RESTRICTED FEEDING MANAGEMENT FOR FINISHING

CATTLE: EFFECTS ON PERFORMANCE,CARCASS

TRAITS, ECONOMICS, BODY COMPOSITION,

RUMINAL FERMENTATION AND BLOOD

METABOLITE AND HORMONAL

PROFILES

By

WILLIAM JEFF HILL

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Oklahoma State University
Stillwater, Oklahoma
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Master of Science
Oklahoma State University
Stillwater, Oklahoma
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Thesis Approved:

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Thesis Adviser

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Dean of the Graduate College

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Format of Dissertation

This dissertation is presented in the Journal of Animal Science style format, as outlined by the Oklahoma State University graduate college style manual. The use of this format allows for independent chapters to be suitable for submission to scientific journals. Four papers have been prepared from the data collected for research to partly fulfill the requirements of the Ph.D. degree. Each paper is complete in itself with and abstract, introduction, materials and methods, results and discussion, implications and literature cited section.

CHAPTER I

INTRODUCTION

Both the feedlot business and the beef industry as a whole have become very sophisticated and technologically advanced. There have been great advances in the fields of feed additives, grain processing, and growth promoting compounds. These technological advances and their implementation have accomplished much in terms of making the production of beef more efficient and more profitable. These advances have collectively ensured a low cost to the end user, the consumer. However, today the other competitive meats, namely pork and poultry, have made even greater strides in improving efficiencies and lowering their costs of production resulting in lower prices at the meat counter. This has resulted in increased per capita consumption of pork and especially poultry over the last ten to fifteen years at the expense of beef. While beef production is inherently less efficient than the production of other meats it does have many unique advantages, which should ensure its future as a staple protein source. However, we must always be concerned about increasing efficiency and keeping costs low.

As previously stated most of the improvement in efficiency has come from technological advances and increased growth potential through genetic selection. While these mechanisms will remain important into the future the relative rate at which new technologies can be implemented coupled with ever more stringent FDA approval criteria will limit the rate at which these type of systems will improve efficiency of beef production. Additionally, the use of growth promotants and feed additives is becoming a more and more sensitive issue with the ever increasing number of health and safety conscious public. So in short if the beef industry is going to remain a viable protein source in an ever increasing competitive market it must strive to improve efficiency and cut costs by new and innovative ways. One area that has recently received attention as means of improving feed efficiency in the feedlot sector is restricted ,or better termed, intake managed feeding. Strategically, controlling and manipulating feed intake has consistently proven to be an effective means of improving feed efficiency and possibly adding more predictability to finishing cattle performance.

With these things in mind the objective of the research contained in this dissertation was to identify specific intake manipulation strategies which improved feed efficiency and then further characterize these systems with respect to carcass characteristics and total economic viability. Additionally, one of the goals was to better understand the mechanism by which intake manipulation improves feed efficiency.

CHAPTER II

REVEIW OF LITERATURE

Growth and Development

Growth and development of various species of animals has intrigued and perplexed both livestock producers and scientists for many years. Even the definition of the term 'growth' is debated. Schloss (1911) defined growth as a correlated increase in the mass of the body in definite intervals of time in a way characteristic of the species; Brody (1945) defined growth as production of new biochemical units brought about by cell division, cell enlargement, or incorporation of materials from the environment; whereas Hammond (1952) and McMeekan (1959) defined growth as an increase in weight until a mature size is reached. Because weight can increase by intussusception of water, Weiss (1949) concluded that weight alone cannot be used to define growth. Based on the previous statements it is apparent that no single definition of growth is universally accepted.

Development also has multiple definitions. It has been defined as the directive coordination of diverse processes into an adult or into an "organized heterogeneity" (Needham 1931); as involving growth, cellular differentiation, and or development of form (Lewis, 1939); as a progressive change (Spratt, 1954); and as changes in body shape and or conformation until the body structure and its various parts reach maturity (Hammond, 1952; McMeekan, 1959). Some investigators consider growth as a component of development whereas others distinguish development as being increases in specific components, i.e., bone, muscle or fat. However, Maynard and Loosli (1962) maintained that "true "growth involves an increase in the structural tissue and should be distinguished from the mass increase that results from fat deposition as a reserve tissue. But Pomeroy (1955) points out that "while it is sometimes convenient, agriculturally, to distinguish between growth and fattening, the distinction is an arbitrary one and there seems to be no logical reason for regarding the deposition of fat in the fat depots as not being part of the growth process".

During growth and development, form and composition of an animal changes. Hence, growth and development cannot be clearly distinguished nor adequately defined separately. Furthermore, these

phenomena are important processes in animal agriculture and consist of more than a simple increase in size or weight. There is no complete explanation as to why growth starts, how it is regulated, or why it stops at some definite point that characterizes adult development (Maynard and Loosli, 1962).

Cumulative weight plotted against animal age follows a sigmoid curve; this curve is composed of the earlier pre-pubertal self-accelerating phase and the later post-pubertal self-inhibiting phase. Reasons for deceleration post-pubertally are not well understood despite years of study with isolated muscle and bone cultures (Owens et al., 1993). Experiments with transformed muscle cell culture studies indicate that growth inhibition is due either to a limitation in resources (space, nutrient supply, growth factors) or to accumulation of products of inhibitory factor that restrict cell division (Owens et al., 1993). Specific blood serum proteins have been found that stimulate or inhibit in vitro muscle cell proliferation (Hathaway et al., 1990; Dayton and Hathaway, 1991). Because growth rate is retarded when substrate supply is limited, some researchers have speculated that growth deceleration is due simply to a reduction in intake of energy above maintenance. However, if this were true, force feeding should increase lean body mass of maturing animals; that has not been observed in most research trials (Owens et al., 1993).

From an economic standpoint, the goal in beef production is to maximize lean or muscle tissue and minimize waste fat while maintaining enough fat to make meat palatable and tasty. Slaughter weight, sex, shape, nutrition, and breed all can influence carcass composition; these are the major factors that producers can use to alter carcass composition. In animals well advanced in the fattening stage, muscle growth slows down; coupled with continued fat deposition with its high energy cost and the cost of maintaining a large amount of depot tissue, animals nearing maturity have a low biological efficiency for growth (Berg and Butterfield, 1976).

Watson (1943), in analysis of the data of Haecker (1920), emphasized the importance of a high plane of nutrition to maximize physiological efficiency. Doubling the food intake above maintenance can increase efficiency by 4.8 times. On a protein return basis, he concluded that the optimum is obtained by full-feeding cattle to a live weight of 840 pounds when carcass fat is 22.2 percent and carcass yield is 60%. On an energy return basis, cattle should be fed to a live weight of 1700 pounds when carcass fat is

35%t and carcass yield is 64%. Considering both fat and protein, then the ideal is a 1150 pound animal when carcass fat is 24 percent and carcass yield is 59 percent.

Effects of Gender on Growth

Gender influences growth of body tissues, carcass composition and distribution of weight among tissues. The most pronounced impact of gender on carcass composition is apparent during later stages of maturation or fattening. Heifers begin to deposit fat at a lighter weight than steers, and steers fatten at a lighter weights than bulls of the same genetic background (Berg and Butterfield, 1976). Therefore, to obtain the same percentage carcass fat, the optimum slaughter weight is heaviest for bulls, intermediate for steers and lightest for heifers.

The influence of gender on muscle growth also influences carcass composition. Genders differ in their weight distribution among various muscles. Although differences between heifers and steers are not pronounced, bulls have proportionately larger muscle mass in the forequarter muscles; meat from forequarter wholesale cuts usually are lower in price than meat from hindquarter cuts (Berg and Butterfield, 1976). However, to take advantage of the ability of bulls to gain weight faster and more efficiently, to fatten later, and to produce heavier carcasses without excess fat, one is forced to accept a less ideal muscle weight distribution. Bulls also have higher muscle:bone ratios than heifers or steers at the same level of carcass fat. This is because at a specific fat level, bulls have heavier carcasses; bulls have greater impetus for muscle growth than steers or heifers (Berg and Butterfield, 1976). In some countries other than the U.S., bulls are individually housed or tethered and fed to produce beef. For several reasons, large scale feeding of bull in the U.S. probably will never prove viable. The predominant reasons include 1) behavioral problems, namely fighting and riding and handling difficulties, when bulls are fed together in large groups; 2) substantial packer discounts for bullock carcasses because of the reduced marbling and flavor of beef from bulls. The muscle:bone ratio at a specified fatness is similar for heifers and steers (Berg and Butterfield, 1976). Heifers mature and fatten at lighter weights than steers and bulls. Provided that the fattening phase has been reached, and under similar feeding conditions, heifers will be fatter than steers at given weights and steers will be fatter than bulls (Berg and Butterfield,

1976). The "equivalent weight" concept proposed by Fox and Black (1984) and employed by NRC (1996) is one method that can be used to calculate the live or shrunk weights at which bulls, steers, and heifers of similar breeding are similar in body composition and, thereby, should have similar requirements for net energy and nutrients.

Breed Effects On Growth

Currently, more than 100 distinct breeds of cattle have been described (Breeds of Cattle: OSU Homepage). Breeds can differ in terms of their environmental adaptability, milk production, reproductive efficiency, and growth rate. Selection of breeding stock in some breeds from developing countries has been based largely on survival under adverse conditions whereas in developed countries, appearance, i.e., coat color, color pattern, and size of the horn, hump, dewlap, or sheath has served as the basis of selection. For discussion purposes, breeds can be grouped into classes based upon the rate that they mature. Because chemical composition differs with degree of maturity, specific classes may or may not meet carcass weight specifications preferred by packers, meat handlers, and retailers.

Breeds differ in the weight at which fattening begins; they also may differ in the rate at which fat is deposited during fattening. Because fat is the most variable tissue in the carcass and because it represents the major waste product from the carcass, breeds that are late to mature or fatten often are desired when nutrient status is good; however, weight at an acceptable degree of intramuscular fat (marbling) may be excessive. In contrast, when feed availability is limited, early fattening breeds are desirable so that they can be marketed economically at lighter weights while still possessing adequate marbling to meet market demands.

Partitioning of fat between the major depots may be altered by selection; certain dairy breeds reach a desired level of intermuscular fat while possessing less subcutaneous fat than typical beef breeds (Berg and Butterfield, 1976). This difference in fat distribution can reduce fat trim loss while maintaining adequate amounts of intermuscular and intramuscular fat. Additionally, within certain beef breeds, carcass expected progeny differences (EPD) can be used to select for increased marbling while maintaining or even decreasing subcutaneous fat deposition (Wilson, 1996)

In general, the maximum growth rate will minimize cost of beef production. This is because the maximum growth rate is associated with lean (and water) deposition in the body rather than fat deposition, and lean deposition is more efficient in terms of converting feed to body weight. However, the search to maximize growth rate and efficiency may lead to selection for later fattening, a factor desired in terms of maximum lean and minimum waste fat, but not desirable from the standpoint of extremely heavy carcasses and excessive portion sizes at the point that sufficient intramuscular fat is deposited for cattle to grade choice. Consequently, selecting for large mature weight and very late maturity under today's carcass-based pricing system can result in severe economic penalties. Additionally, selection for greater mature weight will increase the weights of dams and sires in the herd; maintaining very large cows and bulls requires more feed. So larger cow size has negative economic repercussions. If the mature weight of the cow herd size is maintained at a moderate levels and calf size is increased merely through sire selection, dystocia may increase. Selection for reduced birth weight simultaneously with greater yearling weight might solve this problem. Another problem is that replacement animals must continually be added to maintain cow-calf operations. Using only large sires forces producers maintaining moderate cow size to find alternative herds from which to purchase moderate-sized replacement heifers.

Factors Affecting Dressing Percentage

Although live weight often is used as a measure of growth, its usefulness as a measure of economic value is limited. Live weight is not precisely related to either carcass weight or the amount of edible product. Dressing percentage is calculated as carcass weight divided by live weight times 100.

Dressing percentage increases as body weight increases (Field and Schoonover, 1967). While dressing percentage was 51.4% for cattle with a live weight of 200 to 300 lb, this increased to 60.3% for cattle with live weights between 1100 and 1200 lb. The major increase in dressing percentage occurred between 200 and 900 lb live weight with little further change as live weight increased to 1300 lb. For dressing percentage to increase, the weight of the carcass relative to offal must increase. This can occur due to retention of a higher fraction as carcass, in terms of fat retention with the carcass, or a smaller fraction of live weight being the gut and its contents. Indeed, as animals mature, gut weight plateaus

before body weight plateaus. Because fat deposition and proportion of weight comprised of the digestive tract and its contents are changing simultaneously, relative importance of these two factors to dressing percentage is difficult specify.

Fatter animals of a specific body weight have a higher dressing percentage. The data of Field and Schoonover (1967) could be explained as being due to increased fatness. Fat deposition alters dressing percentage simply because proportionally more fat is deposited in the carcass than in the non-carcass portion of the body. Callow (1944) detected no significant relationship between dressing percentage and percentage of muscle tissue; at all dressing percentages studied, about 31.7 percent of live weight was present as carcass muscle tissue. Consequently, dressing percentage depended almost entirely on the stage of fatness of the animal. For every increase of 1 percent in dressing percentage on a live-weight basis, dissectable carcass fat weight increased by 1.43 percent while chemical fat of the muscular and fatty tissues increased by 1.47 percent. Combined weights of fat and muscle tissue increased by 1.23 percent while bone decreased by .23 percent. Regression equations for the carcass indicated that with fattening, every 1 percent increase in fatty tissue was associated with a decrease in muscular tissue of .7 percent and a decrease in bone of .26 percent. Tulloh and Seebeck (as cited by Berg and Butterfield, 1976) put the situation clearly: "if you consider the three carcass components - bone, muscle and fat - and relate them to body weight by the exponential (allometric) equation $y=ax^b$, then fat is the ONLY component contributing to an increase in dressing percentage, because the 'b' value is approximately one for muscle, less than one for bone and greater than one for fat.. Irrespective of carcass composition, the offal components taken together, have a 'b' value of less than one; therefore, they contribute (in a negative way) to a higher dressing percentage as body weight increases". Further discussion of allometric growth will be provided latter. Since offal has a 'b' value less than one it could be argued that the proportional size of offal is shrinking and that this decrease rather than increase in fat. This could equally well explain the increased dressing percentage. However, it seems likely that the propensity for fat to increase is exceeded by decrease in offal weights especially at excessive weights and degrees of fatness.

The nature of the diet, as it influences the weight of the digestive tract and its contents also can markedly alter dressing percentage. Butterfield et al. (1966) found that 4 week old calves had a higher

dressing percentage (55.2%) than 8 week old calves fed roughage (51.4%) and the percentage continued to drop until at 22 weeks of age it reached 46.1%. This change occurred despite a doubling in live weight. In a subsequent study, Butterfield et al. (1971) found that milk-fed calves at a wide range of intakes increased in dressing percentage as they grew. The difference in these patterns undoubtedly are due to differences in the physical nature of the diets, one being high in roughage (lucerne, cereal chaff and bran) and the other being only milk. The nature of the diet can impact dressing percentage of older cattle, as well. Preston and Willis (1969) fed Brahman bulls higher forage or high concentrate diets; those fed forage had a dressing percentage 3.8 percent lower than those fed concentrate diets. These bulls had live weights that were almost identical and, based on fat trim, were of similar fatness. Additional support of effects of diet on dressing percent was provided by Gill et al. (1976). Diets for finishing steers consisted of either 14, 30, or 75% corn silage with the remainder being grain. Although live weight gains were similar, dressing percentage and carcass weights were lower for steers fed the diet containing 75% corn silage. Backfat at 12th and 13th rib was greater for the 14% silage diet suggesting that the degree of fatness may have accounted for the some of this difference in dressing percent. However, KPH and marbling scores were greater for the 30 and 75% silage diets, indicating that total carcass fat may have been similar. Consequently, nature of the diet and differences in offal weight probably contributed the most to the difference in dressing percent.

Another factors that can influence dressing percentage is the relative proportion of non-carcass parts. Compared with Hereford cattle, Charolais crossbreds had a higher dressing percentage as a result of a lighter hide (Berg, 1964). Newman and Martin (1971) found a similar advantage for Charolais crossbreds over Simmental crossbreds. Whether relative size of the other non-carcass parts, such as head, feet and viscera, can be reduced to enhance dressing percentage is not certain but seems worthy of study. The lower dressing percentage of older cattle might be associated with continued growth of the head and skull. Because live weight cannot consistently and accurately predict carcass weight, live weight gains should be adjusted for differences in dressing percentage or calculated based on carcass weight (i.e., carcass weight divided by a common dressing percent) to adjust for such differences (Goodrich and Meiske, 1971). This procedure not only gives more accurate figures of weight gain on the basis of carcass

tissue, but also can increase the statistical power of detecting treatment differences. By crediting fatter animals with greater weight gain, this adjustment helps adjust for caloric differences but may undervalue products that result in leaner carcasses.

Allometric Expression of Growth

Huxley (1932) studied growth of parts of the body relative to the whole through use of the allometric equation of $y=ax^b$ where y = size of the organ or part, x = size of the rest of the body, and b = the growth coefficient of the organ or part. This equation was found by Huxley to provide reasonable and quantitative descriptions of many organ-to-body relationships. The use of this equation is based on the assumption that relative changes in component parts during growth are more dependent on the absolute SIZE of the whole rather than on the TIME taken to reach that size. The equation is solved by regression of logarithm transformed factors (ln Y= ln a + b ln W). In the comparisons by Berg and Butterfield (1976) 'b' represents the ratio of the percentage post-natal growth of 'y' to the whole 'x'; thereby, it enables relative maturity to be expressed. If an organ or tissue grows at the same rate as the total body, 'b' will equal 1. For late-maturing tissues, 'b' will exceed 1.0 while an early maturing organ or tissue that does not increase as rapidly as the total body will have a 'b' that is less than 1.0. Such relationships are of particular interest for evaluating alterations in body ratios at a specified body weight when the pattern of growth has been altered experimentally. i.e., using growth stimulants or measuring response to compensatory or retarded growth.

The allometric equation was used to compare the growth of muscle plus bone by Elsley et al. (1964) for sheep (age: 2 to 9months) and pigs (age: 4 to 20 weeks)and by Berg and Butterfield (1966) (age: 6 to 60 months) and Mukhoty and Berg (1971) (age : 11 to 18 months)for cattle. The growth coefficient for bone in beef cattle was low (less than 1.0), for muscle it was intermediate (although greater than 1.0) and for fat it was high (generally from 1.5 to 2.0). These coefficients indicate that during post-natal growth, bone grows at a low impetus rate, muscle is intermediate and fat grows at a high impetus rate. In contrast, early post-natal life, before puberty, the growth rate of muscle should exceed that of fat giving a higher 'b' value for muscle than for fat (Berg and Butterfield, 1976).

These relative rates of growth for different components seem logical based on the relative importance each component relative to function and survival of an animal during specific growth phases. Obviously, bone must develop during pre-natal life to function efficiently at birth; therefore, it develops early in life. Although some muscles need to function at birth, need for muscle should peak for the young adult animal; therefore, it develops later. Apart from thermogenic requirements the first few days of life, fat tissues are the least essential of the three tissues early in life; thereby, development can be delayed (Berg and Butterfield, 1976).

With postnatal growth and development, body composition and proportions continue to change. At birth the head is relatively large, legs are long, and the body is small; at maturity, the head is relatively small, legs relatively short, and the body is large. Such changes are the result of different rates of growth of various body parts (Hedrick, 1968).

Isaachsen (1933) compared weight and several body measurements at birth with those from five year-old cattle. Birth weight represented only 6.5% of the mature weight. Leg length at birth was 63 percent that at maturity; height at the withers was 56 percent; width of hips, 31 percent; and width of chest, 37 percent. The difference in the relative development of the distal parts (leg and height at withers) and the proximal parts (hips and chest) indicates that distal parts developed earlier than proximal parts of the body. Brody (1945) also observed that 50 percent of the height of withers was completed before birth as contrasted to only 6 percent of the body weight.

Notter et al. (1983), studying effects of breed and feed intake level on the allometric growth patterns of sheep (48 - 258d of age) segregated body components into groups based on growth rate. These groups were: 1) approximately isometric (.9<b<1.1) that included carcass weight, pooled offal, pelt, empty gastrointestinal tract and trimmed cuts; 2) components with a moderately positive allometry (1.1 < b <1.4) that included body wall thickness; 3) components with a strong positive allometry (b > 1.4) that included body fat, body energy, fleece, backfat thickness and kidney, pelvic and heart fat (KPH); 4) components with a moderately negative allometry (.7 < b < .9) that included fat-free body, fat-free dry body, vital organs, head, feet, blood, longissimus muscle area and body moisture, protein, and ash, and 5)

components with a strong negative allometry (b < .7) that included metacarpal and metatarsal bone length.

One of the assumptions of the basic allometric equation is that 'b' is constant and does not vary with body weight. Notter et al. (1983) indicated 11 components varied with body weight by more variation being accounted for by the model $Y=aW^b e^{cW}$ (fitted as ln y =ln a + ln W + cW). He also indicated that breed had significant effects on of 18 body components measured; however, the growth coefficient 'b' differed by breed for only nine of the measured components. Thus, most differences between breeds were associated with the proportionality constant (a) or total body weight (W).

To test whether breed groups differ in their rate as well as in the onset of fattening, growth coefficients were calculated among several breed groups within sexes (Mukoty and Berg, 1971). Breed groups of bulls, steers, and heifers had significantly different 'b' values reflecting genetic differences in the proportionate increase in fat relative to muscle and bone. These differences could be due either to time rapid fat deposition begins fattening or rate of fattening. Later, Berg and Butterfield (1976), after adjusting percentage of fat to a constant muscle plus bone weight, concluded that differences in fat deposition appeared to be more closely related to the time fattening accelerates than to differences in the rate of fattening.

Mukhoty and Berg (1971) found no significant difference between genders in growth coefficients for muscle or for bone; genders had similar ratios of muscle to bone at all stages of maturity. The main difference between genders was related to the impetus for fattening; the impetus for fat growth is greater at lighter weights for heifers than for bulls with steers being intermediate.

Luitingh (1962) studied developmental changes in beef steers as influenced by fattening, age, and nutrition. Ranked in growth rate from slowest to fastest, the shoulder was slowest, the round, chuck, loin, plate, neck, brisket were intermediate, and fastest were the fat depots, flank, cod, and kidney fat. He divided the body parts into three distinct categories: (1) a group where the percent change in weight of the body part tended to be directly proportional (b ≈ 1) to the percent change in live weight (blood, shoulder, round, and rump, 8-11th rib area, neck, and loin); (2) a group where the percent change in the weight of the body parts tended to be less than unity (b < 1) of the percent change in the live weight (head, feet,

kidney, hide, pluck, liver, and kidney fat), and (3) a group whereby the percent change in body parts tended to be more than the percent change in live weight (b > 1) (chuck, 12-13th rib, plate, brisket, and major fat depots other than kidney knob).

Plane of nutrition also may influence component gains. Relative effects of different levels of feed intake (ad libitum, or 85% and 70% of ad libitum) on body component gains of ram lambs were examined by Notter et al. (1983). Rams fed ad libitum had progressively more rapid relative rates of fat gain and progressively less rapid rates of water gain; rates of protein gain were not altered by feed intake level. The growth coefficient for body water at a given body weight decreased with age for rams given free choice access to feed. Thus, for growing rams, an increased relative rate of fat deposition and a decreased relative rate of moisture deposition was associated with maturation. When young rams were held at a constant weight (although not necessarily at energy equilibrium) for a long period of time, the maturation process (characterized by increased fattening) appeared to take precedence over the growth process (characterized by protein deposition). The effect that this may have on final mature weight is not clear.

In a study of compensentory growth in beef steers, Carstens et al. (1991) reported that the allometric accretion rates for carcass chemical components relative to the empty body were not affected by treatment. However, the absolute accretion rates for steers previously restricted in growth (1 lb/ d, from 540 to 715 lb) were greater during realimentation for noncarcass protein (.821 vs .265 lb/d), noncarcass water (.861 vs .507 lb/d, and empty-body protein (.835 vs .601 lb/d) than for steers that previously had gained weight continuously.

Changes in Chemical Composition

The major chemical components of the body are water, protein, fat and ash. Maturity is accompanied by an increase in the proportion of fat and a decrease in the proportion of water and protein in the body. Empty bodies of cattle range from less than 2 to nearly 50 percent fat, from approximately 80 to 40 percent water, and from 20 to 12 percent protein (Berg and Butterfield, 1976). At birth, calves are high in water and low in fat. Protein, ash and water percentages decrease with age and fattening. Although many have assumed that composition of the fat-free empty body is constant, being an

assumption on which body water is used as an index of body composition, such may not be the case. As animals grow and mature, water concentration decreases while protein and ash in the fat-free body increase (Berg and Butterfield, 1976). This decrease in the ratio of water to protein ratio is greatest during the first year of life but it continues to drop slowly into old age (Haecker,1920; as cited by Berg and Butterfield, 1976). Although the water:protein ratio has been suggested as an index of chemical maturity (Bailey et al., 1960), the ratio drops more quickly from 100 to about 500 lb live weight than at heavier weights according to Reid et al. (1963).

Berg and Butterfield (1976) summarized some of the major chemical differences between young and older animals and the relative change in each component with time or increasing maturity. In the young animal about 50 pounds of water are stored in the empty body for each 100 pounds increase in live weight. In older animals this is only about 40 pounds. For each 100 pounds increase in live weight, about 15 pounds of protein and 3 pounds of ash are stored by young animals with only slightly less for older animals unless excessive fattening is taking place. The amount of fat stored is quite low for calves but higher at later stages of a steer's growth with values from 6 to 36 pounds of fat per 100 pounds gain being reported. As a percentage of wet weight gained, total dry matter represents about 25 percent for the calf and over 50 percent for the finishing steer. Based on data from Haecker (1920), for the empty body weight increment from 100 to 200 lb, calves stored 22.77 lb. of dry matter; for the empty body weight increment from 1,400 to 1,500 lb., steers gained 52.88 lb. of dry matter. This difference points out the fallacy of basing calculations of efficiency of feed or energy use on either live weight or empty body weight. Because protein, fat and ash, comprise different fractions of various organs and tissues, chemical composition of the total body gives only a gross picture of specific body changes. It falls short of providing insight into the chemical composition of the specific organs or of the major tissues muscle, fat and bone. Fortunately, several of the early workers (Haecker, 1920; Moulton et al., 1922) did separate chemical analyses for some organs and tissues before combining the results for the body as a whole. In 100 lb. calves 42 percent of the protein was found with muscle plus fat, 27 percent was found with the skeleton, and the remainder (31 percent) is found in non-carcass parts of the empty body. The percentage of total protein with muscle plus fat increased to 58 percent for the 1,500 lb. steer, percent of total protein

with the skeleton decreased to 16 percent, and in the non-carcass fraction decreased to 26 percent. The percentage of total protein found in the carcass stayed fairly constant from 100 to 1,500 lb live weight, between 70 and 74 percent of total. Water percentage follows a similar pattern as protein except that the amount of water in the skeleton dropped markedly, comprising 20 percent of 100 lb calves but only 7 percent of 1,500 lb. animals. The weight distribution of fat also changed markedly as animals grew. The percentage of the total fat in the skeleton was higher than that in muscle plus fat in the 100 lb calves. But in the carcass of 1,500 lb. steers, only 5 percent of the total fat was found in the skeleton with 69 percent of fat in muscle plus fat tissues. The proportion of the fat in the non-carcass tissues did not change greatly, increasing from just over 20 percent to about 25 percent of the total fat of the body as the animals grew from 100 to 1,500. These data illustrate that distribution of the chemical constituents in the body changes as animals grow and fatten. These factors need to be considered when relating chemical composition of the empty body to composition of the carcass or of meat tissues.

The chemical composition of individual muscles differs (Callow, 1962; Garrett and Hinman, 1971). Callow (1962) reported that as a percentage of wet weight, fat range from 1.3 percent of the foreshin to 11 percent of the loin.

Fat depot sites also differ in the fat, protein, and water percentage. Kidney fat has the lowest percentage of moisture and protein but the highest percentage of fat. Fatter animals have a higher percentage of chemical fat in each fat depot. Callow (1962) reported that the average percentage of chemical fat in subcutaneous, intermuscular (seam), and kidney fat tissues were 69.5, 67.7 and 94.4 percent, respectively. On the average, muscles from a steer more than one year of age is approximately 74 percent water, 21 percent protein, 4 percent fat and 1 percent ash. The amount of fat in muscle varies with the general level of fatness in the body and differs among muscles, usually being quite low (2% or less) in shin and leg muscles versus being high (up to 13%) in muscles of the rib, loin and abdominal wall (Johnson et al., 1973).

The major change in composition of the animal body with maturity relates to accumulation of fat (Callow, 1947, 1948, 1949, 1950). Fat normally is deposited at widely different rates in different parts of the body; this causes marked differences in the proportions of fat found in different areas (Hankins and

Titus, 1939). Fatty deposits first appear in younger animals around viscera and the kidney; with increasing age and adequate caloric intake, fat depots appear between muscle layers, beneath the skin and, finally, in the form of marbling between the muscle fibers. With fattening, the percent chemical fat in the muscular tissue increases while the percent protein decreases (Callow, 1949, 1950). Similarly, the percent of triglycerides in fatty tissue increases as an animal become fatter while the percentages of other constituents (e.g., water) of the fatty tissues decrease (Lush, 1926).

Body weight strongly influences on carcass composition of growing animals. Some experiments support the concept that body composition is driven by maturity and is independent of rate of growth. Results of other trials indicate that rapid growth brought about by a high plane of nutrition increases the proportion of fat in the body at a specific weights. Although energy intake is the most important dietary consideration, deficiencies in other nutrients also may influence on body composition.

Dietary Protein Effects on Composition

A deficiency in protein in the ration might be expected to reduce protein content of the body. Animals with a higher continuous impetus for muscle growth, such as bulls, or late fattening breeds, may require more grams of protein (Berg and Butterfield, 1976). Stated another way, such animals might respond to higher protein intake by an increased growth rate or increased muscle deposition. Reid (1972), drawing from reports of Norton et al. (1970), noted that low protein rations resulted in higher concentrations of fat in carcasses of lambs. Norton et al. (1970) fed very young lambs diets containing either 12, 28.5, or 45.5% protein. The lower protein diet resulted in a much more carcass fat than the 28.5% level with only a slight difference from carcasses of lambs fed a 45.5% protein diet. Andrews and Orskov (1970), using heavier lambs, found more fat was deposited per unit of live weight by lambs fed two lower protein diets (10 and 12.5%) than by lambs fed diets containing 15% or more protein. Thus lower levels of dietary protein seem to result differentially increase fat deposition at a specific body weights.

Relationship of Chemical Composition to Physical Separation

Chemical components - water, protein, fat and ash - of physically separated muscle, fat and bone differ with development and maturity as discussed previously. The chemical component showing the greatest variability is fat which proportionately replaces water and protein of the body. Similarly, physically separable fat deposition replaces muscle tissue deposition. Approximately 50 percent of the total body water and total body protein are found in muscles. More than half of the chemical fat is found in the fat depots of the body. Consequently, muscle growth parallels water and protein accretion in the body while chemical fat relates more closely to increased fatty tissue depot storage. Validity of this theory of physical separation of chemical components can be questioned. Because not all protein is found in muscle tissue and fatty tissues contain various levels of fat, one can readily question physical separation. Reid (1972), in comparing data from an early Illinois study on three types of pigs, found that chemical composition was quite similar among types whereas physical separation revealed that one type had more separable fat than the other two did. However, because the data were not obtained from the same pigs, sampling error may have been responsible for the difference. In contrast, Reid (1972) reported a very close relationship of chemical composition to physically separated components with two groups of lambs; physically separated fat was equal to 36.6 and 31.9 % of carcass weight, while chemically, fat comprised 34.8 and 30.0% of carcass weights, respectively. Correlations between carcass protein and dissected fat lean and between carcass ether extract and dissected fat for individual animals from these two groups of lambs were very high with relatively low residual coefficients of variation. Unfortunately little data of this sort are available to directly compare chemical components with physically separated components. Yet, similar though not identical conclusions would be expected using either composition measurement in most studies of growth.

Nutrition Effects on Growth and Composition

That plane of nutrition affects rate of gain in live or carcass weight is well known and needs no documentation. How rate of gain influences relative growth of various tissues is less clear. Callow (1961) slaughtered animals fed at four different planes of nutrition to a constant live weight and found significant differences in the percentage of fat in the carcass; those fed at the highest plane in the final feeding period

had fatter carcasses than fed more moderately. However, due to diet differences they also had lower dressing percentages and hence, lighter carcasses. Similarly, Henrickson et al. (1965) performed a similar experiment where animals were fed on four planes of nutrition for a constant gain endpoint (400lb). In this trial carcass weights were not different, but increasing plane resulted in greater a carcass fat percentage. Waldman et al (1971) used Holstein steers and started their experiment at birth. Their moderate plane was designed to result in 60 to 70 percent as rapid gain as the high plane group given ad libitum access to feed. Composition was estimated from the Hawkins and Howe (1946) formula based on rib cut dissection and analysis. Cattle were slaughtered at various live weight throughout the trial with the final live weight being 1300 lb. Data from this trial illustrate that with more rapid growth, ratio of fat to muscle plus bone was greater with higher plane of nutrition and proposed that one can control the ratio of fat to non-fat tissues by altering the plane of nutrition if cattle are fed for similar periods. In contrast Guenther et al. (1965) fed half-sib Hereford steers from weaning on two planes of nutrition, high and moderate. Body composition was estimated at the start and as the experiment progressed. Guenther et al. (1965) indicated that when cattle were fed on two different planes of nutrition than on a age constant basis there was a greater amount of fat deposited, but if they were fed to similar weight endpoint a similar body composition was achieved.

Whether plane of nutrition affect the muscle to bone ratio is not clear. Callow (1961) found no significant difference in the muscle: bone ratio among steers fed at four different planes of nutrition. Although the data of Henrickson et al. (1965) were not statistically analyzed with respect to muscle:bone ratios, their results seem to be similar to those of Callow (1961).

Reid (1972), comparing sheep fed on different planes of nutrition, concluded that the most important variable affecting body composition was empty body weight. Plane of nutrition affected the time taken to reach a certain body weight, but it did not affect carcass composition at that weight. Age at slaughter had little effect on body composition independent of weight. Notter et al. (1983) similarly found no difference in final composition of sheep fed at three different levels of growth. However, they reported an effect of age independent of weight; older rams at a specified weight tended to be more mature and fatter. In contrast the data of Haecker (1920) indicate that slower growing steers on pasture had less fat at

a specific weight than faster gaining steers fed in a lot. Similarly Pryor and Laws (1972) showed that steers which grew faster on a high level of wheat had significantly more carcass fat at similar carcass weights than steers which grew slower on a lower proportion of grain.

Byers (1980), comparing cattle of different mature size fed under two different planes of nutrition, concluded that level of nutrition altered composition of the carcass at specified slaughter endpoints. His two planes of nutrition were achieved by feeding a 65% grain-35% corn stover diet (moderate energy) or only grain (high energy). These data lend credence to the concepts that 1) backgrounding or growing small mature size cattle can increase their potential for total protein and lean tissue production and 2) feeding high energy "finishing" rations to larger sized cattle during the total feeding period will minimize the time and carcass weight needed to reach a desired amount of carcass fatness.

To evaluate energy level effects independent of dietary ingredients Byers (1980) provided either limited amounts of or ad libitum access to shelled corn diets for individually fed Angus crossbred or Charolais Steers. Results were similar to those with forage versus grain diets. The Angus crossbred cattle fed at both intakes had similar final weights, but the full fed steers were approximately 20% fatter than their limit-fed counterparts. Even though the limit fed Charolais steers were fed to 14% heavier weights than the full fed Charolais, full fed animals still were 20% fatter at slaughter. The larger sized cattle responded more in fat deposition to increased level of energy than the smaller sized cattle did; consequently, at a similar body weight, the difference between full and limit fed Charolais in percent body fat was much greater than between full and limit fed Angus crossbred cattle. These results indicate that the fat deposition response to an elevated energy levels is greater with larger than smaller sized cattle. While larger size cattle fed low energy diets will be extremely large when desired carcass fatness is reached due to their inherently high level of daily protein growth, their ability to increase their rate of fat deposition on high energy diets allows them to achieve desired carcass fatness endpoints at much lighter and more marketable weights.

Ever since Brody (1964) developed his growth curves for animals relating body weight to three factors (i.e., post-conception age, mature weight, and a deceleration factor) a debate has raged between

two schools of thought about chemical composition of the body during growth. The concept supported by much of the research is that body composition at a given empty body weight is fixed (Reid and Robb, 1971; Jesse et al., 1976). Hence, altering the rate of growth should have no impact on composition at a given empty body weight. In contrast, cattle producers for years have fed "growing rations" to cattle of smaller frame size to increase carcass weight at slaughter, the time when animals had accumulated an adequate amount of intramuscular fat. Note that this practice of growing cattle would be ineffective if the former concept were valid. Whenever, two intelligent groups disagree on a topic, both are usually correct, they simply are not fully defining their position. Body composition when expressed as a percentage of mature weight or size may be fixed, but mature size, rather than being fixed may be elastic (Owens et al., 1995)

Effects of Maturity on Composition

At a specific fraction of mature mass, body composition seems to be constant; the degree to which nutrition can alter mature mass is not certain. If mature mass is altered, body composition at any given mass will be altered. Moulton (1923) confirmed that the relative fatness of animals of the same species does not influence the composition of the fat-free body and also that the water content of the fat-free body decreases slightly with age. The point in time when the fat-free composition becomes reasonably constant was called 'chemical maturity' by Moulton (1923) who judged that this occurred at an age equal to 4.0 or 4.5 percent of total life expectancy.

Mature body size or mature weight has received several definitions. Several workers have employed the definition of mature body weight proposed by Taylor as discussed by Keele et al. (1992). By that definition, mature weight is the point of body weight equilibrium for cattle fed forage diets. At this point, chemical fat content of the empty body is approximately 25%. In contrast, others including Brody (1964) and Fox and Black (1984) have used the point at which protein accretion ceases as an estimate of mature body weight. Based on this definition and analysis of literature data, Owens et al. (1995) concluded that protein accretion ceases when empty body fat equals 36.2%. Fat content at the point where protein mass was maximum has been shown to be surprisingly constant at 34 to 37% of empty body

weight, across various frame sizes and muscling types. This indicates that "mature weight" for animals of different frame size might be defined as the weight at which fat content of the empty body reaches 34 to 37% (Owens et al., 1993).

Whether mature size of cattle can be altered readily by nutritional restriction remains debated. Depending on the severity of the restriction and the specific nutrient involved, size of an animal when it becomes mature has been reported variously to decrease, remain unchanged or increase during growth (Owens et al., 1995). Discrepancies among reports may relate to the timing or severity of deprivation or the nutrient involved. Very severe nutrient restriction, especially for protein, can reduce mature size of swine and cattle (Berg and Butterfield, 1976; Pond et al., 1990; Widdowson and Lister, 1991). However, a moderate degree of restricted feeding during growth failed to alter composition of rib sections of the carcass (Winchester and Howe, 1955; Winchester and Ellis, 1956). Based on the relationship of fat percentage to degree of maturity, restricted feeding should not alter mature weight of finished steer. Echoing this theme, Long (1988) stated that the "genetic potential of cattle dictates their carcass composition at any weight regardless of whether they reach that weight in a short or a long period of time". In contrast, several researchers (Lake et al., 1974; Lewis et al., 1990b) have reported that restricting energy intake during the late pre-pubertal or early post-pubertal period markedly reduces fat content of finished steer at a specific weight. Again this composition change could be interpreted to imply that restricting growth increased mature weight.

Limits to Gain:

During growth, cellular constituents are involved in continuous catabolism and synthesis (Schoenheimer and Rittenberg, 1940). Certain tissues associated with digestion (e.g., gastrointestinal tract and liver) have faster protein and cell turnover than skeletal muscle. Fractional protein synthesis in the ruminant gastrointestinal tract ranges from 10 to 30% daily (McBride and Kelly, 1990) and the digestive tract alone can account for 28 to 46% of whole-body protein synthesis. By comparison, half-life for myofibrillar protein generally ranges from 18 to 50 d (Swick and Song, 1974). Thus, despite its mass,

skeletal muscle may not be the primary site of protein synthesis even in rapidly growing ruminants (Owens et al., 1993).

Byers (1980) fed 120 Hereford steers corn silage diets at varying rates to alter rate of gain; protein growth approached a maximum rates of approximately 85g/d when daily live weight gain was approximately 1.65 lb. As protein growth rate plateaued, rate of fat deposition accelerated rapidly with rate of gain (Byers, 1980). Percentage protein in gain decreased as rate of gain increased. In another study by Byers (1980), corn stalklage and high moisture corn in four diets were fed to 160 Hereford calves averaging 506 lb for 165 to 325 days. Rates of protein growth increased with rates of gain up to approximately 2.2 lb day where protein growth rate plateaued. Protein growth did not increase at faster rates of gain. Other research documenting a similar relationship between rate and composition of growth comes from studies of Woody (1978) and Garrett (1979). Both studies indicated that the maximum rate of protein gain was attained when daily live weight gain was approximately 2.2 lb. However, rates of protein deposition are greater for larger than smaller mature size cattle at any weight or rate of gain. Nevertheless, rates of protein growth for either small or large cattle increases very little when rate of gain exceeds 2.2 lb/day. This leads to the hypothesis that there is some biological limit for daily protein growth and that rate is exceeded by rapidly growing cattle.

The impact of rate of gain on body composition has been examined by Byers (1980), Old and Garrett (1987), and Slabbert et. al. (1992). These workers all tested the impact of reducing rate of gain on rates of fat and protein by restricting feed intake. In most of these studies, reducing rate of gain by restricting feed intake reduced fat content of gain when compared with the overall regression line noted for cattle given ad libitum access to feed. Restricting feed intake has reduced protein accretion in several studies. In all but one study, fat accretion was reduced. Often, however, final body composition was not altered enough for differences to be significant. If accretion of fat alone is reduced, restricting energy intake should increase the protein : fat ratio of the empty body. Based on the concept of constancy of body composition, these data also could be interpreted to suggest that restricting feed intake increases mature body size. Nevertheless, results of limit-feeding studies have been extrapolated directly to cattle given ad libitum access to feed and, combined with the fact that maturation increases fat content of the body, have

been interpreted to indicate that animals with faster rates of gain will accrete more fat and less protein. In the literature analysis of Owens et al. (1995), protein accretion did not reach a plateau but continued to increase at higher rates of empty body weight gain. Regression values indicate that rate of empty body weight gain was more related to rate of protein accretion than to rate of fat accretion, a logical conclusion if fat accretion were to reach a plateau. In view of the scatter of points determined by Owens et al. (1995), it is not surprising that many workers in the past have failed to detect significant differences in body composition with only slight differences in rates of gain and, based on lack of a significant effect, have concluded that rate of gain did not alter body composition. These plots could be interpreted to suggest that fat accretion rate may reach a ceiling whereas rate of protein accretion does not, but instead remains dependent on animal maturity (Owens et al., 1995). The maximum fat accretion rate of approximately 550g/d for steers and bulls given ad libitum access to feed with daily empty body weight gains higher than 3 kg conflicts directly with the classic concept that fat accretion at a given physiological age for a specified genotype is greater with more rapid gains (Owens et al., 1995). Nevertheless, this regression is across rather than within genotypes. In most of the studies that support the concept that faster gains increase fat deposition, the supply of feed available to a genetically similar group of cattle was intentionally limited. As discussed previously, fat accretion might be affected differently by restricting energy intake than occurs in animals that differ in their energy intake when given ad libitum access to feed. Restricting feed intake also could affect body composition either by altering the hormonal status or cascade of growth hormone to IGF or by changing the quantitity of specific nutrients available for metabolism (Owens et al., 1995). The fact that restricting feed intake enhances energetic efficiency more than expected form net energy relationships (Old and Garrett, 1987; Hicks et al., 1990) supports the concept that limiting energy intake alters composition and thereby may increase mature size. If one accepts the concept of constancy of composition at a given fraction of mature size, then animals with greater mature size automatically would deposit more protein at a given rate of fat accretion (Owens et al., 1995).

