COMPENSATORY GROWTH IN SOKOTO GUDALI BULLS

BY

OBIABO WILSON EHOCHE

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Department of Animal Science,
Faculty of Agriculture,
Ahmadu Bello University,
Zaria.

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O. W. EHOCHE

Date: July, 1987

CERTIFICATION

This thesis entitled Compensatory growth in Sokoto Gudali bulls by O.W. Ehoche, meets the regulations governing the degree of *Doctor of Philosophy of Ahmadu Bello University and is* approved for its contribution to scienctific knowledge and literary presentation.

Dr. W.S. Alhassan
(Chairman, Supervisory Committee)
School of Agriculture A.T.B.C/
A.B.U. Bauchi.

Professor N.N. Umunna
(Member, Supervisory Committee
Department of Animal Science
Ahmadu Bello University, Zaria.

Professor N.N. Umunna
Head, Dept. of Animal Science
A.B.U. Zaria.

Dean, Postgraduate School
A.B.U. Zaria.

ABSTRACT

Forty-eight Sokoto Gudali bulls belonging to two age groups were used to study compensatory growth. The animals were fed either low (L), moderate (M) or high (H) plane of nutrition during three periods. The feeding periods were arranged to give LLH, LMH and LHH feeding regimes. Feed intake, growth, physiological parameters and body compositional changes were measured at various stages of the trial.

Daily Liveweight gains during the full feeding period averaged 0.53, 0.67 and 0.79 kg/day respectively for animals on LHH, LMH and LLH feeding regimes and were significantly higher in LLH and LMH animals than in LHH controls. Animals on LLH and LMH feeding regimes were more efficient In converting dry matter Into empty body weight gain than the bulls on LHH feeding regime.

Serum thyroxine feveLs showed no significant differences between feeding regimes during both feed restriction and. full feeding periods. Younger bulls had significantly higher serum thyroxine values than the older bulls at alL stages of trial. Plasma urea nitrogen levels were significantly lower in LLH and LMH bulls during feed restriction and during the first part of the full feeding period, but similar to the level of LHH controls during the last part of the full feeding period.

At final slaughter dressing percentage was significantLy lower in LLH (50.1%) and LMH (49.5%) than in LHH (52.8%) bulls. Carcass lean were 68.9, 69.3 and 67.7% respectively for LLH, LMH and LHH and were significantly higher in favour of LLH and LMH animals. The control LHH bulls had significantly higher fat

percentages but lower bone percentages than LLH and LMH bulls.

Animals on LHH feeding regime were more efficient in converting ML to carcass energy gain than LLH and LMH animals at the end of the full feeding period. Digestible crude protein efficiencies for carcass protein gain were 17.55, 26.19 and 35.39g DCP/g protein gain, respectively for LLH, LMH and LHH bulls. It was concluded that increased efficiency of protein utilization during the first half of full feeding was Largely responsible for compensatory growth response in Sokoto Gudali bulls.

DEDICATION

This thesis is dedicated to the fond memory of my late parents, Ehoche Ogbole and Anugba Ameh, whose love and encouragement through my junior years in primary and secondary schools gave me the foundation for higher education and a career.

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In Nigeria, the traditional system of cattle husbandry comprises nomadic and semi-nomadic herding. With an estimated 90% of Nigeria's total cattle production under the control of the pastoralists (Ogunfowora et al., 1975), the system constitutes the major component of beef cattle production. These pastoralists move their livestock south or north of the country, depending on the season and availability of forages.

The adverse effect of seasonality of rainfall on the productivity of beef cattle maintained under the extensive grazing system is well known. Growth rates of grazing cattle fluctuate as a result of the seasonal patterns of forage growth. Thus, during the wet season when there is an abundant supply of good quality forages, cattle gain body weight. During the dry season, however, there is decline in both the quantity and quality of forages available for grazing animals. Cattle grazing these poor quality forages without supplemental feeding lose body weight and condition. In the Northern Guinea Savanna, de Leeuw (1971) reported that cattle on natural grazing during the dry season lost 15-20% of the weight they had attained at the end of the rainy season. Zemmelink (1974) observed that unsupplemented cattle grazing upland shrub in the Northern Guinea Savanna lost 300-400g body weight per head per day in the dry season. However, the animals are able to grow rapidly and recover body weights during the ensuing wet season. This ability to recover from a period of undernutrition and grow at relatively rapid rates is known as compensatory growth.

The implications of the concept of compensatory growth and its application to beef cattle production are very important in developing countries such as Nigeria that depend largely on natural pastures to feed livestock. In Nigeria, the supply of cereal grains and industrial by-products to supplement dry season grazing is inadequate (Umunna et al., 1980). The problem of dry season feed supply is compounded by difficulty and cost of conserving enough of the surplus wet season forages in the form of hay or silage.

It may be necessary and more economical to consider a production system that fully exploits compensatory growth. Feeder cattle may be maintained over the dry season on low plane of nutrition. Such cattle will then exhibit compensatory growth either during the wet season grazing or when fed high energy diets to finish in confinement. In spite of its advantages and the widespread seasonal occurrence, there is a lack of published information on compensatory growth responses of Nigeria's grazing livestock. Indeed, no research has been published on compensatory growth in the indigenous cattle. In sheep, Lakpini (1981) studied compensatory growth response of male and female Yankasa lambs following a period of low protein intake. The study examined efficiency of feed utilization for live weight gain and changes in carcass lean, fat and bone for compensatory lambs and controls continuously fed high protein diets. Further work is needed to determine the mechanisms involved in compensatory growth responses of grazing livestock in Nigeria.

The primary objectives of this study were:

1. to determine effect of age of Sokoto Gudali (Bokoloji) bulls on subsequent compensatory growth following a period of feed restriction.
2. to determine the roles of feed intake and feed digestibility in compensatory growth response.
3. to examine physiological changes that occur during growth restriction and subsequent compensatory growth.
4. to observe changes occuring in carcass physical and chemical composition during growth retardation and during the subsequent period of recovery.
5. to determine the efficiency of energy and protein utilization in Sokoto Gudali bulls during compensatory growth.

CHAPTER I

REVIEW OF LITERATURE

Introduction

Animal growth, and in particular compensatory growth, is a complex phenomenon that is influenced by a variety of factors. The purpose of this review is to bring into perspective, the many diverse facets of compensatory growth in meat production studies with cattle. The review, therefore, is composed of four main sections:

i. concept of animal growth.

ii. occurrence of compensatory growth in cattle.

iii. factors contributing to accelerated growth following suppression.

iv. body compositional changes in compensatory growth.

1.1. Concept of animal growth

Growth is a complex phenomenon which lacks a clearly defined meaning. However, the term growth has been used to describe cell multiplication or mitosis, cell migration, protein synthesis, reproduction, increase in dimension, linear increase, gain in weight and gain in organic mass (Gall, 1969). Growth of an organism takes place as a cellular process by increase in the number of cells or hyperplasia, increase in cell size or hypertrophy, and the formation of intercellular substances. Thus in the early stages of muscle growth, the increase is mainly in cell number, later the increase is entirely in the size of the

cells. Adipose tissues, on the other hand, grow partly by the addition of new cells, but largely by the continued intracellular accumulation of lipids (Hafez, 1969).

The growth of the cell involves the synthesis of a wide variety of cell constituents such as nuclei, chromosomes, mitochondria, cytoplasmic organelles, enzymes and cell membranes. The nucleus is the functional centre of the cell, controlling its growth, differentiation and biochemical processes (Hafez, 1969). The growth characteristics of a species are contained in the genes.

Growth in the biological sense is intimately connected with metabolism and the organization of living systems in self-reproducing units (Gall, 1969). This is the concept of growth as it pertains to the animal as a whole. It involves a correlated increase in total body mass resulting from an increase in size of the individual tissues and organs (Carlson, 1969).

Hammond (1932) as cited by Palsson (1955), in his studies on the growth and development of mutton qualities in the sheep, established the basic principles of animal growth and development. The studies show that as animals grow not only do they increase in weight but their body proportions also change. The changes are as a result of the different tissues growing at different rates. The organs and organ groups also exhibit marked heterogonic growth; some like the brain, eyes and gut-organs vital for maintenance of life - are early developing.

The developmental changes in the animal are caused by waves of growth (Palsson, 1955). Palsson (1955) described a primary wave of growth from the cranium down to the facial parts of the

head and backwards to the lumbar region. A secondary wave of growth starts from the lower parts of the limbs (metacarpals and metatarsals) down to the digits and upwards along the limbs and the trunk, also ending in the lumbar region which is the latest maturing part of the animals. A similar pattern of an early onset of high growth intensity at centres near the extremities passing with an increasing growth rate backwards and upwards to the lumbar region also occurs in each of the major tissues, bone, muscle and fat. More recently, however, Butterfield (1964) as cited by Preston and Willis (1970) showed that the abdominal - not the loin and lumbar - muscles develop last.

1.1.1. Patterns of Post-natal growth in Beef cattle

The basic principles of animal growth and development were subsequently verified in cattle (Callow, 1948; Berg and Butterfield, 1968; Butterfield et al., 1971; Mukhoty and Berg, 1971; and Berg et al., 1978a). The findings of these workers show that post-natal growth in beef cattle generally involves two aspects. The first is an increase in overall body mass per unit time measured by the liveweight growth for the whole animal. This assumes a sigmoid curve as the animal matures. Thus from birth, given adequate nutrition, a calf will grow along a sigmoidal curve showing acceleration up to puberty and slowing down thereafter as maturity is approached (Berg and Butterfield, 1976).

