical heat production with that observed by respiration calorimetry and reported that the results of individual trials differed considerably but that errors tended to compensate. In 57 trials the observed differed from the computed heat production by only $\pm 0.4\%$. Forbes and co-workers (1928, 1930, 1932) used both direct and indirect calorimetry to study metabolism in relation to plane of nutrition. Heat production values were very similar whether determined by direct or indirect methods. The curve of heat production in relation to the plane of nutrition was reversed or S shaped curve. Mitchell et al. (1932), by the use of open circuit respiration calorimetry, found that metabolizable energy and heat increment per kg. of dry matter consumed increased but

net energy per kg. of dry matter decreased as the level of feed intake increased from one-fifth to full feed.

Forbes et al. (1932) determined the fasting heat production of steers by direct calorimetry and found a continual decrease as the fast progressed with no definite lower level being reached. Later (1941) Forbes and Swift considered the use of fasting heat production as a base value to be invalid. They stated that the heat production determined at or slightly above maintenance, therefore, is considered the most practicable base from which to measure dynamic effects in nutrition. Blaxter (1962) suggests that maintenance energy requirements of ruminants are simply 1.2 times their fasting energy expenditures. However, fasting heat production can be used as a base line in energy metabolism studies because it can be considered as being equal to the net energy required for maintenance at no activity.

Marston (1948) determined fasting heat production of merino ewes aged three and a half years with open circuit respiration calorimeters. He found that heat production varied according to previous plane of nutrition. The fasting heat production values, expressed as $\text{kcal}/\text{W}_{\text{kg}}^{.73}/\text{day}$ were 74.5 for sheep previously fed at two times maintenance, 59 for those at one-half maintenance and 68 for intermediate levels of feeding. Blaxter (1962) also noted that the fasting metabolism of wethers ranged from $63 \text{ kcal}/\text{W}_{\text{kg}}^{.73}/\text{day}$ for yearling lambs to $52.4 \text{ kcal}/\text{W}_{\text{kg}}^{.73}/\text{day}$ for those over six

years old. These values are all lower than those reported by Flatt and Coppock (1963) for dairy cows. They reported values of $76.2 \text{ kcal/W}_{\text{kg}}^{.73}/\text{day}$ for cows previously fed ad libitum, 71.6 for one-half maintenance and 73.5 for maintenance level. Thus the metabolism of sheep tends to be below the interspecies mean of $70 \text{ kcal/W}_{\text{kg}}^{.73}/\text{day}$ (Kleiber, 1961) while that of dairy cows is a bit higher.

The heat increment of a feed can be determined from the heat production on feed and on fast after each digestion balance experiment (Colovos, 1961). Colovos et al. (1963) determined heat increment by the difference in heat production on feed and on fast to estimate net energy values of dairy cattle rations. They used three sets of open dairy female twins to study the effects of low and high fiber content with varying amounts of urea added. There was a considerable decrease in the heat increment when the animals were fed the concentrate mixture (15% fiber) containing 2% urea. Hamilton (1939) studied the heat increment of diets with respect to the balance of protein. He reported that a smaller heat increment will be obtained when a diet is balanced and satisfies all of an animal's requirements. The heat increment of the diet decreases coincident with every increase in the percent of protein from 4 to 18 percent.

Information about energy utilization in growth is relatively sparse and rather limited with respect to respiration calorimetry studies. Blaxter (1962) shows that

the energetic efficiency of lipogenesis varies with the nature of the diet. The efficiency of fat synthesis was low -- about 25 to 30% -- when all-roughage rations were given but rations consisting entirely of concentrates were used with an efficiency of over 60%. These results suggest that the higher the acetic:propionic acid ratio in the digestion products, the lower the efficiency of body fat synthesis. Since growth of the protein mass of the body is associated with a concomitant deposition of fat, the relative energetic efficiency with which growth as a whole is made will only slightly exceed the efficiency of fat synthesis (as measured in adult life).

Respiration Gaseous Exchange

Two serious difficulties are associated with open circuit respiration calorimetry: (1) accurate measurement of the volume of air passing through the chambers and (2) accurate analysis of O_2 , CO_2 , and CH_4 in the expired air. To obtain an accuracy of 1% in the daily CO_2 production and the O_2 consumption of the animal, gas analysis of the out-going and in-going air must be accurate to 0.002-0.003% since the errors in the gas analysis and in volume measurement may accumulate (Van Es, 1958). Modern instruments have minimized these problems. Brouwer (1958) derived formulae for calculating the results of respiration calorimetry studies. Increased speed and reliability of calculations has been accomplished by electronic data

processing equipment as described by Flatt and Tabler (1961).

Balance studies provide information as to metabolic processes and effects of specific rations and such studies can be repeated on an individual. This method involves an expensive and laborious procedure and animals are subjected to unnatural conditions; however, many basic problems related to animal nutrition can be answered with respiration calorimetry studies.

Slaughter Technique

A method of determining net energy that has received considerable attention in recent years is the comparative slaughter technique. The method involves slaughtering comparable animals at the beginning and the end of a feeding experiment and determining energy retention by the difference between initial and final body caloric content and attributing the gain in energy to the ration fed (Blaxter, 1956). This technique has been primarily developed and improved at the California station (Garrett, 1959; Lofgreen and Otagaki, 1960; Lofgreen et al., 1962; Lofgreen, 1965; Garrett, 1968; Garrett and Hinman, 1969). Complete chemical analysis of the body is unnecessary since the entire composition can be estimated with an acceptable degree of accuracy if either the fat or water content is known (Lofgreen and Otagaki, 1960). The specific gravity can be used to estimate the percent body water, from which the body fat and protein percentages can be estimated.

Pearson, Purchas, and Reineke (1968) stated that the rationale for estimating fatness or leanness, or both, from density is based on the assumption that the body is a two component system, the two components being the fat tissue and the fat-free body.

Rathbun and Pace (1945) conducted the first analysis relating specific gravity of animals to body composition. They determined specific gravity on eviscerated guinea pigs and showed evidence that the body specific gravity increases as the fat content decreases. Da Costa and Clayton (1950) used shaved eviscerated rats to evaluate the validity of the specific gravity technique. They concluded that specific gravity was as good an index of water content as it was of fat content and calculated regression lines for estimating body fat and water from body specific gravity. Kraybill et al. (1952) extended the use of specific gravity to beef cattle in the estimation of separable fat and body water. Reid et al. (1955) obtained data from several sources (139 beef and 117 dairy cattle) to derive equations for estimating the fat and protein content of the whole empty body.

Lofgreen and Otagaki (1960) explained in detail the development and usefulness of the comparative slaughter technique. Net energy for maintenance (NE_m) can be obtained by extrapolation of the curve of heat production plotted against ME intake, both expressed as $kcal/W_{kg}^{.75}/day$ (Garrett et al., 1959). Net energy for production (NE_p)

can be estimated by the increment method (Lofgreen, Bath, and Strong, 1963) and net energy for maintenance plus production (NE_{m+p}) by the use of a reference standard (Lofgreen, Bath, and Young, 1962).

A proposed system for expressing net energy requirements and feed values for growing and finishing beef cattle was presented by Lofgreen and Garrett (1968). This system separates the requirements for maintenance from that for body gain, expresses the net energy of the feed for these two functions and is adaptable to practice.