The relationships between fat and protein mass to empty body weight by regression analysis of available literature shows a general shape of curve matching most literature relationships. Mass of fat

increases quadratically with weight whereas protein mass increases more linearly (Owens et al., 1995). This is the logical consequence of having an accretion rate for fat that is greater than that for protein. This change in body composition can be ascribed to degree of maturity and should not be extrapolated to suggest that rate of weight gain alters composition of gain. When net energy intake is restricted, rate of fat accretion often is reduced although protein growth may continue at normal rates if protein intake is adequate (Anderson et al., 1988a).

Curves developed by Byers (1980) indicate that as rate of gain increases, both protein and fat accretion increase, with fat increasing at an increasing rate and protein accretion possibly decelerating. In contrast, no deceleration in protein accretion is evident in values cited by Fox and Black (1984), Lemieux et al. (1990), or Slabbert et al. (1992). Unfortunately, correlations between rate of weight gain and accretion of protein and fat are confounded by such factors as maturity, genetics, age, and weight. On a theoretical basis, the question of whether faster gaining animals are depositing more fat can have two different, but reasonable, answers. First, faster gaining animals will be fatter if they have the inherent capacity to dispose of more calories by fat accretion. This, in turn, could mean that such animals are more mature. Second, if animals that gain less rapidly have lower energy intakes, they may be physiologically younger and thereby leaner than rapidly gaining cohorts (Owens et al., 1995). However, if faster gaining animals have a larger mature size, a higher initial protein mass, or altered hormonal status that enhances protein accretion, then faster gaining animals should be no fatter than their contemporaries (Owens et al., 1995). Indeed, in results from Gill et al. (1993a,b), it was calves that were early-weaned and had the slower feedlot gains that had more empty body fat at a lighter slaughter weight, not cattle that had grazed forage for several months.

Both age and nutrition appear to exert a profound influence on the size of muscle fibers. The effects of age and differing nutritional regimens on muscle fiber diameter have been examined in cattle by Robertson and Baker (1933), Brady (1937), Hiner et al (1953), Everitt and Carter (1961), and Yeates (1964). The general consensus is that, in a specific muscle, muscle fiber size is limited by age; this limit cannot be exceeded by nutritional treatments. (14)

Joubert (1956) also studied the changes of width and depth of this muscle. He found that width

reached a maximum earlier than depth and responded more to plane of nutrition. He reported that the

correlations between muscle fiber diameter and the depth and width of longissimus muscle for immature

animals were very high (.98 and .93), but for mature animals, correlations were lower (.96 and .65).

McMeekan (1940b, 1941) suggested that each muscle has a limit in muscle fiber size that is determined

by age; this limit cannot be exceeded despite a prolonged period at a high plane of nutrition. Hence, after

muscle development has reached a maximum, additional gain in weight must be due solely to fat

deposition. Thereby, any increase in muscle weight of mature animals beyond the point of maximum

muscle size must be due to deposition of intramuscular fat. The percent of intramuscular fat deposited

between muscle fibers appears to be more dependent upon age than plane of nutrition or state of fatness

(Palsson and Verges, 1952; Andrews, 1958). (15). However, more recent studies comparing cattle started

on feed at different ages have shown that although calves will require more days on feed, they reached

finished weight at a younger chronological age, have slower feedlot gains, lower feed intakes, superior

feed efficiencies, higher marbling scores, more backfat, and higher numerical yield grades than older

cattle that have been backgrounded for some period of time (Lunt et al., 1986; Sindt et al., 1991; Hickok

et al., 1992). Additionally, Brazle et al. (Growth symposium, 1996; Texas Tech University, in press),

using ultrasound measurements, reported that even at the time of weaning (200 to 240 d of age), some

calves may have sufficient marbling to grade choice.

Compensatory Gain:

The phenomenon of compensatory growth tends helps to assure that growth retarded animals

achieve reach a mature weight reasonably similar to nonretarded animals. Composition, within limits,

may be influenced by final weight through the phenomenon of compensatory growth. Certain

physiological factors associated with the growth curve, such as sexual maturity, probably are more

influenced by weight than by age (37) Butterfield et al. (1971) fed calves milk to grow at three rates from

birth. The highest plane group had uninterrupted growth, as did the medium group, whereas the third

group was held at its birth weight for 72 days before being allowed to grow heavier. Slaughter and tissue

dissection took place at seven fixed weights from 44 to 88 kg live weight. At any specified slaughter weights, no difference in carcass composition between the calves for the three different planes of nutrition was detected. This indicates that within quite wide limits of growth rate, body composition is related to the body size, not plane of nutrition. These measurements were taken at a stage of life before fat deposition became important. These results do not necessarily preclude the possibility that the relative rate of fat deposition can be altered by plane of nutrition later in life. Nevertheless, results indicate the importance of adjusting carcass composition to an equal carcass weights.

An increase in visceral mass, and increase in the protein:DNA ratio, or cessation of proteolysis during realimentation of restricted animals may explain compensatory weight gain responses (Trenkle, 1974). Bergen (1974) reported that protein synthesis rate of rat muscle tended to be increased by moderate energy restriction but to be depressed by severe feed restriction. By reducing the negative feedback of fat mass on protein accretion, protein mass and thereby size at maturity may increase beyond that of animals that have not been restricted (Owens et al., 1996).

Park et al. (1994) stair-stepped feed intake of rats, restricting intake to 40% of normal during weeks 5-7 and 9-11 and to 70% of ad libitum thereafter. Late in the study (13 to 25 weeks), those rats that experienced intake restriction were 5 to 6% heavier. Feed efficiency also was improved for rats whose intake had been restricted. Hogan (1929) restricted growth of steers until they reached 39 to 51 months of age; he weighed and measured these steers for 7 years. Although intake restriction resulted in lower weights during the restriction period, maximum weight of the steers that had been restricted exceeded those of the steers given more feed early in life.

The relative growth rates of bone, muscle and fat are altered during weight loss. The depletion of fat and muscle glycogen is rapid; the degree of depletion of muscle protein and bone depends on the severity and length of time on the feeding regime. Butterfield (1966a) studied weight loss and realimentation using 23 Polled Hereford half-sib steers. He indicated that muscle loss and gain paralleled the change in muscle plus bone weight. The absolute amount of bone loss during weight loss did not drop but increased normally during realimentation. Fat was markedly depleted during weight loss but did not reach expected levels during repletion relative to control animals. Although the loss of fat to muscle

seems greater when considered on the basis of percentage loss (70 vs 21%) the actual amounts of each tissue lost were quite similar.

If a weight loss is imposed on reasonably fat steers, about equal weight of muscle and fat are used up in the point that 16 percent live weight has been lost. During this time, only a small amount of bone is lost. Beyond this point, further weight loss from the carcass comes increasingly from the muscle tissue as fat mobilization decreases to an insignificant proportion. Realimentation or compensation results in a increase in muscle towards a point of normal muscle-bone relationship; fat tissue weight will reach the same level as uninterrupted controls only if the compensatory period is sufficiently long. Carstens et al. (1991) reported that relative accretion rates for carcass protein, water, ash and fat were no greater for steers exhibiting compensatory growth than for steers continuously growing even though at 450 kg empty body weight, steers making compensatory growth contained more protein (16.6% vs 14.8%) and less fat (24.2% vs. 32.4%). The weight of gut fill in restricted fed steers was 10.8 kg less before realimentation but 8.8 kg more at the end of realimentation indicating that gut fill can explain much of the compensatory weight gain. They concluded that reduced NEg requirements were reduced (18%; due to compositional differences) during realimentation, but that changes in gut fill and weights accounted for most of the compensatory weight gain response.

As reviewed by Moran and Holmes (1978) and Hogg (1991), the magnitude of compensatory growth depends on a number of factors. These include age when restriction begins, the severity, duration and nature of undernutrition, the re-alimentation diet and time, and breed type. Compensatory growth seems to alter composition most during growth but it has limited impact on body composition at maturity.

A model showing how body tissues compete for nutrients in the blood stream (Hammond et al., 1971) requires some modification in light of current knowledge. According to that model, during growth on a low plane of nutrition, bone has priority over muscle; therefore, animals should have a lower muscle:bone ratio. This is not the case (Elsley et al., 1964).

LIMIT FEEDING

By definition, the term "limit feeding" implies any feeding system which restricts intake during some phase of production to less feed than would be consumed voluntarily. Under the broad umbrella of "limit feeding" are many methods, degrees, and durations that a limit feeding program can be implemented. The mechanism, degree, and duration of restriction depends on specific goals of feeding as well as management constraints. Unfortunately, "limit feeding" is a vague and useless term unless the exact goals, mechanisms, degrees, and durations of a specific limit feeding program are defined.

Limit feeding programs can be grouped into four classes: 1) high concentrate rations limit fed for the purpose of controlling rate of gain by growing cattle, 2) finishing diets in which intake is restricted (80 to 95% of ad libitum) throughout the feeding period, 3) finishing diets similar to 2 but after which cattle are given some period of free choice access to feed, and 4) short term (usually less than 20-30 d) restrictions specifically for adapting cattle to their finishing diet. Each of these is a "limit feeding" program, but each has its own goals and each requires a different type of management. Within each of these general classifications are several variations which result in hundreds of specific "limit feeding" programs. The various limit feeding systems, their goals and effects on performance, carcass characteristics, body composition, digestibility, passage rate, organ weights, metabolism, energetics, and endocrinology will be discussed below. In addition, some explanations for observed responses will be explored, and potential management considerations to be considered when implementing a limit feeding program will be discussed.

Limit Fed Growing Rations

The term limit feeding often is perceived as feeding a concentrate diet at a specific level of restriction in order to achieve a desired rate of gain. With the development of the net energy equations, this system of limit feeding became a practice commonly used practice in grower feedlots. This program is designed to "'grow" cattle of a smaller, early maturing type at an ADG between 1 and 2.5 lb. before allowing them ad libitum access to their finishing diet. The rationale behind this system is that through limiting rate of growth, these earlier maturing cattle have time to gain more lean tissue and will achieve a

carcass weight meeting industry standards (550-850 lb) before they become excessively fat and incur substantial economic penalties associated with discounts for excessively fat (yield grade 4) carcasses. This type of system is designed to mimic grazing programs in terms of allowing youthful cattle time to grow prior to being finished. But in comparison with grazed cattle, feedlot diets may produce a lower cost of gain because of the low cost per unit of net energy.

The performance of limit fed growing cattle produces consistent gains. In brief, limit fed cattle have 1) decreased feed intakes, as expected by the design, and 2) greatly improved feed efficiencies as compared to conventional forage based growing diets. The greater the difference in the concentrate level between the limit fed concentrate and the conventional forage diet, the greater the difference in feed efficiency. Daily gains which can favor either concentrate or roughage feeding depending on the level of concentrate and its degree of restriction. Differences in digestive tract fill can seriously bias the interpretation of these comparisons, especially during short periods, so care should be taken when interpreting gain and efficiency data. The difference in ADG and efficiency between cattle limit fed concentrate vs free choice fed roughage diets can be attributed largely to greater energy digestibility and greater total amounts of VFA and proportionally more propionate being produced in the rumen; this reduces the amount of energy lost as methane. Although greater diet DE and ME likely accounts for the majority of the benefit from "limit-fed" high concentrate diets vs traditional high forage diets, additional improvements in metabolic efficiencies should not be ignored; these will be discussed later.

One question that has not been fully resolved and merits further study is the impact of various growing systems on subsequent feedlot performance. Wagner (1988) compared steers limit-fed a high concentrate diet with steers full-fed the same amount of energy from a high roughage diet. During the growing period, rate of gain (2.15 vs 1.74 lb./d) and feed efficiency (6.09 vs 10.19) favored the limit-fed steers. After these cattle subsequently were given free choice access to a single finishing ration, those that had been limit fed gained more rapidly, were more efficient, and required fewer days to finish (102 vs 117 d). Similarly, Goldy et al. (1988) examined the effects of five growing phase treatments on subsequent finishing performance. Their five treatments included: (1) free choice high concentrate, (2) limit- fed high concentrate (35% roughage), (3) limit-fed high concentrate (20% roughage), (4) silage

plus grain at 25% of dry matter (DM) intake, and (5) silage only. After day 84, all steers were given free choice access to a high concentrate finishing ration. During the growing phase, limit-fed steers gained more efficiently than steers fed silage + 25% grain or silage only. During the finishing phase, those steers that had been limit-fed during the growing phase tended to gain faster and be more efficient than steers given free choice access to feed during the growing phases regardless of growing diet composition. Feed intakes were not different among rations during the finishing phase, ranging from 23.48 to 24.49 lb. of DM daily. In further support of this concept, Hussein and Berger (1995) fed graded levels of wet corn gluten feed in diets containing a large amount of corn silage (offered ad libitum) or in diets containing only 5% corn silage with intake restricted (at 80% of ad libitum) during growing (127 d); for finishing, cattle had free choice access to diets containing 5% corn silage for 84 d. During the growing phase, cattle fed all diets had similar ADG, but DMI was 20% lower for restricted cattle; this led to more efficient gains (.220 vs. .183, gain:feed). During the finishing phase, steers that previously had been limit fed tended gain faster (2.44 vs. 2.29 lb./d) and to eat more feed (14.7 vs 14.0 lb./d) but have efficiencies equal (.166 vs .163) to those that previously had been given free choice access to silage diets. Averaged over the entire trial, restricted intake steers gained similarly (2.46 vs 2.44 lb./d); but because they consumed less total feed (12.7 vs 14.0 lb./d), they had an improved feed efficiency (.195 vs .176). Digestibility of DM, OM, NDF, CP and GE during the growing phase numerically favored cattle limit fed the higher energy diet. However, during the finishing phase, digestibilities were similar. Similarly, at the end of the finishing phase, carcass measurements (carcass weight, dressing percent, rib eye area, fat thickness, KPH % and percent Choice) all were similar between cattle fed by these two growing regimens. Liver abscess incidence tended to be higher for cattle grown on the high concentrate diet. Monensin was provided in the diet (25 g/ ton) , but authors did not indicate whether tylosin was added.

Wagner (1988) reported cattle previously limit-fed a high energy growing diet with cattle that had been full-fed a high roughage growing diet. During finishing, those that previously had been limit fed gained faster (3.58 vs 3.28 lb./d) and were more efficient (6.18 vs 7.11) whether they were given unlimited access to a finishing diet or restricted to 93% of ad libitum for the first 70 days of the finishing phase. Mader and Wagner (1988) examined the effects of feeding program during growth (traditional

high roughage vs limit-fed high energy), type of corn fed (whole vs rolled), and growth-enhancing implants. The limit-fed growing diets consisted of 21% alfalfa hay, 71% dry corn and 8% supplement whereas the traditional growing diets consisted of 42% corn silage, 23% dry corn, 33% alfalfa hay and 2% dry supplement. During the growing program, ADG favored cattle fed the traditional diet. However, after cattle were placed on full-feed (28 days later), performance favored steers previously managed on a restricted feeding program. Over the entire feeding trial, final weights and daily gains were slightly favored previously restricted steers with total feed cost per pound of gain being approximately 4.5% less for the limit-fed calves. Similarly, Loerch (1990) in a series of three trials showed that limit feeding of an all concentrate diet improved efficiencies over ad libitum intake of corn silage diets at similar energy intakes due primarily to improvements in DM digestibility (36 and 11% for cattle with intake restricted by 30 and 20%) as compared to steers given free choice access to corn silage. However in contrast to the previously mentioned trials, no differences during the finishing phase were detected.

Another less traditional limit-fed growing system was examined by Lusby et al. (1990). He used "limit fed" high concentrate rations to grow early weaned (roughly 60 d old) calves at a rates of either 1.0 (trt 1) or 1.5 lb./d (trt 2), or given free choice access to the same diet (trt 3). In a fourth treatment, calves continued to nurse their dams for an additional 120 d and were provided a salt-limited 20% CP creep feed being weaned (trt 4). After the time of normal weaning, all cattle were given free choice access to a high concentrate finishing ration until they reached .5 inches of backfat. With the most extreme restriction, to achieve only 1.0 lb./d, the small amount of the high concentrate diet was insufficient to satisfy the calves. These calves consumed their feed (average of 6.2 lb.) within 5 min. They appeared to be hungry continuously, they consumed soil and attempted to paw hay residues out of the pen. Although 1.0 lb./day is not a low rate of gain for cattle on a full feed of roughage, some minimum daily amount may be needed to provide satiety. The amount of feed for a projected 1.5 lb./day gain was consumed within 1 to 2 h. Calves from this group appeared comfortable. While calves in Treatment 1 had ADG very close to that projected (1.08 vs 1.0 lb.), calves in Treatment 2 calves gained about .4 lb./d faster than expected. Full-fed calves gain 3.86 lb./d during the same period. ADG of calves during the finishing phase generally were related inversely to ADG during growing or nursing. Calves from Treatment 1 tended to gain faster

than calves from Trt 2 (3.23 vs 3.06 lb./d) while full-fed calves from Trt 3 made the lowest DMI and ADG during finishing. Calves from Trt 4 gained at a similar rate during finishing as calves from treatment 2. Similar gain and feed intake for Trts 2 and 4 before and during finishing suggests that limit feeding does not affect finishing gains when calves are limit-fed at the same rate they would have achieved on pasture. Feed efficiency during finishing was best for Trt 1 calves, suggesting that calves limit-fed at low rates of gain can make compensatory gain. Age at slaughter tended to be youngest for calves that were full-fed from weaning to slaughter whereas Trt 1 calves tended to be the oldest at slaughter. Days from initiation of the finishing phase to slaughter tended to be lowest for Trt 3. Calves full-fed high concentrate from an early age did not reach an equivalent level of fatness at a lighter weight than calves grown more slowly. Quality grade and marbling score were not increased by feeding high concentrate diets from an early age. Rib eye area, yield grade, KHP and dressing percent were similar for all treatments. Lean maturity scores were greatest for Trt 1 while skeletal and overall maturity scores also tended to be highest for Trt 1. Differences in maturity scores probably reflect the greater age at slaughter of Trt 1 calves.

In summary, cattle of various ages and weights can be successfully and economically grown using limited amounts of high concentrate diet. Such programs have no negative effects on subsequent finishing performance; indeed, "limit-fed" growing systems may prove beneficial to performance during the finishing phase. Such programs permit greater predictability in terms of animal performance, feed inventory, and labor resources. Additionally, once the decision is made to start cattle on the finishing diet previously "limit-fed" cattle already are adapted to their diet; only the intake level needs to be changed. Such a feeding system reduces the need to purchase, store and process a large amount of roughage and often decreases the duration of time that cattle need to be full fed.

Limit Feeding in Finishing Programs

Intake restriction during part of the finishing period has been tested widely and, at least to some degree, has been implemented commercially. While few feedlot managers would admit to limit feeding cattle intentionally, many nutritionists and feed callers have adopted a "slick bunk policy". Simply put, this means calling for delivery of an amount of feed so that no feed remains in the bunk for a short period

of time each day. Although most feedlots do not like to have bunks empty or "slick" for more than 1 to 2 hr./d, some limit feeding proponents manage feed intake so that bunks are slick for 12 or more hours each day. Such a system is a marked departure from the traditional goal of feedlot personnel based on the assumption that to encourage maximum consumption and theoretically optimum performance, feed should be in front of cattle continuously. Recent research has demonstrated that although ADG is correlated positively with DMI, optimum feed efficiency occurs at some DMI less than maximum. Indeed, Meissner et al. (1995) reported that individually fed steers with very rapid live weight gains (over 4 lb./d) consumed no more feed than steers gaining at a slower rate. Their results and other literature evidence indicate higher intakes have a detrimental effect on feed:gain whether expressed on a live weight gain or carcass gain basis. Indeed, as cattle reach market weight, live ADG and DMI often decrease even though carcass ADG may continue unabated. Although high ADG still is important to reduce yardage cost and shorten days on feed, striving for maximum feed intake often has adverse effects on feed efficiency.

Armed with these findings, prudent feedlot nutritionists and managers have widely adopted a slick bunk policy. They have discovered that limit feeding has additional advantages in terms of reduced bunk cleaning, less feed waste and, in certain circumstances, increased consumption when averaged over the total feeding period. Because most feedlots are in the business of selling feed, limit feeding programs that markedly decrease total feed consumption over the entire finishing period have been met with some resistance. In contrast, programs that increase total feed consumption are welcomed. The purpose of the following discussions is to outline several "limit-fed" finishing programs and discuss the benefits and detriments of each.

Limit Feeding Through out the Total Finishing Period

Limit feeding programs that restrict intake throughout the entire finishing period usually restrict intake to between 80 and 95% of ad libitum intake. Most research in this area has limited feed intake to a specific percentage of voluntary intake of unlimited cattle the previous day, week or fortnight. Additionally, in most studies, limit-fed cattle have received fortified diets so that daily intakes of protein, minerals, and feed additives were not reduced. Results from these trials have been reasonably consistent and will be summarized without further explanation to the specifics of each trial except where pertinent.

Obviously, the degree to which feed intake is decreased varies with the specific trial; in most trials, intake has been reduced by 10 to 20%. Most studies (Murphy and Loerch, 1994; Glimp et al., 1989; Daughterty and Clare, 1992; Hicks et al., 1990) have reported that ADG is decreased in proportion to the degree to which intake of net energy for gain is reduced. However, in some studies like that of Hicks et al. (1989), ADG was not reduced. Typically, ADG on a live weight basis is depressed more during the first half than during the second half of the trial (Murphy and Loerch, 1994; Hicks et al., 1990); whether this has any physiological importance or simply reflects the weighing error due to reduced gut fill of limit fed cattle is not clear. Feed efficiency over the entire trial typically has consistently been improved (5-10%) with limit feeding, with the greatest improvement noted with greater degrees of restriction up to 15-20% (Murphy and Loerch, 1994; Daughterty and Clare, 1992; Glimp et al., 1989; Hicks et al., 1990; Hicks et al., 1989). Additionally, the majority of the improvement typically occurs during the last half of the trial (Murphy and Loerch, 1994; Hicks et al., 1990). Hicks et al. (1990) speculated that cattle may benefit from limit feeding if restriction is only during the last half feeding period. However, this concept has proven invalid in research studies; indeed, restriction during only the final portion of a feeding trial often results in poorer feed efficiency than either free choice or limit feeding throughout the feeding period (Loerch et al., 1995; Larson. 1996). As would be expected when ADG is decreased, cattle must be fed more days in order to achieve similar final weights (Murphy and Loerch, 1994) even though most experiments have fed cattle for an equal number of days, not to an equal final weight. When calculated from mean weight, ADG, and DMI, NE of the diet generally is improved linearly with degree of intake restriction (Murphy and Loerch, Hicks et al., 1994; Glimp et al., 1989).

Carcass characteristics have been consistently and substantially affected by restricting intake throughout the finishing phase. Backfat measured at the 12th rib, and carcass quality grades have been reduced substantially by restricting daily feed intake, but rib eye area generally is not altered (Murphy and Loerch, Hicks et al., 1994; Daugherty and Clare, 1992). While reductions in backfat and thereby decreased USDA yield grades might be advantageous, the severe (often 50 percentage or more) of cattle grading Choice is severe penalty economically. In addition carcass weights and dressing percentages usually are decreased as a result of restricted intake when free choice fed and restricted cattle are fed for

usually are decreased as a result of restricted intake when free choice fed and restricted cattle are fed for the same number of days (Murphy and Loerch, 1994, Hicks et al., 1989, 1990). These depressions in carcass value due to lighter carcass weights and severe depressions in percentage of cattle grading Choice, if sold on some value based marketing system which rewards quality, likely would negate any economic advantage realized from the lower cost of feedlot gain.

Alternative Methods To Restrict Intake Throughout The Feeding Period

While restricting intake to specific levels relative to controls given ad libitum access to feed can be achieved easily in feeding trials, implementing such a program in a feedlot is more difficult because control cattle would need to be maintained and records would need to be updated daily or weekly. One alternative is to use the Net Energy equations to determine the amount of feed needed to achieve a specified pre-determined rate of gain (Zinn, 1986). Such a feeding system, often called "programmed feeding" is implemented easily and has shown improved feed efficiency. Zinn (1986) tested this type of system to achieve a constant ADG of 2.79 lb. for the entire trial. Feed intake was increased incrementally because maintenance requirements increase as animals become larger. Averaged over the entire trial, ADG was not different between the programmed and the free-choice fed cattle, but programmed cattle consumed 6% less feed which improved efficiency by 5%. Cattle fed by this strategy had no less backfat, percent carcass fat or rib eye area than control cattle. Although he did not report carcass quality grade, it is unlikely that quality grade would have been substantially affected if carcass fat was not decreased. One key for success of this program is being able to accurately predict rate gain of control cattle and not restrict performance below that potential genetically. Programmed cattle quickly became "meal eaters" and consumed all their feed within 30 minutes of feeding. Whether an alteration in feeding behavior is necessary to increase efficiency of growth is not clear.

A second approach to restricted feeding feasible for feedlot cattle is to manage feeding such that bunks are slick for some predetermined amount of time. Prawl et al. (1997) fed cattle all they would voluntarily consume but limited the amount time that cattle had access to their feed to either 1.5, 3, 6, 9 or 24 hr each day. All cattle were fed each morning, and gates closed in front of bunks at the allocated time.

Due to significant depressions in performance at 56 d for the 1.5 hr cattle, access time for these cattle was increased to 9 hr at that time so that all cattle could be marketed with the same number of days on feed. Averaged over the entire trial, feed intake was not decreased substantially except for the 1.5 and 3.0 hr cattle that consumed roughly 9% less than other groups. Cattle with only 9 hr of access to feed had numerically greater feed intake than any other group and significantly greater gains and improved feed efficiencies. None of the other restriction times increased ADG or improved feed efficiencies compared to cattle given 24 hr feed access. Although carcass traits were not affected significantly, 1.5 and 3.0 hr cattle had a slightly lower percentage of cattle grading Choice despite no decrease in backfat thickness. These data lend some credence to the theory that intake level alone is not be the only factor responsible for improved efficiency; altered feeding behavior also may be involved. In a similar study, Birkelo and Lounsbery (1992) gave cattle access to feed for 24 hr or 6 to 7 hr per day. Restricting access to feed decreased DMI by 7.9% and ADG by 7% with a trend towards improved efficiency.

A bunk scoring system was tested by Stanton and Robertson (1996) with cattle restricted to 97% of control cattle. The restricted group was fed 97% of the estimated intake of control cattle averaged over the last 3 days. Steers were fed once per day at approximately 9 a.m. Amount of feed remaining in feed bunks was estimated at approximately 1830 using a subjective scoring system during the last 62 days of the trial.

Table 1. Bunk scoring system for limit fed finishing steers (Stanton and Robertson 1996).

Bunk scoring system	
Score	Description
0	No feed remaining in bunk.
½	Scattered feed present. Most of bottom of bunk exposed.
1	Thin uniform layer of feed across bottom of bunk.
2	25 to 50% of previous feed remaining.
3	Crown of feed thoroughly disturbed. More than 50% of feed remaining.
4	Feed virtually untouched. Crown of feed still noticeable.

In this trial, DMI was 99%, not 97% of that of control cattle even though this bunk scoring system should have reduced DMI slightly. Although average daily gain was improved the first 28 d that DMI was restricted, ADG was not altered during the rest of the trial. Feed efficiency was improved due to feed

restriction by 10% during the first 28 days and by 5% over the total 139 day period. No differences were noted in carcass quality or yield grade, but restricted feeding resulted in heavier carcasses. Feed restriction reduced feed cost of gain by $1.65/cwt. Based on a total gain of 496 lb. per steer, restricting DMI resulted in an $8.19 advantage per head.

Restricted Feeding For Only the First Portion of a Feeding Period

Instead of restricting DMI throughout the entire feeding period, one can restrict intake for one segment of the feeding period, often the first portion, and finish cattle with free choice access to feed. The periods of time of restriction and of ad libitum access to feed have varied among experiments. In general, these programs have improved feed efficiency, but unlike limit feeding throughout the entire finishing period, early restriction alone allows cattle to reach comparable final weights and carcass quality grades.

Lofgreen et al. (1987) restricted DMI at two levels (80 and 90% of free choice DMI) until live weights of cattle weighing 544 lb. reached 700 lb.; subsequently, cattle had free choice access to feed for the remaining portion of the 193 d feeding period. It took 53, 59, and 68 days for the cattle to reach 700 lb. for cattle given ad libitum, 90% of ad libitum, and 80% of ad libitum intakes, respectively. Although no significant differences were noted in average daily gain, feed intake, feed efficiency or final weight among the three treatments for the total 193 d feeding period, restricting intake early tended to improve ADG and efficiency. No carcass data were reported.

Loerch et al. (1995) conducted a similar trial restricting DMI of cattle initially weighing 600 lb. until they averaged 820 lb. In this trial, DMI was restricted to 2.0, 2,5 or 3.0 lb./d. based on Net Energy equations or given free choice access to feed. Cattle were weighed every two weeks; DMI was adjusted to meet maintenance requirements as body weight increased. Diets of restricted fed steers were richer in protein, minerals and monensin to ensure equal daily intakes. The restricted phase lasted until steers in a pen averaged 820 lb.; thereafter, all steers were given ad libitum access to feed until they reached 1180 lb. During the restricted period, cattle had ADG of 2.27, 2.68 and 3.08 lb./d, respectively, while steers given ad libitum access to feed gained 3.56 lb./d. The greater the restriction, the less the accuracy of predicting rate of gain. This likely was due to greater digestive and metabolic efficiency with intake

restriction. Similar inaccuracies in accuracy of net energy equations to accurately predict gain of limit fed cattle have been reported by Lusby et al. (1990), Loerch et al. (1995), and Knoblich et al. (1997). Despite these differences in growth rate, feed efficiency did not differ among treatment groups. During the ad libitum phase, calves previously limit were said to have made "compensatory growth" because growth rate tended to be greater even though the differences in rate of gain were not different statistically during this period. Calves that had free choice access to feed throughout had the lowest feed efficiency in Period 2. However, for the total trial, rate of gain, feed efficiency, days fed, total feed intake, and carcass characteristics were not different among the four feeding strategies investigated. Carcass characteristics were not affected by feeding strategy. These calves, approximately 14 mo old when marketed, graded approximately 80% choice. Limiting growth rate to 2.27 and 2.68 lb./d during a growing period for approximately three months was of no benefit to performance or production efficiency and tended to increase length of time on feed. However, restricting gain to 3.08 lb./d during the growing period increased total time on feed by only five days and reduced total feed required by 61 lb./steer.

Wagner (1988) compared the finishing performance of cattle that had been limit-fed a high energy growing diet to that of cattle that had been full-fed a high roughage growing diet. During finishing, cattle were given free choice access to feed or at 93% of ad libitum for the first 70 days of the 115 day finishing phase. Interactions between previous growing program and level of feed intake during the finishing phase were significant. Restricting the intake of finishing cattle that had been grown using a limit-fed, high energy diet resulted in improved feedlot performance (ADG of 3.58 vs 3.28 lb.) and efficiency (6.18 vs 7.11) as compared with cattle fed free choice. However, cattle that had been grown using a high roughage program and had DMI restricted during the finishing period had lower ADG (2.83 vs 3.16 lb.) and depressed efficiency (7.88 vs 7.19) as compared to cattle given free choice access to feed. This suggests that whether or not cattle will respond to a restricted intake finishing regimen may depend upon level of dry matter intake, dietary energy density or rate of gain during previous growing programs.

As stated previously "limit feeding" is a vague term; exact methods and goals of the restriction vary widely. At a recent symposium, Tom Peters (1995) described several restricted intake programs that he has use to achieve specific goals. He summarized close out data from ten years using more than one

million cattle. He defined "program feeding" as using an intake prediction equation to regulate daily dry matter feed consumption based upon initial weight of the cattle. One objective of his program feeding system is to maximize dry matter intake when averaged over the entire feeding period. This differs from the standard feed bunk management that attempts to maximize feed intake on a daily basis without regard for the entire feeding period. By this method, he seeks to maximize dry matter intake during the final 80 days that cattle spend at the feedlot. On his program, steers had greater ADG (3.23 vs 3.00 lb.), greater DMI (22 vs 21 lb.), and had an improved feed efficiency (6.84 vs 7.00). Response by heifers was nil although he speculated that had he had used intake equations for yearling heifers, responses might have been positive for heifers. Another program that he described as "Plateau feeding" is designed to control dry matter intake at specific phases of the feeding period to optimize growth. Also called stair-step feeding, this regime targets long-fed steer calves with initial weights below 600 lb. that normally are fed more than 175 days. The objective of plateau feeding is to delay maximum dry matter intake until the last 140 days that calves are on feed. Danielson et al. (1993) hypothesized that restricting intake as animals grow should improve cellular efficiency. However, when animals are later given unlimited amount of feed, cells will increase in metabolism and proliferate. Plateau feeding has increased ADG (3.04 vs 2.77 lb.) and DMI (18.3 vs 17.9 lb.) and improved efficiency (6.03 vs 6.44). He reserved the term "limit feeding" to describe feeding less than maximum amounts of high energy diets in order to growing calves at a less than maximum rate. By his definition, limit feeding is targeting a specific ADG and controlling DMI of a high energy diet to attain a desired ADG. Because long-fed heifer calves have notoriously poor feed efficiencies, long-fed heifers may be ideal to benefit from limit feeding. Long-fed heifers fed according to this limit feeding growing program had greater ADG (2.80 vs 2.51 lb.), less DMI (16.6 vs 19.1 lb.) and improved efficiencies (5.92 vs 7.65). Such data demonstrate that economic opportunities exist for cattle feeders using non-traditional intake control methods. Maximizing DMI every day that cattle are on feed may not always return maximum economic benefits or even maximize average DMI for the total feeding period. Controlling DMI during the start-up , limit feeding high energy diets, plateau feeding calves and program feeding yearlings are techniques which may improve gain efficiency.

In a continuing search for the ideal feeding strategy, Loerch et al. (1995) compared four different

feeding systems different periods of a finishing program. Switch times were based on weight gain. These

four systems are described below. Maximum gain was expected when cattle were given ad libitum access

to feed.

Table 2. Feeding method to alter rate of gain at various periods of a feeding trial (Loerch et al., 1995)

Feeding System	Increasing gains	Decreasing gains	Constant gains	Maximum gains
Weight periods	----------------------------	--predicted daily gain	--------------------------------	
662-875 lb., period 1	2.5	Maximum	3.0	Maximum
875-1075 lb., period 2	3.0	3.0	3.0	Maximum
1075-1190 lb., period 3	Maximum	2.5	3.0	Maximum

Table 3. Actual performance of cattle fed to achieve various rates of gain during a feeding trial as described in table 2. (Loerch et al., 1995)

Item	Increasing gains	Decreasing gains	Constant gains	Maximum gains
Period 1	2.98	3.48	3.28	3.66
Period 2	3.54	2.95	3.11	1.13
Period 3	3.54	2.73	3.48	3.31
Total trial ADG, lb.	3.29	3.09	3.28	3.35
Total trial DMI, lb.	16.9	17.8	17.9	18.7
Total trial feed/gain	5.13	5.75	5.46	5.56

Gains achieved are shown in Table 3. Averaged across the total trial, growth rate did not differ among

these four finishing systems. Cattle all were fed for the same number of days even though slower

growing cattle should require more days to reach market weight. Cattle fed to achieve a step-wise

increases in growth rate throughout the trial had the lowest daily intakes and the superior feed efficiencies

requiring 241 lb. (9 %) less total feed to reach market weight than those given ad libitum access to feed

throughout the trial. At a feed cost of $100/ton, this equals a saving of $12.05/steer in feed cost.

Carcass characteristics of steers did not differ among these feeding regimens.

Pursuing this concept that gain should increase during the feeding trial, Knoblich et al. (1997)

tried to determine the exact length of time needed at specific stages to optimize feedlot performance. In

this trial steers were initially fed to achieve a predicted gain of 2.5 lb./d until they gained from 70 to 170

pounds (Table 4). Growth rate was increased sequentially after steers had gained specified amounts of

live weight. An additional group of steers were given ad libitum access to feed throughout the total trial.

Table 4. Lengths of feeding at various ADG during a feeding trial (Knoblich et al., 1997).

| Target ADG | Finishing System | | | | |
	1	2	3	4	5
	pounds of gain at each ADG				
2.50	70	170	170	120	
3.00	170	270	170	220	
Ad lib	270	70	170	170	

Table 5. Rates of gain during various periods for the finishing systems described in table 4.

| Period target ADG | Finishing System | | | | |
	1	2	3	4	5
2.50	2.49	2.55	2.49	2.55	1.63
3.00	3.28	4.14	4.14	3.76	3.45
Ad libitum	3.70	3.65	3.50	3.59	2.68
Total trial ADG, lb.	3.32	3.37	3.21	3.32	3.45
Total trial DMI, lb.	17.7	17.0	17.0	17.2	19.1
Total trial feed/gain	5.32	5.05	5.29	5.15	5.52

At slaughter, three steers from each pen were selected for carcass composition analysis. Selection was

made so that the three carcasses from each treatment had an average weight of 731 lb. The 9-10-11th rib

section was removed from the right side of each carcass; ether extractable ether extract, protein, and

moisture of the carcass were calculated from rib section analysis according to the procedures of Hankins

and Howe (1946).

As shown in Table 5, all steers gained close to the predicted 2.5 lb/d throughout the first

restricted feeding period. When fed to gain at a rate of 3.0 lb./d, actual ADG by steers were 10 to 38%

greater than predicted. Longer restriction times resulted in greater increases in compensatory growth.

Despite limited intake, steers in systems 2, 3 and 4 all had ADG greater than the ADG of steers provided

ad libitum access to feed. Limit-fed steers also had superior feed efficiencies compared with steers offered

feed ad libitum. The calves restricted to gain 2.5 lb./d for only 70 pounds of gain (32 days) had lower

ADG and efficiencies of gain than steers restricted for a longer time. Steers that were limit-fed and then

switched to ad libitum intake (systems 1,2,3, and 4) had greater ADG and superior efficiencies of gain as

compared with steers offered feed ad libitum throughout the trial. Rate of gain declined as full-fed cattle

approached market weight; in contrast, rate of gain was increasing for the programmed-intake cattle. When full-fed cattle were large and eating the most feed, their growth rate was slow. In contrast, when programmed-intake cattle were large, they were growing rapidly and spent relatively less time at the heavier BW. Averaged over the total trial, all restricted feeding schedules (systems 1, 2, 3, and 4) led to reduced daily feed intake compared with steers offered feed ad libitum throughout. Calves offered feed ad libitum had poorer feed efficiency than calves on systems 2 and 4; systems 1 and 3 were intermediate. Restricting intake resulted in similar rates of gain as full feeding throughout the entire feeding period. Restricted intake systems 2, 3, and 4 resulted in decreased overall feed intake compared to ad libitum-fed calves. Feed savings per calf were 125, 308, 159, and 233 lb. (systems 1, 2, 3, and 4, respectively) compared with offering cattle feed ad libitum. These represent saving of 4.1, 10.2, 5.2 and 7.7% of the total feed consumed by cattle given ad libitum access to feed; using a feed cost of $190/ton of DM, the feed savings would equal $12.28, $30.35, $15.62 and $22.89 for systems 1,2,3 and 4, respectively. In addition to reduced feed consumption for systems 1, 2, 3 and 4 compared with offering cattle ad libitum access to feed , feed waste was lower with restricted feeding. Feed refusals for systems 1, 2, 3, 4 and 5 averaged 47, 23, 36, 26.4, and 72 lb./steer for the entire trial, respectively. These losses equate to costs of $4.64, $2.23, $3.55, $2.60 and $7.10 for systems 1,2,3,4 and 5, respectively. Therefore, offering steers feed ad libitum was not the most economical or efficient use of feed resources on this experiment. No differences in hot carcass weight were detected. Steers offered feed ad libitum for only the final 77 lb. of weight gain (system 2) had reduced 12th rib backfat, KPH %, and USDA yield grade compared with cattle offered feed ad libitum either throughout the trial or for the final 270 lb. of weight gain (systems 5 and 1, respectively) with systems 3 and 4 were intermediate. There were no differences in dressing percentage, rib eye area, quality grade, of percentage of cattle grading choice due to dietary treatment. Reductions in 12th rib backfat, kidney, pelvic and heart fat, and yield grade with steers on system 2 compared with systems 5 and 1 indicate that manipulating carcass fat deposition late in the feeding period may be both economically and physiologically feasible . Reducing yield grade and internal fat deposition without reducing the quality grade of carcasses would reduce the amount of low-value trim fat without reducing high-value intramuscular fat (marbling). The reduction in feed required to grow a steer to market weight

did not increased days on feed or decrease USDA quality grades. Therefore, feeding systems such as systems 2, 3 and 4 should reduce feed cost and bunk management (feed waste and spoilage) problems compared with offering cattle ad libitum access to feed without increasing yardage or interest costs. Furthermore, systems 2, 3, and 4 would not reduce gross income because carcass weights, quality grades, and yield grades were similar to those from a conventional ad libitum-feeding system.

In a second trial Knoblich et al. (1997) tested four feeding schemes designed to allow for multiple periods of restricted and ad libitum feed intake as shown in Table 6.

Table 6. Schedule of various gains at different times for cattle in a finishing trial (Knoblich et al. 1997).

	Treatment				
	1	2	3	4	5
Period, days	predicted gain or fed ad libitum				
0 to 14	2.75	2.25	2.25	1.74	Ad lib
15 to 28	2.75	2.25	Ad lib	Ad lib	Ad lib
29 to 42	2.75	Ad lib	Ad lib	Ad lib	Ad lib
43 to 56	2.75	Ad lib	2.25	1.74	Ad lib
56 to 70	Ad lib	Ad lib	Ad lib	Ad lib	Ad lib
71 to 84	Ad lib	Ad lib	Ad lib	Ad lib	Ad lib
85 to 98	2.75	2.25	2.25	1.74	Ad lib
99 to 112	2.75	2.25	Ad lib	Ad lib	Ad lib
113 to 128	2.75	Ad lib	Ad lib	Ad lib	Ad lib
129 to 140	2.75	Ad lib	2.25	1.74	Ad lib
140 to market	Ad lib	Ad lib	Ad lib	Ad lib	Ad lib
Total trial ADG, lb.	3.23	3.39	3.37	3.21	3.30
Total trial DMI, lb.	16.6	17.0	16.8	16.6	17.1
Total trial feed/gain	5.13	5.00	5.03	5.15	5.24

Feed intake was restricted for treatments 1, 2, 3, and 4 to achieve the desired predicted daily gains for the designated time periods. Periodic intake restriction did not decrease total ADG. During compensatory periods, steers overcame the retarded growth during periods of intake restriction. Feed intake for the period d 0 to 84 was higher for steers offered feed ad libitum throughout (treatment 5) than those on systems 1 and 4. Feed intakes for steers on systems 2 and 3 were intermediate during this period. Feed intakes for the period d 85 to finish, as well as overall feed intake, were not different among the five finishing systems. Performance responses from d 85 to finish were similar to those from d 0 to 84 except that no treatment effects on feed intake were detected. Overall, performance was nearly identical for each of the five systems investigated. Failure to enhance efficiency by creating multiple short-term

compensatory growth periods indicated that intermittent limitations were not enhancing performance. In contrast with the steers in Trial 1, the steers in the present experiment were given ad libitum access to feed for longer time periods early in the finishing period. The lack of a long-term energy restriction during the more linear phase of growth (as in the previous trial) may be responsible for the lack of performance benefits from restricted feeding in this study. No differences in carcass characteristics were detected. Unlike the steers in Trial 1, the steers in the present experiment all had a substantial period of free choice intake. The periods of restricted feed intake may have been of insufficient duration or magnitude to decrease fat accumulation. Additionally, there were no differences on total DMI due to treatment. As a result, energy intake were similar for the five feeding systems. To elicit differences in growth responses and carcass characteristics, it may be necessary to have a longer period of intake restriction early in the feeding period.