The second aspect of beef cattle growth involves changes in the form and composition of the animal as a result of

differential growth of the component parts of the body, namely, muscle, fat, bone and connective tissues. The growth patterns of the tissues show bone growing at slow rate, and muscle growing relatively fast, so that the ratio of muscle to bone increases with maturity. Fat tissue grows at high impetus rate, particularly after the fattening phase begins. In normal slaughter weight ranges muscle percentage decreases, fat percentage increases and bone percentage decreases with increase in weight or maturity (Berg and Butterfield, 1968).

The most common measure of growth is probably increase in liveweight but very often various other measures of size such as height and length of body are used. A combination of liveweight and measures of size is likely to be more informative than liveweight alone because it records the changes in shape which occurs during normal growth and also demonstrates that an animal may continue to increase in size even though the body weight is kept constant (Pomeroy, 1975).

An alternative method of measuring growth is by means of the relative growth rate. Methods of describing relative growth have been described by Palsson (1955). These include (1) weight of part expressed as percentage of body weight, (2) weight of part expressed as a fraction of body weight at one age compared with the fraction calculated at another age, and (3) by use of equations relating growth of part to the whole body.

Huxley (1932) as cited by Berg and Butterfield (1976) studied growth of parts of the body relative to the whole body by use of allometric equation of

$$Y = ax^b$$

where Y = size of the organ or part

X = size of the rest of the body

b = the growth coefficient of the organ or part

a = constant

when converted to regression, the equation becomes log Y = a + b log X. The growth coefficient 'b' represents the ratio of the percentage or relative post-natal growth of Y on X and it therefore allows relative maturity to be expressed. Thus the size of 'b' is high when Y represents a late maturing tissue, and low when Y represents an early maturing tissue.

The allometric equation has been used to compare the growth of muscle, fat and bone relative to muscle plus bone in beef cattle. (Mukhoty and Berg, 1971, Berg et al., 1978a, Seebeck, 1973b and Fortin et al., 1980a). Seebeck (1968) observed that the allometric equation was easy to handle statistically and concluded that it was the most appropriate model to describe part-to-whole relationship. Similarly, Berg et al. (1978a), who studied the use of linear regressions, ratios and allometric regressions in determining genetic influences in tissue growth patterns, concluded that the allometric regression was the most useful method since it provided the lowest residual standard deviation. Mukhoty and Berg (1971) found that the growth coefficients for bone in beef cattle were all less than 1.0 indicating a fall in proportion of bone as muscle plus bone increased. The growth coefficients for muscle were greater than 1.0, indicating an increase in the proportion of muscle with an increase in muscle plus bone. The growth coefficients for fat

were high, generally from 1.5 to 2.0 showing an increase in the proportion of fat as muscle plus bone increased. The coefficients support the observations that during post-natal growth, bone grows at low impetus rate, muscle growth is intermediate and fat grows at high impetus rate (Berg and Butterfield, 1968).

The growth of chemical components in beef cattle is important since it influences the distribution of nutrients in the tissues. The major chemical components of the animal body are water, protein, minerals or ash and chemical fat. Haecker (1920) as cited by Berg and Butterfield (1976) carried out one of the most extensive studies on body composition in cattle. The studies involved steers slaughtered from 91 to 682 kg live weight. The data showed that relative to liveweiht, water was the major component of the body; it decreased steadily as the animal grew. Protein and ash showed a fairly steady increase relative to liveweight. The amount of chemical fat increased at an accelerating rate, slowing somewhat in the heavier animals. Reid et al. (1968) examined the relationships among the concentrations of the gross chemical components of the empty fat-free and dry body of cattle by means of correlation and regression analyses. They found that with increasing body weight, age and weight of fat, the percentages of water declined, and those of protein and ash increased.

1.1.2. Breed, Sex and Nutritional effects on Post-natal growth patterns in beef cattle

(a) Breed effects

Although carcass composition of cattle appears to be largely a function of weight (Callow, 1948) breed differences in growth patterns exist at any given weight (Preston and Willis, 1970; Koch et al., 1976). Berg and Butterfield (1968) observed breed differences in relative growth between dairy and beef types of cattle. They reported that Hereford steers showed a marked tendency to begin the fattening phase at lower muscle plus bone weights than did the Friesians. There also was less bone relative to muscle plus bone in the Hereford steers. The Friesians had relatively more muscle and bone in their carcasses and less fat than the Herefords. Callow (1961) and Cole et al. (1964) reported similar findings. Cole et al. (1964) found that Angus and Hereford steers had the least percent of muscle, while Brahmans and Holsteins had the highest proportion of separable muscle. Lohman (1971) who compared four breeding groups for fatness at four weights, found that Angus fattened at lighter fat-free weights than did Holsteins, with Angus x Holstein and Charolais x Angus intermediate in fattening patterns. Kertz et al. (1982) showed that in Aberdeen - Angus cattle, muscular growth was due to an increase in cell size, whereas in Holstein - Friesians it was due to increase in the number of cells and/or nuclei or a combination of these with increased cell size.

In an extensive study, Mukhoty and Berg (1971) examined the growth patterns of muscle, bone and fat relative to the growth of muscle plus bone in bulls, steers and heifers of several dairy and British beef breeds over a wide range of slaughter weights. They found that the growth coefficients for muscle and bone were

homogenous between breeds, whereas the growth coefficients for fat were significantly different among breed groups, indicating a genetic influence in the rates of fattening. Similarly, Broadbent et al. (1976), who studied growth and carcass characteristics of purebred and crossbred cattle, found no significant differences between the breeds in the lean contents of their carcasses. However, Angus had carcasses with a higher fat content, a lower bone content and a higher lean to bone ratio than the Friesians and the Ayrshire. Berg and Betterfield. (1976) suggested that breed differences in carcass composition could result from a breed difference in the onset of fattening phase, a breed difference in the rate of fattening or a combination of both.

Despite the relative homogeneity of growth patterns of muscle and bone among breeds (Mukhoty and Berg, 1971; Broadbent et al., 1976), carcass composition adjusted by regression to a common side weight has been found to be significantly influenced by breed (Truscott et al., 1976; Berg et al., 1978a; Geay and Robelin, 1979 and Fortin et al., 1980a). In observing the growth pattern of muscle, fat and bone in the male progeny of eight sire breeds, Berg et al. (1978a) did not find significant sire breed differences in the regression of muscle, fat or bone on carcass or liveweight. Breeds, however, differed significantly in amount of muscle, fat and bone when compared at standard weights. Geay and Robelin (1979) showed that the large sized, late maturing continental beef breeds represented by Charolais and Limousin produced more muscle and protein and less fatty tissues and lipids than did the dairy breeds represented by Friesians

(Holsteins) at the same range of body weight.

Fortin et al. (1980a) compared the physical composition of the carcass and the growth rates of muscle, fat, and bone among bulls, steers and heifers of the Holstein and Angus breeds fed at two levels of energy intake. They noted that the expression of a genetic influence in the growth rate of carcass tissue was altered by the level of energy intake. Thus, whereas in the high energy intake animals, the growth coefficients for muscle, fat and bone did not differ among breeds, different growth coefficient for the different breeds were observed in the low energy intake animals. However, when carcass composition was adjusted to a common side weight, significant differences were observed in tissue growth patterns between high energy intake Angus and Holsteins. Within sex and level of energy intake, they found that Holsteins contained less fat and more bone than Angus, while the muscle content was similar for both breeds. Comparing Bunaji (White Fulani) and Bokoloji (Sokoto Gudali) breeds of cattle fattened and slaughtered at liveweights of 250, 300 or 350 kg, Buvanendran et al. (1983) reported that the two breeds did not differ significantly in percentage of muscle, bone or fat although the Bunaji had a slightly higher muscle percentage and lower fat and bone percentages than the Bokoloji.

The commercial value of beef carcass depends not only on the overall proportions of muscle, bone and fat but also on the distribution of these tissues since some regions or cuts command higher prices than others. Numerous studies have indicated significant differences between breeds in tissue weight

distribution. Mukhoty and Berg (1973) examined muscle weight distribution among several different breed groups. Their results indicated that breed differences were significant although small for abdominal muscles and muscles of the neck region. Percentages of muscle classified as expensive were found to be remarkably similar among breed groups. They concluded that breed differences in muscle-weight distribution in cattle are a minimum when compared at somewhat similar stages of physiological development.

Seebeck (1973b) assessed the effects of body weight loss on Brahman cross and Afrikander cross steers of the F_3 generation with respect to gross dissected carcass composition and the distribution of these components over the dressed carcass. Gross composition was similar in the two breeds, irrespective of the body weight loss treatment. However, the Afrikander steers had heavier muscles around the spinal column and lighter shin muscles, at the same total muscle weight. They also found that the expensive muscles were slightly but not significantly heavier in the Brahman cross steers. Similarly, Carpenter et al. (1961) found that Brahman and $3/_4$ - Brahman rib cuts had more lean than $1/_2$ - and $3/_4$ Shorthorn rib cuts.

Kempster et al. (1976a) studied the distribution of lean among steer carcasses of different breeds and crosses. They found that at equal total lean weight, Charolais x Friesian, Limousin x Friesian and Simmental x Friesian groups had the highest weight of lean in the combined higher priced joints and the Ayrshire and Friesian x Ayrshire groups the lowest. Their results and those of Truscott et al. (1976) and Berg et al.

(1978b) showed that the larger continental beef breeds and their crosses had higher proportion of muscle in the high-priced regions than the traditional British beef breeds and their crosses. Berg et al. (1978b) concluded that differences in muscle-weight distribution of breed groups were probably a reflection of a combination of different maturity status and minor differences in size, shape and muscling.