CHAPTER III

MATERIALS AND METHODS

Feedlot Phase

Twelve Hereford steers, 8-10 months of age averaging 224 kg and of similar genetic background and condition, were randomly allotted into three treatment groups on the basis of weight. The steers were held off feed and water prior to weighing and allotting. The cattle were placed into three pens, (8 x 13 m) by treatment groups. Each pen was equipped with individual feeding stalls. All steers were hand-fed an 80% concentrate finishing ration twice daily until the time respiration calorimetry trials were scheduled.

The planned growth curves and points of respiration calorimetry trials are shown in Figure 1. Points at which respiration calorimetry trials were conducted were designated as time one (T-1), time two (T-2), weight one (W-1), and weight two (W-2).

The three treatments were based on level of feeding. One group of four steers (Lot 1) was fed ad libitum in an effort to produce gains comparable to those of feedlot cattle. The steers in Lot 2 were fed at a level to support gain of approximately 0.5 kg per day until Lot 1 reached

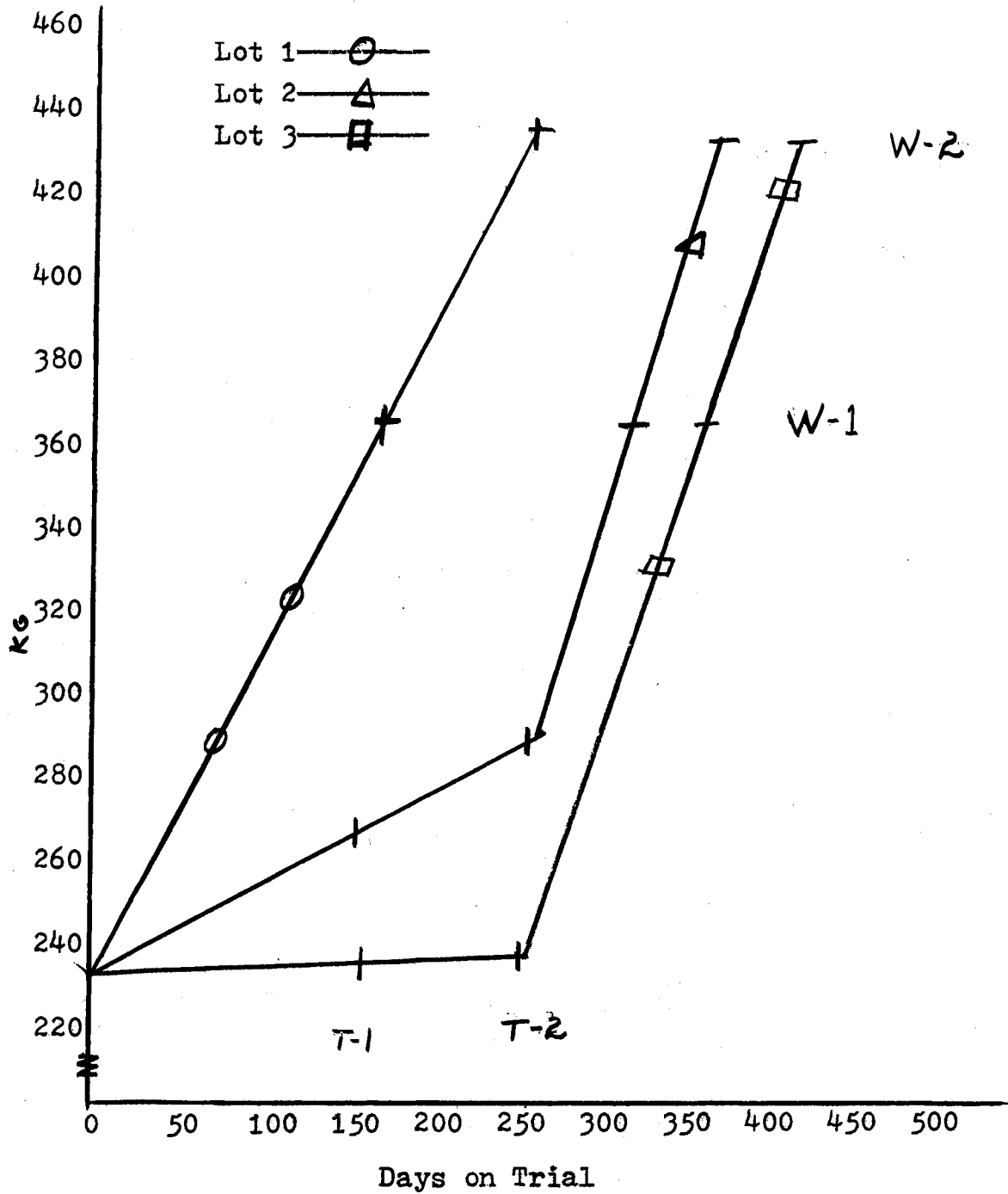


Figure 1. Planned Growth Curves and Points of Respiration Calorimetry Trials

approximately 455 kg. They were then increased to maximum consumption until reaching a weight of approximately 455 kg. The third group (Lot 3) was fed at a maintenance level until Lot 1 reached slaughter weight (455 kg) and then increased to maximum consumption until reaching a weight of approximately 455 kg.

While in the feedlot, all steers were weighed prior to the morning feeding every 28 days. Total feed consumption and feed consumed per unit of gain were recorded for the entire experiment as well as the full-feeding periods of Lots 2 and 3.

Respiration Calorimetry Trials

When the steers in Lot 1 had reached approximately 360 kg, an energy balance trial was conducted with all three lots of steers. This trial was designated as T-1. A 10-day adjustment period was followed by a 7-day fecal and urine collection with all animals in metabolism stalls. The urine was acidified with HCl and daily aliquots of feces and urine were stored in a refrigerator until completion of the collection period. The samples were mixed, subsampled, and stored in a freezer for future analysis. Each fecal sample was dried at 60°C in a forced-air oven, ground through a 1 mm screen in a Wiley mill and stored in a glass jar for future analysis.

Following the excreta collection period, the steers were placed in one of two open circuit respiration chambers

similar to those described by Flatt et al. (1958) for three days, the last two of which included two consecutive 24-hour gas collection periods. The chambers were sealed at least 12 hours prior to the start of gas collection. Outdoor air was pulled into the chambers and circulated by a fan with the temperature being maintained at approximately 18°C. Exhaust air was pulled from the chambers at the rate of 350 liters per minute and volume was measured by dry gas meters. Two spirometers constantly sampled the air passing through each chamber. The samples collected were analyzed for oxygen, carbon dioxide, and methane. Beckman IR-315 infrared instruments were used for CO₂ and CH₄ analysis, and O₂ was measured by a Beckman paramagnetic analyzer.

At the end of the 24-hour period the meters were again read and residual chamber air and the air in the two spirometers was analyzed. These analyses were repeated at the end of the second 24-hour period. Barometric pressure, room temperature and exhaust air, wet bulb and dry bulb temperatures were recorded each time.