Other Limit Feeding Programs

While limit feeding programs have implemented during large segment of the feeding period as described above, limit feeding also has been used in specialty programs. Two such programs, similar in concept but different in philosophy, were developed to help start cattle on feed. Most cattle that enter a feedlot arrive directly from having grazed pastures or being fed forage. In the feedlot, the diet is changed from being based on forage to one consisting predominantly of cereal grain. During this transition or step up period, drastic changes occur in the ruminal environment. The changes are coincident with other stresses such as weaning, commingling, transport, and a new environment. Cole (1993) postulated that metabolic stresses induced by overfeeding newly arrived cattle may negatively impact the immune response by animals. The diet change can trigger subacute or acute acidosis and hamper performance for the remainder of the feeding period. To reduce drastic ruminal changes associated with large fluctuations in energy intake during this period, Preston et al. (1995) developed a program that he termed "limit maximum intake." By limiting intake to a set maximum, wide fluctuations in intake are avoided. The upper intake limits proposed were 2.3, 2.5, 2.7 and 2.9 times the calculated maintenance net energy needs (based on initial weight) for weeks 1, 2, 3, and 4, respectively. This limited maximum intake regimen

A second problem associated with the step up period relates more to feedlot management and diet composition. Most feedlots are well equipped to handle and process grain. Handling and processing forage, that constitutes a large percentage of the step up diets, is cumbersome. Further, in the Southern Great Plains, forage is more expensive than grain per unit of net energy; thereby, roughage feeding increases the cost of gain. The goal of a feedlot is to adapt cattle to their high concentrate diet as rapidly as possible using as little roughage as possible while not compromising animal health. In an attempt to simplify the practice of starting cattle on high energy finishing diets, "aggressive" starting programs have been developed (Larson, 1995). These programs have a goal of avoiding wide swings in daily feed intake during start-up, reducing roughage use because of its high nutrient cost, and maintaining high feed intakes for extended feeding periods. One such aggressive program starts cattle abruptly on their final ration but intake is limited to only 1.7% of body weight initially. Daily intake is increased 2.0 lb./hd when cattle continue to clean up their daily allotment of feed. Using such a system, cattle were adapted to ad libitum access to feed in only 7 days vs 16 days with more conventional roughage-diluted starting diets. Steers fed the conventional diets 4.3% more weight and ate more feed over the entire trial, the majority of which occurred during the first 28 days. Feed efficiency did not differ by starting system.

Mechanisms By Which Limit Feeding May Improve Feed Efficiency

Whether used in a growing or finishing program, limit feeding usually improves feed efficiency. However, no single reason can fully explanation why efficiency is improved. Several mechanisms that have been proposed will be discussed below. But because limit feeding programs are diverse in type and response, no single mechanism may be active in every system. Instead, some combination of factors may be involved in any given system with certain factors being more important than others.

Digestibility, Passage Rate, Rumen Fermentation Patterns

With limit feeding, one would expect that diet digestibility should increase. Under most conditions, intake and digestibility are related inversely (NRC, 1978; ARC, 1980). As feed intake increases, rate of passage is accelerated, which causes decreased time for digestion and thereby

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With limit feeding, one would expect that diet digestibility should increase. Under most conditions, intake and digestibility are related inversely (NRC, 1978; ARC, 1980). As feed intake increases, rate of passage is accelerated, which causes decreased time for digestion and thereby digestibility of slowly fermented materials, especially fiber components, to decrease (Owens et al., 1986a). Although several cattle studies (Rust and Owens, 1982; Owens et al., 1986a b) generally indicated that restricting intake to levels near maintenance will increase digestibility of less thoroughly processed grain-based diets, effects of slight restrictions (<15%) in feed intake of feedlot cattle remain largely unknown. Passage rates (calculated by chromium concentrations) and digestibilities (determined from acid insoluble ash) measured by Hicks et al. (1990) were not different between cattle with restricted vs ad libitum access to feed. However, variability in digestibility estimates were quite large, partially due to low content of acid insoluble ash in the diet. Similarly, Old and Garrett (1987) reported that neither intake level (ad libitum, 85% of ad libitum, 70% of ad libitum) nor protein level (8.9, 11.0, 12.9%) affected digestibility of their high concentrate diet. In contrast, decreasing intake improved digestibility in a trial by Murphy et al. (1994). They fed wether lambs a high-concentrate diet (92%, ground corn and 8% ground corn cobs) diets at ad libitum intake and 90, 80, and 70% of ad libitum intake. Restricting intake increased digestibility of DM, OM, ADF, starch, and CP. For each 1% reduction in DMI, digestibility of DM, ADF, CP, and starch increased by .142, .423, .497, and .046 percentage units, respectively. Nitrogen retention was quadratic; retention was maximum with intake at 89% of ad libitum. They concluded that diet digestibility and N utilization were enhanced when restricted feeding program was used when equal amounts of protein, vitamins and minerals were provided each day. Zinn and Owens (1983) fed cattle at a rate of 1.2, 1.5, 1.8 and 2.1% of body weight a diet consisting of 63% dry rolled corn with 6% dehydrated alfalfa meal and 14% cottonseed hulls. As intake was increased, starch digestion in the rumen increased slightly but ruminal digestion of organic matter and, especially, acid detergent fiber digestibility declined. At the highest level of feed intake, no ADF disappearance occurred in the rumen. The lower ruminal pH observed with high intakes would be expected to decrease ruminal cellulose digestion, but whether limit feeding will substantially increase ruminal pH is not clear.

If digestibility is altered by limit feeding, then the impact of limited intake should be greater when diets contain less extensively processed grains or a larger amount of slowly fermented roughage. Murphy et al. (1994) utilized ruminally fistulated steers to compare effects of intake (ad libitum or 70% of ad libitum) and corn processing (whole or rolled) on digestion and ruminal metabolism. Digestibility of DM and OM was affected by a grain processing x intake interaction. When intake was high, the rolled corn had 4% lower DM digestibility than whole corn diet. Conversely, when intake was low the rolled-corn diet had an 8% higher digestibility than the whole-corn diet. Galyean et al. (1979a) observed DM digestibilities of 77.6 and 84.1% at 2.0 and 1.3 x maintenance, respectively, when 84% cracked corn diets were fed; these diets also contained cottonseed hulls and dehydrated alfalfa meal. When intake was low, grain processing resulted in substantial improvements in digestibility of DM, OM, N, and starch. In contrast to these results and those of Murphy et al. (1994), Galyean et al. (1979b) reported that when 72% corn diets were limit fed (1.25 times maintenance), no differences between whole and ground corn in total tract digestibility of DM, OM, CP, or starch were detected. Whether the discrepancy between results of Galyean et al. (1979b) and Murphy et al. (1994) is due to source or level of dietary roughage or to animal age or size and its effect on chewing time is not clear.

Merchen et al. (1986) fed sheep diets containing two forage levels (75% alfalfa with 22% corn and 25% alfalfa with 65% corn (16.7% CP) at two intakes (2.6 and 1.7% of BW). The low forage diets at the high intake produced a higher molar proportions of propionate and lower proportion of butyrate in ruminal fluid than the low forage diets at the low intake level or the high forage diets at either intake level. Less of the total tract organic matter digestion occurred in the rumen when wethers were fed at high intakes. Neither of these observations would support an advantage for restricted feeding. However, these diets contained more forage and restrictions imposed were greater than in most limit feeding studies. Murphy et al. (1994) reported that intake level had little impact on proportions of acetate and propionate when whole corn was fed, but with rolled corn, the higher intake reduced acetate and increased propionate. Diets in that trial were fed either ad libitum or 70% ad libitum. In agreement with this study, Rumsey et al. (1970) observed that the proportion of acetate decreased and of propionate increased with intake when all concentrate, ground-corn diets were fed. One and two hours after feeding, no intake

effects on ruminal VFA concentrations were evident (Murphy et al., 1994). At 3 or 4 h after feeding, steers receiving the low intake had greater concentrations of ruminal VFA than high intake steers. This likely is due to lower ruminal volume of steers with lower DM intake. Twelve hours after feeding, no effects of intake on ruminal VFA concentrations were evident. Ruminal fluid pH was related inversely to total ruminal VFA concentrations (Murphy et al., 1994). One hour after feeding, steers fed high intake all-concentrate diets had lower ruminal pH (5.63) than low intake steers (6.01). This intake effect on ruminal pH also was apparent 2 h after feeding (pH of 5.38 vs 5.67 for high vs low intake). Perhaps steers receiving less feed consumed a greater percentage of their daily feed allotment within the first 2 h after feeding and had increased salivary flow associated with consumption and, therefore, had greater ruminal buffering capacity shortly after feeding. Alternatively, pH and buffering of ruminal contents probably were greater before feeding in limit fed steers and this may have neutralized acids postprandially.

Passage and ruminal dilution rates also may be related to digestibility and ruminal fermentation. Murphy et al. (1994) when comparing cattle fed ad libitum vs 70% ad libitum and corn processing (whole or rolled) reported that ruminal liquid volume measured hours after feeding was reduced as a result of reducing DM intake of the all concentrate diets. This finding disagrees with data reported by Galyean et al. (1979a) in which feeding an 84 % cracked corn diet at 1.3 and 2.0 times maintenance intake did not alter ruminal liquid volume. Feeding mixed grain-forage diets results in greater saliva flow than feeding diets high in readily available starch (Wise et al., 1968), and the longer the time spent eating, the greater the amount of saliva produced. The lower ruminal liquid volume observed for animals on the low-intake diet may be a result of more rapid meal consumption and decreased saliva flow. Steers fed the low-intake diets consumed their daily allotment of feed in less than 1 h. The greater ruminal volume observed for high compared to low intake was consistent for both corn processing types. This similarity lends credence to the explanation that the differences in ruminal liquid volume with intake are the result of different rates of feed consumption. Ruminal turnover was reduced as a result of restricted DM intake according to Murphy et al. (1994). Similarly, Galyean et al. (1979a) reported that ruminal liquid dilution rates were 3.5 and 5.3% for steers receiving intakes of 1.3 and 2.0 times maintenance, respectively. Garza and Owens (1989) reported that total weight of solids in the rumen increased as intake was increased from 1.0

to 1.4, and 1.8% of BW. However, intake level did not affect rumen liquid volume, because outflow increased linearly with intake.

Murphy et al. (1994) reported ruminal ammonia concentrations were greater for steers receiving low intake than for steers receiving high intake at all times sampled. They attributed this to the greater intakes of CP and urea of restricted steers that were formulated to provide equal daily CP intakes.

While digestibility increases as intake decreases, the magnitude of this change cannot fully explain the observed performance responses in most limit feeding programs. Indeed, Zinn et at. (1995) stated that although a decrease in intakes will increase DE, the ME of the diet may not be altered because at a lower intake, loss of methane is increased. Measured 4 hours after feeding, ruminal pH, acetate, and methane loss all were greater for intake restricted cattle; ruminal ammonia, propionate, and butyrate were greater at higher intakes. This statement may not apply to limit fed high energy growing programs. With such diets, improved digestibility and shifts in ruminal VFA proportions should favor propionate production and could account for much of measured improvement from limit feeding. However, other potential mechanisms should not be discounted.

Effects of Restricted Feeding on Organ Weights

Another mechanism implicated in the observed improved feed efficiency with controlled feeding is that maintenance requirements are decreased because weight of the gut and vital organs is decreased. Synthesis of protein is an extremely active and energy-demanding process (Waterlow et al., 1978); tissues with the greatest rates of protein synthesis are not muscle but in liver and gut tissue. Only about 14% of total protein synthesis occurs in striated muscle. Even at peak growth the rate of protein deposition in muscle was only about 1g/day in rats (Pullar and Webster, 1977). This is only about 8% of total protein synthesis. Moreover, species comparisons reveal a close linear relationship between protein synthesis and heat production. These results suggest that protein synthesis is a major contributor to metabolic heat production and that the majority of synthesis and heat production is occurring in tissues not associated with growth and meat production. Peak efficiency is achieved at an intake somewhere below ad libitum. This observation is reinforced by some unpublished calorimetric data for beef cattle from the Rowett

Institute which suggest that not only does the energy value of the gain increase markedly at high intakes of ME, so too does the heat increment of feeding; further increments of ME intake fail to increase in the energetic efficiency. Thus, protein synthesis and heat production in the gut are related more closely to the quantity and quality of nutrients available for metabolism than to work involved in processing and eliminating indigestible nutrients. Consequently, they are unlikely to be affected by small changes in the roughage content of the diet.

With limited energy intake, liver size may be reduced leading to a reduced maintenance requirement. As proportional size of the liver increases, maintenance energy expenditures increase (Ferrell et al., 1986). Rust et al. (1986) noted that liver weight of Holstein steers increased as feed intake increased from 70% of ad libitum to ad libitum. Lunt et al. (1986) reported that liver mass of beef steers increased at the rate of .52 kg per kg of daily gain. With limit feeding, weight gains generally decrease slightly, so liver weight might be expected to decrease. A more regular supply of energy and nutrients also could reduce liver size because changes in metabolic flux would be reduced. Most studies that have measured weights of liver, gut and vital organs and have noted reductions with limited energy intake have used severe nutritional stress (i.e., animals held close to maintenance) for comparison with animals consuming feed ad libitum (Burrin et al., 1990) or at least gaining live weight (Freetly et al., 1995). These findings suggest that level of feed intake changes the relative proportion of visceral organs to body mass. In addition, the effect of level of feed intake on changes on the relative contribution of viscera organs to whole-body metabolic rate appears to be primarily a result of differences in organ size rather than tissue-specific metabolic activity (Burrin et al., 1990). With 80 days of feed restriction, oxygen consumption by the hepatic and portal drained viscera were decreased by 60 and 65%, respectively (Freetly et al., 1995). Additionally, Rumsey et al. (1970) reported that respiratory rate and heart rate both increased as intake was increased from .5 to 2.0% of BW. These results could partially explain why the greater restrictions (i.e., up to 20%) may improve efficiency more than lesser restrictions in cattle limit fed throughout the entire feeding period. However, final wet liver weight was no lower in limit than ad lib steers in studies by Hicks et al. (1990) or Murphy and Loerch (1994) despite improved feed efficiencies. Nevertheless, a decreased organ weight could explain in part the improved performance of cattle limit fed

high concentrate growing diets as compared to those given ad libitum access to roughage diets. Freetly et al. (1995) reported that upon realimentation, hepatic tissue required 21 d and portal drained viscera required 29 d to recover to fall within 5% of the new steady-state O2 consumption rates. During realimentation, O2 consumption rate reached within 1% of new steady-state levels after 21 to 42 days. While these results could explain temporary increases in efficiency of limited fed cattle, it seems unlikely that can fully account for the differences; most ad libitum feeding periods that follow restriction exceed 30 days. So it appears likely that decreased maintenance energy requirements may explain a portion but not all of the improved feed efficiencies noted with limit feeding programs.

Day to Day Variation in Feed Intake

Additional potential reasons for improved efficiency are reduced variation in feed intake, both from animal-to-animal and from day-to-day with limit feeding (Zinn, 1987). He proposed that animals with ad libitum access to feed exhibit wide day-to-day fluctuations in feed intake; these could cause digestive disturbances and decrease feed utilization. In support of this concept, Stock et al. (1995) summarized variation in intake from several trials measured both within and across days. They reported that across all trials, day to day variation in intake was correlated negatively (r=-28) with gain/feed ratio. However, this correlation would include several sources of variation such as trial (animals, diet, environment), incidence and severity of acidosis, and treatment differences. Considering only the data from cattle fed 100% concentrate, the negative correlation was larger (r=-.49). But using only data with cattle fed 92.5% concentrate diets, the correlation disappeared (r=-.03). At least three reasons may explain why these correlations differ. First, one has fewer observations with 92.5% concentrate diets. Secondly, with 92.5% concentrate, acidosis incidence would be lower and this would reduce intake variation. Third, variation may actually be less with the 92.5% concentrate diets due to fewer extreme values.

Effects of Restricted Intakes on Animal Feeding Behavior

One additional mechanism that has received little attention is altered behavior that reduces energy expenditure. Lake (1987) reported that for the first several days of restriction, limit-fed cattle in a

commercial feedlot appeared restless, but following an adjustment period of 7 to 14 d, they settled into a routine and appeared calmer than cattle given ad libitum access to feed. If limit-fed cattle are more lethargic, the reduced exercise and activity would reduce maintenance energy requirements. However, limit feeding did not alter steer behavior (time spent ruminating, eating and lying) in a trial by Hicks et al. (1990). Nevertheless, several workers have reported that limit-fed cattle quickly develop into meal eaters and consume all their feed within a few hours. What effect that this has on performance in not known but deserves study. Prawl et al. (1997) reported that restricting access to feed to 9 hr./d slightly increased intake and performance of cattle. A stable intake pattern will reduce the day-to-day fluctuation in substrate flux and may alter hormonal status although with larger, intermittent meals, variation within a day may be greater with limit-fed than free choice fed cattle. Additionally, if cattle consume their feed quickly and aggressively, they are less likely to sort their feed and consume a diet not representative of the diet they are offered. Hence, intake restricted cattle should receive a more balanced diet (i.e., representative of the formulated diet in protein, energy, minerals, feed additives). This alone could account for a large percentage of the observed improvements.

Differences in Body Composition and Retained Energy.

Limit-fed cattle may have a different body composition based on observations that measurements of depot fat often are less than for cattle given ad libitum access to feed (Hicks et. al., 1990; Murphy and Loerch, 1994; Lofgreen, 1969; Hironaka and Kozub, 1973; Levy et al., 1974; Anderson, 1975; Garrett, 1979; Hironaka et al., 1979, 1984; Lofgreen et ., 1983; Glimp et al., 1989). This alone would improve feed efficiency because, on a wet tissue weight basis, more energy is used to deposit fat tissue, at 10% water, than to deposit lean tissue that contains about 75% water (Webster 1980). However, in all the studies that have reported a decrease in fatness, intake was restricted throughout the feeding period, i.e., until cattle were marketed. In other studies where intake has been limited for only a portion of the trial (Loerch et al., 1995; Wagner, 1988; Knoblich et al., 1997), no decrease in fatness has been reported. So while decrease fat deposition could explain a portion of the improved efficiencies in certain trials, that cannot explain the improved efficiencies in other trials.

Ferrell and Jenkins (1995) reported that over a broad range in feed intake, the relationship between rate of gain and feed intake was not linear; as feed intake increased above maintenance, the incremental increase in rate of gain diminished. They suggested that growth rate, body composition and mature size per se were not the primary determinants of maintenance or efficiency of feed utilization. This was particularly evident when efficiency comparisons were made at a fat-constant end point or when efficiency of lean tissue or protein accretion was considered. Multiple regression analyses by Webster (1980) indicated that the amount of energy required to deposit one gram of fat tissue was about four-fold greater than to deposit one gram of lean tissue, primarily due to the greater water content of lean tissue. The energy content of lean meat is about 4.8 kJ/g and for fat it is about 39 kJ/g. If feed-restricted cattle deposit more lean and less fat, this automatically improves efficiency of weight gain. In addition, level of energy intake above maintenance influences efficiency. During growth, ME intake obviously exceeds heat production (H) resulting in energy retention. But at maturity, with no additional energy being retained, heat production equals ME intake. Due to reduced dilution of maintenance, efficiency of energy retention (RE) reaches a peak at about 25% of mature body weight and declines steeply thereafter. As an animal matures, the ratio of fat to protein of retained tissue increases. Thus the ratio of weight gain (g) to energy gain (Mcal) declines with maturity. This causes feed conversion efficiency, which reflects both the RE/ME ratio and the energy content of retained tissue, will be relatively constant during the first third of growth but will decline steeply after animals reach about 30% of mature size. This point equates to the beginning of the finishing period for feedlot cattle.

Because energy density for fat is about eight times that of lean tissue, it often is assumed that the leaner animal automatically is more efficient at converting feed to gain. This association is valid if the leaner animal is less mature. But at a similar degree of maturity, experimental data reveal no clear association between leanness and efficiency of growth. Even rapidly growing animals fail to retain more than about 30% of ME intake; the remainder is dissipated as heat (Webster, 1980). The proportion of ME retained as protein in the edible carcass seldom exceeds 8%, even for intensively raised livestock like broiler chicks. For beef cattle in semi-intensive production, the proportion of ME deposited as protein in meat is below 3%. The proportion of ME retained as fat is more variable, being determined both by

genetics and nutrition; but fat can account for only about 5 to 20% of the ME consumed. Therefore, it seems fruitless to select simply for low fat content and ignore the two dominant factors in the energy balance equation, ME intake and heat production. Animals that have less fat could have less fat due either to an altered body composition (and larger mature size), to lower ME intake or to greater heat production, both of the latter leading to slower and less efficient growth (Webster, 1980). The Pietrain pig provides an example where selection has decreased fatness through reduced feed intake. It converts equivalent amounts of ME to protein and fat with an efficiency identical to that of the Large White (Fuller et al., 1976) but still is leaner. The Pietrain is leaner than the Large White in commercial conditions simply because it consumes less feed. An example of increased heat production leading to decreased fat is provided by comparison of the very lean red deer calf with the young fat lamb. The amount of ME retained as protein is the same for both species. But the greater rate of energy deposition as fat in the lamb is matched exactly by an increased dissipation of energy as heat by the deer (Simpson et al., 1978). Similarly, heat production by bulls is about 20% higher than that by steers at the same food intake and stage of maturity (Webster et al., 1977). When raised intensively on high energy feeds fed at or close to appetite, bulls tend to convert food to gain more efficiently than steers because their greater heat production is more than counterbalanced by the lower energy content of their much leaner carcass. When bulls and steers are grown more slowly at ME intakes not much above maintenance, the higher heat production by the bull becomes a disadvantage making the steer the more efficient at converting feed to live weight. Andersen (1978) has convincingly demonstrated this interaction between sex and plane of nutrition in bull, steers and heifers.

On a theoretical basis, Kielanowski (1976) speculated that the efficiency of utilization of ME for protein and fat deposition were about 45% and 75%, respectively, in simple-stomached animals such as pig and rat. To determine these values in animals, energy costs of protein and fat deposition were calculated by multiple regression analysis by Pullar and Webster (1977). They conducted experiments using lean and genetically obese Zucker rats; these strains differ greatly in their partitioning of retained energy between heat, protein and fat at the same age and ME intake. They observed efficiencies of utilization of ME for protein and fat deposition to be exactly similar to the estimates of 45 and 75% given

by Kielanowski (1976). Assuming that lean gain is four times as efficient as fat gain, then a 6% improvement in efficiency would require a 24% increase in the lean:fat ratio in gain. A 27% restriction only increased the lean:fat ratio in the gain by about 10% (Sainz, 1995). Based on these results, limit feeding programs that result in altered body composition could explain less than half of the observed improvements in feed efficiency.

Fox et al. (1972) conducted two trials to study protein and energy utilization during compensatory growth in steers. They studied effects of plane of nutrition (5 to 6 months maintenance then full-fed or continuously full-fed). In each trial, representative steers were slaughtered at the beginning of the trial, at the end of the maintenance period, and at 364 kg and 454 kg to determine body composition and protein and energy gain. Steers making compensatory gain had higher daily gains and feed efficiencies than controls during the full-feeding period despite being provided with an equal amount of metabolizable energy per unit of metabolic weight. The increased efficiency of energy and protein utilization during the full feeding period was responsible for compensatory growth. Net energy for maintenance and gain and efficiency of metabolizable energy utilization tended to be higher for compensatory steers. Compensatory steers consistently were more efficient in protein utilization than controls, particularly during the first part of the full-feeding period. Although compensatory steers required a longer time to reach 364 or 454 kg than steers full fed continuously, total metabolizable energy required to reach 454 kg was increased only slightly. Total protein intake required by compensatory steers to reach 364 or 454 kg actually 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. The results of this experiment indicate that the NEm and NEg value of a ration and the efficiency with which dietary protein is utilized is not independent of the previous nutritional treatment of the cattle. Note that in this experiment, the compensatory cattle were not provided with all the feed they would have eaten and thereby were limit fed. How much of the advantage of compensatory gain cattle observed in these experiments can be attributed to the limit feeding is not known.

Similarly Old and Garrett (1987) fed cattle of two different breeds (predominantly Hereford or Charolais) at three intake levels -- ad libitum (AL), medium (85 AL)and low (70 AL). Intakes were adjusted periodically so that steers at the two lower intakes (70 AL and 85 AL) would gain at approximately 70 and 85% of the rate of AL steers of the same breed. Crude protein levels were 8.9, 11.0 and 12.9%. All steers were slaughtered commercially and body composition was estimated from carcass density. NEm values were not different among intake groups. Steers with ad libitum access to feed produced gains higher in fat and had lower NEg values than did 70 AL or 85 AL steers. Efficiency of ME use for gain (kg) also was less for AL steers (.29) than for 85 AL (.33). Gain of the 70 AL groups was leaner than that of 85 AL and AL steers.

Black (1974) with sheep, and Fortin et al. (1981) with cattle, have shown that as ME intake increases, the proportion of energy partitioned to fat increases however findings in the literature on effects of energy intake on body composition have given various answers. Murray et al. (1974) and Jesse et al. (1976) reported that cattle fed different energy intakes were not different in composition when slaughtered at equivalent weights. In contrast, Byers and Rompala (1979), Byers (1980a) and Fortin et al. (1980) indicated that higher rates of gain produced fatter animals at similar weights. Stepwise polynomial regressions, EB fat(kg) vs average daily gain (ADG: kg, EB basis) and EB fat vs EB weight, indicated that EB fat to be highly correlated with ADG and EB weight. However, empty body fat was more highly correlated with body weight than with rate of gain when gain was altered by reducing feed intake. Multiple regressions of EB fat on ADG (EB) and EB weight indicated that much more of the variation in EB fat is explained by changes in weight rather than changes in rate of gain. The standardized coefficients were .71 and .25 (Hereford steers) and .73 and .17 (Charolais steers) for EB weight and ADG (EB), respectively (Old and Garrett, 1987).

Limit Feeding and Endocrinology Relationships

Hormonal and blood metabolite status would be expected to differ between cattle given limited vs ad libitum access to feed. The fact that hormonal and metabolite status plays a major role in animal production needs no documentation. An altered hormonal and metabolite status has been implicated as

the major factor responsible for the improvement in performance noted with growth-enhancing implants even though mechanisms are not completely understood. Nutrient flux is closely regulated by hormones to ensure that supply of energy and glucose is adequate for bodily function during times of nutritional stress and that energy is stored during times of excesses energy intake. Involvement of hormones in energy homeostasis is discussed below.

Growth Hormone: Secreted in bursts, growth hormone (GH) concentrations in blood peaks during periods when secretion is stimulated. In contrast with its name, growth hormone has a high concentration in plasma of animals on low feeding levels; this matches findings that malnourished humans have elevated plasma GH (Daughaday, 1975). Such findings have led to the suggestion that growth hormone is involved with mobilization of body energy stores. However, the main function of GH is to stimulate growth and protein accretion through increasing anabolic processes and turnover of metabolite pools of the body.

Wheaton et al. (1986) reported that plasma GH concentration exhibits frequent surges varying in amplitude but occurring at a rate of .7/hr. Fox et al. (1974) found in all but two treatment groups that steers exhibiting compensatory growth had lower plasma growth hormone levels than control steers. Thus, the relationship between rate of protein deposition and plasma growth hormone level was negative.

Insulin and glucose: Partitioning of glucose between tissues and rate of glucose utilization depend upon two factors -- plasma glucose concentration and insulin concentration. An increase in portal blood glucose levels after feeding enforces and maintains the stimulation of insulin secretion. High concentrations result in fat synthesis and deposition and maximal stimulation of muscle protein synthesis. Moderate increases of insulin and glucose concentrations provide less stimulation of glucose utilization by adipose tissue but still provide maximal stimulation of muscle protein synthesis. Whether plasma concentration of insulin and glucose is the first limiting factor for muscle protein synthesis is not known. In all species, feed uptake is associated with a sharp rise in insulin level; peak concentrations occur from 10 to 30 min after feeding. During feed uptake, insulin secretion is stimulated by parasympathetic reflexes and by gastrin released from the stomach (Fajans and Floyd, 1972). This may be a conditioned reflex. Insulin peaks even if the animal is fasted for a day (Bassett, 1974a). Investigations on the

relationship between insulin level and plasma nutrient concentrations in pigs (Siers and Trenkle, 1973; Anderson, 1974) has revealed that insulin secretion except during this 30 minute postprandial time interval is determined primarily by plasma glucose concentration. Unlike nonruminants, ruminants do not absorb large amounts of glucose after a meal. Indeed, the pancreas of ruminants, unlike that of nonruminants, responds to propionate infusion with an increased insulin output (McAtee and Trenkle, 1971). Results from studies on diurnal and nocturnal concentrations of plasma insulin and plasma sugar in cows and bulls (Hove, 1974; Blom et al., 1976) indicate that the glucose concentration in ruminants also is the main factor regulating insulin level. However, their correlations between glucose concentrations and insulin concentrations were not high enough to exclude the possibility that other factors have an independent effect on pancreatic insulin secretion. A high insulin level after feeding has a positive influence on metabolic balance in adipose tissue by depressing activity of hormone sensitive lipase. With fat synthesis continuing but fat catabolism depressed, this results in fat accretion during the postprandial period. High insulin levels post feeding, thorough increasing amino acid uptake by muscle cells, also are the main reason why rate of muscle protein synthesis is highest shortly after feeding and low in the post absorptive phase. Murphy et al. (1994) fed corn in either the whole or rolled form to steers at either low (70% of ad libitum) or high intakes (ad libitum); intake level had no effect on blood glucose and plasma concentrations of insulin followed similar patterns for steers receiving either the low or the high intake level. However, 6 h after feeding, steers receiving the higher feed intake had lower plasma insulin and its concentration remained numerically higher at all sampling periods.

Thyroid hormones also play a role in determining basal metabolic rates and capacity for protein production. Thyroxin secretion is affected by energy intake and adapts to level of nutrition. Fox et al. (1974) reported that during the compensation phase, thyroid secretion rates by steers increased to or above the level of controls as the full feeding period progressed. These changes in thyroid secretion rates suggest that less energy was required for maintenance during the period of energy restriction and the first part of the full feeding period than later; this contributed to the ability of the cattle to utilize energy and protein more efficiently when placed on full feed.

After feeding, free fatty acid concentrations drop in all animal species. The rate of tissue uptake and utilization of FFA is a linear function of the plasma level under normal physiological conditions. Therefore, plasma concentrations of FFA is dictated by the FFA output from adipose tissue cells. Because plasma FFA level during the day remain consistent related inversely to plasma insulin, it follows that insulin is the main factor responsible for controlling FFA release from adipose tissue.

Obviously, hormonal and metabolite status vary with changes in total nutrient intake as well as intake patterns (i.e., frequency and possibly rate of meal consumption) so they may be involved with responses to limit feeding programs. Most data in this area has compared hormonal and metabolite status of animals that have undergone a severe intake restriction, i.e., being held at maintenance for some time period and then re-fed. However, in a few trials cattle restricted at milder levels have been studied that would be more similar to most limit feeding programs.

During a restriction period that lasted for almost 5 months, Blum et al. (1985) reported that steers had decreased concentrations of thyroxin (T4), 3,5,3'-triiodothyronine (T3), insulin (IRI), and glucose while plasma concentrations of growth hormone (GH) and nonesterified fatty acids (NEFA) were elevated compared to steers that had not been restricted. During re-feeding, heat production and energy balances increased and nitrogen balance was transiently increased. In response to re-feeding, concentrations of T4, T3 and IRI increased within days while GH decreased. Within 2 d of re-feeding there was a drastic drop in NEFA and an increase in blood glucose. Similarly, Murphy and Loerch (1994) reported that T4 and T3 were decreased in steers that were fed 80 and 90% of ad libitum throughout the finishing trial.

Yambayamba et al. (1996) fed heifers either at ad libitum intakes or severely restricted intakes so that heifers maintained body weight for 95 days after which they were fed an amount of feed equal to that consumed by those given ad libitum access to feed at a similar body weight. Blood samples were collected from individual heifers on d 0, 20, and 48 d (during the restriction period) and 104, 125, and 195 d (during re-feeding). For the first 20 d, feed restriction did not affect GH secretion but on d 48, plasma GH concentration was greater for intake-restricted heifers than for heifers given ad libitum access to feed. Realimentation of the restricted heifers did not alter GH status immediately (d 10 of re-feeding),

but with 31 d of re-feeding, GH concentrations in previously intake-restricted heifers had fallen to a level similar to that of continuously fed heifers. On d 20 of feed restriction, mean plasma IGF-I and insulin concentrations were lower for intake-restricted than continuously fed heifers and this trend continued throughout the feed restriction period. With re-feeding, IGF-I and insulin concentrations rose faster than GH with no difference due to previous restriction by d 10 of realimentation of the experimental period. Neither total T4 nor total T3 concentration was affected by feed restriction during the first 20 d of feed restriction but by d 48, both T4 and T3 concentrations were lower for intake restricted than continuously fed heifers. By d 31 of re-feeding, the concentrations of both thyroid hormones was similar for both groups of steers. Heat production by both groups of heifers tended to increased during the study although after 90 d of feed restriction, daily heat production was lower for intake restricted than continuously fed heifers, probably due to decreased thyroid hormone concentrations at this time. Plasma glucose and NEFA concentrations were significantly and oppositely affected by feed restriction. On d 20, plasma glucose concentration was lower for intake-restricted than continuously fed heifers. After intake was increased, glucose concentration rebounded so that after only 10 d, plasma concentrations were similar for both groups of heifers. Meanwhile, plasma NEFA concentration on d 20 of feed restriction was higher for intake restricted than continuously fed heifers, presumably reflecting greater lipolysis. By d 48, NEFA concentration was even higher, but with only 10 d of realimentation, differences between treatments were no longer significant.

Hayden et al. (1993) compared energy restricted and then -realimented (RR) with nonrestricted (NR) steers. Their restriction period lasted 92 d and steers were fed isonitrogenous (13% CP) forage-based diets containing either a low (2.13 Mcal ME/kg) or adequate (2.76 Mcal ME/kg) energy level.. After the 92-d REST period, both treatment groups were realimented with a high-energy diet consisting of whole-shelled corn and corn silage (11% CP; 3.02 Mcal ME/kg;). During d -3, 31, and 59 of realimentation, catheters were inserted on the jugular veins of 12 steers (n= 6/treatment) and blood samples were collected every 30 min. from 0700 to 1600 for correlation with changes in body composition. At the end of REST, NEFA concentrations in RR animals were 23% greater than levels in NR steers. During realimentation, circulating concentrations of NEFA declined rapidly in RR steers to a

concentration comparable to that in the NR group by d 31 of energy repletion. The change in plasma

NEFA concentration during dietary alteration was correlated positively (r=.66) with the circulating

concentration of GH. In contrast to GH, IGF-I (r= -.64) and insulin (r = -.59) were negatively associated

with plasma NEFA concentration throughout realimentation. During repletion, the level of glucose rose

immediately in RR steers and was comparable to that in NR animals by d 31 through 59. Plasma T4 was

reduced by 36% in energy limited animals during REST. Similar to the results demonstrated during

REST, T4 remained lower (average 18.5%) in RR animals throughout the realimentation period.

Although T3 an dT4 were strongly correlated with dietary consumption in this study, responsiveness of T4

was more closely associated with DMI in RR steers. During realimentation, the concentration of plasma

T3 increased markedly and linearly in RR steers reaching levels similar to the NR group by d 31. T3 was

moderately correlated with empty body accretion of protein and fat (.67 and .70, respectively). Besides

T3, positive correlations between T4, rT3, and accretion of empty body protein and fat also were evident

in RR steers during realimentation.

Nutritional status can profoundly affect circulating levels of pituitary-secreted GH. Many reports

have demonstrated that concentration of GH in cattle is elevated during restricted energy intake. This

enhancement is due to an increase in GH amplitude, not in frequency of pulses of GH. Mean

concentration of plasma GH was 45% greater in energy-limited steers than normal steers (Hayden et al.,

1993). With re-feeding, GH concentrations dropped reaching levels comparable to steers never restricted

by d 31 of realimentation. Averaged across time periods of this study, GH concentration was correlated

negatively with accretion of empty body protein (r = -.70) and empty body fat (r = -.51); this is because

plasma GH concentration declined during energy repletion. In contrast to GH, plasma IGF-I

concentration was reduced by 43% by limiting energy intake. Presumably, the number of hepatic GH

receptors was decreased and this decreased production of IGF-I. Although hepatic GH receptor binding

and mRNA quantity are not affected by dietary restriction or repletion, the population of GH receptors

within liver was decreased because liver mass was reduced during intake restriction. With refeeding,

plasma concentration of IGF-I increased (from an initial value of 153 to 345 ng/mL) reaching a value

equal to that of nonrestricted steers by d 59 of realimentation. During realimentation, DMI (r=.60) and

accretion of empty body fat and empty body protein were correlated (r=.68; r=.82) with plasma IGF-I concentration. This infers that biosynthesis of IGF-I is altered by nutrient status and that sensitivity of peripheral tissue (primarily muscle) is as important as nutrient-driven biosynthesis of this hormone during realimentation. Reacting similarly to IGF-I, plasma insulin concentration increased (from an initial value of .47 to 1.79 ng/mL) with refeeding. Blum et al. (1985) demonstrated similar increases in circulating insulin concentration with energy repletion of steers. But unlike IGF-I, insulin concentration of refed steers exceeded that of steers not restricted by d 59 of realimentation. Although insulin levels tended to be greater in refed steers displaying compensatory growth, the correlations between plasma concentration of insulin and accretion of empty body protein and fat (r=.79; r=.69) were comparable to those to IGF-I during realimentation.

Obviously, hormonal and blood metabolite levels play a key role in maintaining and regulating the energy status of animals. Further, these factors may explain in part the differences observed in body composition of severely energy restricted animals and the subsequent changes during the compensatory growth phase. But the impact of hormonal under less severe restriction remains largely unknown. For animals restricted throughout the entire finishing phase, body composition differences, as discussed previously, may explain partially the observed improvements. However, whether such composition differences are the cause of or in response to changes in hormonal status is not fully understood. For cattle limited for only a portion of a feeding study, compositional effects are minor or nonexistent and no effects on hormone concentrations have been reported to date despite repeated observations of improved efficiency. One exception is that thyroid hormones may remain decreased for a period of time following intake restriction.

Moderate feed intake restriction (less than or equal to 15%) improves feed efficiency by about .6% for each 1% restriction. More severe feed intake restriction (>15%) decreases feed efficiency. The optimum degree of restriction probably falls between 12% and 15%. Multiple mechanisms may be operating to produce these effects with their relative contributions differing with the degree of restriction. For example, moderate restriction increases digestibility and ME content of the feed slightly. In addition,

a small but continuous reduction in available energy should increase the lean:fat ratio in the gain slightly which in turn improves efficiency of weight gain by reducing energy content of gain. But these mechanisms alone seem inadequate to account fully for the increased feed efficiency in intake-restricted animals. To account for the 6% improvement in efficiency observed with 10% intake restriction would require a reduction in the maintenance energy requirement by 18%! Although changes in maintenance of this magnitude are possible, it seems more likely that more modest reductions in maintenance costs, coupled with improvements in nutrient supply and reductions in energy content of gain must be responsible for the observed effects. Based on the net energy system the relationship between intake above maintenance and energy gain is linear. Because maintenance energy requirements often total half of the total net energy required, greater feed intakes should lead to better feed efficiency based simply on dilution of maintenance. Though true in theory, this statement ignores potential changes in biological efficiency and genetic limitations to protein and fat accretion. Young or light weight animals have an ability to consume much more energy above maintenance than older or heavier animals. Consequently, for maximum efficiency throughout the total feeding period while not increasing the time needed to achieve market weight, the ideal system should be to feed at a rate to optimizes the animals genetic potential to efficiently utilize energy above maintenance for productive growth throughout the feeding period. If an animal can consumes energy in excess of its genetic potential for protein deposition early in the feeding period, some degree of restriction at this time should be advantageous. Similarly, as an animal grows and its maintenance requirement increases, higher feed intakes will help dilute the maintenance requirement. An alteration in dilution of maintenance, obtained through restricting cattle early and increasing intakes latter in the feeding period, could explain the feed efficiency benefits noted by Peters (1995); Knoblich et al. (1997) and Loerch et al. (1995) without violating net energy relationships.

Management Considerations

While a wide variety of limit feeding programs can be utilized in different scenarios for achieving specific goals such as improving animal performance, better managing feed supplies, growing cattle more cost effectively, and decreasing feed costs, certain management factors need to be considered

when implementing a limit feeding program. The first question often asked is: "Cattle that are restricted in intake and go without feed for an extended periods of time often display aggressive behavior at the feed bunk. Are bunk space requirements increased by limit feeding?" This question is difficult to answer because experimentally, most cattle are fed in small pens with only 5 to 10 head per pen. Zinn (1989) in two trials with restricted intake compared 6, 12, 18, and 24 inches of bunk space/head. Intakes were restricted to allow gains of only 3.2 lb./d (trial 1) and 2.7 lb./d (trial 2). Allowing more than 6 inches of bunk space per head did not appreciably improve performance. Pens were 15.5 ft wide x 24 ft deep and each pen housed 4 head. However, with so few cattle per pen and only moderate intake restriction, it is hazardous to extrapolate these results to large pen sizes and more restricted feed intake. Keys et al. (1978) tested bunk space requirements for dairy heifers limit fed to gain 1.65 lb./d. Linear bunk space for yearling Holstein heifers was altered by altering the number of animals per pen so that 6, 12, 18, and 24 head to feed from a 16 ft bunk; this yielded 32, 16, 11, and 8 inches of bunk space/head. Diets consisted of grass legume silage and a 14% crude protein concentrate mix fed in a dry matter ratio of 2.75:1. The percentage of heifers able to feed from the bunk at one time and the average daily gain for the 32, 16, 11, and 8 inch groups were 100%, 1.8 lb.; 100%, 1.45 lb.; 67%, 1.58 lb.; and 50%, 1.03. The groups spent 4.82, 4.72, 4.30, and 3.55 hr. per day eating. Reducing bunk space to 8 inches/head reduced DMI and total eating time/day. They concluded that a bunk space/head of 11 inches is required to ensure that daily gains of yearling Holstein heifers given restricted feed intake are optimum. The question of how much bunk space is needed in the large pens found in most feedlots is not clear, but results from these trials indicate that bunk space requirements may be a function of the degree of restriction. With only slight restrictions so that ADG is greater than 2.5 lb. or cattle have access to feed for periods in excess of 8-12 hr per day, bunk space requirements may not be different from those used normally for ad libitum feeding. However, if restrictions are more severe and cattle consume all their feed within 2-4 hr., an increased bunk space may be necessary so that smaller, less aggressive animals are not crowded out.

Another management concern is: "If cattle are restricted in intake does the concentration of CP, vitamins, minerals and feed additives need to be increased to insure adequate performance?" In most

research studies, concentrations of nutrients have been increased or so high that they would be adequate even with intake restriction. In a few trials, levels of dietary CP and ionophores have been tested.

The first question addressed was response to increased dietary CP or bypass protein. In a study to determine the effects of restricting intake on protein dynamics in the rumen and flow to the small intestine Zinn and Owens (1983) fed a high concentrate diet (63% dry rolled corn with 6% dehydrated alfalfa meal and 14% cottonseed hulls) at 1.2, 1.5, 1.8 and 2.1% of BW . As level of feed intake increased flow of N, nonammonia N, microbial N and feed N to the small intestine increased linearly. Bypass of feed N increased form 44 to 71% of fed N. At the highest intake level, ruminal protein degradation and protein solubility were almost equal. At lower intake levels, feed protein degradation exceeded N use by microbes, but at the higher level of intake, microbial protein synthesis exceeded N available from protein degradation. Microbial efficiency increased as feed intake was increased to 1.8% of body weight. Apparent digestion of N in the small intestine increased with feed intake. These results suggest that restricted feeding will 1) reduce ruminal protein escape and supply of intestinally digested protein, 2) decrease the need for ruminally degraded protein, 3) decrease efficiency of microbial growth, and 4) increase ruminal fiber digestion. Both retention time and contingent characteristics of fermentation in the rumen appear to be involved in these alterations.

Similarly, Merchen et al. (1986) reported that wethers fed at high intakes had increased flow of both bacterial and nonbacterial non ammonia nitrogen. When fed low forage at a high intake level, wethers had greater quantities of bacterial N reaching the duodenum than when fed high forage at high intakes or either diet a low intakes. Duodenal flows of total, essential, nonessential and all individual amino acids were increased when wethers were fed at high intakes with either the forage or the concentrate diet. Amino acid profiles of duodenal digesta were similar, regardless of diet.