In experiments to compare muscle growth and distribution in two breed - types, Hereford and Dairy Synthetic, Jones et al. (1980) found that growth coefficients were homogenous among breeds, indicating that breed did not influence relative muscle growth. However, some significant though minor breed differences were found when muscle weight distribution was adjusted to constant side muscle weight. Dairy Synthetic animals had significantly more muscle in the high-priced cuts (sum of round, sirloin, loin and rib) than Hereford animals. Fortin et al. (1980b) obtained similar results when comparing growth rates and distributions of muscle in the trunk and thoracic and pelvic limbs of Holstein and Angus bulls, steers and heifers. They found that, while the growth rates of muscle in the three joints relative to the carcass side or total muscle were similar for the Angus and Holstein, there were significant but small breed differences in the distribution of muscle in the trunk and pelvic limb. Holstein animals contained more muscle in the pelvic limb and less muscle in the trunk than did their Angus counterparts. They concluded that the commercial importance of these significant but small differences was questionable.

breed groups in fat trim distribution for round, loin, rib, chuck, flank and kidney and pelvic fat. Similarly, Berg et al. (1978c) reported small but significant differences among sire breeds for the amount of fat in each joint at a standard amount of total fat on the carcass.

Few studies have been reported of genetic influences in patterns of bone growth and distribution. This is probably because bone distribution in beef carcasses has less commercial significance than either lean or fat weight distribution. Seebeck (1973b) found that Afrikander cross steers tended to have slightly lighter leg bones and heavier axial skeleton and ribs than Brahman crosses at the same total bone weight. Similar differences were recorded between Friesian and Angus carcasses by Truscott et al. (1976), Friesians having more of their bone weight in their legs and Angus more in the thoracic region. Kempster et al. (1977) and Berg et al. (1978d) reported small, but significant differences between breed groups in distribution of bone weight in all joints and bone groups tested.

(b) Sex effects

Numerous reports indicate that at equal weights and ages, heifers, steers and bulls differ in growth patterns of muscle, fat and bone. The most pronounced sex influence on growth patterns is achieved through the fattening process. Sex influences the onset of fattening with heifers fattening at lighter weights than steers and steers at lighter weights than intact males (Bradly et al., 1966 and Berg and Butterfield, 1968). Berg and Butterfield (1976) indicated that fattening

relative to muscle plus bone growth appeared to be curvilinear with the sharp rise occurring earlier in heifers than steers and in steers earlier than in bulls.

Mukhoty and Berg (1971) found that muscle and bone weight adjusted to a common muscle plus bone weight were similar for sex groups. Similarly, sex did not have a significant effect on growth coefficients for fat although in all comparisons growth coefficients for fat were lowest for bulls, intermediate for steers and highest for heifers. Sexes, however, differed significantly in weights of fat adjusted to common muscle plus bone weight, heifers being fatter than steers and steers fatter than bulls.

In the study by Fortin et al. (1980a) no sex influence on the growth rates of muscle, fat and bone relative to the carcass side and muscle plus bone was detected in the Angus breed. When carcass side composition was adjusted by regression to a common side weight, they found that Angus steers contained more muscle and less fat than heifers but less muscle and more fat than bulls. In a latter study, Fortin et al. (1981) observed that among Holsteins, rates of deposition for subcutaneous, intermuscular and internal fat relative to weight of carcass side were influenced by sex. The growth coefficients for these fat depots were lower for bulls than for steers or heifers. However, when rate of deposition was expressed relative to total fat, no sex influence was detected.

Mukhoty and Berg (1973) appraised sex influence on muscle weight distribution and reported a general trend of heifers

having a higher percentage in the proximal pelvic limb and abdominal areas than steers while steers exceeded bulls. They observed that sex influences reflected the differential development of bulls compared with other sexes as they mature. Muscle of the neck and thorax in bulls increased in proportion and other groups decreased. Thus the bulls had a higher proportion of their muscles in the neck and shoulder regions and heifers had a greater percentage in the high-priced regions. Similar findings were reported by Jones et al. (1980) and Prescott et al. (1964). Prescott et al. (1964) found that the difference in carcass proportions between bulls and steers was reduced after removal of the kidney and channel fat which was heavier in the steers.

Contrary to the above reports, Fortin et al. (1980b) did not find significant sex influences on the distribution of muscle in trunk and thoracic and pelvic joints. Similarly, Fortin et al. (1981) found that the distribution of subcutaneous, intermuscular, internal and intramuscular fat was not affected by sex among Holsteins and Angus.

Jacobs et al. (1977) compared bulls and steers in terms of composition, wholesale yields and retail values. They found that bull carcasses had larger rib-eye areas, less trimmable fat and higher retail yields than steers. Boneless bull carcasses contained less crude fat and more crude protein than steers.

(c) Effects of Plane of Nutrition

The influence of plane of nutrition on the growth pattern of muscle, bone and fat in cattle has been demonstrated in numerous

studies (Callow, 1961; Luitingh, 1962; Hendrickson et al., 1965 and Andersen, 1975). In a study involving Hereford steers, Hendrickson et al. (1965) determined the effect of different nutritional planes at different times on growing - fattening calves. They observed significant differences in fat, lean and bone among treatments. Andersen (1975) found that the relative weight of lean and bone increased and fat decreased when the feeding levels were reduced.

Waldman et al. (1971) studied weight and nutritional influences upon the carcass composition of Holstein steers slaughtered at birth, 91, 227, 341, 455 and 590 kg liveweight. The animals were fed to two levels, moderate and high planes. Their moderate plane was designed to result in 60 to 70 percent as much gain as the high plane group which were full-fed. They found that muscle growth to 91-227 and 341 kg weights was not different regardless of nutritional variation. However, animals reared to 455 and 590 kg on medium regimens produced significantly more muscle than those reared on high regimens. Similarly, Callow (1961) dissected the joints of cattle grown at either a high or a moderate plane of nutrition into bone, muscle, and fat and found the weight of muscle to be greater in the moderate group. Hinner and Bond (1971) found that the weight of muscles increased more rapidly in Angus steers restricted in their feeding than the full-fed control animals.

Other workers contend that animals reared on high plane of nutrition tend to produce more muscle than those reared on moderate plane. Guenther et al. (1965) examined the effect of plane of nutrition on carcass composition of Hereford steers

slaughtered on both an age and a weight-constant basis. They noted that the high level calves deposited lean in all parts of the carcass at a faster rate than did the moderate calves slaughtered at the same time. However, when the moderate calves were fed to approximately the same liveweight as the high calves, only small differences were noted in the lean content of the various wholesale cuts. Levy et al. (1974) similarly found that animals on 100 percent level of feed intake had a higher percentage of saleable meat in their carcasses than those that were restricted in their feeding.

The plane of nutrition was not a significant factor in the study by Suess et al. (1969) in which Holstein calves fed two nutritional levels were compared. They reported that muscle growth coefficients were not significantly different between high and medium planes of nutrition. Butterfield and Johnson (1971) obtained similar results and concluded that "under differences of feeding encountered commercially, no changes of practical importance in the relative growth of muscle are likely to be produced which are attributable to rate of growth of the musculature".

Seebeck (1973b) found that body-weight loss affected muscle-weight distribution, the most marked effect being that the relative proportion of abdominal muscle fell during body-weight loss. Seebeck and Tulloh (1968a,b) who examined the effects of developmental growth and a 13 percent body weight-loss on carcass composition of Angus steers, obtained similar results.

Callow (1961) slaughtered animals from four planes of nutrition and found a significant difference in the percentage of fat in the carcasses; those in the high plane in the final feeding period had fatter carcasses than those on the moderate plane. Hendrickson et al. (1965) supported this finding, noting that cattle grown at 0.9 kg/day had more fat in a three - rib joint than others grown at 0.7 kg/day.

The growth coefficients for fat relative to carcass side weight was affected by the level of energy intake (Fortin et al., 1980a). The growth coefficient for fat was larger for the high energy intake animals than for the low energy intake animals. Fortin et al. (1981) similarly found that among Angus steers, the rate of fat deposition in the subcutaneous and intermuscular depots were generally lower for the animals in the low energy intake group. Warwick et al. (1964) reported differential abilities of monozygotic bovine twin pairs to deposit intramuscular fat when fed on different rations.

Others have found little relationship between the plane of nutrition and the rate of fat deposition. Butterfield et al. (1971) slaughtered calves at predetermined weights after being fed individually on fresh and reconstituted whole milk at three levels. The highest level of feeding was ad libitum and the lowest was aimed at keeping the calves at their birth weights for 72 days before providing extra milk to allow growth to proceed. They found that the amount of fat in the carcass was not significantly affected by the rate of liveweight increase. Similarly, the distribution of subcutaneous fat was unaffected by weight-loss treatment (Seebeck, 1973b) while the hindquarter

intermuscular fat was decreased and the forequarter intermuscular fat was increased at the same total intermuscular fat weight.

The pattern of growth and distribution of bone in cattle as influenced by plane of nutrition has been shown by few studies. The results of these experiments generally indicate that bone development is related both to age and to body weight. Guenther et al. (1965) found that when calves were compared on a weight - constant basis, the moderate level calves tended to deposit more bone in all cuts than their high level counterparts. They suggested that bone deposition was more related to animal age and feedlot time than to nutritional levels imposed. Waldman et al. (1971) and Butterfield et al. (1971) also showed that bone growth was associated with body weight and influenced very little by nutritional energy levels during all phases of development. Seebeck and Tulloh (1968b), however, reported an increase in bone weight during a period of weight loss. Seebeck (1973b) obtained similar results but noted that the effects were mainly in the leg bones rather than axial skeleton.

1.2. Occurrence of compensatory growth in cattle

Numerous review studies have been published in recent years concerning most aspects of compensatory growth (Wilson and Osbourn, 1960; Moran and Holmes, 1978; O'Donovan, 1984). The studies show that a wide variety of domestic animals have the capacity to recover from growth restriction and resume growth at accelerated rates during liberal feeding. The phenomenon by which animals previously retarded in growth catch up with their

unretarded counterparts as a result of relatively higher rates of gain during full feeding is described as compensatory growth.