Heat production was calculated from oxygen consumption, carbon dioxide and methane production, and urinary nitrogen excretion by the formula developed by Brouwer (1958):

$$HP = 3.869 O_2 + 1.195 CO_2 - 0.516 CH_4 - 0.227 P;$$

where HP = heat production (kcal/day), O₂ = oxygen consumed (liters), CO₂ = carbon dioxide produced (liters),

CH_4 = methane produced (liters) and P= protein oxidized (grams urinary nitrogen x 6.25) with the gases being corrected to dry, standard temperature and pressure conditions.

Upon completion of gas collection the animals were returned to the feeding pens where they were fed in individual stalls twice daily the same levels as previously described until Lot 1 approached 455 kg. At this time steers in all treatments were again moved to the laboratory by pairs for a second energy balance trial, designated as T-2. Thus trials were conducted at two times with all animals at comparable ages.

Immediately after the second trial (T-2), Lot 1 cattle were placed in holding pens by pairs and fasted for three days. They were returned to the chambers for three additional days of fasting, the last two of which included two consecutive 24-hour gas collection periods to determine fasting heat production. Chamber operating procedures and gas analyses were the same as previously described. Fasting heat production was calculated from the amount of oxygen consumed and the caloric value of oxygen based on the respiratory quotient (Carpenter, 1964). After completion of the fasting trial the animals were slaughtered and specific gravity measurements made for calculation of body composition.

After being transferred to the feeding pens Lots 2 and 3 were increased to maximum feed consumption. When they

approached 360 kg, complete digestion and respiration trials were again conducted as previously described. This was done to permit comparisons across treatments at the same weight and was designated as W-1.

As the steers in Lots 2 and 3 approached 455 kg final energy balance trials, designated as W-2, were conducted including fasting trials. After completion of the fasting trials the steers were slaughtered and carcass specific gravity measured.

Specific Gravity Determination

The comparative slaughter technique was used to determine the change in body composition during the experiment. The initial body composition of the experimental animals was estimated from data obtained on an initial slaughter group composed of animals of similar weight, age, and condition. These animals were slaughtered at Wilson and Company, Oklahoma City, Oklahoma, and weights were taken 48 hours later in order to estimate body composition from calculated carcass specific gravity.

Carcass specific gravity was calculated by the formula

$$\frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}}$$

where weight in air is the chilled carcass weight and weight in water is the pooled underwater weights of the front and hind quarters of both sides. The water used for

underwater weighing was placed in a tank and allowed to equilibrate with the cooler temperature at $5 \pm 2^{\circ}\text{C}$ for two days prior to the time the specific gravity measurements were made. The quarters were weighed separately on a Toledo spring balance scale to the nearest one-tenth of a pound, before the underwater weighing. The underwater weight was determined with an Ohaus torsion beam balance to the nearest gram.

Empty body weight of the initial slaughter group was estimated by the equation

$$Y = 31.8 + 1.45X$$

where Y is empty body weight and X is warm carcass weight in kilograms (Lofgreen and Hull, 1962). Specific gravity of the whole empty body was predicted from the equation

$$Y = 0.9955X - 0.0013$$

where Y is specific gravity and X is carcass specific gravity (Kraybill et al., 1952). The water content of the whole empty body was estimated from the equation

$$X = 100 (4.008 - \frac{3.620}{Y})$$

where X is body water and Y is empty body specific gravity (Kraybill et al., 1952). Percent body fat and protein were estimated from equations derived by Reid et al. (1955) and modified by Garrett and Lofgreen (1967), as follows:

$$\% \text{ body fat} = 337.88 + 0.2406X - 188.91 \log X$$

where X is the percent body water;

$$\% \text{ protein} = (80.80 - 0.00078Z) (100 - \sqrt{W + F})$$

where W represents the percent body water, F the percent body fat and Z the age of the animals in days. The percentages of fat and protein were then multiplied times the empty body weight to obtain the kilograms of fat and protein gained.

The validity and use of these equations has been reviewed by Garrett et al. (1959), Lofgreen and Otagaki (1960), Lofgreen (1965), and Lofgreen and Garrett (1968).

Energy gain (kcal) was obtained using the factors of 5686 kcal per kg of protein (Garrett et al., 1959), and 9367 kcal per kg of fat (Blaxter and Rook, 1953) to convert the estimated kg of fat and protein in the empty body to their respective caloric values. The average total kcal per kg of empty body weight of the initial slaughter group was then used to estimate the initial caloric content of the experimental groups.

At the conclusion of the final fasting trials the animals were slaughtered and the empty body weight was estimated from the warm carcass weight. Carcass specific gravity was determined and the body fat and protein estimated by the same procedure and equations as those used for determining the initial body composition. The gain in body fat and protein was then determined by

subtracting the amount predicted to be present initially from the final estimated amount present.

Energy Utilization

Average daily gain in kcal was calculated on a metabolic size ($W_{kg}^{.75}$) basis. Fasting heat production expressed as $\text{kcal}/W_{kg}^{.75}/\text{day}$ was considered as being equal to the maintenance energy requirement (Lofgreen *et al.*, 1963; Lofgreen and Garrett, 1968). These two were added for each steer to obtain a value of the energy used for maintenance and gain. This value was divided by the average daily intake ($\text{kg}/W_{kg}^{.75}$) to estimate the net energy for maintenance plus production (NE_{m+p}) of the total ration. Net energy for maintenance plus production of the basal (all ingredients of the ration except the grain) was calculated using the values of Morrison (1961) for each ingredient. The computer program developed by Newson (1966) was used to determine the NE_{m+p} of the total ration.

Energy gained was determined during each energy balance trial using the formula

$$EG = ME - HP$$

where EG is the energy for gain or production, ME is metabolizable energy and HP is the heat produced by the animal (Lofgreen, 1965).

Energy retained was also calculated using the carbon-nitrogen balance method. The basis of this method

is the assumption that the materials laid down in the body consist of either fat or protein (Blaxter, 1962). Blaxter and Rook (1953) adopted a statistical approach in which the heat of combustion of different tissues was related to their carbon and nitrogen content. The equation obtained was:

$$\text{kcal energy retained} = (12.55 \times \text{grams Carbon retained}) - (6.90 \times \text{grams Nitrogen retained})$$

Laboratory Analysis

Feed and fecal samples that had been previously dried at 60°C in a forced-air oven and ground through a 1 mm screen in a Wiley mill were analyzed for dry matter and nitrogen (A.O.A.C., 1960). Gross energy was determined by combustion in a Parr adiabatic oxygen bomb calorimeter, and carbon was determined as outlined by Smith *et al.* (A.O.A.C. 1965). Wet fecal samples were used for nitrogen determination to avoid nitrogen loss in drying. Urine samples were filtered prior to being analyzed for nitrogen and carbon to remove contaminating materials. Gross energy of urine, which had been dried in polyethylene bags at 20°C and 20 mm mercury, was determined by combustion in a Parr adiabatic oxygen bomb calorimeter (Nijkamp, 1965).

Statistical Analysis

The data were analyzed as a split plot design with treatments being the main plots and days being the

subplots (Cochran and Cox, 1957). Standard errors of difference between two treatment means, two day means for one treatment, and two treatment means for one day were calculated and used to determine the least significant differences between treatment means and day means.

CHAPTER IV

RESULTS AND DISCUSSION

Ingredient and the dry matter compositions of the ration are shown in Tables I and II respectively.