Additionally, Rahnema et al. (1987) fed 81.5% steam-processed flaked sorghum grain diet at either 95% or 75% of ad libitum. Higher intake levels increased the quantities of OM, CP, and trichloroacetic acid precipitable protein entering the small intestine and the amounts digested post-ruminally and in the total tract. However, with the higher level of intake, the percentage of bacterial protein present in the abomasum and the percent of post ruminal bacterial protein digestion were

decreased; amounts of bacterial protein and non-bacterial protein entering the small intestine and digested post-ruminally were greater in steers fed 95% ad lib. This data indicated that increasing intake of a high steam flaked sorghum diet increases amount of OM and protein presented to and absorbed in the lower gastrointestinal tract.

These data can be interpreted to suggest that restricting intake may require decrease the supply of protein delivered to the animal and, if requirements are not changed, additional amounts of either total protein or bypass protein may be needed. In support of the need for greater total protein concentration in limit fed diets Sip and Pritchard (1991) reported that cattle limit fed a high concentrate diet at a rate to gain 2.2 lb./d required 111% of the protein need predicted by NRC (1984). In support of greater need for bypass protein, Loerch (1990) reported that blood meal increased ADG gain by 11% for restricted cattle but by only 6% for ad libitum silage fed diets; supplemental blood meal had no effect during the finishing phase.

The only feed additive tested yet under limit feeding conditions has been the ionophore monensin. Based on the fact that severe intake restriction reduces the molar proportion of propionate, one might expect monensin to be more beneficial under limit feeding conditions because one of the modes of action of monensin is to increase the propionate to acetate ratio. However, responses to feeding monensin were the same for cattle that were limit feeding as those given ad libitum access to feed, increasing rate and efficiency of gain with both feeding systems (Sip and Pritchard, 1991; Daughterty and Clare, 1992; Loerch, 1990). Sip and Pritchard reported that gain increased when monensin level was increased from 120 to 180 mg/d with no further improvement from feeding 240 mg/d. Effects of various implanting schemes for limit-fed cattle has not been explored but merits study.

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CHAPTER III

THE EFFECT OF PREVIOUS ENERGY AND INTAKE LEVEL ON SUBSEQUENT FEEDLOT PERFORMANCE

W. J. Hill F. N. Owens , M. T. Van Koevering, D. R. Gill and S. D. Welty.

ABSTRACT

Twenty seven crossbred steers (708 lb.) were stratified by weight into 3 treatment groups of 9 steers each for a 130 day feeding trial. For the first 62 days of the trial, group 1 had ad libitum access to a 78% corn ration (conc), group 2 was limit fed 15 lb. of this same ration (limit), and group 3 was given ad libitum access to a 36 % corn ration (rough); for the final 68 days of the trial (period 2), all steers had ad libitum access to the concentrate diet. All cattle were individually fed once daily. On day 62, six steers (2 per treatment) were slaughtered; carcass data, body composition and organ weights were measured. Average daily gain was reduced (P<.01) by limit feeding during period 1 with no differences in ADG between CONC and ROUGH. However, during period 2 when all cattle were fed a single diet and intake level (ad libitum), ADG did not differ although LIMIT cattle tended to gain faster. Over the entire 130 days ADG were similar with LIMIT cattle tending to have the lowest and ROUGH cattle the highest . During period 1, DMI was substantially greater for rough cattle than CONC cattle. DMI was not different during period 2 indicating that previous intake or roughage level did not alter subsequent DMI. Feed efficiency (F/G) was poorer (P<.05) for rough than for LIMIT and CONC during both periods and overall on live weight basis. Compared to CONC cattle, LIMIT cattle had numerically poorer F/G during period 1 but better F/G during period 2. Differences between treatments in gut fill markedly altered data interpretation. Digestibility was higher (P<.05) for CONC and LIMIT compared to ROUGH. Carcass protein gain during period 2 was higher (P<.05) for rough and limit than conc. Limit feeding concentrate during period 1 tended to reduce protein but not fat deposition at day 62 and to reduce fat but not protein deposition between day 62 and day 130. Feeding a higher roughage diet during period 1 tended to increase both fat and protein on day 62 and to increase protein on day 130. Although daily variation in DMI was imposed and thereby reduced by limit feeding, variation increased equal to non-restricted cattle

during the subsequent ad libitum feeding period. variation increased equal to non-restricted cattle during the subsequent ad libitum feeding period.

(Key words: body composition, organ weights, intake level, feedlot, steers)

Introduction

Three prevalent systems used by the feedlot industry to grow and finish cattle are (1) full feeding a high energy diet from start to finish, (2) full feeding a low energy (roughage based) diet followed by full feeding a high energy diet, and (3) limit feeding a high energy diet followed by full feeding a similar high energy diet. Previous diet and intake level may impact finishing performance, carcass characteristics, body composition, and production economics. Many producers and feedlot managers believe that a grazing period is necessary for cattle in order to "stretch the gut" so that subsequent feed intake and feedlot performance will be greater. The NRC (1984) predicts that the relationship between feed intake above maintenance and energy retention is linear; consequently, feed efficiency should increase as feed intake increases. However, feedlot pen records indicate that feed efficiency typically does not increase with feed intake even though ADG is increased. This means that high feed intake may not reduce cost of gain (Gill et al., 1986). Additionally Meissner et al. (1995) indicated that the fastest gaining and most efficient cattle were not necessarily those with the highest feed intakes. The objectives of the current trial were to determine how levels of intake and diet type fed during a 62 day growing phase affected performance during the growing and finishing phases of production.

Materials and Methods

diets and animals: twenty-seven crossbred yearling steers (708 lb.) were stratified by weight into three treatment groups (nine weight replications per treatment). The 130 day feeding trial consisted of 62 days (period 1) during which intake or diet composition was altered followed by 68 days (period 2) during which steers had ad libitum access to a high concentrate finishing diet. The first group or control cattle (CONC) was given ad libitum access to the finishing diet (Table 7) for the entire 130 d. Each steer in the second group (LIMIT) received 15 lb. of the CONC diet each day for 62 days followed by 68 days during

which they had ad libitum access to the same diet. Steers in the third group (ROUGH) were given ad libitum access to a diet containing much more alfalfa hay pellets and cottonseed hulls (Table 7) for 62 days followed by 68 days during which they had ad libitum access to the high concentrate diet. Nutrient content of the concentrate diet was in excess of requirements so that LIMIT cattle would have adequate daily protein intakes and avoid altering diet composition. Although the trial was designed so that rate of gain should be similar for LIMIT and ROUGH cattle, intakes by ROUGH cattle were higher than expected so that their ADG was nearly equal to that of CONC cattle.

Each steer, housed individually in a pen with slatted cement floor and covered fence line bunk, was fed once daily at 0800. Prior to the initiation of the trial, each steer received routine vaccinations (blackleg, IBR, BRSV, BVD, PI3), was dewormed (Ivomec), and was implanted with Revalor (Hoechst-Roussel Agri-Vet, Somerville, NJ). Prior to the initiation of feeding all cattle were grazed together on native range pastures.

Measurements and calculations: Initial weight was the average weight on two consecutive days. On day 62 (end of period 1) six steers (2 steers per treatment) were slaughtered; these were the heaviest and lightest weight replication of each treatment. Carcass traits and organ weights were measured and body composition was estimated by specific gravity. Organ weights were taken as they were removed. Rumen and large intestine were weighed full; they were emptied, rinsed, excess water was removed and reweighed. Fill was determined by difference. No attempt was made to empty the small intestine; hence only full weights are available. Ruminal fluid was collected from these six steers for VFA analysis. Ruminal samples were strained through 4 layers of cheese cloth and a 5 mL aliquot was mixed with 250 mg of metaphosphoric acid (Erwin et al., 1961) in preparation for VFA analysis. Volatile fatty acids were analyzed gas chromatographically (Harmon et al., 1985). The remaining 21 steers were slaughtered on day 130 with carcass traits and body composition being determined. Organ weights were not determined but carcass weights and composition were estimated. All weighing and slaughter occurred early in the morning with no shrink imposed and thereby reflect full weights and dressing percentages for unshrunk cattle.

Body composition was determined by specific gravity (Garrett and Hinman, 1969). Specific gravity measures were taken after approximately 48 hr of chilling at 2° C. Compositional measures were determined on one half the carcass only, with appropriate adjustments for measured water temperature (average =4°).

Carcass weights of remaining cattle on day 62 were calculated from measurements on slaughtered cattle; dressing percent on day 62 were 56.7%, 58.4%, and 60.4% for CONC, ROUGH and LIMIT, respectively. These values were multiplied by individual unshrunk live weights to estimate carcass weights of the remaining steers in each respective treatment. Weights of fat, water and protein in the carcass of remaining steers on day 62 were estimated in a similar fashion. Adjusted 62 day live weight was calculated by dividing individual calculated carcass weight by a constant (58%) dressing percentage to avoid weight bias associated with differences in gastrointestinal tract fill.

Period one gains and efficiencies were calculated by two different methods: 1) unshrunk live weight, and 2) carcass-adjusted weight. Period two gains and efficiencies were calculated by four different methods. These included 1) unshrunk live weights 2) carcass adjusted day 62 and carcass adjusted final weight based on a common dressing percentage of 64%, 3) unshrunk final but carcass adjusted day 62 weight, and 4) carcass adjusted final and unshrunk live day 62 weights. Total trial gains were calculated based, both on either unshrunk weights or with final live weight adjusted to a common (64%) dressing percentage.

All cattle were slaughtered at the Oklahoma State Abattoir with carcass measurements were taken after a 48 hr chill. Carcass measures included: 1) longissimus muscle area, measured by direct grid reading of the longissimus muscle at the 12th rib; 2) subcutaneous fat over the longissimus muscle at the 12th rib, taken at a location 3/4 the lateral length from the chine bone end; 3) kidney, pelvic, and heart fat (KPH) as a percentage of carcass weight, and 4) marbling score (USDA, 1965), the latter two being appraised visually by trained meat scientists.

Fecal samples were obtained at the end of period 1 twice daily for 3 consecutive days. The time of collection was altered by 4 hr each day so the composite sample should represent a 24 hr composite. Chromic oxide, fed for 7 days prior to and throughout this collection period, was delivered in a pellet

(10% chromic oxide, 90% cottonseed hulls) added to the feed to supply 10 grams of chromic oxide per head daily. Composited fecal samples were dried (100 °C), ground through a 2 mm screen, and analyzed for ash and chromium (Hill and Anderson, 1958).

Variation in intake from day to day was determined by calculating the standard deviation across days for each animal within each period; this value was analyzed a response variable similar to other performance data. Additionally, standard deviations in intake across all animals within a treatment were calculated for period one; these are displayed graphically. No statistical comparisons were conducted on this measurement. Similar graphs for period 2 revealed no visual differences between treatments.

All data were analyzed as a randomized complete block design by the general linear models procedures of SAS (1988).

Results and Discussion

Animal performance: Performance results are summarized in Table 8. During period 1, live weight ADG was least (P<.01) for limit fed steers. This decreased gain compared to CONC would be expected because less of the same diet was being fed. We had hoped that LIMIT and ROUGH cattle would have had similar ADG, but because 31% of the ROUGH diet was cottonseed hulls, a feed with a very fast passage rate despite of its high fiber content and low digestibility, the ROUGH cattle consumed enough extra net energy to support substantially greater gain. Although there was no statistical difference in ADG between CONC and ROUGH steers, ROUGH cattle had numerically greater gains due to greater (P<.05) intakes despite the lower energy density of the higher roughage ration. Utilizing the NRC (1984) equations for large frame compensating medium frame steers, ration energy values and actual feed intakes, predicted gains were very close to observed live weight gains. NRC predicted ROUGH cattle should gain 4.44 vs the observed 4.56, probably due to greater gastrointestinal tract fill. The predicted ADG by CONC steers was .03 lb. greater than measured live weight gain. This agreement is not surprising because the animal and ration were of the type used to develop the net energy equations. However, NRC (1984) equations underpredicted ADG of LIMIT cattle by .1 lb. for reasons that are not clear. Similar under prediction of gain by cattle limit fed high concentrate diets have been reported by others (Lusby et al., 1990; Loerch et

al., 1995, Knoblich et al., 1997); this may reflect the greater efficiency of net energy use by cattle that are limit fed.

Although limit fed cattle gained slower during period 1, carcass weight at this time was not significantly different from ADLIB cattle; LIMIT cattle had slightly heavier carcasses than CONC cattle and ROUGH cattle having carcass weights (Table 10.) about 60 lb. heavier than either group fed concentrate. Limit feeding reduced total weight of dressed items by 55 lb. less dress off items (Table 9) with significantly less head and hide weight. This resulted in a 3.4% and 6.5 % greater dressing percentage for LIMIT than ROUGH and CONC cattle, respectively. The gastrointestinal tract and its contents accounted for 55% of the dressed items with remainder being hide, head, feet, blood, and internal organs all of which ,with the exception of feet, were numerically lowest for LIMIT cattle. This decrease in weight of gastrointestinal tract (by 38%) and liver (by 18%) may partially explain the greater than expected ADG and improved efficiencies of LIMIT during period 2 to be discussed later. As proportional size of the liver increases, maintenance energy expenditures increase (Ferrell et al., 1986). Rust et al. (1986) also noted that liver weight was less for cattle fed 70% of ad libitum than for cattle given ad libitum access to feed. Their level of restriction is very similar to ours (72% of ad libitum). When adjusted for this difference in dressing percentage, ADG of LIMIT steers was not significantly different from CONC steers, but both were less (P<.05) than for ROUGH steers.

Feed intakes (DM) for all treatments were surprisingly similar during period 2 (Table 8) indicating that the previous intake level did not affect the subsequent feed intake level. Similarly, Goldy et al. (1988) reported that cattle previously limit fed a high concentrate ration vs ad libitum consumption of either silage or silage plus 25% grain did not differ in DMI during the subsequent finishing period. These results would suggest that the concept that cattle should consume forage to "stretch their gut" to achieve high DMI in the feedlot is not necessarily valid. However, in contrast to these results Gill et al. (1991) reported that cattle which grazed native range for longer periods of time had higher DMI during the feedlot phase than cattle grazing the same pastures, but for a shorter time. However, these results might likely be attributed to a greater age and leaner body composition for backgrounded cattle than calves placed in the feedlot at weaning time rather than specific effects of roughage intake. In several studies,

calves have been reported to have lower feedlot DMI than yearling cattle (Lunt et al., 1986; Sindt et al., 1991; Hickok et al., 1992; Hill et al., 1995).

Day to day variation in DMI was substantially reduced by limit feeding during period 1. Increased day to day and within day intake variation (Figure 1). However, this day-to-day variation did not continue into period 2; instead, variation was similar among all treatments (Figure 2.). High day to day variation in DMI of high concentrate diets might cause subclinical acidosis or be a result of subclinical acidosis (Stock et al., 1995). Intermittent acidosis probably is not responsible for the high variation in DMI of ROUGH cattle because that diet contained only 36% dry rolled corn grain.

Gains and efficiencies during period 2 were highly dependent on the method of calculation (i.e., live weights or carcass-adjusted live weights). Though none of the treatments differed in ADG during the second period, some numeric differences were substantial, presumably due to differences in fill of the gastrointestinal tract. First, when calculated using live weight (unshrunk) at 62 days, ADG tended to be greatest during period 1 for LIMIT cattle. However, when gain is calculated using carcass-adjusted 62 day weights, ADG tended to be greatest for CONC cattle. Similar to gain results, relative feed efficiencies depended on calculation method but, in this case an additional factor (DMI) enters the equation. When based on live weights at 62 days, efficiencies tended to be the best for LIMIT cattle. One might conclude that LIMIT cattle were making compensatory gain. However, using carcass-adjusted 62 day weights, CONC cattle were more efficient.

Feed efficiency for the total trial on a full live weight basis was worse (P<.05) for ROUGH cattle due to poorer efficiency when the high roughage diet was fed. Numerically, results were similar based on carcass-adjusted final weight but differences were not significant. This is due to substantially larger variation in feed efficiency associated with adjusted weights, only a portion of which is due to differences in animal weights but is magnified by differences between LIMIT cattle in DMI.

Differences in results with calculation method can lead to misleading interpretations. Based on full live weights, limit had adverse effects on both gain and efficiency during the first period that was more than overcome when these cattle were given ad libitum access to feed. Similar effects on feed efficiency have been reported widely (Lofgreen et al., 1987; Loerch et al., 1995, Wagner, 1988; Peters,

1995) However, when the trend for a higher dressing percentage of limit-fed cattle was considered, ADG was not depressed as markedly by limit feeding and feed efficiency during both periods tended to be improved by limit feeding. Goodrich and Meiske (1971) discussed in detail the effects that differing diets and digestive tract fill can have on interpretation of data. Results from this trial would support those of Goodrich and Meiske (1971) and reiterate the need for careful interpretation of growth traits where cattle are fed different diets or different amounts of feed.

Over the entire trial unadjusted ADG was not affected by feeding system, but tended to favor the ad libitum fed groups. Adjusted ADG was not different within the ad libitum fed groups but both were superior to the limit fed cattle. Averaged over both periods intakes were greatest for ROUGH lowest for LIMIT and intermediate for CONC. On a full weight or unadjusted basis limit feeding improved feed efficiency 4.7 and 23.6 % over CONC and ROUGH, respectively. However, on a carcass adjusted basis there was no difference in efficiency between LIMIT and CONC steers, but both were 20% superior to ROUGH. The fact high concentrate diets produce better feed efficiencies that high roughage rations can be ascribed to increased energy digestibility and a greater proportion of VFA being propionate with high concentrate rations. In this trial, DM digestibility of the high concentrate diets were 81% as compared to 73% (Table 8) for the high roughage diet while molar percentages of acetate and propionate at the end of period 1 were 30 and 57 compared to 69 and 36, respectively, for concentrate versus roughage fed cattle, respectively (Table 12). Table 12 presents volatile fatty acid proportions and performance data only for cattle slaughtered at the end of period 1 even though their performance closely mirrored performance of all cattle.

Carcass characteristics and body composition. Only a few carcass parameters differed at the end of period one (Table 10); numerical trends are of interest because these values are based on only 2 steers per treatment. Carcass backfat tended to mirror ADG with LIMIT cattle having slightly less backfat than CONC (.18 vs .20 in), both tending to be less than for ROUGH cattle (.30 in). Ribeye area followed a similar pattern with both being proportional to carcass weight and presumably dependent on growth rate. However, carcass composition determined by specific gravity and expressed on a percentage basis yielded slightly different results. The LIMIT and ROUGH cattle had approximately 1% more fat than CONC

cattle. Although this increase is slight, when multiplied by carcass weight this yielded more (P<.01) pounds of fat for ROUGH and LIMIT than CONC cattle. ROUGH cattle also had more (P<.05) pounds of protein and water due to heavier carcasses than CONC or LIMIT. The ROUGH cattle also had higher (P<.05) marbling scores than CONC or LIMIT. Whether or not this increase in marbling was due simply to a faster growth rates or an increased molar proportions of ruminal acetate to serve as a substrate for intramuscular fat deposition is unclear.

By the end of the trial LIMIT and ROUGH cattle both tended to be leaner than CONC cattle (Table 11). Both CONC and ROUGH cattle tended to have greater rates of carcass gain than LIMIT cattle during period 2. Rate of fat gain during period 2 tended to be greater for CONC than ROUGH or LIMIT cattle whereas rates of protein and water gain were greater for ROUGH and LIMIT than CONC. In essence, LIMIT cattle tended to compensate in protein and water gain when they were given ad libitum access to a high concentrate ration while ROUGH cattle tended to accrete more lean. Nevertheless, the majority of the tissue gained by all cattle during the second period was fat. Backfat measurements support contention that carcass fat was greater for CONC than LIMIT or ROUGH. These data support other observations where greater growth rates or heavier carcass weights are associated with greater fat deposition as was the case for ROUGH cattle (Byers, 1980; Guenther et al., 1965). In contrast, the fact that LIMIT cattle were slightly fatter after restricted feeding (period 1) and then slightly leaner after ad libitum feeding does not support the current dogma. Although it might not be surprising to find that all cattle had similar fatness at the end of the restricted feeding period as CONC cattle because carcass weights were similar, it is surprising that during the subsequent feeding period that the ratio of lean to fat being deposited was greater for CONC steers. There is no literature data on body composition of limit fed cattle slaughtered at similar end points to compare to these findings. The standard dogma is that faster rates of gain are associated with more fat deposition. However, with limit feeding, an altered hormonal or metabolic status could redirect nutrient flow. Limit fed cattle rapidly became meal eaters, consistently consuming their entire day's feed within 2 hr; CONC cattle had an irregular intake pattern. However, when LIMIT cattle were allowed ad libitum access to the same diet, they developed an intake pattern similar to the CONC cattle as shown in Figure 1. These values are averages across all steers on a

treatment, which tends to smooth the lines. Daily intake patterns of individual CONC and ROUGH cattle exhibited very large day to day variation whereas daily DMI for LIMIT cattle was small because a limit was imposed.

Carcass weight was lighter (P<.06) for LIMIT cattle indicating that restriction was too severe to be compensated by days available in period 2. Although carcass weight was less for LIMIT cattle, ribeye area was not different among any of the treatments supporting the concept that these steers had greater rates of accretion of lean during period two. Leaner, lighter carcasses of LIMIT steers coupled with equal ribeye areas resulted in lower numerical yield grades. Although LIMIT and ROUGH fed cattle tended to have less external fat, marbling scores for all treatments were roughly equal.

Implications

Intake by roughage-fed cattle can be high when a forage like cottonseed hulls, that has a very fast passage rate, is fed. This permitted cattle fed a roughage diet to consume more energy and gain live weight faster than cattle fed concentrate diets despite substantially poorer feed efficiency. However, when subsequently fed a high concentrate diet, cattle started on roughage had no greater DMI than cattle limit fed a high concentrate diet. By limiting the amount of a high concentrate ration for several months prior ad libitum feeding, feed efficiency was improved on a live weight basis but not on a carcass weight-adjusted basis. Gains by limit-fed cattle exceeded those predicted by net energy equations. Because of their higher dressing percentage, relative live weight gains may underestimate tissue gains by limit fed cattle. The exact level and length of restriction to optimize feed efficiency without sacrificing carcass weight and grade when cattle subsequently are given ad libitum access to feed remains to be determined. Energetic benefits from limit feeding may be associated with lower mass of internal organs, i.e., liver, more regular eating patterns and less acidosis, and altered metabolite or hormonal status leading to greater fat accretion early in growth followed by a greater rate of lean deposition later. Limit feeding may alter growth patterns of carcass versus non-carcass tissue and body composition independent of actual overall growth rate.

Table 7. Diet ingredients and nutrient composition (DM).

	Concentrate	Roughage
Ingredient, %		
Corn, dry rolled	78.15	35.89
Alfalfa hay, pelleted	4.00	19.40
Cottonseed hulls	4.00	31.04
Cane molasses	3.41	3.39
Soybean meal	8.44	8.39
limestone	.94	.93
Salt	.33	.33
Rumensin 60	.0256	.0254
Tylan 40 .	.0128	.0127
Vitamin A-30,000	.0113	.0112
Manganous Oxide	.0034	.0034
Urea	.56	.56
Nutrient composition:		
NEm, Mcal/cwt.	94.79	73.04
NEg, Mcal/cwt.	60.78	40.30
Crude protein, %	14.06	14.15
K, %	.77	1.14
Ca, %	.51	.84
P, %	.31	.26

Table 8.   Effect of feeding program on cattle performance and the subsequent feedlot performance.

Item	CONC	ROUGH	LIMIT	SEM	P<
Weights, lb.					
Initial	706	718	708	4.33	.14
final live	1196	1232	1155	27.22	.33
final adjusted[e]	1147	1184	1089	28.79	.13
Average daily gains, lb./d					
Predicted, period 1 (NRC 1984)	4.06	4.44	2.89		
period 1, live (actual)	4.03[a]	4.56[a]	2.78[b]	.24	.01
period 1, carcass adjusted	3.69[a]	4.66[b]	3.37[a]	.24	.01
period 2, live	3.48	3.61	4.16	.29	.27
period 2, adjusted[x]	3.06	2.82	2.63	.33	.62
period 2, adjusted[y]	3.79	3.52	3.63	.29	.82
period 2, adjusted[z]	2.75	2.91	3.16	.31	.64
overall, live	3.79	3.99	3.47	.20	.44
overall, adjusted[e]	3.41	3.62	2.95	.22	.14
Feed intakes					
period 1	18.9[a]	29.1[c]	14.9[b]	.72	.01
period 2	24.4	24.7	23 1	.26	.62
overall	21.9[a]	26.0[c]	19.1[b]	.88	.01
Efficiencies					
period 1, live	4.84[a]	6.40[b]	5.44[a]	.23	.01
period 1, adjusted	5.34[a]	6.26[c]	4.47[b]	.24	.01
period 2, live	7.13[a]	6.99[a]	5.64[b]	.42	.05
period 2, adjusted[x]	8.44	8.97	9.39	.86	.74
period 2, adjusted[y]	6.51	7.19	6.53	.53	.53
period 2, adjusted[z]	9.61	8.69	7.59	.87	.30
overall, live	5.81a	6.57b	5.55a	.14	.01
overall,adjusted,[e]	6.38	7.33	6.51	.39	.19
digestibility	81.8[a]	73.3[b]	81.0[a]	1.07	.01

a,b,c   means with different superscripts differ (P<.05).
e   calculated based on carcass weight divided by a common dressing percent.
x   calculated based on adjusted final and adjusted day 62 weight.
y   calculated based on live final and adjusted day 62 weight.
z   calculated based on adjusted final and live day 62 weight.

Table 9. Dress off item weights of cattle slaughtered at the end of period one (n=6).

ITEM	CONC	ROUGH	LIMIT	SEM	P<
Dress off weights, lb.					
Blood	28.4	31.85	26.65	1.52	.24
feet	19.5	16.5	17.9	1.47	.50
head	31.8a	31.5a	28.5b	.13	.01
hide	76a	81b	66c	.65	.01
liver	15.8	15.7	11.4	.31	.68
pluck	15.9	13.6	13	1.92	.61
heart	4.0	3.8	3.7	.24	.68
tail	2.8	2.8	2.8	.19	.95
kidney	2.3	2.3	1.8	.18	.27
spleen	2.0	2.0	1.8	.18	.68
G.I. tract weights, lb.					
rumen, full	142	140	120	3.72	.08
rumen, empty	31.4	34.7	27.9	1.58	.18
rumen, fill	111	105	92 5	.28	.23
Small intestine	33.7	32.7	26.5	4.37	.56
large intestine full	15.6	25.9	19.7	2.16	.14
large intestine empty	9.4	16.3	10.7	2.07	.24
large intestine fill	6.1	9.5	8.0	1.53	.45
total tract full	191	199	165	5.94	.10
mesenteric fat	12.8	12.1	10.2	2.24	.74
Dressing percent	56.7	58.4	60.4	1.01	.24

[a,b,c] means with different superscripts differ (P<.05).

Table 10. Body composition and carcass traits of cattle slaughtered at the end of period one (n=6).

ITEM	CONC	ROUGH	LIMIT	SEM	P<
Carcass composition, %					
% fat	16.3	17.5	17.7	1.31	.74
% water	61.4	60.4	60.3	.99	.74
% protein	18.6	18.3	18.3	.26	.74
Energy	2.53	2.64	2.66	.11	.26
Carcass composition, lb.					
Protein	100^a	113^b	101^a	1.58	.05
Fat	89^a	108^b	98^c	.80	.01
Water	330^a	371^b	333^a	5.22	.05
Carcass traits					
carcass weight, lb	531	601	541	17.1	.17
backfat, in	.20	.30	.18	.04	.29
ribeye area, in^2	9.75	11.0	8.7	1.30	.56
KPH, %	1.5	1.6	1.9	.40	.82
Yield grade	2.5	2.5	2.8	.49	.89
Maturity	A30	A32	A25	4.33	.56
Marblingf	290^a	380^b	310^a	11.54	.05

[a,b,c] means with different superscripts differ (P<.05).
[f] small degree of marbling = 400.

Table 11. Body composition and carcass traits for cattle at the end of the trial (n=21).

Item	CONC	ROUGH	LIMIT	SEM	P<
Carcass composition, %					
Fat	30.3	28.18	27.9	1.14	.32
Water	50.7	52.3	52.5	.87	.34
Protein	15.8	16.2	16.2	.23	.36
Carcass composition, lb.					
Protein	115.6[a]	122.8[b]	113.2[a]	2.38	.05
water	371.3[a]	396.7[b]	366.3[a]	7.7	.05
fat	223.9	213.4	194.4	12.52	.29
Gains, lb./d					
Carcass	2.78	2.68	2.48	.20	.56
Fat	1.98	1.65	1.48	.18	.14
Water	.53	.71	.70	.13	.62
Protein	.20	.26	.24	.04	.74
Carcass traits					
Carcass wt, lb.	734	758	697	18.4	.13
Backfat, in	.52	.43	.37	.06	.27
Ribeye area, in^2	11.98	11.94	11.97	.34	.99
KPH, %	1.64	1.68	1.61	.09	.85
Marbling[f]	368	384	370	17.0	.80
Yield grade	3.10	3.1	2.60	.20	.20
Dressing percent	61.4	61.6	60.4	.69	.25

[a,b,c] means with different superscripts differ (P<.05).

[f] small degree of marbling = 400.

Table 12. Performance data for slaughtered steers ONLY at the end of period one (n=6).

ITEM	CONC	ROUGH	LIMIT	SEM	P<
Animal weights, lb.					
Initial	717	732	728	3.75	.18
adjusted live[e]	949[a]	1054[b]	913[a]	15.4	.04
unshrunk live	934[a]	1031[b]	897[a]	15.8	.04
carcass	531	601	541	17.1	.17
calculated[f]	946	1033	901	23.21	.11
error[g]	-11.65	-1.6	-3.95	10.05	.79
dressing percent	56.7	58.4	60.4	1.01	.24
Performance data					
ADG, lb./d	3.74[a]	5.19[b]	2.98[a]	.30	.07
ADG, lb./d, adjusted[z]	3.21	4.92	3.28	.48	.20
Feed intake, lb.	18[a]	31.5[b]	15[a]	1.04	.01
Feed:Gain	4.8	6.11	5.04	.31	.16
Feed:Gain, adjusted[z]	5.7	6.4	4.6	.50	.23
Volatile fatty acids					
acetate, mM	33.2[a]	69[b]	28.5[a]	3.48	.01
propionate, mM	55.1	35.6	58	6.85	.18
butyrate, mM	6.7[a]	21.4[b]	10.0[a]	2.99	.05
acetate/propionate	.60[a]	1.94[b]	.49[a]	.21	.02
total, mM	95	126	96.5	11.0	.23
acetate %	34.9[a]	54.7[b]	29.5[a]	2.25	.01
propionate, %	58[a]	28.3[b]	60.1[a]	2.70	.01
butyrate, %	7.1	17	10.4	2.85	.17

[a,b,c] means with different superscripts differ (P<.05).

[e] carcass weight divided by a common dressing percent.

[f] sum of all dress off items at time of slaughter.

[g] difference between actual live weight at slaughter and calculated weight.

[z] calculated using the adjusted live weight.

Figure 1. Daily Intake by Treatment and Standard Deviations for Period 1.
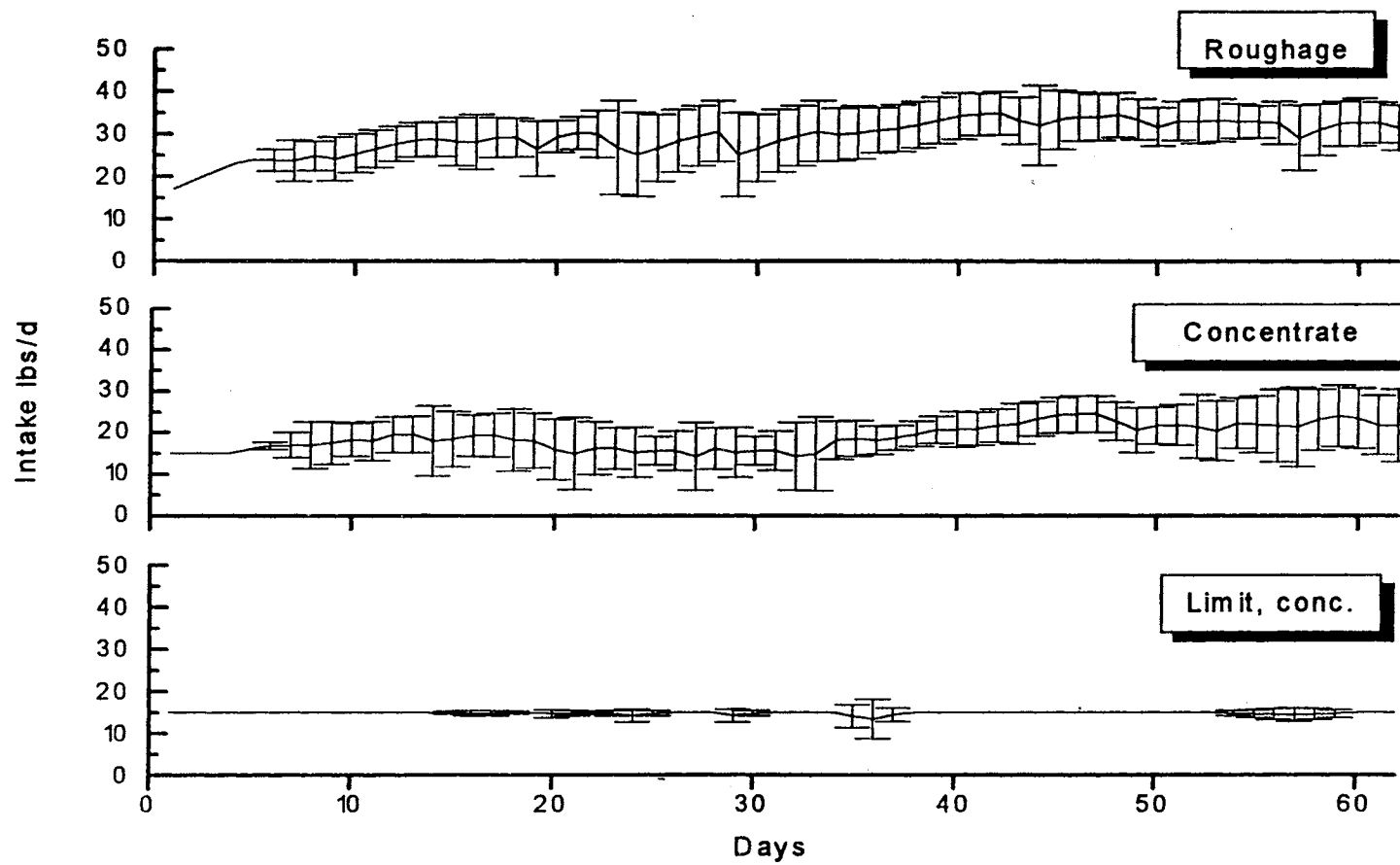
Figure 2. Intakes and standard deviations averaged across days by Period for Each Treatment.
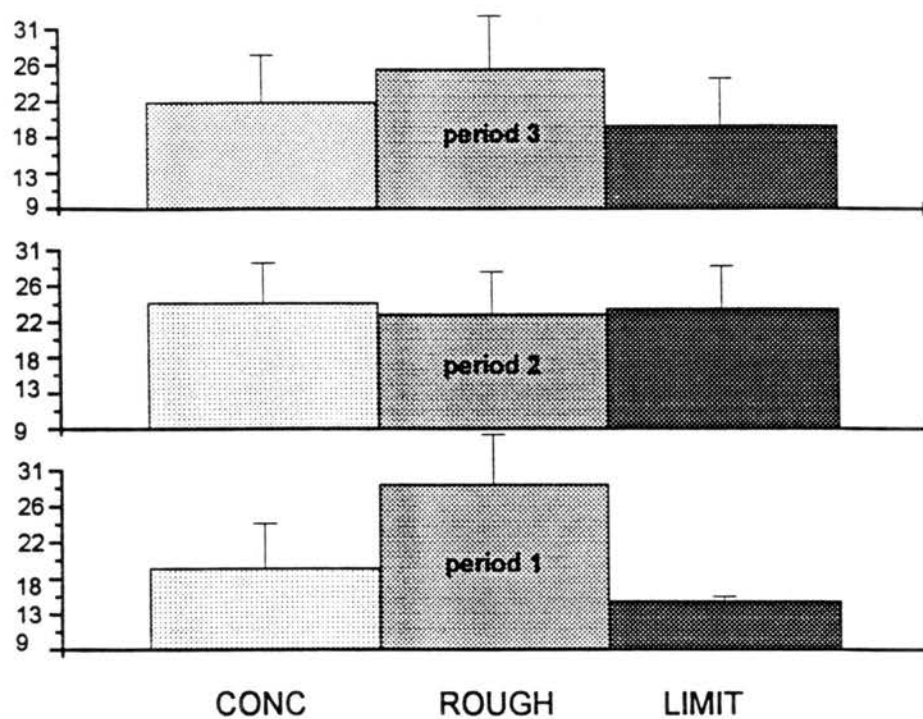
Standard deviations for CONC and ROUGH are different (P<.05) than LIMIT during period 1.

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CHAPTER IV

EFFECTS OF LIMIT FEEDING AND CORN PROCESSING ON FEEDLOT PERFORMANCE AND CARCASS CHARACTERISTICS .

W. J. Hill , D. S. Secrist, F. N. Owens , and D. R. Gill

ABSTRACT

Brangus x English crossbred, fall born steers (n=144; initial BW = 541 lb.) from a single ranch entering the feedlot at three different times were fed diets consisting of corn (either whole, rolled coarse, or rolled fine) and were limit fed or given either ad libitum access to their fed until they had gained 300 lb. (period 1) after which all steers were given ad libitum access to feed (period 2). Cattle were fed to an average backfat of 1.3 cm and slaughtered by entry date. The corn form by feeding management interaction was not significant. Daily DMI during period 2 (18.7 lb.) was not different (P=.88) but due to intake restriction during period 1, total trial DMI was less (P=.02) for limit fed cattle (16.9 vs 18.3 lb.). Limit feeding reduced (P=.01) ADG (2.90 vs 3.52 lb.) during ADG tended to be slightly higher (P=.07) during period 2 (3.10 vs 2.82 lb.) leading to a tendency for reduced (P<.09) ADG for the total trial (3.04 vs 3.2 lb.) for limit fed steers. Although feed/gain was not different (P=.74) during period 1 (4.83 vs 4.75), feed/gain during period 2 was 12.4% superior (P<.02) for cattle that previously had been limit (6.13 vs 7.00) which led to a trend (P= .13) for an improved feed:gain for the total trial (5.32 vs 5.62) based on live weights. This advantage was reduced when gain was expressed on a carcass adjusted (63.5% dress) basis (5.46 vs 5.64; P=.32) due to a numerically (P=.20) lower dressing percentage for cattle previously limit fed (62.8 vs 63.4%). Although carcass weight was decreased (P=.05) by limit feeding (699 vs 720 lb.) reflecting lower ADG, no other carcass characteristics were affected by limit feeding. Efficiency improvements (live basis) from limit feeding were 6.6%, 4.7% and 5.3% for July, September and November start dates, respectively. Restricting intake by 15% for the first 300 lb. of gain in the feedlot improved feed efficiency by 3.2% (carcass weight basis) and 5.3% (live weight basis).
(Key words: Limit Feeding, Steers, Feedlot)

Introduction

The feedlot industry competes with other meat producing industries for food grains. To be successful, the beef industry must find new methods to increase efficiency of production. Improved grain processing methods, feed additives and implants have helped to improve performance and efficiency and, thereby, profitability of beef production. Additional benefits appear possible through improved feeding management via manipulating dry matter intake at specific times of a feedlot finishing period (Peters, 1995; Knoblich et al., 1997). Maximum dry matter intake every day that cattle are fed may not yield maximum economic return. Controlled feed intake programs offer a simple, no cost method to improve feedlot efficiency. Unfortunately, little information is available on interactions between intake manipulation and other factors such as grain processing, protein levels, ionophore level and implanting strategy. The objectives of this trial was to evaluate how corn processing method and cattle age or background altered the benefit of limit feeding cattle.

Materials and Methods

Animals and diets Predominately black, Brangus X English crossbred, fall born steers (n=144) were received in either July, September and November of 1994 at the feedlot facilities at Stillwater, OK. All calves all originated from the same ranch in northeastern Oklahoma. At weaning (June 1994) the calves were stratified by weight and assigned randomly into blocks of equal weight and either: 1)went directly to the feedlot, 2) grazed native range until being placed in the feedlot in September or 3) grazed native range until being placed in the feedlot in November. Cattle were placed on feed at different times to meet market timing objectives of the cattle owner. For purposes of this trial, starting time was considered to be a block with each treatment imposed within each block.

Upon arrival at the feedlot, steers in each block (n = 48) were weighed, vaccinated with modified live virus 4-way respiratory and 7-way clostridial vaccines. After weighing, steers were stratified by weight and allotted randomly to treatment and pen ensuring an equal weight distribution in pens within each block. The treatments were arranged in a 3 X 2 factorial with date entering the feedlot serving as the block. Three corn processing treatments (finely rolled, coarsely rolled or whole corn) were used with

supply of feed for the first half of the feeding period being unlimited (ADLIB) or limited to 83% (LIM) of

that consumed by the ADLIB steers. For the last half of the feeding period, all steers had unlimited access

to feed. The diets differed only in the extent of corn processing.

The steers were housed (8 head/pen) in 18 outside pens (6 pens/block and 3 pens/treatment

combination) with slatted floors and covered cement fence line feedbunks. Cattle had 37 cm of linear

bunk space per head. Table 13 contains relevant days on feed and implant information. All calves were

implanted twice, initially with Synovex-S® and later with Revalor-S®. The second implant was given on

a date calculated from the expected marketing date which turned out to be 77 to 93 days prior to slaughter.

All cattle were wormed with a feed-borne anthelmintic (Safeguard®) after feed intakes had stabilized.

Isocaloric and isonitrogenous diets based on dry corn (Table 14) were fed once each day at 1600.

Individual basal ingredients (corn, cottonseed hulls and protein supplement) were assayed for dry matter,

crude protein and starch content. Corn was rolled with a stacked roller system equipped with two pair of

rollers provided by Automatic Feed Mfg. Co., Pender, NE. Corn samples were taken weekly; geometric

mean diameter was determined at a commercial laboratory as calculated by the method of Ensor et al.

(1970). Geometric mean particle size averaged 1,550 μm for the finely rolled corn, 3,100 μm for the

coarsely rolled corn, and 5,700 μm for the unground (whole) corn grain.

Quantity of feed provided to pens of cattle that were limit fed was equal to 90% of the previous two

week mean DMI of the corresponding ADLIB pens within each block. Because of the time lag between

ADLIB and LIM cattle, limit fed pens received an average of 83% of the intake of ADLIB fed pens until

steers had gained approximately 300 lb (period 1) This was approximately half of the total feeding

period. During the second half of the trial (Period 2), all cattle had unlimited access to their diet.

Fecal samples, collected from steers from each pen at each weighing (monthly), were dried at 100°C

for 48 h, ground through a 2 mm screen, and analyzed for starch, crude protein (AOAC, 1990), and total

purines (Zinn and Owens, 1986). Starch was measured as alpha-linked glucose (MacRae and Armsrong,

1968) modified by the use of a blood glucose kit (sigma Chemical, St. Louis, MO).

Steers were weighed following transport to the feedlot (5 hours) and at 28 d intervals thereafter. The

carcass-adjusted final weight was calculated by dividing hot carcass weight by 63.5%, the mean dressing

percentage for all cattle. A 4% pencil-shrink was applied to all live weights (except initial) for calculating ADG. ADG during period 1 was calculated as the slope of the regression line through the corresponding interim weights. Period 2 ADG was calculated in the same manner using interim weights and the carcass-adjusted final weight. ADG over the entire trial was calculated from arrival weight (d 0) and carcass-adjusted final weight. Metabolizable and net energy values of the diet were calculated using ADG, DMI and mean animal weights by the equations of Hays et al. (1986).

All animals were slaughtered at a commercial packing facility (Excel Corporation, Dodge City, KS). Carcass data, collected following a 48 hr chill, included longissimus area, measured by direct grid reading of the longissimus at the 12th rib, subcutaneous fat over the longissimus at the 12th rib measured ¾ the lateral length from the chine bone end, kidney, pelvic and heart fat (KPH) as a percentage of carcass weight and marbling score (USDA, 1965), the latter two being appraised visually by Oklahoma State University meat science faculty . Final yield grades were calculated from these measurements..