1.2.1. Compensatory growth observations in calves

Several experiments have been conducted that demonstrate compensatory growth in calves following periods of under-nutrition. Heineman and Van Keuren (1956) fed three energy levels to beef calves to determine the effects of wintering rates of gain on their subsequent performance on irrigated pasture. During the wintering period, the average daily gain for high, medium and low energy levels of feeding were 0.59, 0.46 and 0.15 kg/day respectively. Average daily gains on pasture were, however, 0.86, 0.87 and 1.11 kg per day respectively, suggesting a negative correlation between winter gains and subsequent pasture gains. Similarly, Kercher et al. (1965) found that summer gains on pasture and feedlot gains were inversely proportional to the previous winter gains by steer calves.

In a study designed to compare the growth of castrated male calves reared under two planes of nutrition, Broadbent et al. (1969) observed that restricted feeding for 12 weeks to the time the calves were turned out to grass created a difference of 23.6 kg per head in liveweight gain in favour of full-fed animals. At pasture the restricted animals gained faster than the full-fed controls although there was a commulative difference in liveweight gain of 7.1 kg in favour of the latter group at slaughter. Carroll et al. (1964) obtained similar results with heifer calves. They found that during liberal feeding heifers previously restricted in protein intake increased in liveweight

125.9 kg compared to 117.7 kg for controls.

Folman et al. (1974), in a study with bull calves, examined the effect of two liberal levels of energy fed during refeeding following a maintanence period of 90 days. They noted that during the refeeding period, previously restricted bull calves showed compensatory growth and gained significantly faster than the respective continuously fed controls.

Restricted nutrition for 200 days did not impair the capacity of Hereford calves to resume normal growth when grazing or when held in yards and fed on a high quality ration (Tudor and O'Rourke, 1980). These workers found that calves that had been restricted and allowed to recover on pasture grew faster than unrestricted controls also finished on pasture. They noted, however, that calves that had been restricted and allowed to recover in yards did not demonstrate compensatory growth, although they did exhibit growth rates equivalent to those of the unrestricted controls. Similarly, other workers have found no evidence of compensatory growth response in previously restricted calves. Stuedemann et al. (1968) examined the effect of various nutritional levels imposed from birth to eight months of age on subsequent growth of calves and found no significant differences in the average daily gains of the calves from the various treatment groups. The workers attributed the inability of the animals previously restricted in feeding to compensate with greater average daily gains to variation in severity and time of imposition of the restriction.

Wardrop (1966) underfed calves during the first 13 weeks of postnatal life and found that when fully fed from 13 to 52 weeks the calves did not exhibit compensatory growth. He concluded that short periods of undernutrition in early life can cause permanent stunting. Levy *et al.* (1971) underfed calves at maintenance and 125% maintenance levels for 30, 75 and 120 days, followed by full feeding. During realimentation the daily gain and body dimensions of the restricted animals were significantly lower than those of the control animals full fed throughout. They suggested that none of the restricted feeding treatments was severe enough as to cause weight loss, and possibly to stimulate some compensatory growth.

1.2.2. Compensatory growth observation in older growing cattle

Most of the reported studies on compensatory growth in older growing cattle are on pasture fed animals with or without supplementary concentrate feeding. Thus, Joubert (1954) who studied the influence of winter nutritional depressions on the growth of cattle, reported a tendency for animals wintered on low plane of nutrition to make higher relative increases on pasture in summer than those wintered on high plane.

Bohman (1955) wintered cattle at two planes of nutrition using an early-and late-cut hay. Steers fed the poorer quality late-cut hay gained less during the winter but gained faster during the following summer pasture feeding than those fed the higher quality early-cut hay. However, the entire difference on weight at the end of winter period was not compensated at the end of the grazing period as the steers fed the late-cut hay were still lighter than those fed the early-cut hay. In a subsequent study (Bohman and Torrell, 1956) complete compensation was obtained at the end of the second summer as steers wintered in the late cut hay were as heavy as those wintered on the better quality forage.

Lawrence and Pearce (1964a) studied the growth rate and conformation changes of cattle subjected to different levels of nutrition during their yearling winter and then realimented on grass. Average daily gains during the winter were 0.73, 0.34 and 0.01 kg per day for the high, medium and maintenance rations respectively. Average daily gains during the 5-months recovery period were, however, 0.57, 0.98 and 1.20 kg per day respectively. They noted that summer gain was increased by 0.35 kg for each kg decrease in winter gain. In a similar study, O'Donovan et al. (1973) fed young bulls high, medium or low plane of nutrition in confinement during the winter dry season followed by grazing on Pangola pastures during the subsequent summer. Animals fed on high, medium and low plane of nutrition during the dry season gained 0.64, 0.50 and 0.0 kg/day respectively. Corresponding gains on pastures were 0.29, 0.32 and 0.74 kg/day, indicating a compensatory growth response.

In investigations to determine the influence of stocking rate (4.5, 9.0 and 13.5 steers per hectare) on beef production from irrigated pastures, Hull et al. (1965) noted that at all levels of grazing intensity, steers previously fed low energy intakes during winter made greater gains on pasture than those previously fed the medium energy intake. O'Donovan et al. (1972), who fed cattle two winter planes of nutrition reported similar findings. The winter planes of nutrition were "low" (hay only) and "medium" (hay plus 1.8 kg concentrate). The former group of 18 bullocks lost an average of 21.5 kg while the latter gained 26.5 kg. They observed higher daily gains on pasture of bullocks previously fed on low plane of nutrition.

Baker (1975) compared the winter average daily gain of steers with their total liveweight gain over winter plus the following summer, he found that the groups wintered at 0.5 to 0.6 kg/head/day gained highest, while the total winter plus summer liveweight gain in animals wintered at 0.23 kg/head/day was identical with that in animals wintered at 0.77 kg/head/day. In a similar study Baker et al. (1982) found that spring calving Hereford x Friesian cows restricted over 2 months post-calving, compensated on pasture, having similar weights at the end of the grazing period with the unrestricted controls.

Carroll et al. (1963) examined the effect of a diet restricted in protein and energy on tissue growth and the extent of compensatory growth during realimentation. On the restricted diet, supplemented steers gained an average 0.23 kg daily for 156 days while unsupplemented steers lost 0.11 kg daily.

Realimentation on green pasture for 95 days and on a fattening ration for 158 days resulted in greater weight gain during both periods by steers previously unsupplemented. Bond and Lehman (1967), Meyer et al. (1965) and Horton and Holmes (1978) obtained similar results. In the study by Horton and Holmes (1978), gains were held at 0.22 and 0.50 kg/day for 20 weeks for two groups of Friesian and Friesian cross-bred cattle by restricting intake. During the subsequent 8 weeks on pasture, gains were greater for the low intake group, suggesting compensatory growth response. Meyer et al. (1965) fed steers high, medium and low energy levels during three periods followed by realimentation on high energy ration. They reported that compensatory growth was demonstrated in each period following a low energy intake period, even though the animals were realimented at different planes of nutrition.

Hironaka and Kozub (1973) found that steers restricted in feed intake for 12 or 24 weeks compensated by higher rates of gain when placed on full feed but required a longer time to reach market weight than the full fed controls. Thomson et al. (1982) similarly found that steers previously restricted in feed intake exhibited significantly higher liveweight gains than continuously fed control steers when realimented, but when expressed as empty body weight gain, the difference did not reach significance. They noted that compensatory growth enabled restricted steers to improve significantly their energy conversion ratio compared with control animals. In contrast, Hironaka et al. (1984) reported that control steers continuously full fed consumed the most feed/day, gained the fastest and required the least time to reach market weight than steers that were previously restricted in feed

intake.

The relationship of low to moderate gains at pasture to the degree of later compensation is important since a decrease in gain per animal at above average stocking rate can be offset by a significantly higher meat production per unit area (O'Donovan, 1984). Consequently, several trials dealing with restriction at pasture followed by realimentation on finishing diets have been reported. The findings are, however, variable. Wilkinson and Prescott (1970) reported that Friesian steers grazed at two intensities had mean daily gains of 0.59 and 0.89 (first experiment), and 0.84 and 0.95 kg (second experiment) or respective liveweight differences of 38 and 16 kg at the start of the winter feeding. They found that the higher stocked steers did not make significant compensatory growth over the subsequent winter feeding periods although they had a significantly higher intake of feed organic matter than the control steers.

Lake et al. (1974) supplemented steers grazing irrigated pasture with from 0 to 2.7 kg concentrate and reported that subsequent feedlot gains were not significantly affected by previous energy supplementation. Besides, animals gaining on pasture as a result of high levels of supplement, maintained a slight superiority in the feedlot. In a similar investigation, Coleman et al. (1976) found no consistent trends which suggest that increasing levels of supplementation and rate of gain on pasture result in a decrease in subsequent rate of gain in feedlot. While gains on pasture ranged from 0.38 for animals receiving no supplement to 0.67 kg/animal/day for animals

receiving supplement, they observed that drylot gains averaged 0.99 kg/head/day for all groups, with only a slight tendency for feedlot gains to decrease following higher supplementation on pasture.

Others have found that cattle restricted on pasture can compensate for a period of reduced growth and show faster gains in drylot than their unrestricted counterparts. Perry et al. (1971) fed varying amounts of concentrate to cattle grazing spring pasture and found that animals which gained more during that period gained less rapidly per day in drylot than those which had received lesser amount of concentrates during the pasture phase. They indicated that for each additional kg the cattle gained during the pasture season, they gained 0.20 kg less on the same daily concentrate intake during the drylot finishing period.