Feedlot Phase

During period 1 the rates of gain compared favorably with the desired rates of gain for Lots 2 and 3. All the feedlot performance data of the steers are shown in Table III, including gains, days on trial, and feed efficiency results. During period 1 the steers in Lot 1 had an average daily gain of 0.88 kg, Lot 2 had an average daily gain of 0.30 kg and Lot 3 had an average daily gain of 0.07 kg. Although Lot 3 tended to be more efficient than Lots 1 and 2 during the full-feeding period the difference was not statistically significant. Thus, the over-all efficiency for the complete experiment was greatest for Lot 1. In contrast Lot 2 showed an increase in average daily gain, but no improvement in feed efficiency. This is in agreement with Watson (1944) and Guilbert *et al.* (1944) who concluded that the greatest efficiency is obtained in continuously grown steers. Their conclusions were based on long periods of restriction before full-feed and indicate that if

TABLE I
RATION COMPOSITION

Ingredient	Percent
Rolled milo	62.75
Dehydrated alfalfa meal pellets (17% C.P.)	6.00
Cottonseed hulls	14.00
Soybean meal (44 % C.P.)	10.00
Cane molasses	5.00
Trace mineralized salt	0.50
Ground limestone	0.50
Dicalcium phosphate	0.50
Urea	0.10
Ammonium chloride	0.50
Aurofac-10	0.15

TABLE II
PROXIMATE ANALYSIS OF RATION

Item	
Dry matter (%)	88.58
Crude protein (% , DM basis)	15.19
Gross energy (Mcal/kg, DM basis)	4.364
Carbon (% , DM basis)	43.15

TABLE III
FEEDLOT PERFORMANCE OF STEERS

	(period 1)		
	<u>Lot 1</u>	<u>Lot 2</u>	<u>Lot 3</u>
Initial wt. (kg)	224	237	217
Final wt. (kg)	451	320	237
Days on trial	250	250	250
Daily gain (kg)	0.876	0.300	0.070
	(period 2, full-feeding)		
Initial wt. (kg)	224	320	237
Final wt. (kg)	451	482	455
Days on full-feed	250	171	257
Daily gain (kg)	0.876	0.960	0.868
Kg DM/kg gain	3.375	3.641	3.256
	(periods 1 and 2)		
Initial wt. (kg)	224	237	217
Final wt. (kg)	451	482	455
Total days on experiment	250	454	544
Daily gain (kg)	0.876	0.541	0.441
Kg DM/kg gain	3.375	4.158	4.216

the period of restriction is too extensive before full-feeding, steers cannot fully compensate for the period of reduced growth. In addition, the available energy content of rations used during recovery may not have been adequate for maximum compensatory growth. As Fox (1970) has suggested, the protein to calorie ratio must be optimum for maximum growth.

Respiration Calorimetry

Energy Balance Trial T-1

This trial was conducted after the steers had been on their respective levels of feed for approximately 150 days to compare energy utilization by animals of the same age but of diverse weight. Average weights of the steers were 351.7 kg, 289.1 kg, and 235.1 kg for Lots 1, 2, and 3 respectively. Weights were taken after the completion of the energy balance trial which included a preliminary adjustment period, a digestion trial, and respiration gas collections. Animals were placed in the respiration chambers by pairs according to a schedule which insured equal pairing of cattle on all three treatments. All steers were maintained on their respective dry matter intakes throughout the balance trial.

Since animal weight and dry matter intakes were so diverse, all values were expressed on the basis of metabolic size and dry matter intake. Energy balance results are

TABLE IV
EFFECT OF LEVEL OF FEEDING ON ENERGY UTILIZATION BY STEERS;
BALANCE TRIAL T-1 (150 DAYS)

Item	Lot 1	Lot 2	Lot 3
Avg animal wt. (kg)	351.7	289.1	235.1
DM intake (kg/day)	6.75	3.65	2.44
Energy intake			
GE (kcal/day)	29450.4	15945.4	10630.3
GE (kcal/W ^{0.75} _{kg})	362.30	227.80	177.36
GE (kcal/W ^{0.75} _{kg} /kg DM)	54.05 ^x	62.35 ^y	72.90 ^z
Energy Utilization			
Losses			
HP ¹ (kcal/day)	8932.9	6944.2	5136.0
HP (kcal/kg DM)	1343.0 ^{d,x}	1900.0 ^e	2108.0 ^{e,y}
HP (% of GE)	30.78 ^{d,x}	43.55 ^e	48.31 ^y
CH ₄ (kcal/day)	1371.9	1000.6	752.0
CH ₄ (kcal /kg DM)	203.24	274.14	308.20
CH ₄ (% of GE)	4.71	6.28	6.84
DE (kcal/day)	20641.8	11421.1	7305.0
DE (kcal/kg DM)	3043.0	3126.0	2999.0
DE (% of GE)	69.72	71.63	68.72
ME (kcal/day)	18477.6	10023.1	6182.8
ME (kcal/kg DM)	2719.0	2743.0	2538.0

TABLE IV (continued)

ME (% of GE)	62.30	62.86	58.16
ME (% of DE)	89.32 ^{a,d}	87.74 ^a	84.60 ^{b,e}
EG ² (kcal/day)	10677.9	2675.6	876.5
EG (kcal/kg DM)	1524.8 ^{a,d}	732.2 ^b	359.8 ^e
EG (% of ME)	55.49 ^{a,d}	26.53 ^b	13.42 ^e
ENRT ³ (kcal/day)	11307.3	3581.5	-191.4
ENRT (kcal/kg DM)	1634.0 ^{d,x}	980.0 ^e	-79.0 ^{f,y}

¹HP = 3.869 O₂ + 1.195 CO₂ - 0.516 CH₄ - 0.227 P; where O₂ is L. of oxygen consumed, CH₄ and CO₂ are L. of methane and carbon dioxide produced, and P is grams of urinary nitrogen x 6.25.

²EG obtained by subtracting HP from ME

³ENRT energy retained calculated from C-N balance

a,b,c Values on the same line with different superscripts differ significantly (P < .05)

d,e,f Values on the same line with different superscripts differ significantly (P < .01)

x,y,z Values on the same line with different superscripts differ significantly (P < .001)

shown in Table IV. Digestible energy (DE) and metabolizable energy (ME) values expressed as kcal/kg DM daily or as a percent of GE showed no significant difference ($P > .05$), but energy gained (EG) showed Lot 1 greater than Lot 2 ($P < .05$) and Lot 1 greater than Lot 3 ($P < .05$). Thus, the efficiency of utilization was adversely affected by the lower levels of feeding. This was due to a higher percent of GE being used for maintenance in the lower levels of feeding. Although there was no significant ($P > .05$) difference in the DE as a percent of GE, the ME as a percent of DE was significantly different -- Lot 1 was greater than Lot 3 ($P < .01$), Lot 2 was greater than Lot 3 ($P < .05$). As feed intake increases the losses of urine and methane (as a % of GE) decreases (Flatt, 1966). These values compare favorably with the normally accepted value of 82% (National Research Council, 1971). Rather small differences in digestibility between animals of very diverse age, weight, size, and fatness, and the effects of level of feeding have been found in sheep by Blaxter, Graham, and Wainman (1956) and Graham (1967). The values of ME as a percent of DE reported by Graham and Searle (1972) were 79% to 87% for sheep of very diverse ages and weights compared on both age-constant and weight-constant basis. The values they reported were lower but represented a greater range than the values in this study (84.6% to 89.3%).