Economic calculations Economic calculations were computed in several ways to consider various marketing options and feed costs. Such computations provide insight into the value of limit feeding under conditions of expensive grain and value based marketing. Carcass values employed were a base price for choice carcasses of $ 93.00/cwt with discounts select ($6.00/cwt) and standard grades ($31.00/cwt). Carcass with weights below 250 or above 420 kg were discounted $20.00/cwt and yield grade 4 carcasses were discounted $20.00/cwt. Cattle that graded prime had an $8.00/cwt premium. Had cattle sold live, value of live weight minus 4% shrink was calculated as $63.00/cwt while purchase cost was $68/cwt initial weight. Feed costs were accessed at two corn prices (either $4.00 or $3.00/bu) with a constant value for supplement ($194/ton) and cottonseed hulls ($76/ton). Total cost was the sum of the purchase and feed costs; yardage and management costs, being considered equal for the various treatments, were ignored. Net returns were calculated by subtracting value (either carcass or live) from total cost (either high or low).

This study was a completely randomized block, with a 3 X 2 factorial arrangement of treatments; pen was considered to be the experimental unit in all calculations with date on feed (July, September,

November) considered as a block. Data were analyzed by general linear models procedures of SAS (1988).

Results and Discussion

Lacking any significant corn processing by limit feeding interactions, the majority of the discussion will focus on the main effects of limit feeding and of grain particle size (Table 15.). Because effects of corn processing have been reported previously (Secrist et al., 1996), they will not be discussed here. However, in the few cases where grain processing-limit feeding interaction approached significance (P<.15), additional discussion is provided.

Average daily gain (ADG) was 20% lower (P<.01) 20% during the restriction phase but 10% greater (P<.07) during the ad libitum phase for limit fed cattle leading to slightly greater ADG for cattle given ad libitum access to feed for the full trial. This depression in gain was more severe when calculated using a carcass adjusted final weight (5%; P<.09) than from shrunk live weight (3%; P<.22) due to a slightly lower dressing percent for limit fed cattle. For period 1, a trend (P<.15) for an interaction between limit feeding corn processing was detected (figure 3). While limit feeding consistently reduced ADG, the depression was 33% for whole corn versus 18% for coarse rolled corn and 11.3% for fine rolled corn. In general, as particle size increased, ADG was depressed more by limiting feed intake. Limit fed cattle typically consumed their full daily allotment of feed within 2 hr. This increased feeding aggressiveness presumably reduced the amount of chewing during eating and might have decreased utilization of grain starch. However, fecal dry matter contained no more starch for cattle fed whole corn diets during either period (Table 19) refuting the idea that differences in digestibility or nutrient utilization differences were responsible for the depressed ADG with limit fed whole corn diets.

By design, DMI was 18.8% less (P<.01) for limit fed cattle. However, DMI was not different (P=.88) during period two leading to a reduction in DMI of 8% (P<.01) for the total trial. Indeed, DMI during the second period remained slightly higher for cattle initially given ad libitum access to feed.

Feed efficiency was slightly depressed (P=.74) for LIM during period one but markedly improved (P<.05) by 14% in period two. Similar to ADG, a trend for an interaction (figure 4) between limit feeding

and corn processing was detected (P<.15) with numerical improvements in feed efficiency noted from limit feeding with coarsely and finely rolled corn but being was numerically with whole corn grain. Fecal starch analysis fails to support the idea that decreased starch digestibility can explain this response. Although limit feeding during period 1 tended to improve total trial feed efficiency, the difference was not significant. The magnitude of the improvement depended on whether calculations were based on final live weight (5.3 % superiority) or carcass-adjusted final weight (3.2 %) due to slight numerical differences in dressing percent.

Because limit fed cattle consumed all their feed within a relatively short time and not all cattle could eat simultaneously, one might expect that larger, more aggressive cattle were eating more and gaining faster than smaller, less aggressive cattle. Consequently, animal-to-animal variation in ADG was calculated and analyzed (Table 16.). No period or total trial effects were noted based on live body weights. Indeed, variation was numerically lower (P>.15) for limit fed cattle except for cattle fed whole corn where limit fed cattle had slightly greater variations in ADG during period 1 but lower variation during period 2. Averaged across both periods limit fed cattle consuming whole corn had numerically but not significantly greater variations based on live final weight; this variation was significantly greater (P<.05) based on carcass-adjusted final weight. Whether or not this increased variation in gain for limit fed cattle consuming whole corn can explain why ADG and feed efficiency failed to respond to limit feeding is not clear. Perhaps cattle consuming whole corn could consume feed faster without pausing for water so that the more aggressive cattle indeed ate more feed than the more timid cattle with whole corn. The amount of bunk space needed for limit fed cattle has been of interest to feedlot managers and consulting nutritionists and is difficult to study experimentally because few scientific trials are conducted with more than 10 cattle per pen. Zinn (1989) in two trials compared 6, 12, 18, and 24 inches of bunk space per head with feed intake restricted to allow ADG of either 3.2 lb. or 2.7 lb. He concluded that allowing more than 6 inches of linear bunk space did not appreciably improve performance of limit fed cattle. All his diets all consisted of steam flaked grain. Similarly, in the current trial in which cattle had 15 inches of linear bunk space, no depressions in performance and no increased variations in ADG were detected with the more processed grain, but differences were detected with corn fed unprocessed. Whether

or not there is an interaction between grain processing method and bunk space requirements for limit fed cattle remains to be seen but this topic deserves attention.

Feeding management system had no effect ($P>.20$) on any of the carcass traits measured but some numerical trends in quality grade and marbling score are of interest. Although average marbling score did not differ between treatments, the distribution of marbling scores tended to be different. Only ad libitum fed cattle produced prime carcasses while limit fed cattle tended to have more carcasses grading standard. Only with ad libitum feeding did any price discounts for overweight carcasses take effect.

Generally, limiting feed intake, though improving feed efficiency and slightly depressing ADG has reduced carcass fat and marbling (Murphy and Loerch, 1994; Glimp et al., 1989; Daughterty and Clare, 1992; Hicks et al., 1990). However in each of these trials cattle, DMI was restricted throughout the entire finishing period; this might explain substantial decreases in the percentage of cattle grading Choice. In contrast, Lofgreen et al. (1987) restricted intake only until the cattle reached a predetermined weight after which they were fed ad libitum. Although limit feeding improved efficiency, carcass quality was not reduced. Similarly, Loerch et al (1995) limit fed cattle to achieve specific rates of gain (2.0, 2.5 or 3.0) until they reached 820 lb. after which they were fed ad libitum. During the ad libitum phase, calves that previously were limit-fed tended to have more rapid gains. The greater the intake restriction, the greater the ADG during when feed was available ad libitum. Cattle given ad libitum access to feed throughout the trial had the poorest feed efficiency in the second phase of the trial. Additionally, carcass traits were not affected by treatment. For their total trial, rate of gain, feed efficiency, days fed and total feed intake were not affected by feeding strategy. Restricting gain to 3.08 lb./d during the first half of the trial only increased total time on feed by five days and reduced total feed required by 61 lb./steer. In the current trial feed savings were 280 lb/steer quite a bit greater than those reported by Loerch et al. (1995) primarily due to the fact that the limit fed cattle were not fed any longer than the ad libitum cattle. Generally, limit feeding programs improve feedlot efficiency and reduce cost of gain, but for optimum marbling and similar carcass weight and return, some period of ad libitum intake is needed.

Economic data are presented in table 17. Both carcass value and live value were greater for ADLIB than LIMIT cattle predominantly due to cattle weights. The difference in value between ADLIB

and LIM cattle was greater based on carcass than on live weights because of a lower dressing percent. Although ADLIB had more prime and fewer yield grade 4 carcasses, both of which add to carcass value, more ADLIB cattle had overweight carcasses. The relative difference between carcass and live value for ADLIB and LIM cattle suggests that carcass weight alone could account for roughly half the difference in carcass value between ADLIB and LIM. Feed costs were reduced (8%; P<.05) for limit fed cattle relative to ADLIB due to lower intakes. With higher corn prices, the economic advantage was greater for limit feeding. Total cost mirrored feed costs since purchase cost was the same with feed intake being the only variable. Net returns did not significantly differ, however the numerical differences still seem economically important under certain conditions. Using carcass value and a high corn price, to treatment differences were detected. However, based on carcass value and a low corn price, ad libitum feeding was favored by almost $5.00/cwt. Based on live weight values, net returns were greater for limit fed steers with both corn grain prices with the greatest benefit with more expensive corn grain prices. These data suggest that as rations cost increases, limit feeding becomes more valuable. With the exception of carcass weight, difference in carcass merit were minor suggesting that the carcass value difference potentially could have been recovered by extending the total feeding period or by limit feeding for a shorter period of time. The values used for determining carcass value were an average based on the 1996 beef quality audit data and seasonal variations in price discounts at any one time could alter interpretations slightly. But since the carcass characteristics were quite similar, changes in the price structure should affect both groups similarly.

Stanton and Robertson (1996) reported that 3% restriction of cattle throughout the finishing phase reduced feed cost of gain $1.65/cwt. and, based on 496 lb. of gain and similar carcass characteristics, resulted in an $8.19 advantage per head for limit fed cattle based on feed savings alone. Similarly, Knoblich et al. (submitted) tested feeding systems in which cattle were limit fed to gain at different rates for different lengths of time and later given ad libitum access to feed. They reported that limit feeding reduced feed cost by $12.28 to $22.89 per steer depending on the specific system used. In many studies, carcass values were assumed to be equal because differences were not significant. For more precise calculation of the full return from limit feeding cattle, carcass values should be calculated.

In a similar fashion, limit fed cattle in our study gained 22 pounds less live weight but consumed 280 pounds less feed. Had these steers required 10 pounds of feed for every pound of live weight gained and been fed for 7 days longer, total feed consumption would have been 60 pounds less for the limit fed cattle. At a feed cost of 6 cents per pound of feed, savings from limit feeding would be $3.60 per steer.

In conclusion, limit feeding usually improves the efficiency and profitability of cattle feeding. The majority of the increased profitability is related to savings in feed costs; this advantage is lost unless limit fed cattle have similar carcass merit. Carcass merit can be improved by providing cattle ad libitum intake of feed for the last half of the finishing phase.

Implications

Limit feeding for some portion of the finishing phase of production can improve feed efficiency without sacrificing carcass quality. Although the economics of limit feeding were positive, net return differed with the marketing system. Further work is needed to quantify the optimum restriction level and (or) duration so that limit-fed animals can be marketed with the same number of days on feed without decreasing carcass weight. The efficiency response to limit feeding seemed greater when the corn grain was processed than when corn grain was fed unprocessed, perhaps related to differences in animal to animal competition for feed.

Table 13. Management summary for the date on feed blocks.

Age treatment	July	September	November
Date on feed	July 14,1994	Sept 15, 1994	Nov 15, 1994
Day of Synovex implant	42	0	0
Day of Revalor implant	131	93	82
Slaughter date	Feb 7, 1995	March 7, 1995	May 9, 1995
Days on feed	208	173	175
Days on Revalor	77	80	93
Limit feeding gain	298	310	301
Limit feeding Days	105	93	83
Total 1st period gain	368	355	371

Table 14. Diet and calculated nutrient composition (% of DM).

Ingredient	% of diet dry matter
Dry corn	82.05
Cottonseed hulls	8.00
Soybean meal	4.00
Cottonseed meal	4.00
Limestone	1.00
Urea	.60
Salt	.30
Manganous oxide	.004
Copper sulfate	.001
Zinc sulfate	.002
Vitamin A-30	.01
Rumensin-80	.017
Tylan-40	.013
Calculated [a] nutrient content., dry matter basis	
NEm, Mcal/cwt.	95.0
NEg, Mcal/cwt.	60.0
Crude protein, %[b]	13.4
Potassium, %[c]	.57
Calcium, %[c]	.44
Phosphorous, %[c]	..32
Magnesium, %	.16
Cobalt, ppm	.01
Copper, ppm	8.5
Iron, ppm	51.5
Manganese, ppm	44.0
Zinc, ppm	34.9

[a] NRC (1984)
[b] based on Kjeldahl analysis of individual feeds
[c] analyzed by commercial laboratory

Table 15.   **Performance summary for the main effect of feeding management.**

ITEM	ADLIB	LIMIT	SEM	P<
Weights, lb.				
initial	542	539	2.19	
adjusted live wt	1136	1103	10.91	.05
shrunk live wt	1139	1117	9.55	.13
carcass wt	721	700	6.9	.05
feed intake, lb.				
period 1	16.9	14.0	.41	.01
period 2	19.9	19.8	.47	.88
overall	18.4	16.9	.38	.02
Total feed intake, % BW				
shrunk live, %	1.62	1.51	.03	.05
adjusted live, %	1.62	1.54	.03	.07
Period 1 gain	365	303	7.88	.01
Average daily gains, lb.				
period 1	3.53	2.92	.09	.01
period 2	2.82	3.12	.11	.07
overall carcass basis	3.19	3.04	.06	.09
overall live basis	3.21	3.11	.05	.22
Feed efficiency				
period 1	4.75	4.83	.16	.74
period 2	7.00	6.13	.23	.02
overall carcass basis	5.64	5.46	.13	.32
overall live basis	5.62	5.32	.13	.13
Total feed required, kg	3350	3075	76.5	.05
Calculated Net Energy Values				
ME, Mcal/kg	3.08	3.13	.05	.40
NEm, Mcal/cwt	93.0	95.6	2.18	.41
NEg, Mcal/cwt	61.3	63.0	1.29	.39
Dressing percentage	63.4	62.8	.35	.20

Table 16. Variation in average daily gain for feeding management by particle size interaction.

Particle size	Coarse		Fine		Whole			
Feeding treatment	ADLIB	LIM	ADLIB	LIM	ADLIB	LIM	SEM	P<
Item								
period 1	.51	.32	.57	.50	.54	.63	.11	.52
period 2	.52	.69	.65	.56	.62	.57	.07	.20
Overall (live)	.36	.22	.42	.45	.34	.46	.06	.17
Overall (Carcass)	.41	.34	.53	.40	.33[a]	.53[b]	.05	.03

[a,b] limit vs ADLIB within a processing method differ (P<.05).

Table 17. Impact of limit feeding on carcass characteristics.

ITEM	ADLIB	LIM	SEM	P<
Carcass traits				
ribeye area, sq inches	11.9	11.7	.18	.46
ribeye area / carcass cwt.	1.65	1.68	.02	.32
KPH, %	1.90	1.80	.056	.24
backfat, inches	.54	.52	.02	.65
yield grade	3.1	3.0	.06	.40
% YG 4's	8.33	9.72	2.69	.72
marbling[a]	313	320	9.61	.63
% prime	4.16	0.0	1.96	.16
% choice	43	49	3.46	.23
% select	51.4	48	5.54	.67
% standard	1.39	2.78	2.12	.65
% heavy carcasses	1.38	0	.98	.34

[a] slight amount of marbling (200-299) small amount of marbling (300-400).

Table 18. Economic parameters for the main effect of feeding management system.

ITEM	ADLIB	LIM	SEM	P<
Animal value				
Carcass[c]	633	611	9.58	.13
live[d]	717	703	6.0	.13
Costs				
purchase	369	366	1.49	.30
feed high[e]	238	218	5.43	.03
feed low[f]	190	174	4.34	.03
total high[e]	606	585	6.04	.03
total low[f]	559	541	4.98	.03
Net returns				
carcass basis high[ce]	26.74	26.46	9.66	.98
carcass basis low[cf]	74.53	70.35	9.52	.76
live basis high[de]	111	119	6.77	.43
live basis low[df]	159	163	6.25	.67
cost of gain high[e]	.40	.39	.008	.52
cost of gain low[f]	.32	.31	.006	.52

[c] value calculated based on carcass premiums and discounts.
[d] value calculated based on a common price ($63/cwt.) and live weight.
[e] calculated using a corn price of $4.00/bu.
[f] calculated using a corn price of $3.00/bu.

Table 19. Impact of limit feeding on composition of feces.

ITEM	ADLIB	LIMIT	SEM	P<
Fecal Starch				
Period 1	20.5	19.8	1.03	.64
Period 2	19.8	19.7	2.14	.95
Overall	20.3	19.9	1.26	.85
Fecal Crude Protein				
Period 1	21.3	18.1	2.02	.28
Period 2	19.9	19.0	.32	.10
Overall	20.5	18.5	1.0	.19
Fecal Purines				
Period 1	14.1	14.0	.67	.92
Period 2	12.8	12.6	.40	.68
Overall	13.5	13.4	.44	.82

Figure 3. Average daily gain for the feeding management x corn processing interaction.
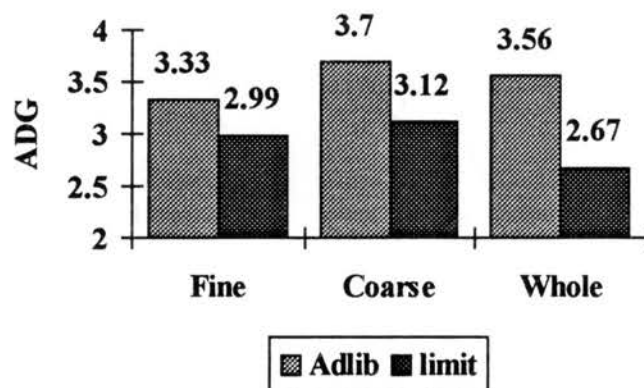
Figure 4. Feed:Gain ratio for the feeding management x corn processing interaction.
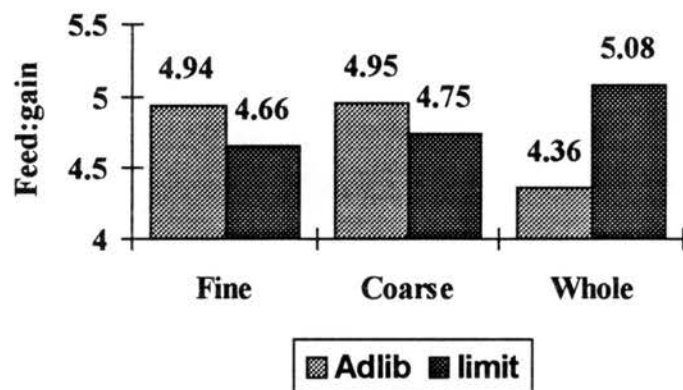
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CHAPTER V

EFFECTS OF INTAKE RESTRICTION AND PROTEIN LEVEL ON FEEDLOT STEER PERFORMANCE.

W.J. Hill, D.S. Secrist, F.N. Owens and D.R. Gill

Abstract

Crossbred fall-born steer calves (n=73; avg 560 lb) from two university research herds were utilized to determine the effects of restricting intake by 7.5% (Lim7.5) or 13% (Lim13) and protein supply either equal in percentage (12.5%,LOW) or in grams (925, HIGH) to that of steers fed ad libitum. The basal diet was a 95% concentrate utilizing whole shell corn. Intake was restricted only until cattle had gained about 300 lb (period 1). Steers were sacrificed and organ weights and body compositions (specific gravity) determined at the end of period 1 (24 steers), and when steers reached market weight. Data were analyzed by the GLM procedures of SAS using initial weight as a covariate and contrasts for pre-planned comparisons. At the end of period 1, despite different intakes, gastrointestinal weights were not different (P>.30). Percentages of carcass as fat and protein were not different (P>.25). However, within the restricted intake groups, HIGH had greater (P<.06) marbling than LOW (266 vs 219). ADG during period 1 was linearly decreased (P<.05) by restricting feed intake although restriction improved feed efficiency. However, feed:gain (FE) for LO was superior (P<.08) to HI for LIM1 (4.31 vs 4.65) but inferior (P<.08) to HI for LIM2 (4.92 vs 4.57). During period 2 DMI tended (P<.10) to be lower for Lim7.5 than ADLIB (19.8 vs 17.3 lb) with no differences (P>.10) in ADG. Similarly, FE during period 2 did not differ (P>.10) among treatments, but did consistently favor the restricted groups numerically. DMI over the entire trial was greater (P<.08) for ADLIB than the restricted groups (17.2 vs 16.1) with no differences in ADG. Similarly, FE over the entire trial was not significantly different among treatments but did numerically favor Lim7.5. Restricted feeding at levels less than 13% for half the feeding period does not affect carcass composition and additional protein does not appear beneficial until feed restriction exceeds 7.5% of ad libitum.

(Key Words: Restricted Intake, Protein, Feedlot, steers)

Introduction

Restricted or limit feeding programs generally improve feed efficiency of finishing cattle. While several methods and degrees of restricted intake can be used, the most common and successful programs have restrict intake throughout the feeding period or just for an early segment of the feeding period and thereafter provide free choice access to feed. Restriction levels have varied from 5 to 20% below ad libitum DMI; optimum efficiency improvements have been seen with about 15% restriction or feeding at 85% of ad libitum DMI (Sainz, 1995). While restricting cattle throughout the entire finishing period usually has improved feed efficiency, restriction for the full feeding period usually has increased the number of days on feed and decreased the percentage of cattle grading Choice (Murphy and Loerch, 1994; Hicks et al., 1989, 1990). In contrast, programs that allow unlimited DMI during the last half of the feeding period generally have improved efficiency without extending the feeding period or depressing carcass quality (Loerch et al., 1995; Knoblich et al., submitted; Peters, 1995). While restricted feeding appears to be a viable means for improving efficiency and if done properly does not affect carcass quality, why efficiency is improved remains unclear. Several explanations for the improvement in efficiency have been advanced. These include reduced weight of the digestive tract and other organs, reduced maintenance requirements, decreased feed waste, altered body composition, altered hormonal status, and improved digestibility. Because one gram of wet tissue retained as protein contains less energy than one gram stored as fat, decreased fatness of limit-fed cattle has been implicated as one explanation for the improved efficiencies. However, all of the trials that have observed that fat content decreased have been trials in which cattle were restricted throughout the entire finishing period (Murphy and Loerch, 1994; Hicks et al., 1990; Glimp et al., 1989). In trials where limit fed cattle have been given ad libitum access to feed for the last half of the trial, reductions in carcass fat have been minor or nonexistent (Loerch et al., 1995; Knoblich et al., submitted). How slight restrictions (i.e., 10 -15% below ad libitum DMI) affect body composition during the restriction phase separate from the total feeding period has not been studied extensively although Hill et al. (1996) reported that limit feeding for 63 days did not decrease but instead tended to increase carcass fat of steers. In contrast, after 130 days of feeding, when cattle were given ad libitum access to feed the last 67 days, carcasses of previously limit fed steers tended to be slightly leaner

than carcasses of steers that had received continuous access to feed throughout the total feeding period. These findings conflict with the standard dogma that slower growing cattle are less fat after a specified time on feed (Guenther et al., 1965). One key difference between these contradictory results is that in most trials, slower growing cattle either have been fed lower energy (forage based) diets or else they have been limit fed concentrate diets so that rate of gain was substantially below those of cattle given ad libitum access to feed. Additionally, in most limit feeding trials limit fed cattle were provided additional levels of protein to insure similar daily CP intakes. However, whether or not this added protein is needed or not has not been studied. The objectives of this trial were limit feed cattle at two restriction levels and either maintain equal daily percentages of protein or provide equal daily total CP intakes. Additionally, we wanted to further the available information on the optimum restriction level and how these restrictions affect body composition, gut, organ and other offal tissue weights both at the end of the restriction period and after a period of ad libitum consumption. We also wanted to feed the cattle to similar end points and determine the economics both from feed saving, as well as, from a carcass value standpoint.

Materials and Methods

Animals: Seventy-three crossbred steers were utilized in a trial to determine how different levels of feed restriction and protein levels would affect feedlot performance, body composition, organ weights and carcass characteristics. Calves originated from two different university maintained cow herds. The first herd (n=51) consisted of normal (205 d) weaned fall born calves and made up three replications based on predominant breed type. The three reps consisted of an Angus x exotic cross, Angus x Angus cross or a Hereford x Angus cross. All cattle from this source were fed in three head pens. The exotic influence consisted of either limousin for Gelvieh sires. The final replication (n= 22; BW=515) was from a herd consisting primarily of English breeding (Hereford x Angus). The calves from this herd were also fall born but had been early weaned (60 d) and grazed on wheat pasture prior to entry into the feedlot. These cattle were fed separately in another barn with pens capable of handling four head per pen.

Cattle were recieved July 19, 1994, vaccinated with a modified live IBR, PI3 (Sanofi Animal Health, Inc overland park Ks) and Blackleg, dewormed (Ivomec) weighed and allocated to treatment. On August 4, cattle were weighed revaccinated and implanted with Synovex S (Syntex).

Treatments and diets: Treatments were 1) ad libitum feeding throughout the feeding period 2) 93% of ad libitum intake with the same dietary concentration of protein for approximately 300 lb. of gain then fed ad libitum 3) 93% of adlibitum intake with the same grams of protein intake as ad libitum for 300 lbs of gain then fed ad libitum 4) 86% of ad libitum intake with the same dietary concentration of protein for 300 lbs of gain then ablibitum 5) 86 % of adlibitum intake with the same grams of protein intake as adlibitum for 300 lbs of gain then adlibitum. The treatment design and pertinent information is listed in Table 20. The ad libitum feeding of previously intake restricted cattle was determined when the pen averaged approximately 300 lbs of gain at which time the middle sized steer in the pen was slaughtered for determination of organ weights, body composition and carcass traits. Additionally, at that time, the remaining steers in that pen were allowed ad libitum access to a diet containing 12.5% CP until finish. The final slaughter was determined on an individual animal basis when it was estimated the steer in question would either grade low choice or was in danger of achieving a carcass weight greater than 900 lb.

All cattle were fed in partially enclosed pens with slatted concrete floors and equipped with fence line bunks and free flow waters. Feeding occurred once daily at approximately 0900. The composition of the basal diet is listed in Table 22. The additional protein required for the two groups of restricted cattle was accomplished adding additional supplement to the basal diet.

Table 20. Treatment designations describing intake and protein levels

Treatment designation	Level of intake	% CP	grams CP/d	days restricted	gain during restriction
Adlib	100%	12.5	851	101	352
Lim7.5, LOW	92.5%	12.5	795	92	319
Lim7.5, HIGH	92.5%	13.4	851	105	332
Lim13, LOW	87%	12.5	738	108	319
Lim13, HIGH	87%	14.4	851	108	339

Measurements and calculations: Body composition, organ weights and carcass characteristics were determined at three times during the course of trial. First, prior to the time treatments were imposed (PREKILL) and cattle were started on feed, two animals per breed type and source block were slaughtered for the determination of beginning body composition and organ weights. Second, after the pen had averaged approximately 300 pounds of gain (INTERIM) the mid sized steer from each pen was slaughtered, and at the end of the finishing period (FINAL) all cattle were slaughtered, for determination of body composition, organ and offal weights and carcass traits. During all kill periods cattle were slaughtered first thing in the morning, prior to feeding, with no imposed shrink. On the kill floor, the following weights were taken: live weight, carcass weight, hooves, head, hide, liver, pluck (lungs and esophagus), heart, tail, rumen, small and large intestine. Hooves, head, hide and tail were designated as external. Liver, pluck, heart, rumen, small and large intestines were classified as internal. Rumen and intestine weights were classified as gut. Following slaughter cattle were chilled at 34 degrees F for 48 hrs and then the following measurements were obtained: 1) longissimus muscle area, measured by direct grid reading of the longissimus muscle at he 12th rib; 2) subcutaneous fat over the longissimus muscle at the 12th rib, taken at a location ¾ the lateral length from the chine bone end; 3) kidney , pelvic and heart fat (KPH) as a percentage of carcass weight, and 4) marbling score (USDA, 1965). And 5) lean and skeletal maturity. The percentages of fat, water and protein determined via specific gravity procedure (Garrett and Hinman, 1969) on one side of carcass, one quarter at a time.

Average daily gains, feed intakes and feed efficiencies during the first phase of the trial when intake restrictions and protein levels were imposed (period 1) all animals were utilized in the analysis. However, for the all ad libitum and common protein phase (period 2) the early weaned block was removed because of the lost intake data, which occurred because of combining pens due to space limitations. Daily gains during period 1 was calculated by a regression of full live weight on days on feed, where the slope was determined to be ADG. The mid term or end of period 1 weight was calculated from initial weight and the regression generated ADG multiplied by days in period 1. Second period and final daily gains were calculated using carcass weight divided by a common dressing percentage and either the initial

weight or the calculated mid term weight for final and second period, respectively. Additionally, period 2 and total gains were calculated on a live weight basis.

Economic calculations Economic calculations were computed in several ways to consider various marketing options and feed costs. Such computations provide insight into the value of limit feeding under conditions of expensive grain and value based marketing. Carcass values employed were a base price for choice carcasses of $ 93.00/cwt with discounts select ($6.00/cwt) and standard grades ($31.00/cwt). Carcass with weights below 550 or above 900 lb were discounted $20.00/cwt and yield grade 4 carcasses were discounted $20.00/cwt. Cattle that graded prime had an $8.00/cwt premium. Had cattle sold live, value of live weight minus 4% shrink was calculated as $63.00/cwt while purchase cost was $68/cwt initial weight. Feed costs were accessed at two corn prices (either $4.00 or $3.00/bu) with a constant value for supplement ($194/ton) and cottonseed hulls ($76/ton). Since cattle were fed for different numbers of days on feed yardage was accessed at $.25/hd/day. Total cost was the sum of the purchase and feed costs and yardage and management costs, being considered equal for the various treatments, were ignored. Net returns were calculated by subtracting value (either carcass or live) from total cost (either high or low).

Regression analysis: Regression coefficients (β's) were generated by period and overall for all measured body part weights as well as carcass traits and body composition measurements against both days on feed and body weight. These coefficients give an estimate as to the unit change for each component both by day and per pound of body weight. Once these coefficents were generated they were outputted back into the data set and simply analyzed as another response variable by treatment, specific analysis description will be given below.

Huxley (1932) studied growth of parts of the body relative to the whole through use of the allometric equation of $y=ax^b$ where y = size of the organ or part, x = size of the rest of the body, and b = the growth coefficient of the organ or part. This equation was found by Huxley to provide reasonable and quantitative descriptions of many organ-to-body relationships. The use of this equation is based on the assumption that relative changes in component parts during growth are more dependent on the absolute

SIZE of the whole rather than on the TIME taken to reach that size. The equation is solved by regression of logarithm transformed factors (ln Y= ln a + b ln W). In the comparisons by Berg and Butterfield (1976) 'b' represents the ratio of the percentage post-natal growth of 'y' to the whole 'x'; thereby, it enables relative maturity to be expressed. If an organ or tissue grows at the same rate as the total body, 'b' will equal 1. For late-maturing tissues, 'b' will exceed 1.0 while an early maturing organ or tissue that does not increase as rapidly as the total body will have a 'b' that is less than 1.0. Such relationships are of particular interest for evaluating alterations in body ratios at a specified body weight when the pattern of growth has been altered experimentally. i.e., using growth stimulants or measuring response to compensatory or retarded growth and were calculated in the current trial both by individual period and over the entire trial. Similar to the previous regressions these 'b' values were exported and analyzed as another response variable.

Statistical Analysis: Cattle were blocked based upon the source and breed type instead of strictly by weight to decrease the variation in body composition due to differences in genetics and background. Because of this decision there was considerable variation in the initial weight between treatments, therefore initial weight was utilized as a covariate. The data were analyzed as a randomized complete block design with a two by two plus 1 arrangement of treatments. Treatment differences were separated by the use of orthogonal contrasts for pre-planned comparisons and are described in Table 21.

Results and Discussion

Cattle performance results for all treatments are listed in tables 23-26. No statistical differences existed in any of the weights during any part of the trial as this was the intent, based on the design of the trial. Similarly, dressing percent did not differ (P>.05), but tended to mirror the numerical differences in carcass weight. Intakes by design were reduced (P<.05) during period 1 for both restricted feeding treatments compared to ad libitum, as well as, the two restriction levels differing (P<.05) from one another. During period 2 when all cattle had ad libitum access to the same diet and protein level intakes were not significantly affected. However, the greater restriction level in period 1 resulted in a numerically greater intake in period 2 compared to the lower intake restriction level, while both restriction levels

remained below the ad libitum fed throughout group. This lack of compensation in intake resulted in overall similar intakes for the restricted fed cattle, but both were below (P<.08) the ad libitum fed cattle. There was a tendency (P<.11) for a protein x restriction level interaction for ADG during period 1. Although none of these differences were significant, the general trend was for the higher level of protein to be beneficial at the greater restriction level , but not at the lower restriction level. There were however significant intake level effects during period 1. The ad libitum fed and the lower restriction level gained faster (P<.05) than the greater restriction level, but there was no difference (P>.50) between the low restriction level and ad libitum fed. During period 2 and overall there were no differences in ADG between any of the treatments calculated either on a live or carcass adjusted basis. However, there was a tendency (P<.15) for ad libitum fed cattle to gain slightly faster than all the restricted groups on a carcass adjusted basis. Feed efficiency (lb feed/ lb gain) during period 1 in general was not affected by restriction level and did not differ from ad libitum fed cattle. There was however a restriction level x protein level interaction (P<.05). The greater protein level was beneficial (P<.08) for the greater restriction level, but detrimental (P<.08) or at least not advantageous for the lower protein level. However, there was no carry over effect in period 2, but it should be noted that with the exception of the Lim13 low protein the average numerical advantage for limit feeding in relation to ad libitum feed during this period was roughly 12 %. Similarly, feed efficiency over the entire trial tended (P<.10)to be affected by restriction level x protein level interaction. Again, with the greater protein level only being advantageous for the greater restriction level. Additionally, if one excludes the Lim13 low protein treatment the average advantage for limit feeding in relation to ad libitum feeding was roughly 5%.

Body and organ weights as well as carcass traits and composition are listed in Table's 27-30. At the end of the restriction period (period 1) in spite of similar carcass weights there was a difference in dressing percent (P<.05)which was affected by restriction level x protein interaction similar to previously reported ADG's and feed efficiencies. The higher protein level with the greater degree of intake restriction had greater (P<.05) dressing percents where the opposite was true for the lower intake restriction. Additionally, ad libitum fed cattle had higher dressing percents than all restriction groups. It appeared the dressing percent was correlated to ADG. The greater the rate of gain the higher the dressing

percentage. None of the external dress off items were affected by feeding or protein level. However, rumen plus content weights were affected by a restriction level x protein interaction. At the greater restriction level the higher protein level resulted in a decreased (P<.05) rumen plus contents weight compared to the lower protein level. In contrast at the lower restriction level the greater protein level resulted in heavier rumens however this difference was not significant (P>.15). In spite of lower intakes levels (when averaged across all restriction and protein levels) the restricted cattle tended (P<.12) to have greater rumen weights than the ad libitum fed cattle. Similar responses were noted for total internal and gut weights, but because none of the other constituents of gut or internal organs were affected by feeding or protein level these differences can be attributed to the rumen weights. Increased rumen plus content weights for restricted fed cattle might be attributed to slower passage rates. Similar results have been previously reported by Hill (1997). Although there was no statistical interaction for liver weights the trend was there similar to the previously reported ADG and feed efficiency results. It appeared that the faster more efficient gaining cattle had heavier liver weights. Marbling scores were not affected by feeding level, but the higher level of protein increased (P<.05) marbling scores compared to the lower protein level and the ad libitum fed cattle. Carcass fatness measured as backfat thickness, KPH, and percent fat as determined by specific gravity was generally not affected (P>.05) by feeding level, but was affected by a restriction level x protein level interaction. Backfat measured at the 12th and 13th rib was increased for the Lim13 high protein as compared Lim13 at the low protein level, whereas Lim7.5 had similar backfat measurements at either protein level. Additionally, Lim13 high protein had greater numerical backfat measurements than any other treatment. KPH followed the same pattern as backfat. Carcass composition measured by specific gravity also followed a similar but slightly different pattern but was not statistically significant. Lim7.5 at the low protein level and Lim13 at the high protein level had the greatest numerical percentages of carcass fat followed by the ad libitum fed cattle, while Lim7.5 at the high protein level and Lim13 at the low protein level were the leanest. The reasons for these responses in carcass composition are not apparent. Within the limit fed groups the interaction with protein level for increased fatness mirrored the greater growth rates associated with this interaction and therefore the faster growing cattle were fatter. This increased fatness related to increased growth rate may not be so

surprising. However, the fact these same cattle were also numerically fatter than the ad libitum fed cattle, which had the fasted numerical gains is somewhat surprising. However, Hill (1997) reported similar carcass composition's for cattle at the end of a 63 day limit feeding program similar to the one described in this trial. No other carcass traits or compositional differences existed at the end of this period.

Results for final body part and organ weights as well as carcass traits and composition are listed in tables 31-34. Final live weight was generally not affected (P>.10) by treatment due to the fact that we made an effort to feed all cattle to a common end point. However, due to labor restraints of the OSU meat lab not all cattle could be slaughtered when it was deemed they were ready. Therefore some slight differences existed that for the most part mirrored the differences as previously discussed for growth rate. Similarly, there were no differences in carcass weight or final dressing percent. The sum of all external dress off items did not differ (P>.10) with the various treatments. However, there was a tendency (P<.15) for there to be an interaction for this parameter. Similar to the previously discussed interaction's the Lim13 high protein group had heavier external dress off items compared to the low protein group where the opposite was true at the lower restriction level. None of these difference's were significant and were probably a result of the greater growth rates associated with those groups. The majority of the differences in the external dress off items for the interaction were accounted for with significant differences in the hooves (P<.01) and head (P<.10) with no differences in the hide and tail weights. There were no feeding level effects on any of internal or gut weights at the end of the feeding period. However, there was a tendency for both internal (P<.10) and gut (P<.10) weights to be affected by protein level independent of intake level. This response was due to a heavier (P<.10) rumen weight for the low protein level as compared to the high protein level. The reasons for this discrepancy in rumen weights due to protein level are not apparent. Marbling scores were not affected by feeding or protein level by the end of the trial. Backfat thickness was affected (P<.07) restriction x protein level interaction at the end of trial. Little difference due to protein within Lim13 group was evident, however, within Lim7.5 the high protein level group was fatter than the low protein level group. This observation is the exact opposite of what was evident at the end of period 1. Ribeye area was affected (P<.05) both by degree of restriction and level of protein, but there was no (P>.50) interaction between these two factors. The general response

was for the lower level of restriction and lower level of protein to produce larger ribeye areas. Additionally, except for the Lim13 high protein group all other treatments had larger ribeye areas than the ad libitum fed cattle. Carcass composition measured by specific gravity at the end of trial did not differ (P>.30) for any of treatments. However, cattle ad libitum throughout the entire trial did have more (P<.07) KPH than any of the previously intake restricted cattle.

Results from the economic analysis are summarized in table 35. As described previously in the materials and methods economics were calculated both on a live and carcass merit basis using either $4.00 or $3.00 corn. The only factors significantly affected were yardage due to the differing number of days required to get cattle to a visually accessed common end point and was lower (P<.05) for ad libitum fed cattle compared to all other treatments. Additionally, cattle fed high levels of protein tended (P<.07) to have lower yardage costs than those fed low levels of protein. Similarly, High protein fed cattle had lower feed costs than low protein fed cattle. However, in spite of these differences there were no differences in total profitability on a live basis or total losses on a carcass merit basis. There was a substantial difference in profitability depending on how returns were calculated. While one of these differences were statistically significant by treatment due to large variations some points are worth mentioning. On a live basis all cattle were profitable at either corn price. However, on a carcass merit basis all cattle lost money at a $4.00 corn price and only the restricted cattle at the high protein level made any money at $3.00 corn price. The major reason for the large discrepancy between the live and carcass calculated profits is due to substantial discounts for cattle grading select and a high proportion of yield grade 4's and heavy carcasses. This is especially evident for the ad libitum fed cattle which had 17.5% YG 4's and 18.4% heavy carcasses. On a carcass merit system all restricted fed cattle either made more or lost less money than ad libitum fed cattle. While none of these differences were statistically significant they might very well be economically important.

Daily accretion rates for all measured parameters during both periods and overall are summarized in tables 36 and 37. Carcass weight, dressing percent, tail, percent carcass water, percent carcass protein and pounds of fat were all affected (P<.05) by a restriction level x protein level interaction during both periods and all followed the same pattern. Carcass weight, dressing percent, tail and pounds

of fat daily all increased daily with the greater restriction level at the high protein level increasing faster where as at the lower restriction level the low protein increased faster. During period 2 the opposite was true which resulted in no net difference in accretion rates for these parameters overall. The percent carcass protein and water followed the same pattern except that they decreased at faster rates during period 1 and then decreased at slower rates during period 2 with the same no difference overall. Additionally, the liver and heart both were affected (P<.05) by the interaction during period 1 and followed the same pattern as previously described, but was unaffected during period 2 or overall. Carcass weight over the entire trial increased at a faster (P<.05) rate than all other treatments. However, in spite of this faster increase in carcass weight compared to the other treatments the ad libitum fed cattle had slower (P<.05) increases in dressing percent during period 2 with no differences overall. Similarly, ad libitum fed cattle tended (P<.10) to have faster increases in liver weight over the total trial and faster increases in pluck during period 1 (P<.10) and overall (P<.05). Similarly, pluck increased faster (P<.05) during period 1 for the high protein fed cattle as compared to the low protein fed cattle with no differences in period 2 or overall. Because carcass data was not measured on the preliminary slaughter cattle accretion rates for period 1 could not be calculated. However, backfat was affected by the restriction x protein level interaction during period 2 similar to the other factors thus far discussed with this interaction during this period. Backfat increased faster for the greater restriction level at the lower intake level than at the higher protein level with the opposite being true at the lower restriction level. Similarly, fat accretion as a percentage during period calculated by specific gravity actually decreased for the greater restriction level and high protein level whereas it increased at the lower protein level and again the opposite was true for the lower restriction level. Fat accretion expressed both as percentage and as total pounds both increased (P<.05) faster for the ad libitum fed cattle as compared to all other treatments.

Accretion rates per unit of BW for both periods and overall are summarized in table 38. Similar to the daily accretion rates the carcass accretion rate per unit of BW was affected (P<.05) by the restriction x protein level interaction during period 1. Carcass gains per unit of BW were greater for the high protein level when cattle were restricted by 83% of ad libitum, but when cattle were restricted 92.5% of ad libitum the carcass accretion rate was greater for the low protein level, with no differences during period 2 or

overall. Dressing percent during this period was affected in the same manner. Additionally, cattle fed ad libitum throughout the entire trial had greater (P<.05) accretion rates per unit of BW than all other treatments. The overall rate of head growth per unit of BW also was affected (P<.05) by the restriction x protein level interaction, but in a slightly different manner. There was no difference due to protein level at the greater restriction level, however , at the lower restriction level the low protein level grew faster per unit of BW than did the high level of protein. Liver growth was affected (P<.05) by this interaction as well during period one with no affects during period 2 or overall. Liver growth per unit of BW during period 1 was greater for the high protein level at the greater restriction level but was lower for the high protein level at the lower restriction level. This response mirrored the daily accretion rates during the same period. Internal organ growth rate per unit of BW was also affected (P<.05) by the restriction x protein level interaction during period 1, but behaved in an opposite fashion. In this case the high protein level growth rate was less than the low protein growth rate at the greater restriction level and the high protein growth rate at the lower restriction level was greater than the low protein level at the same restriction level. This same pattern existed for gut growth as well but occurred during period 2 instead of period 1. Additionally, the overall growth rate per unit of BW of internal organs and the period 2 growth rate per unit of BW of gut was greater for ad libitum fed cattle than all other treatments. Both percent carcass fat and pounds of carcass fat determined by specific gravity behaved in the same manner and was also affected (P<.05) by the restriction x protein level interaction during periods 1 and 2 with no overall net effect. Both percent and pounds of fat accretion per unit of BW was increased for high protein at the greater restriction level, but decreased for high protein at the lower restriction level during period 1. During period 2 the opposite pattern was observed, which acted to cancel each other out and result in no net overall effects. Similarly, water accretion expressed as a percentage of carcass weight during period 1 was actually negative for the high protein level at the greater restriction level and positive for the low protein level at the same restriction level, with the opposite being true in period 2. In contrast for the lower level of restriction water accretion was negative at both protein levels during period 1 with the magnitude being greater for high protein level than the lower protein level. However during period 2 the low protein level was positive whereas the high protein level was negative. Carcass percent protein

accretion per unit of BW during period 1 was also affected (P<.05) by the interaction and followed the same pattern as water. The only difference between percentage water and protein accretion was that protein was not affected by any treatment during period 2 and all rates were negative during this period.