In a subsequent study (Perry et al., 1972), cattle on spring plus summer pastures were supplemented with 0 to 8.5 kg of concentrate per head daily. The workers reported that gains during the drylot finishing phase were negatively correlated with the previous gains on pasture, showing evidence of compensatory growth. Hinks and Prescott (1972) obtained similar results with grazing steers supplemented with barley. They found that during the drylot finishing period, the unsupplemented groups maintained a higher rate of gain compared to the supplemented group and by the time of slaughter had fully compensated in terms of liveweight for their slower gains at pasture.

1.3. Factors contributing to accelerated growth following periods of feed restriction

The ability of an animal to recover from effects of feed restriction varies considerably. An animal may cease to grow altogether on removal of the nutritional restraint or it may show partial or complete recover of its normal size and development (Wilson and Osbourn, 1960). Several factors have been suggested as possible reasons for the variations in compensatory response following undernutrition. The factors may be categorized as (1) those factors associated with the animals ability to recover and, (2) those factors associated with the recovery mechanism itself.

1.3.1. Factors associated with the animal's ability to recover

(a) Nature of undernutrition

Animals' growth may be retarded by restricting any one of the many nutrients in its diet. The nature of the nutrient restricting growth may be important in governing the extent of any recovery during realimentation (Wilson and Osbourn, 1960).

Blaxter (1950), studied energy and protein needs of calves in terms of whole milk requirements. He found that at the maintenance level of nutrition the energy needs of the calf was met by 2.8 litres of whole milk containing 4 percent fat. To supply just sufficient protein for maintenance however, only 0.6 litres was required. He concluded that the ill-effects of underfeeding milk diet was due more to a lack of energy than a protein shortage. However, Winchester and Howe (1955) showed that if the energy fraction only of the ration was restricted, cattle would be maintained at constant weight for 6 months,

without a loss in the subsequent power of recovery. Similarly, Fox et al. (1972), reported that cattle subjected to a period of energy restriction could recover.

The study by Bohman and Torrell (1956) suggests that protein restriction may be more harmful than an energy shortage. This is probably because there is little reserve protein in animals and consequently active tissues must be depleted during undernutrition and the damage thus inflicted may well prove irreparable (Wilson and Osbourn, 1960).

Others have found, however, that complete recovery is possible in animals subjected to either energy or protein restriction. Winchester et al. (1957) compared the effects of restiction of calves by either rations differing in quantity and quality. The eight treatments produced very large differences in response during the restriction period. At one year of age the cattle were full-fed until slaughter at maturity. They found that in spite of the widely different compositions of the ration as regards energy and protein content, the efficiency of feed utilization and the meat quality were similar for all eight treatments. It would therefore, appear that complete recovery is possible after quite severe restriction of either the energy or the protein content of an animal's diet. Similarly, Donald and Allden (1959) found that a check in the growth of wether weaners resulting from grazing mature sown pasture deficient in protein and energy did not affect ultimate size nor influence subsequent productivity.

(b) Severity and duration of undernutrition

Wilson and Osbourn (1960) classified nutritional restrictions as severe (when animals lost weight), moderate (when animals maintained weight) and mild (when animals made small weight gains) and suggested that there could be fundamental differences in the responses of animals during recovery, depending on the severity of restriction. Not only the severity but also the duration of restriction is considered to play an important role in the ability of animals to recover (Bohman, 1955; Wilson and Osbourn, 1960; Hight and Barton, 1965).

Wilson and Osbourn (1960) reported that realimentation following upon short periods of restriction resulted in increased growth rates compared to unrestricted control animals. Normal weights were eventually reached in the realimented animals. Longer periods of restriction, however, diminished this recovery, resulting in normal weights being achieved at a much later chronological age or sometimes in a permanent stunting of the animals. Similarly, Meyer and Clawson (1964) found that as the severity of undernutrition increased the restricted and realimented animals had difficulty in compensating during refeeding period when given the same quantity of feed consumed by the continuously grown animals.

In the study by Panaretto (1964) ewes were undernourished by feeding progressively diminishing quantities of a mixture of lucerne chaff and oats until they lost 34-39 percent of their initial weight in 150-200 days. The loss in body weight was met by considerable depletion of tissue reserves which in turn

affected the animals' ability to recover completely. Gills (1968) obtained similar results with Merino ewes restricted from weaning to 17 months of age. During realimentation a typical compensatory growth pattern reduced the liveweight difference from 27 percent of the high plane mean at 17 months of age to 5-7 percent. The difference, however, remained at this level for more than 4 years, indicating a permanent stunting effect.

Others have found that the more severe the restriction, the greater is the initial rate of gain immediately after realimentation. Ledger (1973) fed Boran Zebu steers to either maintain weight or lose 15-25 percent body weight over 12-24 weeks and found that upon realimentation animals previously restricted all grew faster than did the full fed controls. He noted that the longer the period of restriction, the greater and more persistent the compensatory growth. Similarly, Buttler-Hogg and Tulloh (1982) showed that the greater weight loss was associated with higher and more persistent growth rates during realimentation in sheep. Also, their study suggests that the more rapid the loss, the more repid will recovery be during realimentation.

(c) Age and/or weight of animal

The age of the animal at the commencement of feed restriction appears to be a significant factor in determining the degree of compensation.

Winchester and Howe (1955) found that complete recovery was obtained in cattle underfed between 6 and 12 months of age. In a

later study, Winchester and Ellis (1957) reported that complete recovery could be obtained even in calves fed maintenance diets from the younger ages of 3-6 months. However, Wardrop (1966) reported data showing no compensatory growth to 12 months of age in calves maintained at a low level of nutrition by nursing for 13 weeks. He concluded that restriction of growth during the non-ruminating phase of the calf's life may have deleterious effect on the subsequent powers of recovery.

The work of Bohman (1955) and Joubert (1954) suggest that older animals are better able to withstand undernutrition and to demonstrate compensatory growth than the younger animals. This view is supported by Morgan (1972) who underfed cattle from 0-16 or 16-32 weeks of life. On refeeding, all calves previously underfed recovered well. However, calves underfed from an early age did not compensate by growing faster during refeeding. Calves underfed from 16-32 weeks, on the other hand, expressed some degree of compensatory growth.

It would thus appear that the powers of recovery from periods of growth inhibition and the ability to express compensatory growth increased with increasing age of the animal (Lawrence and Pearce, 1964a). Similar results have been obtained with sheep. Allden (1968a) found that the effects of retarded growth in Merino lambs during the first 6 months of life persisted for 56 months, whereas undernutrition during the 6-12 months of life lasted for only 11 months. Although all groups ultimately attained normal adult weight and stature, compensatory growth was recorded only for the sheep which were subjected to growth restrictions during 6-12 months of life. (Allden, 1968b).

Morgan and Owen (1972a) found that the reduction of milk allowance for artificially reared lambs had no effect on their subsequent performance. In another report, Morgan and Owen (1972b) noted that growth rate and feed efficiency of lambs in the 15-25 kg were considerably reduced by restriction of milk allowance. However, there was no evidence that restriction in the middle period of growth (25-35 kg) had any effect on the performance of lambs fed ad libitum in the final period. Similarly, Buttler-Hogg and Tulloh (1982) observed that, following periods of nutritional stress during which sheep at different stages of maturity lost similar proportions of their body weight, the more mature sheep made more rapid recovery when ad libitum feeding occurred.

Others have reported contrary findings. Coleman and Evans (1982) studied the effect of age, size and biological type on the feedlot performance of Angus and Charolais steers following two planes of nutrition. They found that growth rates for the growing and finishing phases combined were greater for the younger than the older steers. The younger steers were more efficient in conversion of dry matter and metabolizable energy for live weight gain. Gunn (1964) suggested that compensatory growth response is likely to decline as an animal approaches its mature weight.

Thornton et al. (1979) imposed periods of feed restriction on Merino wethers when their liveweight were either below 23 kg or above 43 kg. They found that both groups exhibited compensatory growth upon realimentation, although there were

marked differences in the meat of immature and mature animals. The meat from immature sheep was depleted of fat, whereas that from mature sheep increased in fat content.

More evidence of the effect of age and/or weight on compensatory growth is available from the study of Saubidet and Verde (1976). They found that in beef cattle subjected to different levels of feed restriction, age and weight differences accounted for 65 and 43% of the compensatory growth responses during realimentation while both parameters jointly explained 73%. They concluded that in restricted and realimented animals, age was the best single predictor of response variation.

(d) Breed effects

Breed differences may exert an influence on the ability of animals to compensate for retarded growth. Joubert (1954) reported that earlier maturing breeds of cattle were more affected by restricted growth than were late maturing breeds. He found that as the age increased the more rapidly maturing Shorthorn cattle of Southern Africa showed greater differences when fed well or poorly than did the slower maturing Afrikaner cattle. Similarly, Wilson and Osbourn (1960) noted that slower maturing breeds were able to make a more rapid recovery from periods of growth restriction than faster maturing breeds.

These results support those of Coleman and Evans (1982) which indicated that restricted late maturing Charolais steers exhibited compensatory growth response when compared with continuously full fed Charolais steers while no difference in average daily gain was observed between restricted and control

early maturing Angus steers.

Preston and Willis (1970), however, suggested that the early maturing breed would tend to lose mainly carcass fat during growth restriction whereas the late maturing ones would tend to lose more muscle and would consequently take longer to recuperate.

(e) Quality of the realimentation diet

There is a considerable body of evidence to suggest that the quality of feed available during realimentation affects the ability of animals to recover from growth restriction and express compensatory growth response. Bohman (1955) noted that the quality of feed available during the summer influenced the ability of beef cattle to recover from winter undernutrition. Lawrence and Pearce (1964a) suggested that compensatory growth is likely to be greatest when the subsequent period of realimentation is accompanied by a change in the type of diet.