Energy Balance Trial T-2

Energy balance results of trial T-2 are shown in Table V. This trial was conducted approximately 250 days after the experiment was begun. This trial was also the final balance trial for Lot 1 since the steers in this lot were approaching slaughter weight (455 kg). Average weights of the steers during trial T-2 were 450.9 kg, 319.4 kg, 236.9 kg for Lots 1, 2, and 3 respectively. One steer in Lot 1 was not included in this balance trial due to his failure to consume adequate feed necessary to support a rate of gain comparable to the other steers in this lot. His average daily gain was less than the treatment mean minus two times the standard deviation for average daily gain which would theoretically exclude 5% of the population. There was no apparent reason for this steer to refuse to eat.

As in trial T-1 the HP for Lot 1 was significantly ($P < .01$) lower than Lots 2 and 3, either expressed as a percent of GE or per kg DM intake because of a larger percent being used for maintenance in the lower levels of feeding. However, there were no differences ($P > .05$) among treatments in DE and ME values expressed as a percent of GE or per kg of dry matter consumed. ME as a percent of DE was significantly ($P < .05$) greater for Lot 1 than Lots 2 and 3 due to greater losses (as a % of GE) of urine and methane. Since Lot 3 did show a large value for EG on the

TABLE V
EFFECT OF LEVEL OF FEEDING ON ENERGY UTILIZATION BY STEERS;
BALANCE TRIAL T-2 (250 DAYS)

Item	Lot 1 ⁱ	Lot 2	Lot 3
Avg animal wt. (kg)	450.9	319.4	236.9
DM intake (kg/day)	7.31	3.65	2.44
Energy intake			
GE (kcal/day)	31886.5	15945.4	10630.3
GE (kcal/W _{kg} ^{.75})	326.38	211.37	176.32
GE (kcal/W _{kg} ^{.75} /kg DM)	44.67 ^x	57.86 ^y	72.42 ^z
Energy Utilization			
Losses			
HP ¹ (kcal/day)	11000.0	6734.4	4600.2
HP (kcal/kg DM)	1505.4 ^{d,x}	1843.0 ^e	1888.0 ^{e,y}
HP (% of GE)	34.50 ^d	42.23 ^e	43.27 ^e
CH ₄ (kcal/day)	1775.2	1105.0	791.0
CH ₄ (kcal/kg DM)	261.1	302.4	324.7
CH ₄ (% of GE)	5.57	6.93	7.44
DE (kcal/day)	23404.6	11838.1	8199.8
DE (kcal/kg DM)	3203.0	3240.0	3366.0
DE (% of GE)	73.40	74.24	77.17
ME (kcal/day)	20756.4	10263.0	7111.1
ME (kcal/kg DM)	2841.0	2809.0	2919.0

TABLE V (continued)

ME (% of GE)	65.09	64.36	66.89
ME (% of DE)	88.65 ^a	86.71 ^b	86.72 ^b
EG ² (kcal/day)	10961.9	2919.9	2220.2
EG (kcal/kg DM)	1500.0	799.0	911.0
EG (% of ME)	52.02 ^a	28.55 ^b	30.83 ^b
ENRT ³ (kcal/day)	10070.1	3149.5	2275.8
ENRT (kcal/kg DM)	1378.0 ^a	862.0 ^b	934.0 ^b

¹HP = 3.869 O₂ + 1.195 CO₂ - 0.516 CH₄ - 0.227 P; where O₂ is L. of oxygen consumed, CH₄ and CO₂ are L. of methane and carbon dioxide produced, and P is grams of urinary nitrogen x 6.25.

²EG obtained by subtracting HP from ME

³ENRT energy retained calculated from C-N balance

a,b,c Values on the same line with different superscripts differ significantly (P < .05)

d,e,f Values on the same line with different superscripts differ significantly (P < .01)

x,y,z Values on the same line with different superscripts differ significantly (P < .001)

ⁱAverage of three steers

calculated maintenance level of feed intake, it is possible that the maintenance requirement was decreased after the extended period of feed restriction. Quinby (1948) stated that the maintenance requirement per unit of body size is decreased by extended periods of feed restriction.

Energy Balance Trial W-1

Results of energy balance trial W-1 conducted at approximately 360 kg are shown in Table VI. While there were no significant differences in GE intake between lots, the DE and ME values were significantly ($P < .05$) different with Lot 2 being the lowest in both cases. Lot 2 had been on full-feed only approximately 35 days and may not have been at maximum feed consumption at this weight. After the period of restricted feeding (250 days) one would expect Lots 2 and 3 to show an advantage in rate of gain (compensatory gain) and efficiency of energy utilization when put on full-feed.

Graham and Searle (1972) concluded that with sheep, over the ranges 5 to 14 months, 18 to 72 kg, 10 to 40% fat, and 47 to 70 cm body length, energy was used with fairly constant net efficiency, although in the comparison between animals of 28 and 48 kg at 10 months, the 28 kg animals were somewhat more efficient.

As suggested by Fox et al. (1972) during recovery the compensatory cattle may require a higher protein:energy ratio to realize maximum compensatory growth early in the

TABLE VI
EFFECT OF LEVEL OF FEEDING ON ENERGY UTILIZATION BY STEERS;
BALANCE TRIAL W-1 (AVG 357 KG).

Item	Lot 1	Lot 2	Lot 3
Avg animal wt. (kg)	351.7	355.1	364.4
DM intake (kg/day)	6.75	5.89	6.79
Energy intake			
GE (kcal/day)	29450.4	25685.5	29621.7
GE (kcal/W ^{0.75} _{kg})	362.30	314.35	355.85
GE (kcal/W ^{0.75} _{kg} /kg DM)	54.05	53.43	52.40
Energy Utilization			
Losses			
HP ¹ (kcal/day)	8932.9	7635.3	10212.0
HP (kcal/kg DM)	1343.0	1315.0	1504.0
HP (% of GE)	30.78	32.07	31.64
CH ₄ (kcal/day)	1371.9	1287.9	1469.8
CH ₄ (kcal/kg DM)	203.2	218.8	216.5
CH ₄ (% of GE)	4.71	5.02	4.96
DE (kcal/day)	20641.8	15827.1	19821.4
DE (kcal/kg DM)	3043.0 ^d	2677.0 ^{a,e}	2920.0 ^b
DE (% of GE)	69.72 ^d	61.34 ^{a,e}	66.92 ^b
ME (kcal/day)	18477.6	13971.0	17571.1
ME (kcal/kg DM)	2719.0 ^d	2363.0 ^{a,e}	2589.0 ^b

TABLE VI (continued)

ME (% of GE)	62.30 ^{a,d}	54.14 ^{b,e}	59.32 ^c
ME (% of DE)	89.32	88.26	88.65
EG ² (kcal/day)	10677.9	5811.8	8445.3
EG (kcal/kg DM)	1524.8	963.0	1208.0
EG (% of ME)	55.49 ^{a,d}	40.77 ^{b,e}	46.65 ^c
ENRT ³ (kcal/day)	11307.3	6271.5	8698.7
ENRT (kcal/kg DM)	1634.0 ^a	1026.0 ^b	1281.0 ^b

¹HP = 3.869 O₂ + 1.195 CO₂ - 0.516 CH₄ - 0.227 P; where O₂ is L. of oxygen consumed, CH₄ and CO₂ are L. of methane and carbon dioxide produced, and P is grams of urinary nitrogen x 6.25.