While these relative differences in accretion rates expressed both as daily increases and increases per unit of body weight are interesting and may be useful for the purpose of modeling. However, they are difficult to interpret and likely confounded with differences in days on feed and body weight and it is hard to draw any major conclusions with respect to how growth at the very basic level is affected by these slight changes in intake and protein level. Additionally, it difficult compare the growth rate of one component to another because of differences in magnitude of change and in some cases differing units. However, the use of the allometric equation by Huxley previously described provides a convenient means to overcome some of these difficulties. First, the allometric equation generates 'b' values which all fall between 0 and 2 and are all in common units. Additionally, it gives an indication of how one parameter is changing with respect to another. This simplification is an effective means of comparing how different overall growth rates effect the growth rate of the individual parts of the whole. A 'b' value of one indicates that the individual part is growing a rate that is equal to the whole. A 'b' value of less than one means that the part is growing or increasing relatively slower than the whole, and conversely, a 'b' value of greater than 1 indicates that the part is increasing at a rate greater than the whole. The results of the allometric generation of 'b' values for all measured parameters calculated for each period separately and over the entire trial are summarized in tables 40 and 41. The following discussions will point out differences due to treatment and where there are no differences due to treatment the 'b' coefficients will be averaged to illustrate general growth rates. Hooves were affected by feeding treatment and grew relatively faster during first period than the second period, but both periods and overall were less than 1 indicating that the hooves grew at a slower rate than the whole body. The head had a greater 'b' value in period 2 than period 1 but both were still below 1 again indicating they grew at a slower rate than the whole body. The liver allometric coefficient , while not significant, tended to be greater for the higher levels of intake during period 1 and then greater for the previously lowest intakes during period 2. Specifically during period one both ad libitum and lim7.5 low protein had 'b' values greater than 1 while the 'b' values for

lim13 at both protein levels were less than 1. However, during period the 'b' values for the ad libitum fed and the lim7.5 groups averaged less than .5 while the lim13 groups had 'b' values very near 1. This same response pattern was evident for pluck as well. The heart across all treatments had values slightly above 1 in period 1 and then slightly below 1 during period, with the overall average being very close to 1. Somewhat surprising the tail on average had 'b' values above 1 during all periods and overall. Internal organs with the exception of the ad libitum fed cattle averaged slightly above 1 during period 1, and all were similar and below 1 during period 2. Overall internal organs averaged very close to 1 indicating the sum of all internal organs tend to mirror overall body growth. Similarly external organs followed a similar pattern. Gut coefficients averaged slightly above one during period 1 and below 1 (.68) during period 2. In spite of the decrease in period 2 the overall coefficients remained very close to 1. Additionally, during period 1 all restricted cattle had 'b' values above 1 whereas the ad libitum fed cattle had values below 1. Carcass coefficients averaged very close to 1 during both periods and overall. However, the values during period 2 were slightly greater than 1 indicating that as cattle get older and continue to grow the relative amount they retain in carcass exceeds that of non-carcass tissue this response is in agreement with observations that dressing percentage increases with time on feed due to increases in carcass tissue (namely fat) and simultaneous relative decreases in gut and other dress off items. Pounds of fat were well above 1 during both periods and overall. In contrast, both pounds of water and protein were slightly below 1 during both periods and overall. These results support the fact the animals continue to increase in fatty tissue at the expense of increases in protein and water. In addition to these overall effects for pounds of fat, water, and protein there were restriction x protein level interactions. Fat 'b' values were affected (P<.05) by this interaction during period 1 only. The response was similar to previously reported interactions in that the high protein level at the greater restriction level deposited fat at relatively faster rates than the low protein group, and the opposite was true at the lower restriction level. Coefficients for both pounds of water and protein during both periods responded similarly with respect to the interaction. Both water and protein 'b' values during period 1 were lower for the high protein level than the low protein level at the greater restriction level while the opposite was true for period 2. In contrast both water and protein 'b' values during period 1 greater for the high protein level than the low protein level at

the lower restriction level, while the opposite was true during period 2. These results in effect canceled each other out when calculated over the entire trial.

Implications

Slight restrictions in intake of feedlot cattle for a approximately half of the total feedlot gain then allowing ad libitum access to the same diet appears to improve overall feedlot efficiency. Increasing the protein concentration of the diet to insure adequate total protein for cattle restricted in intake appears to become important only if the restriction is greater than 92% of ad libitum. The efficiency advantage gained does not appear to be due to decreased maintenance requirements associated with small internal organ and gut weights. However, decreased maintenance requirements associated with less protein mass at the end of the restriction may in part explain the observed results.

Table 21. Description of statistical contrasts made.

Contrast	(P) designation number
Ad libitum vs all restriction levels	1
Protein level within Lim7.5	2
Protein level within Lim13	3
Overall effect of protein level	4
Lim7.5 vs Lim13	5
Restriction level by protein level interaction	6
Ad libitum vs Lim7.5	7
Ad libitum vs Lim13	8

Table 22. Diet and calculated nutrient composition (% of DM) .

Ingredient	% of diet dry matter
Whole corn	87.7
Cottonseed hulls	5.00
Soybean meal	2.5
Cottonseed meal	2.92
Limestone	1.00
Urea	.53
Salt	.30
Manganous oxide	.003
Copper sulfate	.0007
Zinc sulfate	.002
Vitamin A-30	.01
Rumensin-80	.017
Tylan-40	.013
Calculated [a] nutrient content., dry matter basis	
NEm, Mcal/cwt.	96.8
NEg, Mcal/cwt.	62
Crude protein, %[b]	12.2
Potassium, %[c]	.51
Calcium, %[c]	.48
Phosphorous, %[c]	.31
Magnesium, %	.15
Cobalt, ppm	.09
Copper, ppm	7.4
Iron, ppm	45
Manganese, ppm	44.0
Zinc, ppm	34.9

[a] NRC (1984)

[b] based on Kjeldahl analysis of individual feeds

[c] analyzed by commercial laboratory

Table 23. Cattle performance data for both periods and overall for various intake and protein levels.

Intake, level	adlib	lim7.5	lim7.5	lim13	lim13								
Protein, level		LOW	HIGH	LOW	HIGH	p1	p2	p3	p4	p5	p6	p7	p8
Animal weights													
interim slaughter	916	890	903	884	902	.13	.39	.25	.16	.82	.82	.23	.11
final	1249	1293	1235	1244	1258	.77	.15	.75	.46	.73	.22	.68	.94
adjusted final	1234	1319	1233	1258	1253	.32	.06	.92	.17	.57	.19	.28	.53
carcass	765	818	765	780	777	.31	.06	.92	.17	.57	.19	.28	.53
dress %	61.2	63.3	61.9	62.6	61.8	.13	.17	.43	.16	.65	.72	.14	.23
Intakes, lb													
period 1	16.3	15.2	15.0	14.4	14.3	.01	.63	.73	.56	.07	.93	.02	.01
period 2	19.8	17.1	17.4	18.8	19.1	.15	.83	.85	.78	.21	.99	.09	.50
overall	17.2	16.2	15.7	16.1	15.9	.08	.55	.84	.60	.98	.81	.13	.10
Average daily gains													
period 1	3.53	3.54	3.25	2.95	3.12	.07	.15	.37	.68	.05	.11	.51	.01
period 2	3.14	3.03	3.08	3.00	3.32	.89	.90	.39	.47	.73	.55	.77	.95
period 2 live basis	3.33	2.84	3.12	2.92	3.38	.31	.40	.24	.18	.59	.71	.28	.52
total, live basis	3.24	3.23	3.05	2.89	3.07	.32	.43	.45	.96	.41	.27	.66	.20
total, ??	3.31	3.12	3.07	2.82	3.09	.14	.79	.31	.55	.52	.33	.34	.11
Feed : Gains													
period 1	4.66	4.31	4.65	4.92	4.57	.73	.08	.08	.97	.10	.02	.32	.61
period 2	6.38	5.60	5.66	6.29	5.80	.18	.89	.38	.58	.37	.43	.14	.44
overall	5.36	5.00	5.15	5.59	5.19	.45	.48	.11	.42	.13	.10	.18	.85
period 2 live	6.04	6.05	5.61	6.44	5.67	.82	.42	.24	.18	.65	.68	.68	.97
overall live	5.23	5.21	5.13	5.70	5.14	.71	.74	.06	.11	.28	.17	.80	.36
Gains, lb													
period 1	349	323	336	318	336	.13	.39	.25	.16	.82	.82	.23	.11
period 2	273	392	302	352	321	.03	.03	.44	.05	.74	.24	.05	.06
total	632	717	632	656	651	.32	.06	.92	.17	.57	.19	.28	.53
Days on feed													
period 1	101	92	105	108	108	.79	.13	.96	.28	.15	.25	.69	.34
total	199	223	208	227	213	.03	.12	.20	.07	.66	.91	.07	.03
weight difference	-15	27	-1.5	12.9	-5.3	.16	.18	.43	.16	.63	.73	.17	.29

Table 24. Effects of intake level on cattle performance data for both periods and overall.

Item	adlib	lim7.5	lim13	P< (5)	P< (7)	P< (8)
Weights, lb						
end period 1	916	896.5	893	.82	.23	.11
final	1249	1264	1251	.73	.68	.94
Adjusted final	1234	1276	1256	.57	.28	.53
carcass	765	792	779	.57	.28	.53
dress %	61.2	62.6	62.2	.65	.14	.23
Intakes, lb						
period 1	16.3	15.1	14.4	.07	.02	.001
period 2	19.8	17.3	19.0	.21	.09	.50
overall	17.2	15.95	16	.98	.13	.10
Average daily gains						
period 1	3.53	3.40	3.04	.05	.51	.01
period 2	3.14	3.055	3.16	.73	.77	.95
total	3.24	3.14	2.98	.41	.66	.20
period 2 live	3.33	2.98	3.15	.59	.28	.52
total, live	3.31	3.10	2.96	.52	.34	.11
Feed: Gains						
period 1	4.66	4.48	4.75	.10	.32	.61
period 2	6.38	5.63	6.05	.37	.14	.44
overall	5.36	5.075	5.39	.13	.18	.85
period 2 live	6.04	5.83	6.06	.65	.68	.97
overall live	5.23	5.17	5.42	.28	.80	.36
Gains						
period 1	349	330	327	.82	.23	.11
period 2	273	347	337	.74	.05	.06
total	632	675	654	.57	.28	.53
Days on feed						
period 1	101	99	108	.15	.69	.34
total	199	216	220	.66	.07	.03
weight difference	-15	12.75	3.8	.63	.17	.29

Table 25. Effects of protein level on cattle performance during both periods and overall.

Item	LOW	HIGH	P< (4)
Weights, lb			
end period 1	887	903	.16
final	1269	1247	.46
Adjusted final	1289	1243	.17
carcass	799	771	.17
dress %	63.0	61.9	.16
Intakes, lb			
period 1	14.8	14.7	.56
period 2	18.0	18.30	.78
overall	16.2	15.8	.60
Average daily gains, lb/d			
period 1	3.25	3.19	.68
period 2	3.02	3.20	.47
total	3.06	3.06	.96
period 2 live	2.88	3.25	.18
live	2.97	3.08	.55
Feed:gains			
period 1	4.62	4.61	.97
period 2	5.95	5.73	.58
overall	5.30	5.17	.42
period 2 live	6.245	5.64	.18
overall live	5.46	5.14	.11
Gains			
period 1	321	336	.16
period 2	372	312	.05
gain	687	642	.17
Days on feed			
period 1	100	107	.28
total	225	211	.07
weight difference	19.95	-3.4	.16

Table 26. Ad libitum vs restricted feeding effects on cattle performance data for both periods and overall.

Item	Ad libitum	Restricted	P< (1)
Weights, lb			
end of period 1	916	895	.13
final, live	1249	1258	.77
Adjusted final	1234	1265	.32
carcass	765	785	.31
dress %	61.2	62.4	.13
Intake, lb			
period 1	16.3	14.7	.01
period 2	19.8	18.1	.15
overall	17.2	16.0	.08
Average daily gains, lb/d			
period 1	3.53	3.22	.07
period 2	3.14	3.11	.89
total	3.24	3.06	.32
period 2 live	3.33	3.07	.31
total live	3.31	3.03	.14
Feed: Gains			
period 1	4.66	4.61	.73
period 2	6.38	5.84	.18
overall	5.36	5.23	.45
period 2 live	6.04	5.94	.82
overall live	5.23	5.30	.71
Gains			
period 1	349	328	.13
period 2	273	342	.03
gain	632	664	.32
Days on feed			
period 1	101	103	.79
total	199	218	.03
weight difference	-15	8.275	.16

Table 27. Body part, internal organs and carcass composition at the end of the restriction period for intake and protein levels.

| Intake level | adlib | lim7.5 | lim7.5 | lim13 | lim13 | | | | | | | | | |
Protein level		LOW	HIGH	LOW	HIGH	SEM	p1	p2	p3	p4	p5	p6	p7	p8
Live weight, lb	883	866	881	893	893	19.1	.98	.57	.99	.71	.32	.71	.71	.66
Carcass weight, lb	533	525	515	518	534	11.1	.46	.53	.38	.80	.60	.29	.37	.64
Dress, %	60.4	60.6	58.5	57.9	59.7	.52	.05	.01	.06	.76	.19	.01	.18	.05
Body part weight, lb														
Hooves	17.5	16.5	17	17.2	16.5	.98	.56	.72	.67	.93	.95	.58	.57	.61
Head	32.2	30.1	30.8	31.6	30.6	.94	.21	.61	.54	.90	.48	.42	.15	.37
Hide	67.6	70.8	75.2	69.8	70.4	3.47	.34	.37	.91	.51	.41	.61	.23	.58
Liver	12.4	12.7	11.6	10.7	11.7	.62	.36	.24	.33	.97	.14	.14	.80	.16
Pluck	14.1	12.0	13.7	11.9	13.3	.80	.16	.16	.29	.1	.75	.89	.24	.17
Heart.	3.4	3.4	3.4	3.1	3.5	.17	.91	.80	.14	.33	.59	.19	.92	.75
Tail.	2.0	2.7	2.2	2.3	2.4	.24	.20	.13	.69	.47	.57	.19	.16	.34
Rumen.	121	118	139	143	130	6.0	.12	.05	.19	.56	.20	.05	.33	.07
Small intestine	24.3	25.0	25.7	28.8	22.8	2.8	.68	.86	.21	.40	.87	.28	.76	.67
Large intestine	13.9	14.2	13.6	13.6	11.5	13.4	.73	.81	.46	.47	.45	.68	.99	.54
External items	119	120	125	121	120	4.0	.64	.37	.90	.63	.57	.49	.50	.84
Internal organs	189	185	207	211	193	7.7	.28	.06	.16	.85	.45	.05	.47	.21
Gut	159	157	179	185	164	7.3	.17	.05	.09	.99	.33	.05	.36	.11
Carcass traits														
Maturity	128	123	121	123	126	2.8	.16	.69	.58	.87	.36	.49	.11	.34
Marbling[x]	231	205	261	222	261	23.7	.82	.12	.33	.09	.71	.74	.95	.72
Backfat, in	.24	.30	.26	.19	.33	.12	.61	.59	.10	.34	.67	.11	.52	.77
Adjusted backfat, in	.31	.33	.31	.21	.39	.10	.94	.77	.05	.10	.63	.05	.79	.91
Ribeye area, in2	10.4	10.5	10.4	10.0	10.6	.44	.99	.79	.36	.60	.73	.38	.91	.88
KPH, %	2.03	2.37	1.9	1.75	2.14	.18	.99	.09	.21	.84	.30	.05	.66	.69
Body composition														
Fat, %	27.8	29.5	25.3	24.6	28.6	2.34	.77	.22	.31	.97	.74	.12	.89	.69
Water, %	52.6	51.4	54.5	55	52	1.77	.77	.22	.31	.97	.74	.12	.89	.69
Protein, %	16.3	15.9	16.8	16.9	16.1	.47	.77	.22	.31	.97	.75	.12	.88	.69
Energy	3.5	3.64	3.29	3.23	3.56	.20	.77	.22	.31	.97	.75	.12	.88	.69
Fat, lb.	148	155	130	128	156	13.5	.74	.22	.23	.91	.99	.09	.76	.75
Water, lb.	281	270	281	284	275	11.0	.81	.47	.61	.94	.68	.39	.70	.96
Protein, lb	87	84	86	87	85	3.03	.77	.53	.68	.93	.66	.47	.65	.93

Table 27 continued.

Intake level	adlib	lim7.5	lim7.5	lim13	lim13									
Protein level		LOW	HIGH	LOW	HIGH	SEM	p1	p2	p3	p4	p5	p6	p7	p8
Body part, % BW														
Hooves	1.99	1.90	1.93	1.93	1.86	.12	.56	.87	.77	.91	.86	.74	.64	.55
Head	3.65	3.48	3.49	3.55	3.45	.12	.27	.93	.58	.72	.88	.63	.28	.34
Hide	7.66	8.15	8.52	7.82	7.86	.29	.22	.38	.93	.52	.12	.62	.09	.63
Liver	1.40	1.47	1.32	1.20	1.31	.07	.40	.15	.37	.78	.08	.11	.98	.15
Pluck	1.59	1.39	1.56	1.33	1.5	.08	.14	.17	.25	.09	.46	.98	.27	.11
Heart	.38	.40	.39	.35	.40	.02	.89	.66	.15	.39	.35	.16	.80	.62
Tail	2.04	2.73	2.2	2.26	2.41	.03	.23	.13	.67	.48	.51	.18	.17	.39
Rumen	13.6	13.7	15.7	16.1	14.6	.57	.06	.05	.13	.64	.27	.05	.16	.05
Small intestine	2.72	2.87	2.92	3.2	2.6	.30	.65	.91	.22	.39	.98	.30	.66	.69
Large intestine	1.59	1.61	1.54	1.54	1.29	.20	.68	.79	.46	.46	.44	.69	.95	.50

[x] slight amount of marbling =200, small amount of marbling = 300.

Table 28. Effects of intake level on body part, internal organs and carcass composition at the end of the restriction period.

Item	Adlib	lim7.5	lim13	SEM	P< (5)	P< (7)	P< (8)
Live weight, lb	883	874	893	19.1	.32	.71	.66
Carcass weight, lb	533	520	526	11.1	.60	.37	.64
Dress, %	60.4	59.5	58.8	.52	.19	.18	.05
Body part weights, lb							
Hooves	17.5	16.8	16.9	.98	.95	.57	.61
Head	32.2	30.45	31.1	.94	.48	.15	.37
Hide	67.6	73	70.1	3.47	.41	.23	.58
Liver.	12.4	12.2	11.2	.624	.14	.80	.16
Pluck	14.1	12.9	12.6	.802	.75	.24	.17
Heart	3.4	3.4	3.3	.171	.59	.92	.75
Tail.	2.0	2.5	2.3	.236	.57	.16	.34
Rumen	121	129	137	5.99	.20	.33	.07
Small intestine	24.3	25.4	25.8	2.80	.87	.76	.67
Large intestine	13.9	13.9	12.6	13.4	.45	.99	.54
External items	119	123	121	3.99	.57	.50	.84
Internal organs	189	196	202	7.70	.45	.47	.21
Gut	159	168	175	7.25	.33	.36	.11
Carcass traits							
Maturity	128	122	125	2.75	.36	.11	.34
Marbling[x]	231	233	242	23.7	.71	.95	.72
Backfat, in	.24	.28	.26	.12	.67	.52	.77
Adjusted backfat, in	.31	.32	.30	.10	.63	.79	.91
Ribeye area, in2	10.4	10.5	10.3	.44	.73	.91	.88
KPH, %	2.03	2.13	1.94	.18	.30	.66	.69
Body composition							
Fat, %	27.8	27.4	26.6	2.34	.74	.89	.69
Water, %	52.6	53	53.5	1.77	.74	.89	.69
Protein, %	16.3	16.4	16.5	.467	.75	.88	.69
Energy	3.5	3.5	3.4	.197	.75	.88	.69
Fat, lb.	148	142.5	142	13.5	.99	.76	.75
Water, lb.	281	276	280	11.0	.68	.70	.96
Protein, lb.	87	85	86	3.03	.66	.65	.93
Body parts, % BW							
Hooves	1.99	1.92	1.90	.12	.86	.64	.55
Head	3.65	3.49	3.5	.12	.88	.28	.34
Hide	7.66	8.33	7.84	.29	.12	.09	.63
Liver	1.40	1.40	1.32	.07	.08	.98	.15
Pluck	1.59	1.48	1.42	.08	.46	.27	.11
Heart	.38	.39	.38	.02	.35	.80	.62
Tail	.23	.28	.26	.03	.51	.17	.39
Rumen	13.6	14.7	15.4	.57	.27	.16	.05
Small intestine	13.6	14.7	15.4	.30	.98	.66	.69
Large intestine	1.59	1.58	1.42	.20	.44	.95	.50

[x] slight amount of marbling =200, small amount of marbling = 300.

Table 29. Effect of protein level on body part, internal organs and carcass composition at the end
of the restriction period.

Protein level	LOW	HIGH	SEM	P <
Live weight, lb	880	888	19.1	.71
Carcass weight, lb	522	525	11.1	.80
Dress, %	59.3	59.1	.52	.76
Body part weights, lb				
Hooves	16.9	16.8	.98	.93
Head	30.9	30.7	.94	.90
Hide	70.3	72.8	3.47	.51
Liver	11.7	11.7	.624	.97
Pluck	12.0	13.5	.802	.10
Heart	3.3	3.5	.171	.33
Tail.	2.5	2.3	.236	.47
Rumen	131	135	5.99	.56
Small intestine	26.9	24.5	2.80	.40
Large intestine	13.9	12.6	13.4	.47
External items	121	123	3.99	.63
Internal organs	198	200	7.70	.85
Gut	171	172	7.25	.99
Carcass traits				
Maturity	123	124	2.75	.87
Marbling[x]	214	261	23.7	.09
Backfat, in	.24	.30	.12	.34
Adjusted backfat, in	.27	.35	.10	.10
Ribeye area, in2	10.2	10.5	.44	.60
KPH, %	2.06	2.02	.18	.84
Body composition				
Fat, %	27.1	27.0	2.34	.97
Water, %	53.2	53.3	1.77	.97
Protein, %	16.4	16.5	.467	.97
Energy	3.44	3.43	.197	.97
Fat, lb.	142	143	13.5	.91
Water, lb.	277	278	11.0	.94
Protein, lb	86	86	3.03	.93
Body part, % BW				
Hooves	1.92	1.90	.12	.91
Head	3.51	3.47	.12	.72
Hide	7.99	8.19	.29	.52
Liver	1.34	1.32	.07	.78
Pluck	1.36	1.53	.08	.09
Heart	.38	.40	.02	.39
Tail	.28	.26	.03	.48
Rumen	14.9	15.2	.57	.64
Small intestine	3.03	2.76	.30	.39
Large intestine	1.58	1.42	.20	.46

[x] slight amount of marbling =200, small amount of marbling = 300.

Table 30. Effect of intake level on body part, internal organs and carcass composition at the end of the restriction period.

INTAKE	Ad Libitum	Restricted	SEM	P<
Live weight, lb	883	883	19.1	.98
Carcass weight, lb	533	523	11.1	.46
Dress, %	60.4	59.2	.52	.05
Body part weights, lb				
Hooves	17.5	16.8	.98	.56
Head	32.2	30.8	.94	.21
Hide	68	72	3.47	.34
Liver	12.4	11.7	.624	.36
Pluck	14.1	12.7	.802	.16
Heart	3.4	3.4	.171	.91
Tail	2.0	2.4	.236	.20
Rumen	121	133	5.99	.12
Small intestine	24.3	25.6	2.80	.68
Large intestine	13.9	13.2	13.4	.73
External items	119	122	3.99	.64
Internal organs	189	199	7.70	.28
Gut	159	171	7.25	.17
Carcass traits				
Maturity	128	123	2.75	.16
Marbling[x]	231	237	23.7	.82
backfat, in	.24	.27	.12	.61
adjusted back fat, in	.31	.31	.10	.94
Ribeye area, in^2	10.4	10.4	.44	.99
KPH, %	2.03	2.04	.18	.99
Body composition				
Fat, %	27.8	27	2.34	.77
Water, %	52.6	53.2	1.77	.77
Protein, %	16.3	16.4	.467	.77
Energy	3.5	3.43	.197	.77
Fat, lb.	148	142	13.5	.74
Water, lb.	281	278	11.0	.81
Protein, lb.	87	86	3.03	.77
Body parts, % BW				
Hooves	1.99	1.91	.12	.56
Head	3.65	3.49	.12	.27
Hide	7.66	8.09	.29	.22
Liver	1.4	1.33	.07	.40
Pluck	1.59	1.45	.08	.14
Heart	.38	.39	.02	.89
Tail	.23	.27	.03	.23
Rumen	13.6	15.0	.57	.06
Small intestine	2.72	2.90	.30	.65
Large intestine	1.59	1.50	.20	.68

[x] slight amount of marbling =200, small amount of marbling = 300.

Table 31. **Final carcass composition, organ weights and carcass traits for feeding and protein levels.**

| Intake level | Adlib | lim7.5 | lim7.5 | lim13 | lim13 | | | | | | | | | |
Protein level		LOW	HIGH	LOW	HIGH	SEM	p1	p2	p3	p4	p5	p6	p7	p8
Live weight, lb	1230	1261	1200	1221	1235	22.3	.97	.10	.71	.41	.91	.10	.99	.93
Carcass weight, lb	758	787	742	764	764	17.3	.74	.11	.99	.32	.99	.18	.77	.77
Dressing percent	61.6	62.3	61.8	62.5	61.9	.84	.50	.70	.65	.60	.90	.94	.61	.51
Body part weight, lb														
Hooves	19.5	20.1	18.9	19.6	20.6	.55	.27	.01	.01	.77	.05	.01	.97	.06
Head	38.7	41.3	37.8	39.7	39.0	.81	.36	.02	.61	.07	.82	.10	.37	.46
Hide	92.4	88.6	89.2	87.9	101	5.8	.90	.95	.19	.37	.40	.28	.61	.77
Liver	14.7	14	14	13.5	15.1	.96	.60	.96	.34	.52	.78	.44	.56	.74
Pluck	17	16.8	15.6	16	16	.70	.23	.32	.97	.55	.80	.39	.35	.23
Heart	4.6	4.9	4.6	4.6	4.6	.24	.80	.44	.85	.71	.46	.42	.58	.88
Tail	3	3	3.1	3.3	3.1	.22	.58	.87	.58	.81	.54	.55	.85	.43
Small intestine	30	31.2	31.8	35.6	31.3	1.96	.23	.87	.19	.45	.37	.22	.53	.14
Large intestine	15.3	14.9	14.3	13.2	13	1.25	.28	.74	.93	.80	.28	.84	.66	.15
Rumen	158	183	160	183	159	9.8	.19	.16	.15	.10	.97	.93	.25	.24
External	153	153	148	150	163	5.75	.90	.60	.20	.60	.35	.13	.73	.56
Internal	240	265	241	267	239	11.4	.26	.19	.14	.09	.99	.85	.33	.31
Gut	203	229	206	232	203	10.6	.20	.19	.11	.08	.99	.76	.26	.24
Carcass characteristics														
Maturity[x]	148	154	147	151	139	6.4	.99	.49	.26	.26	.44	.68	.72	.69
Marbling	266	235	249	297	264	25.6	.84	.73	.43	.77	.19	.34	.43	.62
Yield grade	3.4	3.0	3.0	3.2	3.2	.37	.46	.94	.94	.99	.61	.92	.40	.69
Adjusted backfat, in	.54	.49	.69	.58	.52	.14	.76	.05	.84	.24	.57	.07	.99	.58
Ribeye area, in2	11.8	13.2	12.3	12.5	11.3	.32	.16	.11	.05	.05	.05	.61	.05	.95
KPH,%	2.61	2.38	2.32	2.12	2.03	.19	.07	.82	.77	.75	.21	.95	.26	.05
Body composition														
Fat, %	30.0	29.6	29.1	28.6	28.2	1.12	.32	.76	.81	.73	.45	.96	.61	.21
Water, %	50.9	51.2	51.6	52	52.3	.85	.32	.76	.81	.73	.45	.96	.61	.22
Protein, %	15.8	15.9	16.0	16.1	16.2	.23	.32	.76	.80	.73	.45	.97	.61	.22
Energy	3.69	3.65	3.61	3.57	3.53	.09	.33	.77	.81	.74	.45	.97	.61	.22
Fat, lb.	228	233	215	219	214	9.5	.43	.24	.76	.35	.46	.46	.73	.29
Water, lb.	386	403	383	397	400	11.6	.39	.30	.85	.59	.66	.31	.60	.33
Protein, lb.	120	125	119	123	124	3.4	.42	.26	.86	.55	.69	.28	.61	.36

Table 31 continued.

Intake level	Adlib	lim7.5	lim7.5	lim13	lim13									
Protein level		LOW	HIGH	LOW	HIGH	SEM	p1	p2	p3	p4	p5	p6	p7	p8
Body parts, %BW														
Hooves	1.59	1.60	1.59	1.61	1.65	.03	.53	.80	.35	.65	.26	.32	.99	.27
Head	3.15	3.29	3.15	3.27	3.16	.08	.45	.32	.44	.28	.96	.86	.50	.51
Hide	7.64	6.99	7.52	7.22	8.06	.42	.65	.43	.23	.22	.41	.69	.44	.99
Liver	1.18	1.11	1.17	1.11	1.22	.07	.66	.54	.32	.32	.77	.72	.61	.81
Pluck	1.38	1.33	1.30	1.32	1.32	.06	.26	.79	.99	.87	.95	.84	.32	.32
Heart	.38	.39	.39	.37	.38	.02	.85	.91	.96	.97	.44	.89	.61	.83
Tail	.24	.24	.26	.27	.25	.22	.50	.53	.59	.97	.57	.34	.75	.38
Small intestine	2.44	2.46	2.69	2.86	2.59	.14	.14	.30	.24	.91	.33	.08	.40	.08
Large intestine	1.24	1.18	1.20	1.07	1.07	.10	.29	.87	.99	.92	.26	.88	.69	.14
Rumen	12.8	14.4	13.5	14.9	13.0	.77	.17	.44	.15	.17	.95	.52	.24	.20

[x] slight amount of marbling =200, small amount of marbling = 300.

Table 32. Intake level effects on final body composition, organ weights and carcass traits.

Item	Ad libitum	lim7.5	lim13	SEM	P< (5)	P< (7)	P< (8)
Live weight, lb	1230	1231	1228	22.3	.91	.99	.93
Carcass weight, lb	758	765	764	17.3	.99	.77	.77
Dressing percent	61.6	62.1	62.2	.84	.90	.61	.51
Body part weights, lb							
Hooves	19.5	19.5	20.1	.55	.05	.97	.06
Head	38.7	39.6	39.4	.81	.82	.37	.46
Hide	92.4	88.9	94.4	5.8	.40	.61	.77
Liver	14.7	14.0	14.3	.96	.78	.56	.74
Pluck	17.0	16.2	16.0	.70	.80	.35	.23
Heart	4.6	4.8	4.6	.24	.46	.58	.88
Tail	3.0	3.1	3.2	.22	.54	.85	.43
Small intestine	30.0	31.5	33.5	1.96	.37	.53	.14
Large intestine	15.3	14.6	13.1	1.25	.28	.66	.15
Rumen	158	172	171	9.8	.97	.25	.24
External	153	151	157	5.75	.35	.73	.56
Internal	240	253	253	11.4	.99	.33	.31
Gut	203	218	218	10.6	.99	.26	.24
Carcass characteristics							
Maturity	148	151	145	6.4	.44	.72	.69
Marbling[x]	266	242	281	25.6	.19	.43	.62
PYG	.52	.52	.56	.15	.57	.99	.58
ADJPYG	.54	.55	.55	.14	.99	.83	.81
Ribeye area, in2	11.8	12.8	11.9	.32	.05	.05	.95
KPH,%	2.61	2.35	2.08	.19	.21	.26	.05
Body composition							
Fat, %	30.0	29.4	28.4	1.12	.45	.61	.21
Water, %	50.9	51.4	52.2	.85	.45	.61	.22
Protein, %	15.8	16.0	16.2	.23	.45	.61	.22
Energy	3.69	3.63	3.55	.09	.45	.61	.22
Fat, lb.	228	224	217	9.5	.46	.73	.29
Water, lb.	386	393	399	11.6	.66	.60	.33
Protein, lb.	120	122	124	3.4	.69	.61	.36
Body parts, %BW							
Hooves	1.59	1.60	1.63	.03	.26	.99	.27
Head	3.15	3.22	3.22	.08	.96	.50	.51
Hide	7.64	7.26	7.64	.42	.41	.44	.99
Liver	1.18	1.14	1.17	.07	.77	.61	.81
Pluck	1.38	1.32	1.32	.06	.95	.32	.32
Heart	.38	.39	.38	.02	.44	.61	.83
Tail	.24	.25	.26	.22	.57	.75	.38
Small intestine	2.44	2.58	2.73	.14	.33	.40	.08
Large intestine	1.24	1.19	1.07	.10	.26	.69	.14
Rumen	12.8	13.95	13.95	.77	.95	.24	.20

[x] slight amount of marbling =200, small amount of marbling = 300.

Table 33. Protein level effects on final carcass composition, organ weights and carcass traits.

Item	Low protein	High protein	SEM	P< (4)
Live weight	1241	1218	22.3	.41
Carcass weight	775	753	17.3	.32
Dress, %	62.4	61.9	.84	.60
Body part weights, lb				
Hooves	19.9	19.8	.55	.77
Head	40.5	38.4	.81	.07
Hide	88.3	95.0	5.8	.37
Liver	13.8	14.6	.96	.52
Pluck	16.4	15.8	.70	.55
Heart	4.8	4.6	.24	.71
Tail	3.2	3.1	.22	.81
Small intestine	33.4	31.6	1.96	.45
Large intestine	14.1	13.7	1.25	.80
Rumen	183	160	9.8	.10
External	152	156	5.75	.60
Internal	266	240	11.4	.09
Gut	231	205	10.6	.08
Carcass characteristics				
Maturity[x]	153	143	6.4	.26
Marbling	266	257	25.6	.77
PYG	.49	.58	.15	.24
ADJPYG	.53	.57	.14	.63
Ribeye area, in2	12.9	11.8	.32	.05
KPH,%	2.25	2.18	.19	.75
Body composition				
Fat, %	29.1	28.7	1.12	.73
Water, %	51.6	52.0	.85	.73
Protein, %	16.0	16.1	.23	.73
Energy	3.61	3.57	.09	.74
Fat, lb	226	215	9.5	.35
Water, lb	400	392	11.6	.59
Protein, lb	124	122	3.4	.55
Body parts, % BW				
Hooves	1.61	1.62	.03	.65
Head	3.28	3.16	.08	.28
Hide	7.10	7.79	.42	.22
Liver	1.11	1.20	.07	.32
Pluck	1.33	1.31	.06	.87
Heart	.38	.39	.02	.97
Tail	.26	.26	.22	.97
Small intestine	2.66	2.64	.14	.91
Large intestine	1.13	1.14	.10	.92
Rumen	14.7	13.3	.77	.17

[x] slight amount of marbling =200, small amount of marbling = 300.

Table 34. Final body composition, organ weights and carcass characteristics.

Item	ad libitum	limit	SEM	P< (1)
Live weight, lb	1230	1230	22.3	.97
Carcass weight, lb	758	764	17.3	.74
Dressing percent	61.6	62.1	.84	.50
Body part weights, lb				
Hooves	19.5	19.8	.55	.27
Head	38.7	39.5	.81	.36
Hide	92.4	91.6	5.8	.90
Liver	14.7	14.2	.96	.60
Pluck	17	16.1	.70	.23
Heart	4.6	4.7	.24	.80
Tail	3.0	3.1	.22	.58
Small intestine	30	32.5	1.96	.23
Large intestine	15.3	13.9	1.25	.28
Rumen	158	171	9.8	.19
External	153	154	5.75	.90
Internal	240	253	11.4	.26
Gut	203	218	10.6	.20
Carcass characteristics				
Maturity[x]	148	148	6.4	.99
Marbling	266	261	25.6	.84
PYG	.52	.54	.15	.76
ADJPYG	.54	.55	.14	.80
Ribeye area, in2	11.8	12.3	.32	.16
KPH,%	2.61	2.21	.19	.07
Body composition				
Fat, %	30	28.9	1.12	.32
Water, %	50.9	51.8	.85	.32
Protein, %	15.8	16.1	.23	.32
Energy	3.69	3.59	.09	.33
Fat, lb.	228	220	9.5	.43
Water, lb.	386	396	11.6	.39
Protein, lb.	120	123	3.4	.42
Body parts, % BW				
Hooves	1.59	1.62	.03	.53
Head	3.15	3.22	.08	.45
Hide	7.64	7.45	.42	.65
Liver	1.18	1.15	.07	.66
Pluck	1.38	1.32	.06	.26
Heart	.38	.38	.02	.85
Tail	.24	.26	.22	.50
Small intestine	2.44	2.65	.14	.14
Large intestine	1.24	1.13	.10	.29
Rumen	12.8	14.0	.77	.17

[x] slight amount of marbling =200, small amount of marbling = 300.

Table 35. Economic data for feeding and protein levels.

| Feeding level | Adlib | Lim7.5 | lim7.5 | lim15 | lim15 | | | | | | | | | |
Protein level		LOW	HIGH	LOW	HIGH	SEM	P1	P2	P3	P4	P5	P6	P7	P8
Carcass value items														
YG 4 's, %	17.5	13.2	14.3	16.6	5.0	20.5	.78	.96	.67	.78	.89	.72	.87	.74
heavy carcass, %	18.4	9.7	0	0	10.0	11.2	.18	.28	.50	.83	.84	.22	.22	.25
light carcass, %	0	0	0	0	0									
Prime, %	0	0	0	0	0									
Choice, %	18.4	0	11.8	16.5	27	17.7	.69	.36	.66	.37	.32	.78	.42	.85
Select, %	81.6	100	88	83	73	17.6	.69	.36	.66	.37	.32	.77	.42	.85
Standards, %	0	0	0	0	0									
Carcass value, $/hd	617	666	658	658	662	45	.30	.88	.94	.97	.96	.87	.38	.36
Live value, $/hd	755	782	747	753	761	19.7	.77	.15	.75	.47	.73	.22	.68	.94
Total feed costs, $/hd														
$4.00 corn	242	257	232	259	239	10.6	.59	.07	.20	.05	.68	.76	.81	.48
$3.00 corn	193	205	185	207	192	8.5	.59	.07	.20	.05	.68	.76	.81	.48
Yardage, $/hd	49.5	56	52	57	53	2.0	.02	.11	.20	.07	.66	.91	.07	.03
Profits, $/hd														
carc $4.00 corn	-83.54	-55.88	-35.13	-67.09	-39.85	40	.36	.74	.67	.60	.87	.91	.40	.45
carc $3.00 corn	-34.95	-4.25	11.56	-15.06	8.34	41	.36	.65	.61	.51	.85	.92	.40	.46
live $4.00 corn	55.10	59.77	53.70	28.21	58.96	15	.72	.72	.15	.37	.42	.17	.92	.45
live $3.00 corn	103.69	111.39	100.40	80.24	107.16	15	.78	.54	.21	.57	.47	.17	.90	.52

Table 36. Daily accretion rates for body parts for the feeding and protein levels.

Intake level Protein level	Adlib	Lim7.5 Low	Lim7.5 High	Lim13 Low	Lim13 High	P1	P2	P3	P4	P5	P6	P7	P8
Carcass weight, lbs													
period 1	2.10	2.19	1.78	1.69	2.41	.76	.21	.04	.47	.78	.03	.70	.86
period 2	2.52	2.03	2.54	2.63	1.83	.54	.33	.14	.68	.90	.09	.64	.51
Total	2.31	2.09	2.09	2.06	2.14	.05	.99	.50	.64	.96	.63	.08	.06
Dressing percent													
period 1	.036	.044	.014	.010	.029	.11	.01	.05	.36	.18	.01	.38	.04
period 2	.005	.013	.042	.041	.021	.04	.04	.11	.67	.75	.02	.09	.04
Total	.026	.026	.028	.025	.025	.98	.53	.96	.68	.50	.63	.77	.78
Hooves, grams													
period 1	23.6	18.6	19.1	17.3	22.2	.55	.94	.56	.64	.90	.72	.57	.61
period 2	13.2	14.1	9.1	15.0	10.0	.86	.55	.56	.40	.94	.99	.86	.90
Total	17.3	16.3	14.1	15.9	16.3	.13	.09	.76	.29	.51	.15	.13	.24
Head, grams													
period 1	38.6	32.7	33.1	31.3	41	.59	.96	.29	.42	.66	.48	.52	.75
period 2	32.2	39.5	39.0	41.3	28.6	.67	.97	.35	.48	.68	.53	.59	.82
Total	37.7	36.8	34.0	35.4	35.4	.20	.21	.97	.37	.96	.35	.28	.21
Hide, grams													
period 1	131	148	151	116	155	.68	.93	.24	.36	.60	.44	.57	.88
period 2	128	116	55	112	65	.25	.32	.33	.17	.80	.99	.28	.32
Total	125	122	103	109	114	.37	.30	.75	.60	.96	.34	.45	.37
Liver, grams													
period 1	21	25	16.8	10.4	16.3	.28	.10	.23	.70	.06	.06	.94	.07
period 2	12.3	5.9	8.2	14.1	14.1	.70	.70	.99	.80	.21	.78	.39	.82
Total	16.8	13.6	12.3	11.8	15.4	.09	.63	.14	.44	.71	.17	.11	.13
Pluck, grams													
period 1	25.9	13.6	19.1	11.4	23.6	.08	.37	.05	.05	.82	.39	.11	.11
period 2	15.0	16.0	6.4	20.0	8.6	.79	.29	.23	.12	.65	.93	.68	.96
Total	20.0	15.0	14.5	14.5	16.8	.03	.83	.37	.62	.58	.43	.03	.05
Heart, grams													
period 1	5.4	6.4	5.4	3.6	7.3	.81	.55	.05	.19	.51	.05	.64	.95
period 2	6.4	5.4	5.9	6.8	3.6	.62	.84	.18	.40	.92	.27	.70	.60
Total	5.9	5.9	5.5	5.0	5.4	.31	.45	.42	.98	.60	.28	.50	.23

Table 36 Continued.

| Intake level | Adlib | Lim7.5 | Lim7.5 | Lim13 | Lim13 | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 |
Protein level		Low	High	Low	High								
Tail													
period 1	4.1	8.2	5.0	5.0	6.4	.22	.06	.37	.40	.46	.06	.18	.39
period 2	4.5	.91	4.5	4.5	2.7	.44	.08	.37	.50	.73	.07	.42	.56
Total	4.2	4.1	4.6	4.6	4.1	.67	.38	.68	.73	.97	.37	.73	.67
Internal organs													
period 1	295	295	370	337	373	.53	.43	.70	.41	.77	.78	.68	.47
period 2	292	237	154	277	.373	.46	.52	.40	.30	.79	.89	.46	.56
Total	271	260	266	301	333	.63	.90	.51	.57	.19	.71	.88	.28
External parts, grams													
period 1	199	207	208	170	226	.91	.99	.21	.36	.78	.38	.84	.99
period 2	179	157	108	173	106	.40	.42	.28	.19	.89	.84	.44	.45
Total	185	180	155	164	170	.28	.22	.76	.50	.98	.28	.36	.29
Gut, grams													
period 1	242	250	329	312	326	.41	.38	.88	.46	.67	.61	.59	.33
period 2	254	209	134	236	142	.45	.52	.43	.31	.85	.92	.47	.52
Total	229	225	234	269	237	.67	.81	.38	.64	.40	.43	.99	.43

Table 37. Rate of daily accretion for carcass traits and carcass composition for the feeding and protein levels.