Swingle et al. (1979) fed cows to constant condition on diets containing 80 or 40% concentrate and 40 or 22% concentrate. In each comparison, they found that higher rates and efficiencies of gain were achieved in the higher concentrate diet, although performance of all groups was acceptable. Similarly, Fox et al. (1972) reported a greater degree of compensatory growth response in steers realimented on a diet of ME content 10.84 than in those fed a diet with ME content 6.28 MJ/kg DM.

When grass silage was the basis of realimentation diet there was no apparent compensation in beef cattle (Wilkinson and

Prescott, 1970; Hinks and Prescott, 1972). However, supplementing grass silage with increasing amounts of barley has been found to increase nitrogen retention and compensatory growth response of heifers (Griffiths et al., 1973). Moran and Holmes (1978) observed that the feeding of high energy diets during realimentation could promote close to maximum compensatory growth response.

1.3.2. Factors associated with the recovery mechanism

(a) Feed intake

There are indications that beef cattle previously underfed consume more feed during realimentation than their full-fed counterparts. Meyer et al. (1965) reported that steers previously restricted in energy intakes consumed more feed relative to body size during recovery than did those previously fed a medium or high energy intake. O'Donovan et al. (1972) attributed the higher daily gains on pasture of bullocks previously fed on low winter plane of nutrition to the significantly higher feed intake of the animals. Similarly, Horton and Holmes (1978), who examined intake, digestibility and body weight gains of beef cattle following periods of restricted growth, suggested that superior gains by the low treatment cattle was a result of their significantly higher feed intakes during recovery period.

In sheep, higher feed intakes during weight regain has also been reported. Allden and Young (1964) found that compensatory growth was associated with a significantly greater herbage intake

by the undernourished sheep. McManus et al. (1972) observed that sheep undergoing compensatory growth drank more water and ingested more feed per unit body weight that did control sheep. Similarly, there was evidence that enhanced appetite was a feature of compensatory regain in weaned lambs following a period of weight loss (Graham and Searle, 1979).

Others have observed no differences in feed intake during realimentation for restricted and continuously full-fed controls (Fox et al., 1972; Hironaka and Kozub, 1973). Saubidet and Verde (1976) found that when realimentation began, feed consumption of previously restricted beef cattle and their full-fed counterparts rapidly became similar. When compared at equal liveweight, the restricted animals had higher intakes than the controls; at an equal age, however, feed intakes were practically the same. They therefore discarded feed intake as a possible explanation for compensatory growth.

The findings are supported by the results of several sheep studies. Meyer and Clawson (1964) found that feed intake per unit of metabolic weight during the refeeding period was similar for restricted and continuously full-fed sheep, and concluded that feed intake was not a factor in compensatory growth. Similarly, Drew and Reid (1975c) reported no increase in feed intake when expressed on the basis of metabolic body size for previously underfed sheep.

Asplund et al. (1975) noted that restricted sheep did not eat a greater absolute amount of feed than the ad libitum animals during the recovery period. However, they did eat considerably

more compared to their body weight. Previously restricted and rehabilitated sheep consumed similar amounts of digestible organic matter as those continuously fed on a high plane (Murray and Slezacek, 1980a). Similarly, although commulative dry matter intake varied widely at the beginning of realimentation the total dry matter intake required to reach 50 kg body weight was not significantly different between restricted and full-fed sheep (Buttler-Hogg and Tulloh, 1982).

By contrast, compensatory growth has been associated with reduced feed consumption. Ledger (1973) noted that Boran-Zebu steers previously restricted in feed intake for 24 weeks consumed 25-34 percent less feed during realimentation than the continuously full-fed controls. Foot and Tulloh (1977) obtained similar results with steers grown on two paths. The growth paths were a 15 percent weight loss from 330 kg live weight, at 0.5 kg/day for 100 days, followed by recovery to 330 kg on ad libitum feed intake, and constant weight at 330 kg for the same length of time as the first group. They indicated that the mean total feed intake of steers previously underfed to lose body weight was 12 percent less than that of the constant weight group.

In sheep, Allden (1968b) found that growth restriction imposed in the first 6 months of life resulted in significantly less herbage intake on the absolute basis during recovery compared to continuously full-fed controls. However, after adjustment for differences in metabolic size, the feed consumption of the two groups was found to be similar. Keenan et al. (1970) reported that, following restricted feeding, sheep ate less feed during the first part of realimentation and no more

during the last part than those which had previously maintained their energy status.

(b) Maintenance requirements

The animal's maintenance requirement has also been associated with its ability to recover from growth restriction. Experimental findings tend to show that animals, either losing or maintaining weight over a considerable time, appear to have lower feed requirements, accompanied in certain instances by a reduced basal metabolic rate (O'Donovan, 1984). The extension of a lower maintenance requirement induced by the low level of feeding during restriction into the full feeding period has been proposed as one of the possible explanations for compensatory response in animals (Wilson and Osbourn, 1960; Fox, 1970).

Restricted animals are generally smaller than controls at the beginning of realimentation and these smaller animals normally have a lower maintenance requirement (Lawrence and Pearce, 1964a; Asplund et al., 1975; Saudibet and Verde, 1976). Foot and Tulloh (1977) found that daily dry matter intake of steers maintained at constant weight declined over time from 5.9 to 4.4 kg. Ledger and Sayers (1977) kept groups of Boran and Hereford x Boran steers at constant live weights of 185, 275 and 450 kg for periods up to 24 weeks. They noted that as time progressed less of the diet had to be fed daily to maintained constant live weight. Similarly, Ledger (1973) observed a progressive decrease in daily intake of dry matter in undernourished steers.

These findings are supported by results from several sheep

studies. Graham (1964), who determined balances of energy and nitrogen in sheep at several levels of feeding and at fasting, found that as the sheep lost weight the net availability of metabolizable energy at each level of food intake declined. Estimated energy requirement for maintenance was depressed by 28 percent after a few weeks of undernutrition in lambs (Graham and Searle, 1979). Similarly, Buttler-Hogg and Tulloh (1982) noted a 34 percent decline in digestible energy requirements for maintenance during compensatory growth in sheep previously underfed. Gingins et al. (1980) also reported lower maintenance requirements in undernourished than in well-fed sheep.

It has been shown that basal metabolism declines as energy intake decrease (Blaxter and Wood, 1951). This might be expected to decrease the maintenance requirement in underfed and refed animals. Fox (1970) reported that metabolic rate of steers was reduced during maintenance and the first part of full-feeding. He indicated that a reduced energy expenditure for maintenance during feed restriction would contribute to the animals ability to make up for a period of retarded growth. Also, a lower metabolic rate during the first part of recovery would contribute to an increase in efficiency of energy utilization during compensatory growth. Similarly, Graham and Searle (1975) observed a reduced metabolic rate per unit metabolic size of weaner sheep during constant weight stasis. These earlier reports on reduction in maintenance needs associated with lowering of basal metabolic rate in restricted and refed animals are confirmed in the recent reports of Murray and Slezacek (1980a) and Searle et al. (1982).

Other workers contend that underfed and full-fed animals have similar maintenance requirement. Meyer and Clawson (1964) subjected sheep to undernutrition followed by full feeding, and found a highly significant linear relationship between gross energy intake and energy gain over levels of energy intake of ad libitum and 84, 68, 52, 36 and 20 per cent of ad libitum, indicating that the maintenance requirement for dietary energy was equal at all levels of nutrition relative to metabolic size. They concluded that since the maintenance requirement was not decreased during starvation, it was not responsible for subsequent compensatory growth. Thomson et al. (1982) estimated maintenance energy requirement of steers and lambs after a mild growth restriction by regressing daily empty body weight gain on metabolizable energy (ME) intake. They found that approximately the same scaled ME intake of restricted and control animals was achieved during realimentation and concluded that maintenance requirement of control and realimented animals was similar. Drew and Reid (1975c) similarly observed that among sheep, there were no significant differences between normal growth and refeeding in maintenance requirements.

(c) Efficiency of feed and nutrient utilization

There are indications that some degree of feed restriction may favour efficiency of feed and nutrient utilization in animals. Fox (1970), who studied protein and energy utilization during compensatory growth in steers, reported a trend for net energy for maintenance and gain and efficiency of metabolizable

energy utilization to be higher for compensatory steers than controls. In addition, compensatory steers were considerably more efficient in protein utilization than continuously full-fed controls. He concluded that increased efficiency of energy and protein utilization during the full-feeding period was responsible for compensatory growth response. After further experiments on pasture, compensatory growth in steers following a period of low energy intake was attributed to an improvement in partial efficiency of feed utilization independent of feed intake (Hull et al., 1965; Meyer et al., 1965).

Folman et al. (1964) found that bull calves fed a maintenance ration for 90 days converted feed to gain more efficiently than controls fed ad libitum. Similarly, Drori et al. (1974) observed that 80-90 per cent of the ad libitum level of feeding promoted the most efficient gains in beef cattle. Horton and Holmes (1978) suggested that cattle previously fed low level of nutrition utilized digested nutrients more efficiently than the high intake controls. During recovery realimented animals required less ME/kg daily live weight gain (Thomson et al., 1982). Also, compared with control, previously restricted animals showed a marked reduction in methane production during feed restriction which persisted throughout realimentation. They suggested improved utilization of ME for protein deposition as one of the possible explanations of compensatory growth.

Although bullocks which lost weight over winter were slightly more efficient on pasture than those which gained 0.26 kg daily over winter, (O'Donovan et al., 1972), the former were less efficient over the combined winter and grazing periods and also when feed efficiency was expressed on the basis of metabolic size. Similarly, inspite of the higher rate of gain and efficiency of feed conversion in the final feeding period of cattle restricted in the first period, as compared with animals on ad libitum feed intake throughout, the former were less efficient when the entire feeding period was considered (Levy et al., 1974). During recovery period, restricted calves were more efficient in converting food into liveweight gain than unrestricted calves but there was no difference over similar live weight ranges (Tudor and O'Rourke, 1980).