²EG obtained by subtracting HP from ME

³ENRT energy retained calculated from C-N balance

a,b,c Values on the same line with different superscripts differ significantly (P < .05)

d,e,f Values on the same line with different superscripts differ significantly (P < .01)

x,y,z Values on the same line with different superscripts differ significantly (P < .001)

recovery period. Since the same ration was fed throughout this experiment, the protein:energy ratio may not have been sufficient to allow maximum potential growth. However, the greatest limitation to normal growth was poor feed intake resulting from inadequate individual feeding facilities.

Energy Balance Trial W-2

The results of energy balance trial W-2 which was conducted at slaughter weight (average weight of 463 kg) are shown in Table VII. While there were no significant differences between treatments at this weight, the same relationships hold true as were present in trial W-1 (Lot 1 was greater than Lots 2 and 3 for efficiency of energy utilization). However, Lot 2 does show a trend for more efficient energy utilization (EG) than Lot 3.

Selected over-all means and the standard errors for each mean of all energy balance trials are shown in Table VIII.

Fasting Heat Production

Fasting heat production may be considered as being equal to the net energy required for maintenance at no activity. The values obtained at the end of trial W-2 were 68, 72, and 74 kcal/W_{kg}^{.75}/day respectively for Lots 1, 2, and 3. This fasting heat production is lower than the value of 77 kcal/W_{kg}^{.75} suggested by Lofgreen and Garrett (1968) indicating that net energy required for

TABLE VII
EFFECT OF LEVEL OF FEEDING ON ENERGY UTILIZATION BY STEERS;
BALANCE TRIAL W-2 (AVG 463 KG)

Item	Lot 1 ⁱ	Lot 2	Lot 3
Avg animal wt. (kg)	450.9	482.3	454.7
DM intake (kg/day)	7.31	7.75	7.71
Energy intake			
GE (kcal/day)	31886.5	34560.6	33080.6
GE (kcal/W _{kg} ^{.75})	326.38	336.31	336.89
GE (kcal/W _{kg} ^{.75} /kg DM)	44.67	43.40	43.70
Energy Utilization			
Losses			
HP ¹ (kcal/day)	11000.1	11251.2	11859.1
HP (kcal/kg DM)	1505.4	1457.0	1540.0
HP (% of GE)	34.50	32.73	35.32
CH ₄ (kcal/day)	1775.2	1814.7	1667.2
CH ₄ (kcal/kg DM)	261.1	234.3	216.3
CH ₄ (% of GE)	5.57	5.40	5.07
DE (kcal/ day)	23404.6	24006.0	23337.0
DE (kcal/kg DM)	3203.0	3099.0	3026.0
DE (% of GE)	73.40	69.43	70.57
ME (kcal/day)	20756.4	21321.2	20673.4
ME (kcal/ kg DM)	2841.0	2753.0	2679.0

TABLE VII (continued)

ME (% of GE)	65.09	61.65	62.47
ME (% of DE)	88.65	88.76	88.54
EG ² (kcal/day)	10961.9	10056.7	9033.4
EG (kcal/kg DM)	1500.2	1291.0	1167.0
EG (% of ME)	52.02	46.89	43.56
ENRT ³ (kcal/day)	10070.1	11828.1	10671.8
ENRT (kcal/kg DM)	1378.0	1520.0	1372.0

¹HP = 3.869 O₂ + 1.195 CO₂ - 0.516 CH₄ - 0.227 P; where O₂ is L. of oxygen consumed, CH₄ and CO₂ are L. of methane and carbon dioxide produced, and P is grams of urinary nitrogen x 6.25.

²EG obtained by subtracting HP from ME

³ENRT energy retained calculated from C-N balance

a,b,c Values on the same line with different superscripts differ significantly (P < .05)

d,e,f Values on the same line with different superscripts differ significantly (P < .01)

x,y,z Values on the same line with different superscripts differ significantly (P < .001)

ⁱAverage of three steers

TABLE VIII
 SELECTED OVER-ALL MEANS AND STANDARD ERRORS

Item	Trial	
	T-1	T-2
HP (kcal/kg DM)	1748 [±] 74.5	1767 [±] 39.9
DE (kcal/kg DM)	3056 [±] 69.4	3276 [±] 66.3
ME (kcal/kg DM)	2667 [±] 69.9	2858 [±] 61.2
EG (kcal/kg DM)	872 [±] 162.5	1031 [±] 179.4
ENRT (kcal/kg DM)	845 [±] 160.5	1029 [±] 132.0
	W-1	W-2
HP (kcal/kg DM)	1387 [±] 71.2	1500 [±] 53.0
DE (kcal/kg DM)	2880 [±] 48.6	3101 [±] 57.4
ME (kcal/kg DM)	2557 [±] 50.1	2750 [±] 65.2
EG (kcal/kg DM)	1224 [±] 156.4	1255 [±] 104.1
ENRT (kcal/kg DM)	1314 [±] 137.9	1428 [±] 184.9

maintenance is not constant. The fasting heat production represents an estimate of the mean net energy requirement for maintenance during the feedlot period. Ritzman and Colovos (1943) working with dairy heifers reported a fasting heat production of $172 \text{ kcal/W}_{\text{kg}}^{.75}$ for dairy heifers at eight days of age compared to $80-85 \text{ kcal/W}_{\text{kg}}^{.75}$ for the same heifers 24-30 months of age, indicating that net energy for maintenance decreases with age and weight.

Net Energy

A plot of metabolizable energy intake against heat production, expressed as $\text{kcal/W}_{\text{kg}}^{.75}/\text{day}$, was used to determine energy equilibrium for each animal. The point representing the heat production of an animal at ad libitum intake was connected with a straight line to the point representing the heat production at zero feed intake (fasting heat production). The mean daily ME intake ($\text{kcal/W}_{\text{kg}}^{.75}/\text{day}$) for each treatment was located on the x axis; the point at which this intersected the regression line was considered to be equivalent to energy equilibrium, which is the amount of ME intake required to maintain energy balance. The plots representing the average for each lot for trial W-2 are shown in Figure 2. Average energy equilibrium was 86, 88, and 95 $\text{kcal/W}_{\text{kg}}^{.75}/\text{day}$ for Lots 1, 2, and 3 respectively. The average metabolizable energy for the three lots was 2.841, 2.753, and 2.679 Mcal/kg of dry matter respectively for Lots 1, 2, and 3 in trial W-2 (Table VII).