Intake level / Protein level	Adlib	Lim7.5 Low	Lim7.5 High	Lim13 Low	Lim13 High	P1	P2	P3	P4	P5	P6	P7	P8
Marbling	.373	.202	0	.607	.216	.66	.44	.33	.22	.26	.88	.40	.91
Adjusted PYG	.006	.003	.008	.008	.004	.76	.02	.04	.84	.58	.01	.63	.98
Ribeye area	.018	.015	.022	.022	.012	.99	.42	.27	.81	.94	.19	.97	.97
KPH, %	.006	0	.003	.001	.005	.21	.27	.30	.13	.52	.97	.19	.35
Fat accretion, %													
period 1	.045	.08	.028	.013	.064	.95	.16	.17	.99	.58	.16	.78	.84
period 2	.031	-.004	.037	.054	-.023	.64	.30	.07	.50	.99	.05	.69	.64
Total	.039	.028	.031	.026	.027	.05	.67	.79	.63	.58	.92	.13	.04
Water accretion, %													
period 1	-.034	-.061	-.022	-.01	-.049	.95	.16	.16	.99	.57	.06	.78	.84
period 2	-.024	.003	-.028	-.041	.017	.64	.30	.07	.51	.99	.05	.70	.65
Total	-.029	-.026	-.024	-.019	-.020	.13	.77	.88	.92	.22	.76	.40	.05
Protein accretion, %													
period 1	-.009	-.016	-.005	-.003	-.013	.97	.15	.17	.96	.59	.06	.80	.83
period 2	-.006	.001	-.007	-.011	.004	.63	.30	.07	.50	.99	.05	.68	.65
Total	-.008	-.007	-.006	-.005	-.005	.10	.75	.97	.80	.18	.85	.35	.05
Fat accretion, grams													
period 1	325	419	254	210	423	.99	.13	.06	.75	.81	.05	.91	.93
period 2	417	259	416	463	164	.39	.23	.04	.43	.83	.03	.52	.36
Total	370	333	322	306	310	.04	.69	.91	.84	.38	.72	.14	.03
Water accretion, grams													
period 1	454	414	404	407	486	.70	.90	.36	.57	.58	.46	.58	.91
period 2	527	481	536	527	486	.87	.69	.76	.95	.99	.63	.88	.87
Total	490	450	459	454	477	.23	.78	.46	.47	.56	.75	.21	.37
Protein accretion, grams													
period 1	142	132	128	125	155	.73	.85	.23	.46	.59	.33	.61	.94
period 2	168	151	166	168	149	.78	.71	.65	.96	.99	.56	.82	.79
Total	155	141	143	143	150	.18	.83	.41	.46	.59	.67	.18	.29

Table 38. Accretion rates per unit of body weight for body part weights for the different feeding and protein levels.

Intake level / Protein level	Adlib	Lim7.5 Low	Lim7.5 High	Lim13 Low	Lim13 High	SEM	P1	P2	P3	P4	P5	P6	P7	P8
Carcass weight, gms														
period 1	309	307	278	273	289	7.66	.02	.01	.16	.39	.16	.01	.09	.01
period 2	289	294	328	332	316	17.5	.16	.19	.53	.62	.45	.18	.32	.12
Total	299	301	296	303	301	5.38	.85	.47	.88	.53	.53	.68	.93	.67
Dressing percent, %														
period 1	.007	.01	.004	.003	.005	.001	.30	.02	.29	.34	.07	.02	.85	.10
period 2	.001	.003	.009	.009	.007	.002	.05	.17	.54	.56	.50	.16	.13	.04
Total	.007	.007	.007	.007	.008	.001	.77	.87	.87	1.0	.66	.82	.92	.66
Hooves, grams														
period 1	6.47	4.42	5.22	5.10	4.54	1.40	.31	.69	.77	.93	1.0	.63	.35	.35
period 2	3.06	3.74	2.27	3.17	2.15	1.34	.88	.45	.60	.37	.80	.86	.97	.81
Total	4.54	4.99	4.42	4.42	4.31	.200	.99	.06	.69	.11	.11	.28	.49	.50
Head, grams														
period 1	10.21	6.81	9.08	9.08	9.08	1.60	.36	.33	1.0	.49	.49	.49	.27	.57
period 2	6.47	10.2	7.94	10.21	8.74	1.78	.18	.38	.56	.31	.82	.82	.25	.19
Total	10.44	11.58	9.08	9.08	9.08	.382	.11	.01	1.0	.01	.01	.01	.81	.01
Hide, grams														
period 1	37.45	43.13	48.80	40.86	38.59	4.05	.25	.34	.69	.68	.14	.34	.11	.65
period 2	29.85	27.12	15.89	24.97	21.56	6.27	.30	.22	.70	.26	.78	.54	.29	.40
Total	34.73	29.62	30.64	32.91	31.78	5.13	.55	.89	.87	.99	.67	.83	.47	.71
Liver, grams														
period 1	4.88	6.81	4.42	2.83	3.97	1.01	.75	.12	.44	.55	.05	.10	.56	.26
period 2	2.01	1.38	2.60	3.40	4.08	1.10	.49	.44	.67	.40	.13	.80	.99	.22
Total	4.31	4.20	3.97	3.63	4.31	.326	.45	.63	.16	.50	.73	.19	.58	.41
Pluck, grams														
period 1	5.56	4.20	4.08	2.81	5.33	.921	.18	.93	.07	.21	.94	.17	.23	.21
period 2	3.18	3.97	1.86	4.20	3.97	1.67	.86	.39	.92	.49	.49	.58	.90	.66
Total	5.10	4.65	3.97	4.42	4.54	.445	.18	.30	.86	.53	.71	.39	.17	.27
Heart, grams														
period 1	1.70	1.81	1.70	1.13	1.81	.281	.79	.78	.11	.33	.32	.18	.86	.51
period 2	1.36	1.36	1.47	1.81	1.25	.361	.78	.82	.29	.54	.75	.36	.90	.70
Total	1.59	1.70	1.47	1.36	1.47	.100	.45	.13	.43	.58	.11	.11	.99	.18

Table 38 Continued.

Intake level Protein level	Adlib	Lim7.5 Low	Lim7.5 High	Lim13 Low	Lim13 High	SEM	P1	P2	P3	P4	P5	P6	P7	P8
Tail, grams														
period 1	1.33	2.27	1.24	1.55	1.47	.369	.48	.07	.88	.16	.52	.22	.37	.70
period 2	1.02	.202	.907	1.31	1.14	.434	.79	.27	.78	.54	.14	.33	.39	.70
Total	.907	1.02	1.13	1.36	1.25	.141	.09	.58	.59	.99	.13	.44	.34	.04
Internal organs, grams														
period 1	72.75	86.2	110	119	94.2	9.56	.01	.10	.08	.95	.39	.02	.05	.01
period 2	61.74	74.91	38.59	74.91	62.42	15.4	.95	.12	.57	.14	.45	.45	.79	.72
Total	57.88	80.92	83.5	94.2	82.8	12.6	.07	.88	.53	.73	.62	.59	.14	.07
External dress off														
period 1	57.8	61.2	68.1	61.2	56.7	4.97	.48	.35	.53	.82	.27	.27	.28	.85
period 2	40.8	44.2	29.5	43.1	36.3	6.86	.74	.15	.49	.14	.68	.57	.64	.89
Total	51.4	55.7	50.1	49.9	49.9	3.33	.99	.26	1.0	.42	.38	.42	.71	.72
Gut														
period 1	67.53	69.4	71.9	82.8	70.3	6.47	.41	.78	.19	.45	.38	.26	.69	.27
period 2	55.6	71.5	96.4	108	81.7	9.27	.01	.08	.06	.90	.24	.01	.02	.01
Total	52.2	65.8	32.9	65.8	51.0	14.0	.91	.12	.47	.11	.52	.52	.87	.72

Table 39. Accretion rates per unit of body weight for carcass traits and composition for the different feeding and protein levels.

	Adlib	Lim7.5 Low	Lim7.5 High	Lim13 Low	Lim13 High	SEM	P1	P2	P3	P4	P5	P6	P7	P8
Intake level / Protein level														
Marbling	.070	.075	.005	.215	.052	.089	.86	.59	.22	.22	.31	.61	.79	.57
PYG	.001	.0006	.002	.006	.001	.001	.60	.49	.10	.48	.18	.11	.93	.31
Adjusted PYG	.001	.0007	.002	.002	.001	.0005	.82	.14	.61	.48	.48	.17	.93	.62
Ribeye area														
KPH, %	.001	.00002	.001	.0006	.001	.0008	.76	.42	.33	.22	.42	.89	.54	.96
Fat accretion, %														
period 1	.015	.019	.007	-.0005	.015	.006	.51	.20	.09	.75	.35	.04	.83	.33
period 2	.007	-.003	.010	.010	-.007	.006	.53	.18	.10	.80	.72	.04	.66	.47
Total	.010	.009	.007	.003	.007	.002	.16	.55	.21	.63	.20	.20	.44	.08
Water accretion, %														
period 1	-.012	-.013	-.005	.003	-.013	.005	.45	.30	.05	.45	.45	.04	.69	.32
period 2	-.005	.001	-.006	-.005	.005	.004	.42	.28	.13	.73	.58	.07	.60	.34
Total	-.008	-.007	-.004	-.006	-.006	.001	.15	.04	.88	.11	.53	.16	.12	.28
Protein accretion, %														
period 1	-.003	-.004	-.002	.0002	-.003	.001	.55	.26	.07	.59	.29	.04	.91	.33
period 2	-.001	-.001	-.002	-.002	-.0001	.001	.91	.62	.36	.76	.68	.32	.78	.94
Total	-.001	-.001	-.001	-.001	-.001	.0004	.29	.67	.67	.54	.54	1.0	.23	.46
Fat accretion, grams														
period 1	113	124	86.2	61.2	119	18.1	.45	.15	.04	.60	.41	.02	.72	.31
period 2	104	78.3	120	119	59.0	19.1	.65	.14	.04	.64	.60	.02	.84	.53
Total	106	320	98.4	114	96.4	96.7	.64	.13	.89	.23	.30	.31	.40	.99
Water accretion, gram														
period 1	140	130	138	153	120	14.7	.76	.71	.14	.41	.88	.19	.73	.82
period 2	131	154	148	150	187	21.6	.25	.85	.25	.49	.43	.35	.46	.18
Total	57.9	141	143	118	146	39.02	.09	.98	.61	.71	.79	.73	.10	.14
Protein accretion, gram														
period 1	43.13	39.7	40.8	44.2	37.4	4.30	.60	.85	.28	.52	.89	.37	.60	.67
period 2	41.3	46.5	45.4	46.5	54.48	5.81	.30	.89	.35	.56	.45	.45	.52	.22
Total	43.01	44.03	41.99	108	45.4	29.6	.61	.96	.15	.28	.27	.31	1.0	.36

Table 40. Allometric growth coefficients for body parts for various feeding and protein levels.

Intake level Protein level	Adlib	Lim7.5 Low	Lim7.5 High	Lim13 Low	Lim13 High	SEM	p1	p2	p3	p4	p5	p6	p7	p8
Hooves														
overall β	.56	.61	.57	.58	.57	.02	.34	.33	.78	.38	.69	.62	.30	.47
prd 1β	.78	.59	.64	.70	.63	.14	.41	.80	.75	.96	.74	.69	.38	.54
prd 2β	.42	.80	.33	.50	.37	.20	.73	.13	.66	.17	.52	.43	.57	.96
head														
overall β	.66	.71	.67	.70	.68	.03	.65	.34	.75	.37	.99	.65	.68	.68
prd 1β	.73	.60	.63	.69	.65	.07	.29	.75	.68	.94	.45	.60	.21	.51
prd 2β	.53	.83	.71	.76	.70	.12	.14	.51	.77	.49	.77	.79	.14	.21
liver														
overall β	.81	.80	.75	.70	.81	.05	.36	.47	.14	.57	.68	.13	.51	.32
prd 1β	1.07	1.19	.87	.63	.79	.18	.33	.22	.53	.65	.09	.19	.86	.12
prd 2β	.48	.26	.55	.90	.95	.28	.58	.48	.91	.56	.09	.67	.81	.22
Pluck														
overall β	.86	.81	.72	.74	.79	.06	.14	.26	.52	.71	.92	.21	.16	.18
prd 1β	1.08	.69	.97	.51	.86	.16	.08	.21	.13	.06	.35	.84	.20	.05
prd 2β	.58	.84	.33	.93	.74	.30	.05	.51	.07	.48	.24	.10	.00	.17
Heart														
overall β	1.01	1.02	1.01	.98	1.04	.04	.98	.90	.29	.50	.83	.40	.94	.92
prd 1β	1.11	1.14	1.05	.82	1.13	.13	.59	.64	.11	.39	.33	.14	.93	.38
prd 2β	.93	.93	.96	.1.24	.785	.21	.84	.91	.14	.32	.72	.26	.97	.75
Internal														
overall β	.89	.97	.867	1.02	.93	.08	.53	.37	.42	.24	.51	.95	.76	.41
prd 1β	.80	.97	1.13	1.22	1.02	.08	.01	.19	.10	.80	.42	.04	.02	.007
prd 2β	.68	.82	.43	.76	.68	.16	.97	.11	.73	.17	.54	.35	.78	.82
External														
overall β	.89	.91	.89	.91	.89	.03	.88	.73	.73	.63	1.0	1.0	.89	.89
prd 1β	.98	-.03	1.09	1.03	.96	.06	.54	.45	.43	.89	.32	.32	.34	.87
prd 2β	.75	.76	.54	.75	.66	.10	.57	.16	.55	.16	.60	.54	.47	75

Table 40 Continued..

Intake level Protein level	Adlib	Lim7.5 Low	Lim7.5 High	Lim13 Low	Lim13 High	SEM	p1	p2	p3	p4	p5	p6	p7	p8
Gut														
overall β	.92	.94	1.00	1.09	.98	.05	.17	.41	.14	.62	.29	.11	.40	.10
prd 1β	.78	1.01	1.20	1.37	1.08	.09	.01	.19	.04	.57	.22	.02	.01	.002
prd 2β	.70	.86	.42	.75	.66	.18	.89	.10	.74	.16	.72	.33	.78	.98

Table 41. Allometric growth coefficients for carcass traits and composition for various feeding and protein levels.

Intake level Protein level	adlib	Lim7.5 Low	Lim7.5 High	Lim13 Low	Lim13 High	SEM	p1	p2	p3	p4	p5	p6	p7	p8
Carcass														
overall β	1.0	1.0	1.0	1.0	1.0	.02	.59	.52	1.0	.64	.64	.64	.50	.76
prd 1β	1.1	1.1	1.0	1.0	1.0	.02	.02	.03	.45	.27	.05	.04	.19	.01
prd 2β	1.0	1.0	1.1	1.2	1.1	.05	.12	.05	.42	.38	.32	.06	.29	.07
Fat, %														
overall β	.38	.37	.32	.32	.32	.04	.26	.37	.89	.59	.50	.46	.44	.20
prd 1β	.54	.58	.50	.13	.57	.16	.62	.72	.07	.27	.25	.12	.96	.36
prd 2β	.29	-.01	.35	.40	-.25	.24	.53	.30	.08	.56	.70	.05	.68	.47
Water, %														
overall β	-.13	-.13	-.11	-.11	-.11	.02	.41	.30	.91	.51	.51	.42	.63	.31
prd 1β	-.17	-.21	-.10	-.03	-.22	.07	.74	.26	.08	.61	.66	.05	.90	.63
prd 2β	-.12	.04	-.13	-.15	.15	.11	.45	.31	.09	.59	.70	.06	.59	.40
Protein, %														
overall β	-.08	-.11	-.09	-.09	-.09	.02	.47	.49	.93	.66	.66	.58	.40	.62
prd 1β	-.14	-.18	-.08	-.03	-.18	.05	.77	.27	.08	.61	.64	.05	.94	.65
prd 2β	-.10	.02	-.11	-.12	-.12	.09	.46	.31	.09	.59	.68	.06	.61	.40
Fat, lb														
overall β	1.37	1.36	1.31	1.31	1.32	.04	.29	.36	.92	.55	.55	.47	.46	.23
prd 1β	1.52	1.57	1.33	1.13	1.55	.15	.47	.27	.07	.57	.47	.05	.71	.35
prd 2β	1.28	.977	1.34	1.39	2.81	.99	.75	.79	.33	.38	.36	.60	.92	.51
Water, lb														
overall β	.83	.87	.90	.90	.89	.02	.44	.31	.83	.56	.56	.39	.64	.35
prd 1β	.84	.79	.90	.96	.78	.07	.79	.26	.08	.63	.68	.05	.94	.68
prd 2β	.88	1.03	.87	.85	1.14	.11	.45	.31	.09	.58	.71	.06	.58	.40
Protein, lb														
overall β	.89	.89	.91	.90	.91	.01	.37	.41	.90	.50	.61	.61	.54	.31
prd 1β	.86	.81	.92	.97	.82	.06	.72	.21	.09	.72	.62	.04	.90	.60
prd 2β	.90	1.04	.88	.87	1.15	.10	.51	.25	.09	.68	.72	.05	.65	.46
Marbling	.28	.37	.13	.84	.23	.34	.78	.63	.23	.24	.43	.59	.93	.56
Adjusted PYG	.59	.31	.81	.82	.62	.23	.83	.14	.55	.51	.50	.15	.93	.63
REA	.37	.41	.63	.65	.35	.17	.46	.39	.24	.81	.90	.16	.47	.53

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CHAPTER VI

EFFECTS OF SLIGHT FEED RESTRICTION AND REALIMENTATION ON HORMONE AND
METABOLITE CONCENTRATIONS IN BLOOD AND RUMINAL
FERMENTATION PATTERNS OF FEEDLOT STEERS.

W. J. Hill, F. N. Owens, D. R. Gill and R. P. Wetteman

ABSTRACT

Ten crossbred steers were used to determine how slight restriction in feed intake and subsequent

realimentation alter feeding behavior, blood hormonal and metabolite profiles and ruminal fermentation.

Steers, approximately 16 months of age and, were assigned randomly to receive ad libitum access

(ADLIB) to an 85% whole corn-based finishing diet or had intake of the same diet restricted (LIM) to

roughly 85% of that consumed by ADLIB steers for the 14 weeks (period 1) of a finishing period.

Thereafter, all steers had ad libitum access to the same diet for 14 weeks (period 2). To monitor feeding

behavior, residual feed was weighed at 2, 8 and 24 hr post feeding. Blood samples were obtained

approximately 2 and 8 hr post feeding throughout the trial and more intensively in weeks 13 and 28 for

determination of glucose, insulin, NEFA, and GH. Ruminal fluid samples were taken at 0, 4 and 12 hr

after fresh feed was provided on 2 days during weeks 7, 12, and 28; weights of total rumen solids and

liquids were determined by evacuation in week 14. During period 1 LIM cattle consumed a greater (P <

.05) percentage of their feed within 2 hr than ad libitum fed cattle (90.3 vs 60.8%). Consumption patterns

were not different between feeding treatments during period 2. The coefficient of variation for daily feed

intake was lower (P < .05) for LIM than ADLIB cattle (12 vs 21.0%) during period 1 but similar during

period 2. Although neither blood glucose nor insulin was affected by feeding treatment, blood

concentrations of both GH and NEFA were reduced (P < .05) when cattle were limit fed. As cattle

reached heavier weights, blood insulin concentrations tended to increase while GH tended to decrease.

Surprisingly, limit fed animals had a greater (P < .05) proportion of propionate in the rumen during

period 1 but not during period 2 despite no differences due to feeding treatment in weights of ruminal

contents or composition of either ruminal or fecal DM at the end of period 1. Alterations in hormonal

status and blood and ruminal metabolites may explain why limit feeding improves efficiency of growing-finishing feedlot cattle.

(Key words: Limit feeding, hormones, metabolites, feedlot steers, feeding behavior)

Introduction

Restricted or limit feeding programs generally improve feed efficiency of finishing cattle. While several methods and degrees of restricted intake can be used, the most common and successful programs have restrict intake throughout the feeding period or just for an early segment of the feeding period and thereafter provide free choice access to feed. Restriction levels have varied from 5 to 20% below ad libitum DMI; optimum efficiency improvements have been seen with about 15% restriction or feeding at 85% of ad libitum DMI (Sainz, 1995). While restricting cattle throughout the entire finishing period usually has improved feed efficiency, restriction for the full feeding period usually has increased the number of days on feed and decreased the percentage of cattle grading Choice (Murphy and Loerch, 1994; Hicks et al., 1989, 1990). In contrast, programs that allow unlimited DMI during the last half of the feeding period generally have improved efficiency without extending the feeding period or depressing carcass quality (Loerch et al., 1995; Knoblich et al., submitted; Peters, 1995). While restricted feeding appears to be a viable means for improving efficiency and if done properly does not affect carcass quality, why efficiency is improved remains unclear. Several explanations for the improvement in efficiency have been advanced. These include reduced weight of the digestive tract and other organs, reduced maintenance requirements, decreased feed waste, altered body composition, altered hormonal status, and improved digestibility. Because one gram of wet tissue retained as protein contains less energy than one gram stored as fat, decreased fatness of limit-fed cattle has been implicated as one explanation for the improved efficiencies. However, all of the trials that have observed that fat content decreased have been trials in which cattle were restricted throughout the entire finishing period (Murphy and Loerch, 1994; Hicks et al., 1990; Glimp et al., 1989). In trials where limit fed cattle have been given ad libitum access to feed for the last half of the trial, reductions in carcass fat have been minor or nonexistent (Loerch et al.,

1995; Knoblich et al., submitted). How slight restrictions (i.e., 10 -15% below ad libitum DMI) affect body composition during the restriction phase separate from the total feeding period has not been studied extensively although Hill et al. (1996) reported that limit feeding for 63 days did not decrease but instead tended to increase carcass fat of steers. In contrast, after 130 days of feeding, when cattle were given ad libitum access to feed the last 67 days, carcasses of previously limit fed steers tended to be slightly leaner than carcasses of steers that had received continuous access to feed throughout the total feeding period. These findings conflict with the standard dogma that slower growing cattle are less fat after a specified time on feed (Guenther et al., 1965). One key difference between these contradictory results is that in most trials, slower growing cattle either have been fed lower energy (forage based) diets or else they have been limit fed concentrate diets so that rate of gain was substantially below those of cattle given ad libitum access to feed (Hill et al., 1996). Limit-fed cattle rapidly become meal eaters, consuming their entire daily feed allotment within 2 to 4 hr. Compared to the smaller, more timely meals of cattle given ad libitum access to feed, limit fed cattle may have altered hormonal and metabolite status and ruminal fermentation patterns; these in turn could alter body composition and explain the performance results. The objective of this trial was to examine how level of feed intake alters feeding behavior, hormonal and metabolite status, and ruminal fermentation patterns of steers both during and following a period of intake restriction.

Materials and Methods

Ten crossbred steers were used to determine the effects of intake restriction and realimentation on blood hormonal and metabolite status and ruminal fermentation patterns. Steers, received when they were weaned (approximately 8 months old), were placed on a diet (50:50 concentrate to roughage) and fed at levels to support only minimal gains. During this period steers were gentled, trained to be haltered, and fitted with permanent ruminal cannulae. Cattle were housed individually in indoor pens with cement slatted floors. At the onset of the trial, when steers were approximately 16 months of age, they were randomly assigned to either receive ad libitum access (ADLIB) to a finishing diet (Table 42) or were restricted to about 85% of ad libitum intake (LIM) of this same diet. The diet was formulated with an

excess of nutrients so that nutrient intake would be adequate for LIM cattle. After a 100 d restriction period (period 1), steers were given ad libitum access to the same diet for 95 d more (period 2). Supply of feed for steers fed ad libitum was about 5% beyond DMI the previous day. The intake-restricted cattle were fed an amount of feed approximately 85% of that consumed by cattle given ad libitum access to feed but changes in the daily feed allotment were infrequent, being about every 30-45 days once cattle had been fed for several weeks. Because we were monitoring feeding behavior, residual feed was weighed at 2, 8, and 24 hr post feeding each week day; on weekends, only unconsumed feed (24 hr) values were recorded. These measurements allowed us to calculate how rapidly cattle consumed their feed. These data were analyzed as repeated measures across time with the main plot being feeding treatment, a subplot (time) being week of the trial, and the feeding treatment by time interaction. Additionally, data were analyzed including period in the model in which the main effects were treatment (feeding method) and period (either restricted or ad libitum during period 1 and ad libitum during period 2) and all interactions. Weeks of the trial were repeated measures in these analyses. Because intake patterns and the variation associated with these intakes provides an insight into feeding behavior, mean weekly intakes and standard errors associated with these intakes were calculated by treatment across the entire trial although treatments were not compared statistically. Additionally the coefficient of variation across days within each treatment and each period combination were calculated and analyzed by the GLM procedures of SAS (1991) as a completely randomized design with a 2 x 2 factorial arrangement of treatments. The effects in the model for this analysis were feeding treatment, period, and the feeding treatment by period interaction.

Blood samples, taken via jugular venipuncture, were harvested in both serum tubes and in plasma tubes which contained EDTA (.1 ml of a 15% solution). Serum samples were allowed to clot for 24 hr at $4°$ C, centrifuged at 2,800 g for 30 min, and the serum was harvested. Plasma tubes were placed on ice and centrifuged within 1 hr at 3,000 g for 15 min for harvesting the plasma. Blood serum and plasma samples were stored at $-20°$ C for subsequent hormone and metabolite analysis. Blood samples were obtained at approximately 2 and 8 hr after the time that fresh feed was offered on day 0, weeks 1, 2, 3. 4, 6, 10, 18 , 20, 22. Weeks 1 through 14 corresponded with the time that LIM cattle were receiving 85% of ad libitum intake (period 1). During weeks 15 through 28, all cattle had ad libitum access to their

finishing diet (period 2). Blood serum samples were assayed for growth hormone whereas plasma samples were assayed for glucose, insulin, and NEFA.

The weekly blood sample data were analyzed by the GLM procedures of SAS (1991) as a 2 x 2 x 2 factorial with repeated measures over time. The main effects were feeding treatment, time within day sampled, period (either restricted or ad libitum) and all interactions. The repeated measures were weeks of sampling. One steer from each treatment was removed prior to calculating statistics due to repeated loss of rumen cannulas and not consuming feed regularly. Additionally, these data were analyzed by removing period and simply considering effects of treatment, sampling period, and their interactions across all weeks of the trial to illustrate the how these parameters changed over time. Means were separated by the PDIFF statement of SAS (1991) protected by a significant (P < .05) F-value.

Additional blood samples were taken as described above at 0, 2, 4, 6, and 8 hr after fresh feed was provided on weeks 13 (period 1) and 28 (period 2) and analyzed as described above. Results from these more frequent samples should characterize the hormonal and metabolite profiles within a day as influenced by feeding system or behavior. Additionally, because GH release is episodic (Wheaton et al., 1986), this frequent bleeding schedule should help to characterize differences due to the feeding system. Statistical analysis of these data followed GLM procedures of SAS (1991) for a split plot analysis by period. The main plot was treatment with the subplot being time within day. These data were analyzed by period because there the number of samples was not equal due to loss of a cannula from one animal during period 2. Means were separated by the PDIFF statement of SAS (1991) protected by a significant (P < .05) F-value.

GH concentrations were quantified in duplicate by RIA (Yelich et al., 1995) with NIH-GHB17 used as a standard. Insulin concentrations in plasma were quantified in duplicate using a solid phase RIA for human insulin (Coat-A-Count progesterone kit, Diagnostics Products Corp., Los Angeles, CA) with bovine pancreatic insulin standards (28.6 USP units / mg, Sigma Chem. Co., St. Louis, MO) and a 200 ml sample volume. The sensitivity of the insulin assay was .05 ng/ ml plasma. Additions of .8, 1.6 and 3.2 ng of insulin in 1 ml plasma resulted in 97%, 109% and 108% recoveries, respectively. When different volumes of plasma were assayed, concentrations remained parallel to the standard curve. Glucose

concentrations in plasma were determined by an enzymatic plus colorimetric procedure (Sigma, No. 510, Sigma Chemical Co., St. Louis, MO). Concentrations of NEFA in plasma were determined by an enzymatic plus colorimetric procedure (Wako-NEFA C, Wako Chemicals Inc., Dallas TX) as modified by McCutcheon and Bauman (1986).

Ruminal samples were taken on 2 consecutive days during weeks 7 and 12 (period 1), and on 2 days during week 28 (period 2.). On each sampling day, ruminal fluid was collected at 4, 12, and 24 hr after fresh feed was provided. Ruminal contents were strained through 4 layers of cheese cloth and pH was measured immediately. A 5 mL aliquot was mixed with 250 mg of metaphosphoric acid (Erwin et al., 1961) in preparation for VFA analysis. Volatile fatty acids were analyzed gas chromatographically (Harmon et al., 1985). A 5 mL aliquot was mixed with 5 mL of 20% trichloroacetic acid solution to preserve it for lactate and ammonia analysis. D-Lactate was analyzed spectrophotometrically (COBAS MIRA Chemistry Systems, St. Louis, MO). Ruminal ammonia concentrations were determined using the alkaline hypochlorite phenol colorimetric procedure (Broderick and Kang, 1980). From the relative proportions of VFA production the percent of total fermentable energy lost as methane was calculated

Data from ruminal samples were analyzed as a split plot within each period using the GLM procedures of SAS (SAS, 1991) with the main plot was feeding method and the subplot being time within sampling day. Hence, for period 1, results are averages over four sampling dates while for period 2, results are averages over two sampling dates. The effect of period could not be tested within this analysis because of one missing observation due to a lost cannula. Means were separated by the PDIFF statement of SAS (1991) protected by a significant (P < .05) F-value.

Immediately prior to the time that LIM cattle were switched to ad libitum feeding (end of period 1), total ruminal contents were evacuated. Weights of filterable liquids and solids were measured; solids were analyzed for starch as were fecal samples collected for three days prior to ruminal evacuation. The analysis for these data was by GLM procedures of SAS (1991) as a completely randomized design with feeding treatment being the only factor. Additionally, because limit fed cattle were growing at a slightly slower rate and therefore had lighter body weights at the time of evacuation, data were additionally analyzed including live body weight as a covariate.

Results and Discussion

Dry matter intake data by period are summarized in Table 43; intake during period 1 was 84.4% of the ad libitum intake, very close to the desired 85 %. During period 2, when the limit fed cattle had ad libitum access to feed, the difference in DMI was not significant (P>.20); cattle previously limit fed tended to have slightly lower feed intake during period 2 with no indication that these cattle compensated for their lower previous intake. During period 1, limit fed cattle consumed a greater (P < .05) percentage of their feed within 2, and 8 hours after feeding than cattle given ad libitum access to feed. However, during period 2, when all cattle had ad libitum access to feed, no difference in speed of feed intake was detected. Percentage of total feed consumed for individual weeks of the trial are presented in Figures 5 and 6. During period 1, except for weeks 4, 6, and 10, limit fed cattle consumed a greater (P < .05) percentage of their feed in two hours (Figure 5), but during period 2, differences in this measurement were detected only during weeks 15 and 17 (Figure 6.). These results indicate that slight restriction (15%) dramatically altered feeding behavior and transformed cattle into meal consumers. However, when allowed ad libitum access to feed, they reverted quickly to become nibblers.

In addition to consuming less total feed in a shorter time, DMI was more consistent both within a day or week across animals and within animal across days or weeks during period 1. Figures 7 and 8 present weekly DMI and standard errors averaged across animals on each feeding treatment. When intake was being limited, the limit fed cattle consistently consumed all their daily allotment of feed so that daily variation in DMI was small (the first 13 weeks of Figure 8). But when these cattle were given ad libitum access to feed, they rapidly reverted to fluctuating and more variable DMI (later weeks of Figure 8) adopting a fluctuating and variable pattern noted with ad libitum cattle throughout the total trial (Figure 7). Day to day variation within animal in DMI for the two feeding treatments by period are presented in Figure 9. These are calculated as coefficients of variation (CV) to remove impact of size of the mean on the standard deviation as an index of variation. Compared to animals given ad libitum access to feed, limit fed animals had substantially reduced (P < .05) day to day CV during period 1 but not CV were similar for treatments during period 2 indicating that fluctuations in DMI was not ingrained by training animals to be meal eaters.

Weekly blood glucose concentrations for the entire trial are illustrated in Figure 10. Except for week 9, when limit fed cattle had lower (P < .05) concentrations of plasma glucose, and week 20, during which limit fed cattle had greater (P < .05) concentrations of glucose than ad libitum fed cattle, blood glucose concentrations of cattle on different feeding systems were not significantly different (Figure 10). Week 9 and 20 corresponded to period 1 and period 2, respectively. Neither the glucose by period interaction nor the main effects of feeding treatment, period or sampling time were significant (P>.15) despite some tendency for glucose to be lower for limit fed cattle during period 1 and higher during period 2. An interaction between feeding treatment and sampling time on blood glucose concentration was detected (P < .05). For limit fed cattle, glucose concentrations were lower for limit fed cattle at 2 hr than at 8 hr post feeding while no difference due to sampling time was detected for cattle given ad libitum access to feed.

It is not surprising that feeding treatments had little affect on glucose concentrations. Blood glucose is a highly regulated metabolite, diets were the same, and intake levels, even for restricted fed cattle, were large enough to support an ADG in excess of 2.5 lb./d.

Similar to the results for glucose, insulin levels differed (P < .05) by feeding treatment only during week 3 of the trial (Figure 11). Averaged across sampling dates of period 1, cattle with ad libitum access to feed tended to have higher insulin concentrations than limit fed cattle did. No interactions between feeding treatment and period or sampling time nor main effects of feeding treatment or sampling period were significant. A period effect was detected in which insulin concentrations were lower (P < .01) in period 1 than in period 2 (Table 44). This may reflect the fact that these cattle, becoming fatter as the trial progressed, had become more insulin resistance. Murphy et al. (1994) detected no significant differences in blood glucose or insulin levels between fed cattle given ad libitum vs 70% of ad libitum feed intake. With more extreme intake limitation, however, one would expect greater depression in blood glucose and insulin concentrations than noted in this study.

In contrast to glucose and insulin, both of which are highly regulated, nonesterified fatty acid (NEFA) and growth hormone (GH) concentrations in blood were significantly affected by feeding treatment. NEFA concentrations on the various weeks of the trial are summarized in Figure 12. In

general, limit fed cattle had lower NEFA concentrations although an exception was found during week 3 when limit fed cattle had greater (P < .05) concentrations of NEFA for some reason that is not apparent. Blood NEFA concentrations, being singificantly lower (P < .05) in weeks 2, 4 and 7, were numerically lower all other weeks for limit fed cattle during period 1. In addition to these weekly differences, a period effect was detected (Table 46) in which NEFA concentrations were lower during period 1 than period 2. Similar to the insulin response, this may reflect the fact that cattle were fatter during period 2 than period 1; one would expect the higher insulin levels of period 2 to have decreased mobilization of stored lipid and thereby decreased NEFA concentrations in blood.

Weekly GH concentrations (Figure 13) followed a temporal pattern similar to NEFA with limit fed cattle tending to have lower GH concentrations than ad libitum fed cattle did during each weeks of the trial; only during weeks 1 and 2 was the difference significant (P < .05). However, the period by feeding treatment interaction approached significance (P < .07) due to an increase in GH concentrations when limit fed cattle were given ad libitum access to feed. No such time effect was apparent for cattle having continuous access to feed (Table 44). During period 2, GH concentration was greater (P < .05) for cattle that previously had been limit fed. Although a significant treatment by period interaction was detected, the interaction was due to a shift in magnitude and not direction; consequently, main effects will be reported. Based on these means, GH concentrations were lower (P < .05) for limit fed cattle (Table 47) and lower during period 2 than period 1 (Table 46). Results for both GH and NEFA differ sharply from results of trials where cattle growth is more severely restricted or when cattle given ad libitum access to feed gain substantially faster than limit fed cattle do (Yambayamba et al., 1996; Yelich et al., 1996; Yelich et al., 1985). In most literature reports where GH and NEFA concentrations were substantially greater for restricted animals, energy intake was restricted to the point that restricted animals made little or no weight gain. However, in trials similar to ours where restriction has been less severe (70-90% of ad libitum), GH and NEFA concentrations have not been measured. Note that both a lipogenic hormone (GH) and one indicator of lipolysis (NEFA) both were decreased by limit feeding in the current trial. These results do not negate the idea advanced by Hill et al. (1996) that slight intake restriction may not reduce rate of fat accretion substantially so that body composition is not leaner when DMI is slightly restricted. Presumably,

GH and NEFA concentration differences are a result of altered feeding behavior. Limit fed cattle consistently ate more feed in a shorter time despite a slight decrease in total feed consumption as seen in figure 5. Further; DMI was more consistent both within day across animals and within animal across days. Mosely et al. (1988) reported that both baseline secretion of GH and total area under the GH response curve were lower in meal-fed than sham-fed steers.

Intensive bleeding results within a single day from periods 1 and 2 are summarized in Figures 14 to 21. Plasma glucose showed no response to feeding treatment or to time of day during period 1 (Figure 14). But during period 2 (Figure 15), a time effect was detected with glucose being greater during the first two hr post feeding than later. Plasma insulin levels during period 1 were greater prior to feeding for limit fed cattle as compared to ad libitum fed cattle, but insulin concentrations were similar (P>.05) at other sampling times. Based on the expectation that postruminal glucose supply fluctuate to a greater degree after a meal in meal fed cattle, it is surprising that the postprandial glucose drop tended to be greater for steers with ad libitum access to feed than those with limited access to feed. Rather than glucose absorption differences, these postprandial changes may reflect trends for insulin to be higher and more variable for cattle fed ad libitum (Figure 17) although no treatment or time effects on insulin were significant (P>.15) during either period. NEFA levels during period 1 did not differ by treatment, but NEFA concentrations were affected by sampling time, being greater (P < .05) at time zero, immediately prior to feeding. An increase in NEFA 24 hours after the last meal is expected, especially if cattle have been without feed for sometime although the cattle with ad libitum access to feed still had feed available to consume. Nevertheless, cattle given ad libitum access to feed typically consume most of their feed shortly after sunrise and shortly before sundown with few meals after midnight, so their last meal prior to bleeding (0800) may have been as much as 8 hr prior to the first blood sampling. Bishop et al. (1992) reported similar that NEFA levels increased as time post feeding of a protein supplement increased. During period 2 neither sampling time nor feeding treatment affected plasma NEFA concentrations. Similarly, GH concentrations during the frequent sampling days did not differ by treatment during either period although GH concentrations tended to be greater prior to feeding than any of the other times post feeding during both periods.

Results of ruminal measurements are summarized in Tables 8 to 13. During period 1, the only

sampling time by period interaction was for total VFA concentration. Because this interaction was due to a

difference in magnitude, not in direction, main effects will be discussed. For period 2 the only time by

feeding treatment interaction was for lactic acid; limit fed cattle had lower and more consistent levels

throughout the day whereas cattle with ad libitum access to feed had the greater lactate concentrations

prior to feeding but these decreased throughout the day. Because large meals can exacerbate lactate

accumulation in the rumen, higher concentrations might be expected in cattle given ad libitum access to

feed, but why lactate concentration should be highest 24 h after feeding rather than at other times is not

clear. Main effects for ruminal measurements for periods 1 and 2 are presented in tables 10 and 11,

respectively. During period 1, limit fed cattle had lower (P < .05) concentrations of lactate and greater (P <

.05) concentrations of propionate; acetate and butyrate concentrations were not significantly different

(P>10). This led to a lower (P < .05) acetate to propionate ratio for limit fed cattle. This contrasts with

results of Merchen et al. (1986) with fed sheep two forage levels (75% alfalfa with 22% corn or 25% alfalfa

with 65% corn) at two intakes (2.6 and 1.7% of BW). Their high intake level of the higher concentrate

diet produced the highest molar proportions of propionate and a lowest proportion of butyrate in ruminal

fluid than either diet at the low intake level. However, their diets contained more forage and the restriction

imposed was greater (50%) than in most limit feeding studies. Murphy et al. (1994) reported that intake

level (either ad libitum or 70% of ad libitum) had little impact on the average proportions of acetate and

propionate from samples taken at 0, 1,2,3,4,6,9, 12 and 24 hr after feeding when whole corn was fed; in

contrast, a higher intake level reduced acetate and increased propionate when the diet consisted of rolled

corn, opposite the difference we detected. In our trial, whole corn was fed. During period 2, no

differences in ruminal parameter due to feeding treatment were detected.

The main effect of sampling time on ruminal fermentation products for periods 1 and 2 are

summarized in Tables 12 and 13, respectively. During period 1, ruminal ammonia concentrations were

lower prior to feeding but rose by 4 and 12 hr post feeding. This pattern was reversed during period 2

when ruminal ammonia concentration was lowest 12 hr post feeding. Ruminal pH during both periods was

highest prior to feeding and fell slightly by 4 and 12 hr post feeding. Ruminal lactate concentration was

highest at 4 hr after feeding in period 1 but before feeding in period 2. Neither the total ruminal concentration of the VFA, molar proportions of acetate, propionate and butyrate nor the acetate to propionate ratio differed at any sampling time during either period.

Weights of evacuated ruminal contents at the end of period 1 are listed in table 55. While not significantly different, weight of ruminal contents tended to be greater (P < .19, .08 and .10 for solids, liquid and total, respectively) for cattle given ad libitum access to feed. However, when adjusted for the 187 lb. lower body weight of limit fed cattle, no difference (P>.90) in weights remained. Similarity in ruminal content weight despite differences in DMI implies that rate of passage and(or) digestion was less (P < .) with limit feeding. Ruminal disappearance, the sum of digestion and passage, calculates to be 2.8 vs 2.73 %/hr for cattle given limited and ad libitum access to feed, respectively. Murphy et al. (1994), when comparing cattle given ad libitum access to feed vs 70% ad libitum intake, reported that ruminal liquid turnover was reduced as a result of restricted DM intake. Similarly, Galyean et al. (1979) reported that ruminal liquid dilution rates were 3.5 and 5.3% for steers receiving 1.3 and 2.0 time maintenance intakes, respectively. One would expect longer retention time to shift site of digestion from the intestines back toward the rumen, however ruminal concentrations of ash, protein and starch in ruminal contents evacuated 24 hr post feeding were similar between treatments. No differences in fecal concentrations of ash, protein or starch between feeding treatments were detected. These data imply that while limit fed cattle consumed more feed in shorter time, total extent of digestion of these whole corn diets was not different. These results are consistent with those reported by Hill (1997) in which cattle were restricted to a similar degree and fed either whole corn or corn rolled to different degrees of fineness had similar nutrient digestibilities.

Implications

Restricting intake of feedlot cattle to 85% of the amount of feed consumed by steers given ad libitum access to feed altered feeding behavior. Limit fed cattle became meal eaters and consistently consumed their full daily allotment of feed within 2 hours. This altered feeding behavior substantially decreasing intake variation both within and across days and resulting in lower and more stable concentrations of growth hormone and NEFA, factors associated with decreased lipolysis and increased fat

deposition. Additionally, this level of restriction increased the relative proportion of propionate in ruminal contents. This change will increase ruminal energy retention. The energy lost as methane expressed as a percentage of the total fermentable energy was decreased by 33% for limit fed compared to ad libitum fed cattle. These alterations in ruminal end products and in hormonal and metabolite concentrations should help to explain why slightly limiting feed supply for cattle often improves energetic efficiency.

Table 42. Diet and calculated nutrient composition (% of DM).

Ingredient	% of diet dry matter
Dry corn	86.9
Cottonseed hulls	5.00
Soybean meal	1.00
Cottonseed meal	5.00
Limestone	1.10
Urea	.50
Salt	.30
Manganous oxide	.006
Zinc sulfate	.005
Potassium chloride	.15
Vitamin A-30	.011
Rumensin-80	.0188
Tylan-40	.013
Calculated [a] nutrient content., dry matter basis	
NEm, Mcal/cwt	96.3
NEg, Mcal/cwt	61.7
Crude protein, %[b]	14.1
Potassium, %	.59
Calcium, %	.53
Phosphorus, %	.32
Magnesium, %	.16
Cobalt, ppm	.10
Copper, ppm	5.4
Iron, ppm	44.0
Manganese, ppm	56.7
Zinc, ppm	39.4

[a] NRC (1984)

[b] based on Kjeldahl analysis of mixed ration

Table 43. Intakes and feeding patterns for the period x feeding treatment interaction.