In sheep it has also been shown that undernutrition would improve efficiency of feed utilization during realimentation. Meyer and Clawson (1964) found that efficiency of energy utilization was increased during full feeding following a period of restriction, and explained compensatory growth response in sheep on the basis of an increased efficiency of feed utilization above the maintenance requirement. Similarly, previously restricted sheep were more efficient in their use of nitrogen than were the ad libitum fed controls. (Graham, 1964; Asplund et al., 1975).

Digestible organic matter intake was utilized more efficiently for gains in sheep rehabilitated after a period of weight stasis (Murray and Slezacek, 1980a). Gingins et al. (1980) indicated that partial efficiency of metabolizable energy

was higher in undernourished and realimented sheep than continuously full-fed animals. In addition, they noted that a protein sparing mechanism (lower heat production and lower nitrogen losses) occurred during undernutrition and continued to operate during realimentation. Buttler-Hogg and Tulloh (1982) found that gross efficiency of dry matter utilization was higher for weight loss-weight gain process than live weight maintenance, and attributed this to a combination of increased growth rates, reduced feed intakes and lower maintenance requirement.

Osman and Bradford (1967) reported that sheep which were fed low plane succeeded by a high plane nutrition produced more gain per unit of feed intake during liberal feeding, though they were less efficient over the total period than those continuously fed on a high plane of nutrition.

Contrary to the above findings, Winchester et al. (1957) reported that neither protein nor energy restriction affected overall efficiency of digestible calories consumed as judged by increase in live weight. Carroll et al. (1964) studied the effect of a low-protein isocaloric ration followed by liberal feeding on the overall efficiency of energy utilization in heifers. They observed similar caloric values of the empty body and carcass, indicating that the protein restricted isocaloric ration prior to liberal feeding had no effect on the overall efficiency of energy utilization. The efficiency of utilization of digestible energy was similar for cattle that were on a full-fed regime throughout the feeding period or on a feeding regime that restricted the cattle to low or medium rates of gain for 12

or 24 weeks followed by full-feeding (Hironaka and Kozub, 1973; Hironaka et al., 1979).

In sheep, Keenan et al. (1969) found that animals which lost and then recovered weight were, overall, only 86 per cent as efficient in food utilization as those that maintained their original weight. Similarly, sheep offered food ad libitum after a period of sub-maintenance feeding were not better in efficiency of energy utilization than those which had previously maintained their energy status (Keenan et al., 1970).

Graham and Searle (1979) found that estimated energy requirement for maintenance in sheep was depressed by 28 per cent after a few weeks of undernutrition, but efficiency of utilizing additional energy was also lowered, cancelling the potential benefit for compensation. There were no significant differences in efficiency of energy retention above maintenance between sheep exhibiting continuous growth and those previously restricted in feed intake (Drew and Reid, 1975c).

Feed digestibility during realimentation is reported to be unchanged (Allden and Young, 1964; Foot and Tulloh, 1977; Buttler-Hogg and Tulloh, 1982), lower (McManus et al., 1972) or higher (Thornton et al., 1979; Gingins et al., 1980).

(d) Hormonal and other physiological effects

Observations on the involvement of hormones and other physiological factors in compensatory growth are quite limited and somewhat contradictory. Armstrong and Hansel (1956) did not detect any effect from level of nutrient intake on growth hormone content of pituitaries from heifers, and concluded that

differences in growth rates of heifers on different feeding levels were due to differences in amount of nutrients available for growth rather than to any differences in hormone production by the pituitary. Similarly, feeding or fasting up to 60 hours or infusion of acetate, propionate or butyrate did not alter plasma levels of growth hormone (McAtee and Trenkle, 1971).

Carl et al. (1968) reported a positive relationship between pituitary growth hormone content per unit of body weight and growth rates of cattle. However, Trenkle (1970) observed a trend for growth hormone to be negatively related to gains when cattle were fed high grain finishing diets. Similarly, Sters and Swiger (1971) found negative correlations between growth rates and circulating growth hormone levels in swine. These results, would suggest that animals exhibiting compensatory growth will show a decrease in circulating growth hormone levels.

Fox et al. (1974) measured growth hormone levels and thyroid secretion rates at different live weights in steers fed two different energy levels continuously (controls) or following a period of restriction (compensatory). They found that compensatory steers had lower plasma growth hormone levels than controls. They suggested that the faster growing animals (compensatory) may remove growth hormone from the circulatory system more rapidly because of a higher tissue utilization rate, resulting in lower circulatory levels of growth hormone. Their data also showed that compensatory steers had lower thyroid secretion rates during the period of feed restriction and during the first part of full feeding period, indicating, a lower

metabolic rate during maintenance and the first part of the full feeding as compared to continuously full-fed controls. They indicated that the lower metabolic rate would suggest a lower energy requirement for maintenance during the period of energy restriction and the first part of the full feeding period. A reduction in the maintenance requirement would result in a higher proportion of the total energy consumed being used for growth than would normally be expected, thus contributing to compensatory growth.

Rule et al. (1985) determined the relationship in cattle between the concentrations of some plasma hormones to concentrations of free fatty acids and glucose in plasma during a prolonged fast. They found that both growth hormone and insulin decreased, concentration of free fatty acids increased and glucose levels decreased, with fasting. They concluded that the endocrine changes were responsible for greater rates of free fatty acid mobilization from adipose tissue and glucose sparing during an energy deficit.

Compensatory growth may also be associated with anatomical changes in the animals' body, enabling it to consume more or utilize ingested feed more efficiently. Lawrence and Pearce (1964b) reported increase in the size of various portions of the digestive tract, including the rumen, reticulum, omasum and intestine. Broadbent et al. (1969) concluded that a considerable part of the apparent compensation in calves previously restricted in feed intake was achieved as a result of a change in gut fill at turn out. Similarly, Winter et al. (1976) reported that compensatory growth in sheep which had been subjected to weight

loss was associated with an increased gut capacity.

1.4. Body compositional changes in compensatory growth

The development of body composition during growth restriction and compensatory growth has been studied by several workers. The reports are however, not so clearly defined. While some data have shown no differences in body composition between restricted, full-fed and continuously full-fed animals, others have indicated contrary findings.

1.4.1. Non-carcass components

In measures of weight gain, empty body weight is a better criterion of evaluation than full body weight (Alhassan, 1974; Fox et al., 1976). This is largely because of gut fill adjustments which tend to exaggerate cattle (Lawrence and Pearce, 1964b) and sheep (Burton et al., 1974) gains.

In underfed sheep, empty body (Meyer and Clawson, 1964) and gastro-intestinal tract (Meyer and Clawson, 1964; Murray and Slezacek, 1980b; Morgan and Owen, 1972b) weights have been shown to decrease. In cattle, body weight loss caused a reduction in the rumen-reticulum and a gain in the hind gut (Seebeck, 1973a).

Changes in the empty body and gastro-intestinal tract weights have also been observed when animals are realimented. Hight and Barton (1965) reported an increase in the empty weights of sheep alimentary tract during refeeding. Winter et al. (1976) indicated that compensatory growth in sheep after a period of weight loss was associated with an increased gut content and a concomitant reduction in the proportion of empty body weight in the full body weight.

There are indications that weight changes occur in internal organs during growth restriction and realimentation. Seebeck (1967) observed that with body weight loss, the heart, liver, gall bladder, kidneys and lungs all declined in weight. These observations were confirmed in a subsequent study (Seebeck, 1973a) which also indicated that the liver showed most rapid weight loss in the early period of weight loss. Foot and Tulloh (1977) found that in cattle, liver weights reduced by nutritional restriction were not fully recovered. Likewise, the heart, liver and hide all lost more weight during weight loss period than they had gained during the growth phase (Winter et al., 1976). The proportions of these components were increased in relation to the empty body during the ensuing compensatory growth.

1.4.2. Physical and chemical composition of carcass

There are numerous, but conflicting, reports on the effects of growth restriction and realimentation on the physical and chemical composition of animals. Lawrence and Pearce (1964b) found that cattle subjected to different levels of restriction during winter and then realimented on grass, had similar carcasses. Morgan (1972), who underfed steer calves either from birth to 16 weeks or 16-32 weeks of age and then refed them did not find significant differences in carcass physical composition. Similarly, restricted feeding during calfhood stage resulted in only small differences in carcass physical composition (Broadbent et al., 1969). These findings are supported by results from sheep studies. Kellaway (1973) found that sheep which were starved and later regrown had similar body composition to sheep

grown continuously. Murray and Slezacek (1976) reported that at the same dissected side weight, the amount of muscle, bone and fat was similar in sheep previously restricted in feed intake and those continuously full-fed. Kirton et al. (1981) concluded that carcass tissue deposition was influenced more by carcass weight than by plane of nutrition.

In other reports, restriction and realimentation have been shown to cause changes in carcass composition. Carroll et al. (1963) found that restricted steers increased in carcass bone and decreased in carcass fat, while realimentation on green pastures resulted in greater lean growth by steers previously restricted compared to controls fed ad libitum. Guenther et al. (1965) fed cattle to slaughter on either high or moderate level to permit the comparison of carcass composition data on both age and a weight constant basis. Guenther et al. (1965) found that the high level fed steers produced more total lean than moderate level fed steers on age constant basis but no significant difference was noted in lean content when the steers were compared on a weight-constant basis. In a similar study, steers that were restricted in feed intake during part or all of the experiment had leaner carcasses than those that were given the diet ad libitum throughout (Hironaka et al., 1984).

In sheep, body weight loss followed by realimentation resulted in leaner carcasses compared to animals continuously grown (Keenan et al., 1969). Drew and Reid (1975c) supported this finding, indicating that realimented sheep had higher muscle to fat gain ratio than those exhibiting continuous growth.