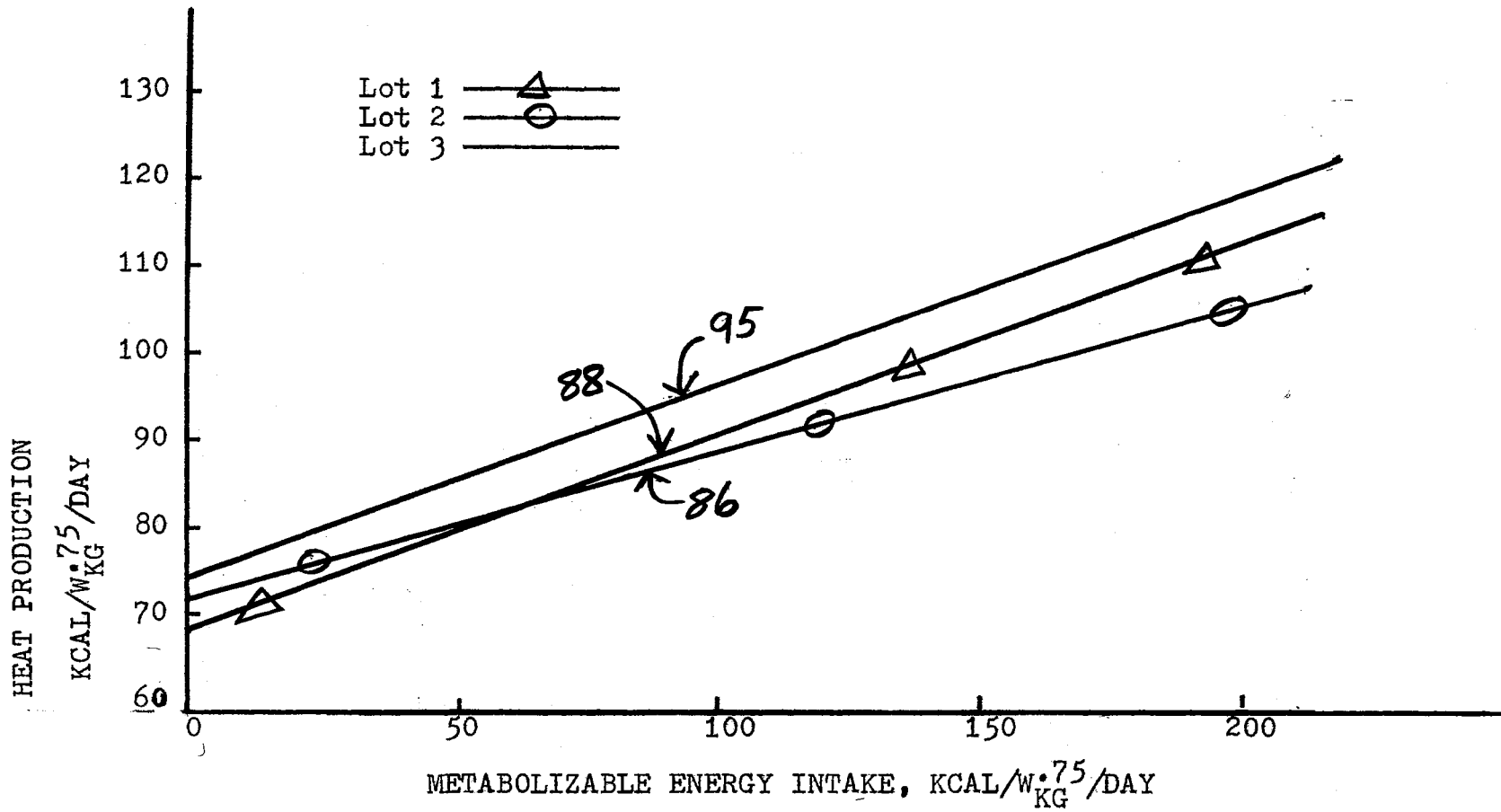


Figure 2. Relationship Between Heat Production and Metabolizable Energy Intake

Thus, the amount of dry matter required to maintain energy equilibrium for Lots 1, 2, and 3 was 30.3, 32.0, and 35.5 grams/ $w_{kg}^{.75}$ /day respectively.

There are two important portions of the plot in Figure 2: (1) heat production associated with level of ME intake from zero to energy equilibrium and (2) heat production associated with level of ME intake from energy equilibrium to ad libitum. The values of net energy are determined by the "difference trial" technique as outlined by Estima, et al. (1967) and Lofgreen and Garrett (1968). The difference in energy balance between fasting and energy equilibrium divided by the difference in dry matter intake between fasting and energy equilibrium gives a measure of the net energy value of the feed for maintenance (NE_m). The difference in energy balance between energy equilibrium and ad libitum divided by the difference in dry matter intake between energy equilibrium and ad libitum gives a measure of the net energy value of the feed for production (NE_p). In every case energy balance is defined as metabolizable energy minus heat production.

The procedures used for determining NE_m and NE_p are shown with average values in Tables IX and X. The results of these calculations are given in Table XI.

All NE_m and NE_p values are almost identical. The magnitude of the differences between the NE_m and NE_p values are not as great as would be expected. Forbes et al. (1930) and Kleiber (1961) have stated that net energy for

TABLE IX

CALCULATION OF NET ENERGY FOR MAINTENANCE (DETERMINED BY
THE "DIFFERENCE TRIAL" TECHNIQUE)- TRIAL W-2

Item	Lot ¹ 1		Lot 2		Lot 3	
	Fasting	Equil.	Fasting	Equil.	Fasting	Equil.
Level of feeding						
ME intake (Mcal/W ^{.75} _{kg} /day)	0	.086	0	.088	0	.095
DM required (kg/W ^{.75} _{kg} /day)	0	.0303	0	.0320	0	.0353
Heat produced (Mcal/W ^{.75} _{kg} /day)	.068	.086	.072	.088	.074	.095
Energy gain (Mcal/W ^{.75} _{kg} /day)	-.068	0	-.072	0	-.074	0
Difference (equilibrium - fast)						
DM intake		.0303		.0320		.0353
Heat produced on fast (Mcal)		.068		.072		.074
NE _m of ration (Mcal/kg DM) ^a		2.244		2.250		2.096

$${}^a\text{NE}_m = \frac{\text{Heat produced on fast}}{\text{DM intake}}$$

TABLE X

CALCULATION OF NET ENERGY FOR PRODUCTION (DETERMINED BY THE
 "DIFFERENCE TRIAL" TECHNIQUE) - TRIAL W-2

Item	Lot 1		Lot 2		Lot 3	
	Equil.	Ad lib	Equil.	Ad lib	Equil.	Ad lib
Level of feeding						
DM intake (kg/W ^{.75} /day)	.0303	.0750	.0320	.0754	.0353	.0785
Energy gain (Mcal/W ^{.75} /day)	0	.0991	0	.0979	0	.0910
Difference (ad lib - equilibrium)						
DM intake (kg)		.0447		.0434		.0432
Energy gain (Mcal)		.0991		.0979		.0919
NEp of the ration (Mcal/kg DM) ^a		2.217		2.258		2.127

$${}^a\text{NEp} = \frac{\text{Energy gain}}{\text{DM intake}}$$

TABLE XI
SUMMARY OF NET ENERGY VALUES FOR MAINTENANCE AND
PRODUCTION BY "DIFFERENCE TRIAL" - TRIAL W-2

	NE _m	NE _p	NE _{m+p}
	(Mcal/kg DM)		
Lot 1	2.244	2.217	2.267
Lot 2	2.250	2.258	2.252
Lot 3	2.096	2.127	2.130

maintenance was higher than for production. The net energy system proposed by Lofgreen and Garrett (1968) shows higher values for NE_m than for NE_p . The similarity of these values suggests that under controlled conditions, as maintained in respiration calorimetry, the efficiency of energy utilization for production of a high energy ration might be equal to that for maintenance. Kiesling (1972) also reported these values to be similar for different processed grains.