Period	Restricted Phase		All Ad Libitum Phase		
Treatment	limited	ad libitum	limited	ad libitum	SEm
Intake	15.4[a]	17.8[b]	18.0	18.9	.73
% eaten in 2 hr.	90.3[a]	60.8[b]	54.5	53	2.52
% eaten in 8 hr.	98.9[a]	83.6[b]	77.1	80.8	2.08
Orts, % of feed offered	2.5[a]	6.4[b]	6.3	5.3	1.13

[ab] means with a period differ by (P < .05).

Figure 5. Percent Of Weekly Feed Consumption That Occurred Throughout The Day During Period 1 By Feeding Treatment.
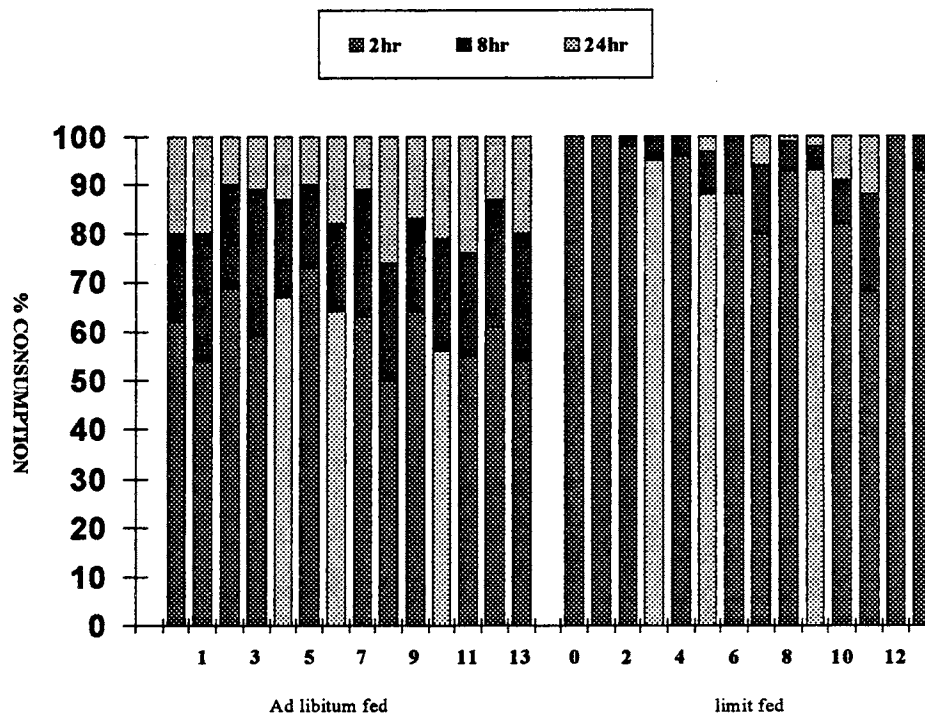

Figure 6. Percent Of Weekly Feed Consumption That Occurred Throughout The Day During Period 2 by feeding treatment.
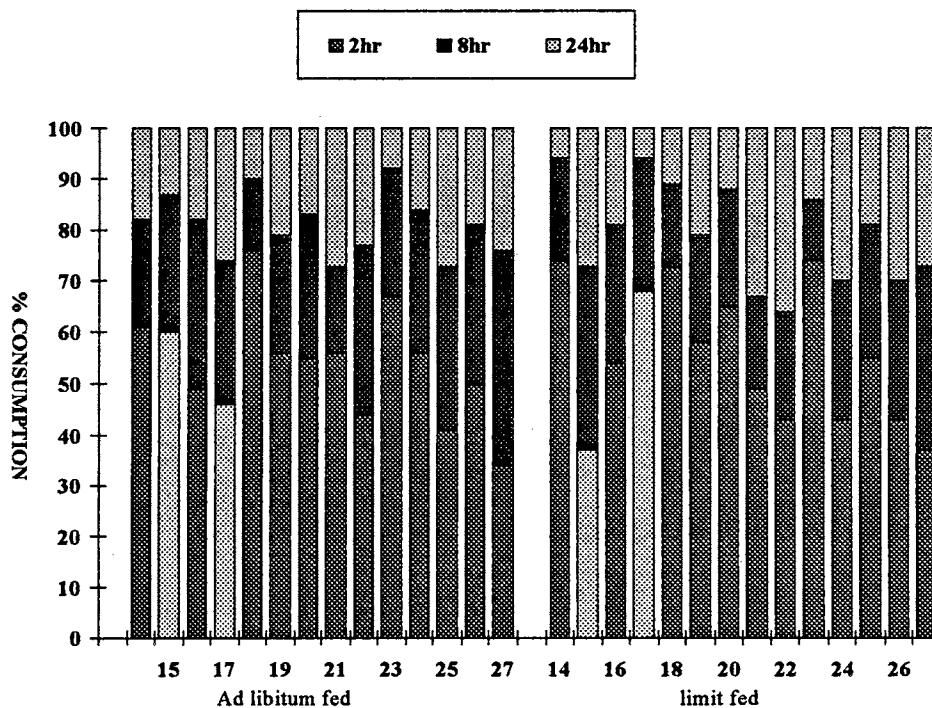
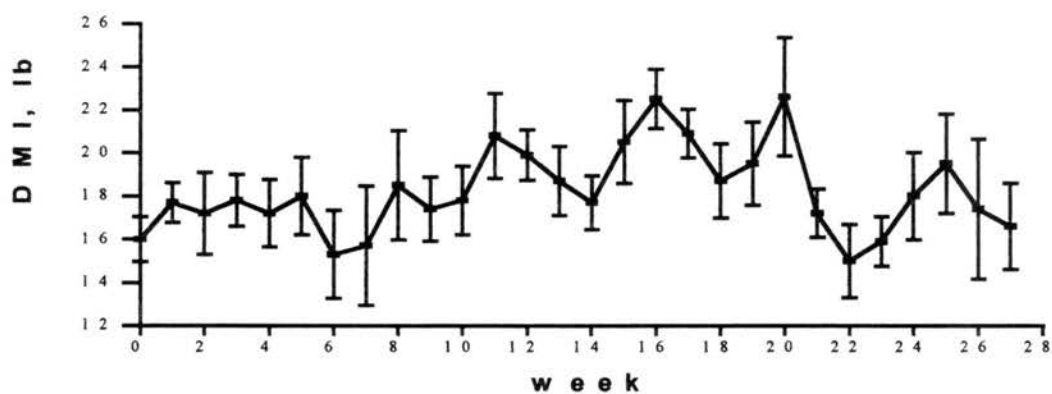**Figure 7. Intake And Standard Error Bars For Cattle Fed Ad Libitum Throughout The Trial.**

Figure 8. Weekly Intakes And Standard Errors For Cattle First Limit Fed Then Fed Ad Libitum.
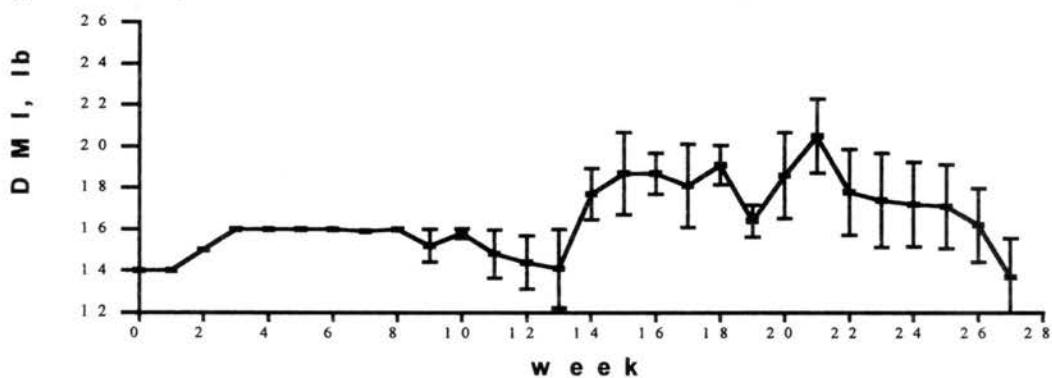

Figure 9. Across Day Coefficient Of Variation By Feeding Treatment For Each Period.
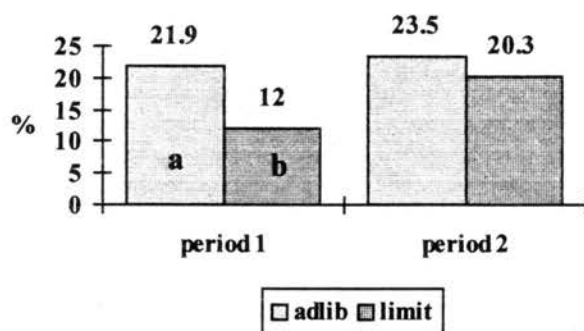
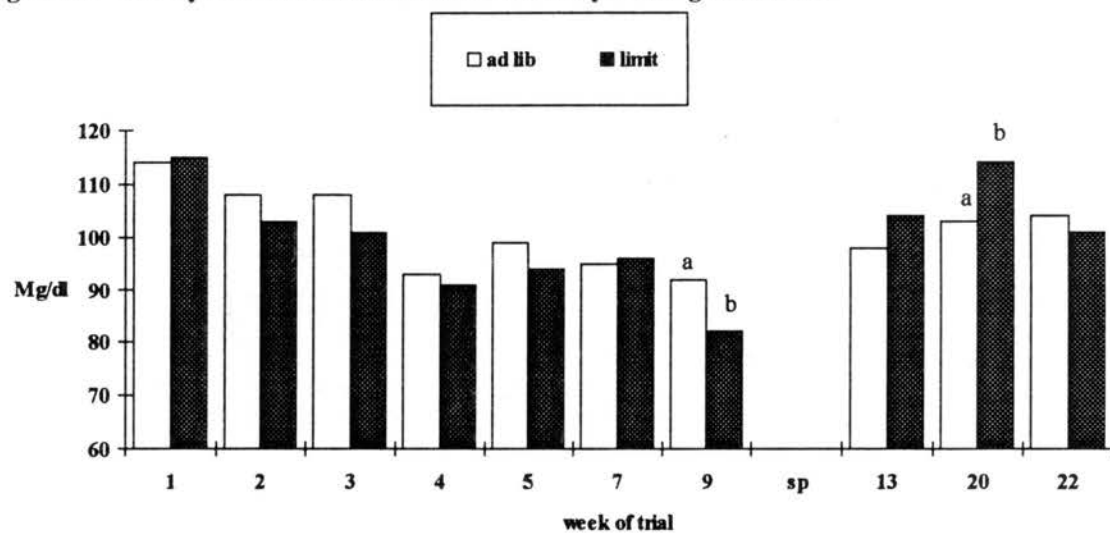**Figure 10. Weekly Plasma Glucose Concentrations By Feeding Treatment.**

Figure 11. Weekly Plasma Insulin Concentrations By Feeding Treatment.
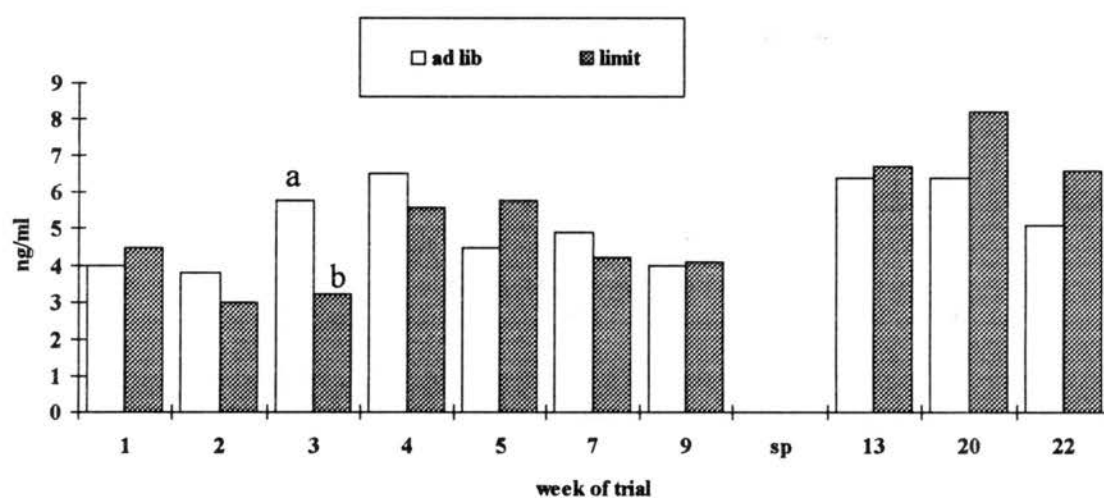
Figure 12. Weekly Plasma Free Fatty Acid Concentrations By Feeding Treatment.
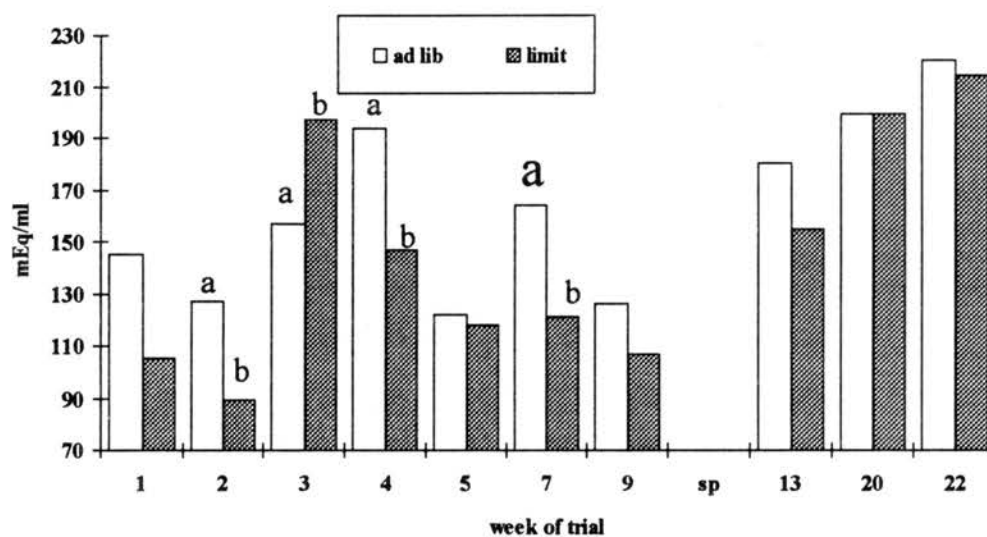

Figure 13. Weekly Serum Growth Hormone Concentrations By Feeding Treatment.
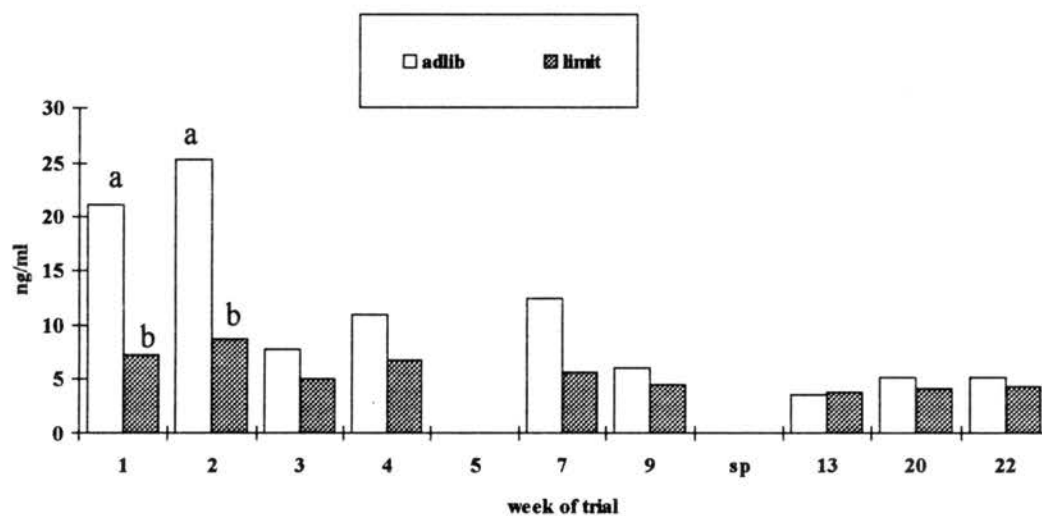
Table 44. Weekly blood parameters for the period by feeding treatment interaction.

Feeding treatment	Limited		ad libitum			
period	1	2	1	2	SEM	P<
Glucose, mg/dL	98	104	100	100	3.40	.36
Insulin, ng/mL	4.2	6.7	4.5	6.4	.85	.65
NEFA, mEq/mL	134	194	148	187	11.0	.26
Growth hormone, ng/mL	6.9[a]	4.0[a]	23.1[b]	4.4[a]	4.52	.07

[ab] means with differing superscripts differ by (P < .05).

Table 45. Weekly blood parameters for the feeding treatment by sampling time interaction.

Feeding treatment	Limited		ad libitum			
Time post feeding	2 hr	8 hr	2 hr	8 hr	SEM	P<
Glucose, mg/dL	97[a]	105[b]	100[ab]	99[ab]	2.13	.05
Insulin, ng/mL	5.7	5.1	5.6	5.3	.29	.60
NEFA, mEq/mL	165	163	162	174	6.58	.28
Growth hormone, ng/mL	5.5	5.5	17.8	9.8	3.86	.28

[ab] means with differing superscripts differ by (P < .05).

Table 46. Weekly blood parameters for the main effect of period.

Item	Period 1	Period 2	SEM	P<
Glucose, mg/dL	99	102	2.38	.37
Insulin, ng/mL	4.4	6.5	.59	.01
NEFA, mEq/mL	141	191	7.7	.01
Growth hormone, ng/mL	15.0	4.2	3.2	.02

Table 47. Weekly blood parameters for the main effect of feeding treatment.

Item	ad libitum	Limit	SEM	P<
Glucose, mg/dL	100	101	2.90	.80
Insulin, ng/mL	5.43	5.45	.93	.98
NEFA, mEq/mL	168	164	6.35	.68
Growth hormone, ng/mL	13.8	5.5	2.36	.05

Table 48. Weekly blood parameters for the main effect of sampling time.

Item	2 hr	8 Hr	SEM	P<
Glucose, mg/dL	99	102	1.54	.18
Insulin, ng/mL	5.7	5.2	.21	.15
NEFA, mEq/mL	163	168	4.74	.45
Growth hormone, ng/mL	11.6	7.6	2.79	.32

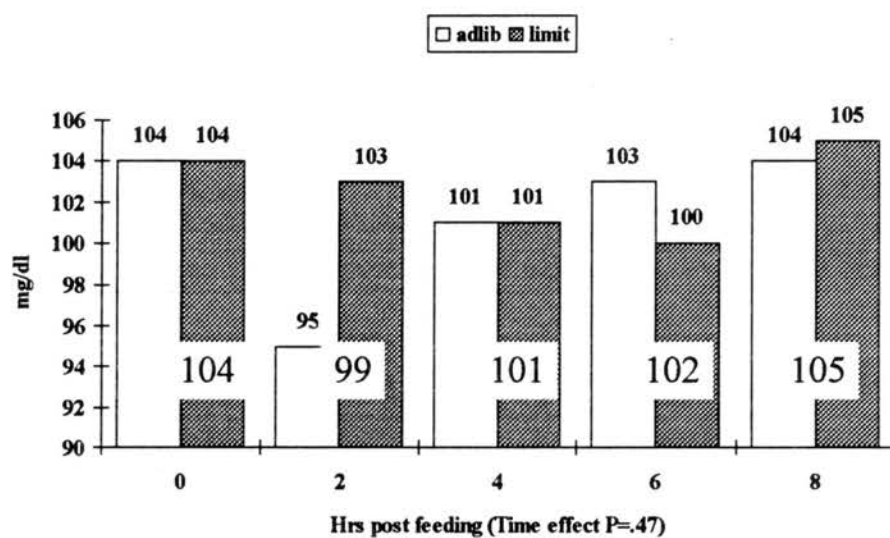**Figure 14. Daily Plasma Glucose Concentration By Feeding Treatment During Period 1.**

Figure 15. Daily Plasma Glucose Concentration By Feeding Treatment During Period 2.
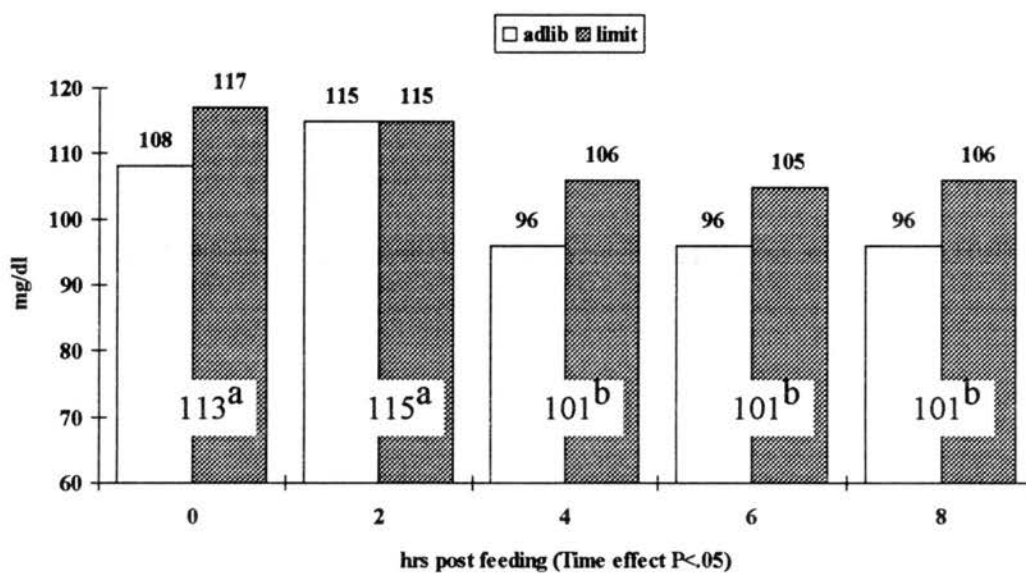
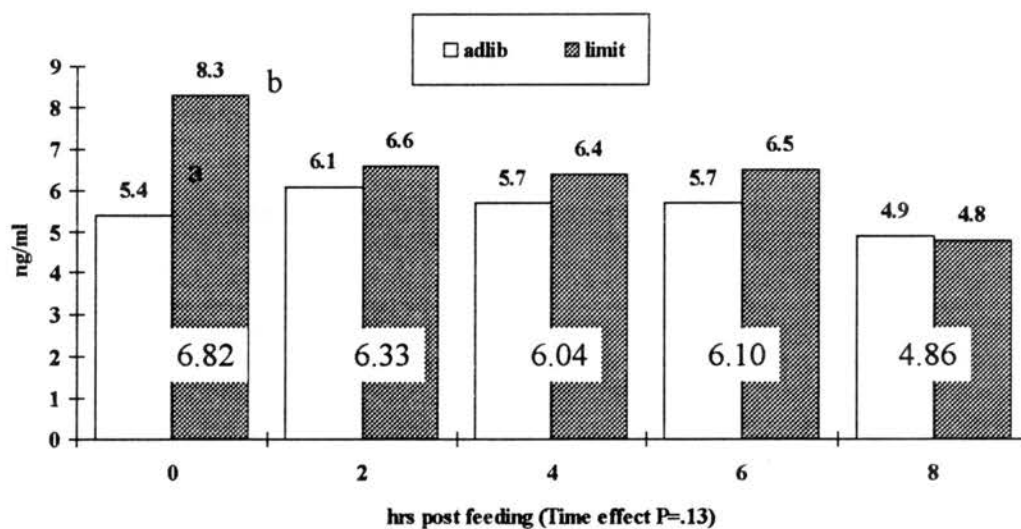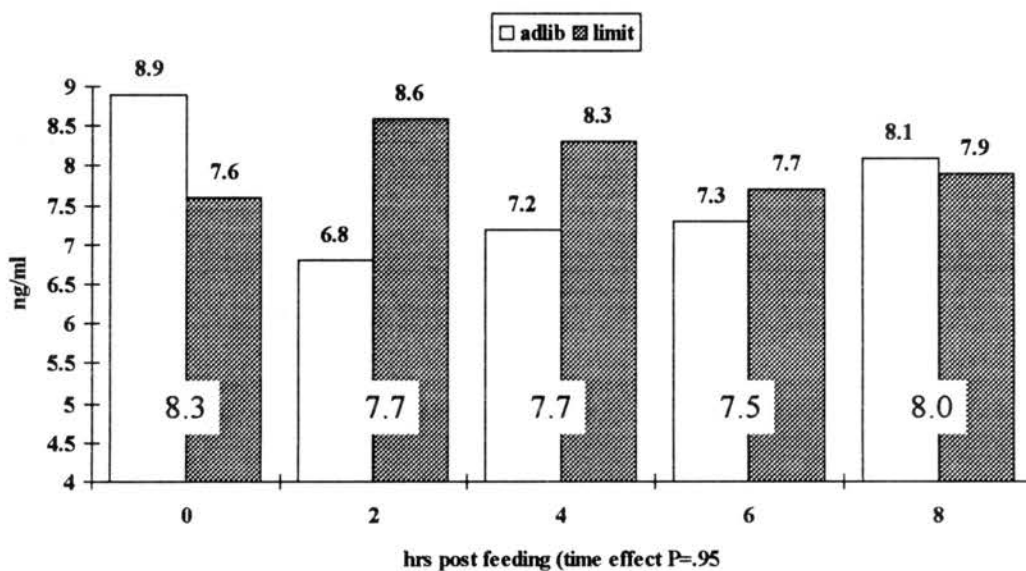**Figure 16. Daily Plasma Insulin Concentration By Feeding Treatment During Period 1.**

hrs post feeding (Time effect P=.13)

Figure 17. Daily Plasma Insulin Concentration By Feeding Treatment During Period 2.

hrs post feeding (time effect P=.95

Figure 18. Daily Plasma Free Fatty Acid Concentration by Feeding Treatment During Period 1.

hrs post feeding (Time effect P<.01)
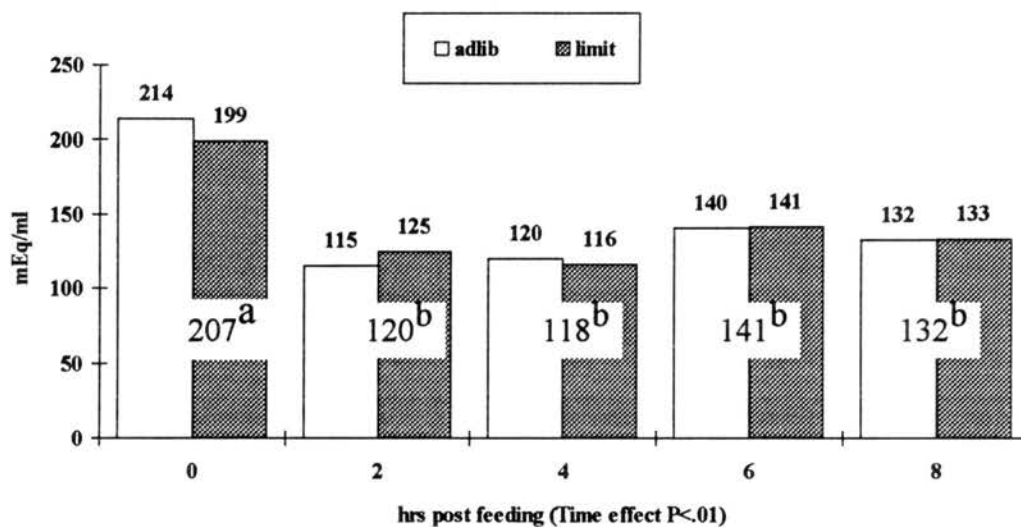
Figure 19. Daily Plasma Free Fatty Acid Concentration by Feeding Treatment During Period 2.

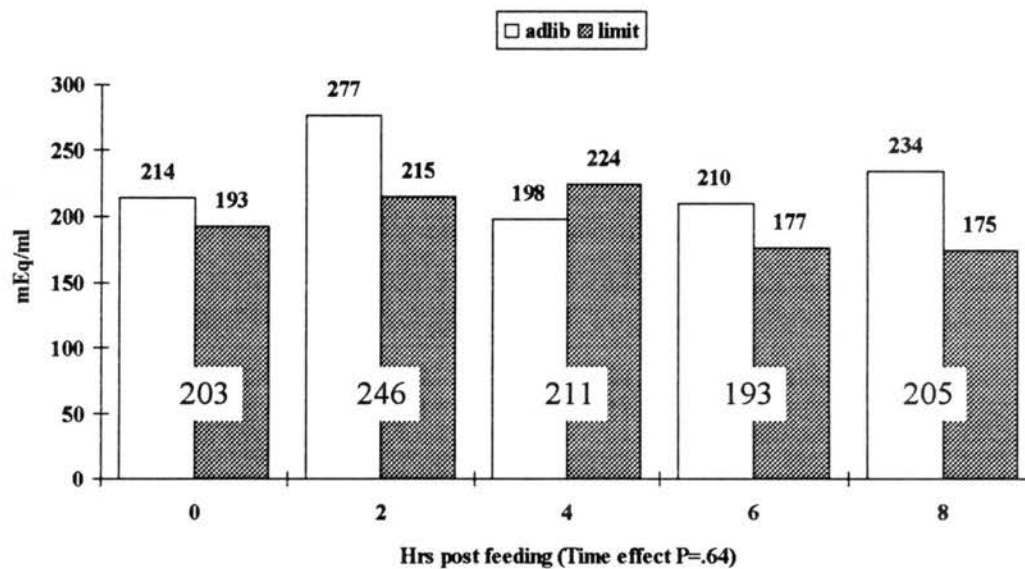Hrs post feeding (Time effect P=.64)

Figure 20. Daily Serum Growth Hormone Concentrations by Feeding Treatment During Period 1.
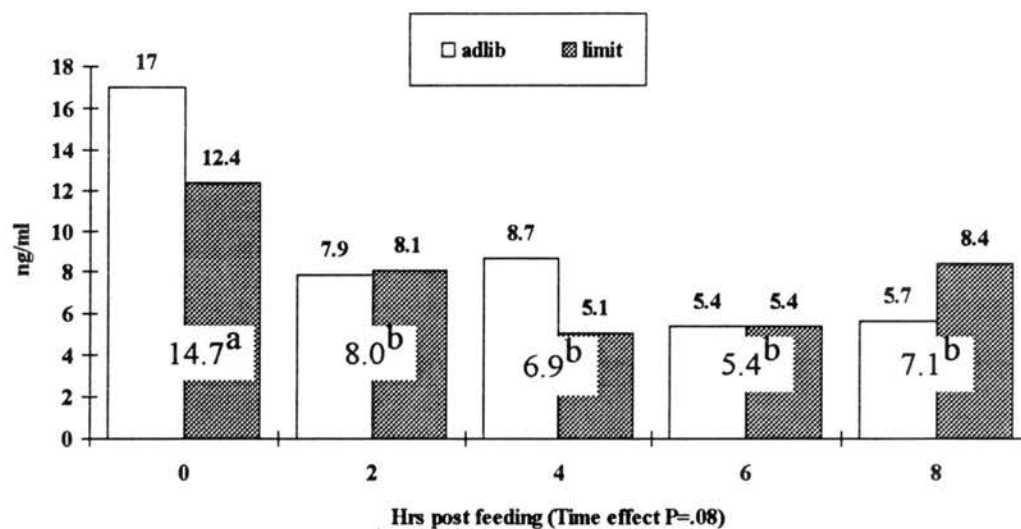

Figure 21. Daily Serum Growth Hormone Concentrations By Feeding Treatment During Period 2.
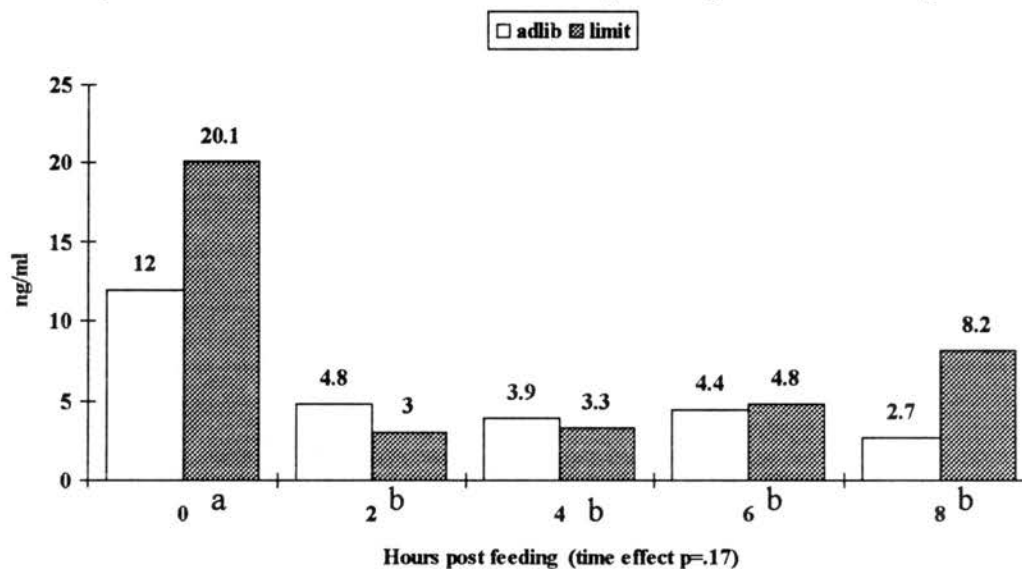
Table 49. Rumen parameters for the feeding treatment by sampling time interaction during period 1.

Feeding treatment	Limited			ad libitum				
time post feeding, hr	0	4	12	0	4	12	SEM	P<
Ammonia	.96	2.68	1.80	2.98	4.00	4.47	.54	.47
pH	6.0	5.9	5.7	6.2	5.9	6.0	.07	.10
Lactate, mg/dL	1.87	2.36	2.25	2.15	3.15	2.25	.16	.07
VFA, mol/100 mol								
acetate	43.6	45.3	43.8	46.7	47.3	46.8	.79	.71
propionate	39.5	38.7	39.2	29.4	29.3	28.9	.62	.77
butyrate	10.3	9.7	10.6	15.1	15.2	15.4	.32	.43
acetate:propionate	1.17	1.24	1.20	1.83	1.86	1.87	.06	.93
Total, mM	133[a]	95	123[a]	119[b]	100	108[b]	3.6	.02
Energy lost as methane, %	10.3	10.7	10.4	13.9	14.0	14.0	.30	.76

[ab] means within a feeding treatment and time post feeding differ (P < .05).

Table 50. Rumen parameters for the feeding treatment x sampling time interaction during period 2.

Feeding treatment	Limited			ad libitum				
Time post feeding, hr	0	4	12	0	4	12	SEM	P<
Ammonia	2.24	3.14	.98	4.84	6.73	4.31	.75	.79
pH	6.09	6.04	5.64	6.08	5.81	5.57	.12	.65
Lactate, mg/dL	2.62[a]	2.62	2.62	4.17[b]	3.00	2.83	.25	.05
VFA mol/100 mol								
acetate	43.1	44.3	42.5	45.9	45.9	46.1	.55	.24
propionate	39.7	38.8	41.6	34.5	35.6	36.1	.89	.41
butyrate	10.3	10.4	10.0	11.6	11.3	10.7	.40	.77
acetate:propionate	1.18	1.25	1.07	1.52	1.49	1.46	.06	.40
Total, mM	120	124	136	115	121	137	9.0	.94
Energy lost as methane, %	10.2	10.6	9.5	12.1	11.8	11.7	.34	.34

[ab] means within a feeding treatment and time post feeding differ (P < .05)

Table 51. Rumen parameters for the main effect of feeding treatment during period 1.

Item	ad libitum	Limit	SEM	P<
Ammonia	3.82	1.82	.83	.12
pH	6.05	5.91	.13	.50
Lactate, mg/dL	2.52	2.17	.09	.05
VFA, mol/100 mol				
acetate	46.9	44.3	2.03	.38
propionate	29.2	39.1	1.98	.05
butyrate	15.2	10.2	1.88	.10
acetate:propionate	1.85	1.21	.17	.05
Total, mM	109	117	7.7	.49
Energy lost as methane, % of F	14.0	10.5	.76	.01

Table 52. Rumen parameters for the main effect of feeding treatment during period 2.

Item	ad libitum	Limit	SEM	P<
Ammonia	5.29	2.12	1.35	.16
pH	5.82	5.92	.16	.66
Lactate, mg/dL	3.33	2.63	.25	.10
VFA, mol/100 mol				
acetate	46.0	43.3	3.5	.61
propionate	35.4	40.0	5.0	.55
butyrate	11.2	10.3	1.5	.69
acetate:propionate	1.48	1.17	.32	.52
Total, mM	124	127	10.0	.88
Energy lost as methane, % of F	11.8	10.1	.003	.38

Table 53. Rumen parameters for the main effect of sampling time during period 1.

Item	0 hr	4 hr	12 hr	SEM	P<
Ammonia	1.97^a	3.34^b	3.13^b	.38	.05
pH	6.1^a	5.94^b	5.89^b	.05	.05
Lactate, mg/dL	2.01^a	2.76^b	2.25^a	.11	.01
VFA, mol/100 mol					
acetate	45.2	46.3	45.3	.56	.33
propionate	34.4	34.0	34.1	.44	.78
butyrate	12.7	12.5	13.0	.22	.26
acetate:propionate	1.50	1.55	1.54	.04	.67
Total, mM	126^a	97^b	115^c	2.5	.01
Energy lost, % of fermentable	12.1	12.4	12.2	.22	.65

^{abc} means with differing superscripts differ by (P < .05)

Table 54. Rumen parameters for the main effect of sampling time during period 2.

Item	0 hr	4 hr	12 hr	SEM	P<
Ammonia	3.54[a]	4.93[a]	2.64[b]	.53	.05
pH	6.08[a]	5.93[b]	5.61[a]	.08	.01
Lactate, mg/dL	3.39[a]	2.81[b]	2.73[b]	.18	.05
VFA , mol/100 mol					
acetate	44.5	45.1	44.3	.38	.34
propionate	37.1	37.2	38.9	.63	.14
butyrate	11.0	10.8	10.4	.28	.32
acetate:propionate	1.35	1.36	1.26	.04	.26
Total, mM	117	123	136	6.3	.14
Energy lost, % of fermentable	11.12	11.20	10.59	.24	.21

[abc] means with differing superscripts differ by (P < .05)

Table 55. Effects of feeding treatment on ruminal content weights before and after adjustment for body weight at the end of period 1.

Item	Limit	Ad libitum	SEM	P<
Animal weight	972	1159	50.7	.04
Rumen contents (unadjusted), lb. DM				
Solids	14.6	22.6	3.8	.19
liquid	56.6	81.3	8.56	.08
total	71.3	103.8	11.6	.10
Rumen contents (BW adjusted), lb. DM				
solids	18.5	18.7	4.3	.97
liquid	67.9	69.9	8.2	.89
total	86.5	88.6	11.3	.91
Ruminal turnover, % /hr	2.80	3.25	.50	.55

Table 56. Ruminal and fecal concentrations of protein, starch and ash at the end of period 1.

Item	Limit	Ad libitum	SEM	P<
Rumen contents				
Ash	3.0	3.0	.29	1.0
Protein	11.5	12.25	.49	.32
Starch	48.8	42.3	4.31	.33
Fecal contents				
Ash	7.25	8.25	1.11	.55
Protein	18.5	17.8	.81	.54
Starch	18.5	17.8	5.05	.92

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CHAPTER VII

SUMMARY OF RESTRICTED FEED INTAKE STRATEGIES FOR FEEDLOT CATTLE

Restricting the intake of finishing cattle has shown to consistently improve feed efficiency between 5 and 10%. The optimum degree and length of time in which to restrict cattle still has not been determined, but some generalizations can be made. Based on previous studies, restricting intake throughout the finishing period will improve feed efficiency but often requires more days on feed and reduced percentage of cattle grading Choice. Based on the results of the trials in this dissertation somewhere between 7.5 and 15% restriction from ad libitum intake for approximately half the feeding period appears to give improved efficiencies without substantially affecting carcass traits. However, in some cases a few additional days on feed may be required to achieve similar carcass weights.

Several interesting things were discovered in the course of the research presented in this document. One interesting point was to dismiss a common belief in the cattle industry that cattle must have a grazing period in order to "stretch their gut" so adequate intakes and performance can be achieved upon entry into the feedlot. While cattle may benefit for a variety of reasons from a grazing period it has nothing to do with stretching their gut. This point was illustrated quite well in trial 1. In this trial substantially different intakes were achieved by diet type and manually restricting intake. These intake patterns were maintained for 62 days and then all cattle were fed the same diet and there was no difference in intake.

Another interesting observation of this research that was never significant, but was repeated in three different trials was that cattle which had undergone these slight (7.5-15%) restrictions had greater percentages of carcass fat than cattle fed ad libitum. However, at the end of the trial the opposite was true. it should be noted that these differences were never significant or even all that great, but the fact that it was there at all is interesting and led to subsequent trials trying to determine why. Based on observations of previous trials and documented results of the last trial it became obvious that cattle feeding behavior is substantially altered by even these slight restriction levels. This altered feeding behavior appears to have an effect on the hormonal and metabolite status of limit fed cattle. Both growth hormone and free fatty

acid concentrations of limit fed cattle were lower than cattle fed ad libitum. These results point to the possibility that there is less fat being broken down by limit fed cattle and hence may explain why they are fatter. Additionally, ruminal propionate production was greater for the limit fed cattle than ad libitum fed cattle. These results may partially explain part of the improvement in efficiency of limit fed cattle.

There is some documentation that when cattle are restricted in intake that the gut and vital organ weights will decrease this has the effect of decreasing maintenance energy requirements and hence when allowed ad libitum intakes will be more efficient. However, in those studies restriction was more severe than in the trials reported here. Indeed, in these trials measured gut and vital organ weights were unaffected by feeding regime.

It appears from the results of these trials that the effects of restricted feeding may be partially dependent on grain processing. In trial 2 cattle were either limit fed early and ad lib fed late or ad lib fed throughout under 3 degrees of corn processing. It appeared that the greater the degree of corn processing the greater the improvement for limit feeding. It was also determined that the variation in gain between cattle that were limit fed was less than that of cattle fed ad libitum. Whether or not this difference is due to more consistent intakes day to day with less possible occurrence of subclinical acidosis is not clear, but could certainly explain a lot. Additionally, because the limit fed cattle consistently came to the bunk and ate aggressively and finished their entire allotment of feed within 2-4 hrs there was little chance for cattle to sort their feed. This may be as important a factor as any in explaining more consistent gains and improved efficiency of limit fed cattle. Since most diets consist of several ingredients like grain, a roughage source and a supplement which contains essential protein, drugs, and minerals if cattle are able to sort individual ingredients then they are not receiving a balanced diet.

Limit feeding or managing of feed intake for finishing cattle offers many potential advantages and indeed most commercial feedlots are practicing what has become known as "slick bunk policy", which theoretically is at least in some capacity limit feeding. However, more aggressive programs are being developed and offer great potential for the beef industry to further improve its efficiency and competitiveness in the market place.

VITA

William Jeff Hill

Candidate for the Degree of

Doctor of Philosophy

Thesis: RESTRICTED FEEDING MANAGEMENT FOR FINISHING CATTLE: EFFECTS ON PERFORMANCE, CARCASS TRAITS, ECONOMICS, BODY COMPOSITION, RUMINAL FERMENTATION AND BLOOD METABOLITE AND HORMONAL PROFILES

Major Field: Animal Nutrition

Biographical:

Personal Data: Born in Muskogee, Oklahoma, August 1, 1969, the son of William B. and Anna L. Hill.

Education: Graduated from Bixby High School, Bixby, Oklahoma, in May 1987; received Bachelor of Science Degree from Oklahoma State University in December, 1991; Received Master of Science Degree from Oklahoma State University in July, 1994; completed the requirements for the Doctor of Philosophy Degree from Oklahoma State University in December 1997.

Professional Experience: Internship at Wheeler Brothers Feedlot, Watonga Oklahoma, May 1991 to August 1991; Research Assistant, Department of Animal Science, Oklahoma State University, January 1992 to August 1997.

Membership: American Society of Animal Science, American Registry of Professional Animal Scientists, Plains Nutrition Council.