Slaughter Technique

Feedlot Performance

Since one steer in Lot 1 was taken off trial, all results for that group are based on three steers. Average daily intakes during the feedlot period are given in Table XII. The average number of days on full-feed was 250 for Lot 1, 171 for Lot 2, and 257 for Lot 3. The criterion for terminating the feedlot phase for individual animals was weight rather than number of days on full-feed. Intakes among the three lots were not significantly ($P > .05$) different for either total ration or the milo portion only.

Weight gain and feed efficiency results for the full-fed phase are shown in Table XIII. While the average daily weight gain was slightly more for Lot 2 than Lots 1 and 3, the differences were not statistically significant. Feed

consumed per unit of gain was less for Lot 3 than the other two lots but again the differences were not statistically significant.

Average energy gain and efficiency are shown in Table XIV. The average daily energy gain was significantly ($P < .05$) greater for Lot 2 than Lot 3.

Net Energy

The calculated net energy values are given in Table XV. The values are similar to those reported by Schneider (1968) -- 1.338, 1.405, and 1.129 Mcal/kg for NE_{m+p} of total ration, NE_{m+p} of the grain and NE_p of the grain, respectively. Kiesling (1972) also reported values of 1.311, 1.375, and 1.003 Mcal/kg for NE_{m+p} of the total ration, NE_{m+p} of the grain, and NE_p of the grain for a dry rolled milo ration. Garrett (1965) reported an average value of 1.315 Mcal/kg for NE_p of milo. The results in this study indicate that net energy values for the ration tended to be greater with Lot 2.

TABLE XII
AVERAGE DAILY INTAKE (FULL-FED PHASE)^a

Feed	Lot 1	Lot 2	Lot 3
Total ration (kg)	7.73	8.64	6.94
Grain (kg)	4.90	5.42	4.36

^aexpressed on 90% dry matter basis

TABLE XIII
 FEEDLOT GAIN AND EFFICIENCY (FULL-FED PHASE)

Item	Lot 1	Lot 2	Lot 3
Initial live shrunk weight (kg)	223.02	318.76	236.44
Final live shrunk weight (kg)	449.97	481.26	453.71
Average daily shrunk weight gain (kg)	0.87	0.95	0.86
Total feed/kg shrunk weight gain (kg)	8.88	9.04	8.08
Grain/kg shrunk weight gain (kg)	5.63	5.67	5.08
Initial empty body weight (kg)	206.95	281.35	218.23
Final empty body weight (kg)	439.58	454.22	425.77
Average daily empty body weight gain (kg)	0.89	1.01	0.83
Total feed/kg empty body weight gain (kg)	8.65	8.51	8.60
Grain/kg empty body weight gain (kg)	5.49	5.34	5.40

TABLE XIV
 RATE AND EFFICIENCY OF ENERGY GAIN AS DETERMINED
 BY THE COMPARATIVE SLAUGHTER TECHNIQUE

Item	Lot 1	Lot 2	Lot 3
Avg initial body energy (Mcal/head)	434.71	590.99	458.40
Avg final body energy (Mcal/head)	1292.82	1353.35	1128.17
Avg daily energy intake (Mcal/head)	33.68	37.44	30.30
Avg daily energy gain (Mcal/head)	3.30	4.46	2.69*
Avg daily energy gain per kg feed (kcal)	429.17	512.72	381.16

* $P < .05$

TABLE XV
NET ENERGY VALUES AS DETERMINED BY THE
COMPARATIVE SLAUGHTER TECHNIQUE

Item	Lot 1	Lot 2	Lot 3
	(Mcal/kg, 90% DM)		
NE _{m+p} of total ration ^a	1.213	1.318	1.282
NE _{m+p} of grain ^b	1.368	1.540	1.482
NE _p of grain ^c	1.059	1.319	1.318

$${}^a_{NE_{m+p}} = \frac{\text{energy for gain and maintenance (kcal/day)}}{\text{average daily intake (kg/metabolic size)}}$$

$${}^b_{NE_{m+p}} = \frac{\text{kcal from gain only per day}}{\text{average daily grain intake (kg/ metabolic size)}}$$

$${}^c_{NE_p} = \frac{\text{average daily gain (kcal/metabolic size)}}{\text{kg grain available for gain/day/metabolic size}}$$

CHAPTER V

SUMMARY

Twelve Hereford steers were used to investigate the effect of previous plane of nutrition upon the efficiency of energy utilization by feedlot cattle. Respiration calorimetry and the comparative slaughter technique were used to determine energy values of a high concentrate ration. During the first phase of the study, one group of steers was fed ad libitum, another group was fed at a level to support gain of 0.5 kg per day, and the third group was fed at a maintenance level until Lot 1 reached slaughter weight. This marked the end of phase 1 and the beginning of phase 2. During the second phase, steers in Lots 2 and 3 were full-fed until they reached 455 kg. All steers were individually fed twice daily the same ration.

Respiration calorimetry trials were conducted with all animals at two time-constant points (150 and 250 days) and two weight-constant points (360 and 460 kg). Also, the comparative slaughter method was used to measure total energy gain during the feedlot phase.

In trial T-1 (150 days) the DE and ME values (kcal/kg DM intake) of the ration were not significantly different, however, energy gain was significantly different -- Lot 1

was greater than Lot 2 ($P < .05$), and Lot 1 was greater than Lot 3 ($P < .01$). In trial T-2 (250 days) the HP values tended to be higher for Lots 2 and 3 than Lot 1; however, there were no significant differences in DE and ME (kcal/kg DM). Lot 1 had a significantly ($P < .05$) greater energy gain than Lots 2 and 3, during 7-day energy balance trial.

In trial W-1 (360 kg) the GE intakes were not significantly different; however, both DE and ME (kcal/kg DM intake) were significantly different across treatments; Lot 1 was greater than Lot 3 and Lot 3 was greater than Lot 2 ($P < .01$) with no differences in EG. In trial W-2 (460 kg) there were no significant differences between treatments. However, Lot 2 did show a tendency for a slight improvement in energy utilization over Lot 3.

Due to inadequate individual feeding facilities, Lots 2 and 3 had poor feed intakes during full-feeding and failed to exhibit compensatory growth as had been expected following the period of restricted-feeding. During the feedlot period average daily dry matter intake and net energy values determined by the comparative slaughter technique tended to be highest for Lot 2. The NE_{m+p} (Mcal/kg 90% DM intake) of the ration was higher when determined by respiration calorimetry than when determined by comparative slaughter technique. The higher values obtained by respiration calorimetry appear to be logical since the maintenance requirement of an animal would be considerably less while confined to a respiration chamber than in the feedlot due

to less physical activity and the absence of environmental stress while in confinement.

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Thesis: EFFECT OF PREVIOUS PLANE OF NUTRITION UPON THE EFFICIENCY OF ENERGY UTILIZATION BY BEEF STEERS AS MEASURED BY RESPIRATION CALORIMETRY AND SLAUGHTER TECHNIQUE

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