Guenther et al. (1965) found that the high-level steers fed to mature weight had more fat than the moderate steers slaughtered at the same time. Others have similarly reported the tendency for restricted steers to have less fat in their carcasses (Hironaka and Kozub, 1973); Hendrickson et al., 1965); Martin et al., 1978). Drew and Reid (1975b) found that sheep which had lost 25% empty body weight to 26 kg and then refed to 31 kg empty body weight had 34% less separable carcass fat than sheep which had been continuously fed to empty body weight of 36 kg then had lost weight from that level to 31 kg empty body weight. .

Murray et al. (1975) found that the weight of bone was significantly greater in restricted cattle than those full-fed, indicating that bone development was related to age and carcasss weight. Callow (1961) and Andersen (1975) obtained similar results. However, in the study by Seebeck (1973b) bone proportion remained approximately constant during body weight loss. Guenther et al. (1965), noted that steers slaughtered at the same age had similar total bone content. However, on a weight-constant basis, the moderate-level steers had more bone than did the high level steers. They concluded that bone growth was related more closely to animal age and duration of feeding than to the level of nutrition.

The effects of restriction and realimentation on the chemical composition of the body has been the subject of consideration by several workers. Guenther et al. (1965) who analysed the boneless carcasses of cattle grown to 440 kg live weight at either 0.91 or 0.77 kg/day found no significant effects

of growth rate on either chemical fat or protein contents. Similarly, Murray et al. (1975) who grew cattle from 300 to 440 kg at three different rates, high (0.8 kg/day), low (0.4 kg/day) and high - maintenance (0.8 kg/day) followed by a period during which body weight was maintained constant, did not find significant differences between groups in water, protein and fat content of dressed carcasses.

Callow (1961) reported that high growth rate in cattle increased the chemical fat and decreased the protein and water content of bone-less carcass tissue. As carcass weight increased, the proportions in the carcass of protein, water and ash decreased while the proportion of chemical fat increased (Seebeck and Tulloh, 1969). Body weight loss led to a significant increase in ash and a decrease in protein.

Swingle et al. (1979) found that in cull range cows realimented on concentrate diets, carcass gain averaged over experiments, consisted 51, 14 and 35% of fat, protein and water, respectively. With increasing weight in realimented cull range cows, the percentage protein decreased and lipid increased (Wooten et al., 1979). Fat increases were minimal after 108 days and protein deposition was at maximum during the first 38 days of realimentation, indicating that protein repletion is rapid and is a priority function when undernourished cows are realimented. Baker et al. (1982) presented results which showed that cattle previously restricted and later realimented on grass deposited more protein and water, but less fat than those full-fed throughout.

In sheep, Keenan et al. (1969) recorded losses of 45% water, 39% fat and 13% protein during restricted feeding. When feed was offered ad libitum the sheep regained their liveweight deficit of 11 kg in 5 weeks, but only 75% of the energy deficit, due to the high water and low fat contents of the regained tissue. This trend was confirmed in a later study (Keenan et al., 1970). Similarly, sheep undergoing compensatory growth laid down less body fat, more protein and retained more water in their bodies than did control sheep (McManus et al., 1972).

These findings are supported by several other reports. Reid et al. (1968) observed that partial fasting followed by refeeding resulted in a little more protein, considerably more water, but much less fat and energy at a given body weight than in continuously grown controls. Likewise, sheep which had undergone weight loss and regrowth tended to deposit less fat and more protein than normal grown controls (Burton et al., 1974). Little and Sandland (1975) reported that the response of sheep to rehabilitation was associated with the accumulation of less fat and more protein than those grown continuously. Sheep realimented after 25% empty body weight loss contained, at 45 kg empty body weight, more body water and protein and less fat and energy than continuously full-fed animals of the same empty body weight (Drew and Reid, 1975a).

Searle et al. (1972) studied the composition of sheep throughout various growth phases. They found that the protein and water content of the gains were high during the early phases and these declined during the later phases of growth. In a subsequent study, Searle et al. (1979) reported a reduction in

protein content with a corresponding increase in fat, during the later stage of weight loss in sheep.

By contrast, sheep which lost weight contained more fat and protein and less water than ad libitum fed controls (Buttler-Hogg, 1984). Realimented sheep showed increases in fat, water and protein (Thronton et al., 1979). Searle and Graham (1975) reported increased water, less protein but similar amount of fat in restricted sheep. During recovery, however, previously restricted sheep gained less water, but more protein and fat compared to controls full-fed throughout. Severely restricted sheep rapidly lost bone water but bone fat continued to increase (Drew and Reid, 1975b). During realimentation bone water soon returned to normal and the previously accummulated bone fat was readily mobilized.

MATERIALS AND METHODS

2.1. Location of the Experiment

The study was conducted in Shika Research Station of the National Animal Production Research Institute, Zaria, Nigeria, from April 1984 to September, 1985. Shika is situated at 11°N Latitude and 640m above sea level. The area lies within the Northern Guinea Savannah Zone. The climate of the area consists of a total annual rainfall of 1100 mm, with about 90% falling during May to September (wet season). Mean daily temperature during the wet season is 25°C and mean relative humidity 72%. The dry season commences with a period of dry, cool weather known as the "harmattan" lasting from October to January. Daily temperatures range from 14 to 30°C, with 21% mean relative humidity. The harmattan is followed by dry, hot weather from February to April. Mean daily temperature at this period vary from 21 to 36°C, with 37% mean relative humidity.

2.2. Animals, Care and Management

2.2.1. Experimental Animals

The study involved Sokoto Gudali (Bokoloji) breed of cattle. The Sokoto Gudali is a short-horned Zebu, and thrives within the Sahelo-Sudan region of Nigeria. Females vary from essentially white or pale grey to a dark cream colour and bulls are grey or cream coloured with dark shading over the head, neck, shoulders

and tail (Wheat and Broadhurst, 1972). Though the pastoralist Fulani keep them primarily for milk, there are indications that Sokoto Gudali is the breed of cattle in Nigeria which produces the most desirable carcasses (Wheat and Broadhurst, 1972; Olayiwole, 1982).

2.2.2. Preliminary treatment and Design of Experiment

Forty eight Sokoto Gudali bulls, consisting of 24 young (aged 12-18 months) and 24 old (aged 24-30 months) were used. The young and old animals averaged 185 (range 160-210) and 255 (range 235-275) kg, respectively. The bulls were purchased from cattle markets around Zaria. Upon arrival, the animals were fed mixed hay ad libitum for 30 days in quarantine during which they were observed for sickness and treated when necessary.

At the end of the 30-day quarantine period, the bulls were weighed and scored for body condition on the scale of 1 = very lean to 6 = very fat based on the system described by Pullan (1978). Thereafter, three animals per age group were slaughtered to determine initial carcass composition. The remaining animals were then dewormed and thereafter fed low (L) plane of nutrition for 90 days (early period) to simulate poor feeding conditions that exist in the dry season. At the end of this early period three bulls per age group were slaughtered. The remaining eighteen animals in each age group were randomly assigned to three treatments in the mid period (91 to 180 days) according to the level of feeding viz, high (H), moderate (M) and low (L). In the final phase of the trial (181 to 270 days) all animals were

finished on a high plane. The three treatment categories were thus designated as LHH, LMH and LLH presented in the schematic design of the experiment (Table 1). The LHH group of bulls constituted the control group.

2.2.3. Feeding, Weighing and Sampling

(a) Feeding

The bulls were confined to individual pens (1 x 7.5m) that had concrete floors and were partially shaded. They were fed Gamba (Andropogon gayanus) hay and concentrate mixture according to the prescribed plane of feeding. The ingredient and chemical composition of the ration are as presented (Table 2). Molasses was diluted with water in a ratio of 3 parts by weight of molasses to 1 part by weight of water before mixing with the rest of the ingredients. This dilution facilitated mixing.

The animals were fed twice daily at 08.00 and 16.00 hours. The concentrate was offered and eaten before the hay was put in the feeding troughs. At the low and maintenance levels of feeding, animals received approximately 25% and 45% of high plane or ad libitum feeding respectively. The ad libitum fed group was offered enough concentrate and hay to ensure a 15-20% feed weigh back. Water and trace mineralized salt were supplied at all times. Orts were taken daily before the morning feeding.

(b) Weighing and measurements

The bulls were weighed at two week intervals to assist dietary manipulation to achieve desired weights. The animals

Table 1: Schematic design of the Experiment.

Period	Duration (days)	Treatment[a]	Feeding level	Number of Animals		
				Young	Old	Total
Initial	0			24	24	48
Early	0-90		L	21	21	42
Mid	91-180	LHH	H	6	6	12
		LMH	M	6	6	12
		LLH	L	6	6	12
Final	181-270	LHH	H	3	3	6
		LMH	H	3	3	6
		LLH	H	3	3	6

[a] LHH = Animals on low plane of nutrition (L) in early period and switched over to high plane of nutrition (H) in mid and final periods.

LMH = Animals on low plane of nutrition in early period, moderate plane (M) in mid period and high plane in the final period.

LLH = Animals on low plane of nutrition in early and mid periods and then switched over to high plane of nutrition in the final period.

Table 2: Composition of the diets used.

Item	Diets	
	Concentrate	Gamba Hay[1]
Ingredients: (%)[2]		
Molasses	25.0	
Cottonseed cake	35.0	
Palm Kernel Cake	15.0	
Wheat bran	13.0	
Rice bran	10.0	
Common salt	1.0	
Bone meal	0.6	
Zoodry[3]	0.4	
Chemical Analysis: (%)[4]		
Dry Matter (DM)	88.6	91.4
Crude protein	17.2	3.3
Neutral detergent fibre	41.7	74.5
Acid detergent fibre	22.7	54.9
Cellulose	16.1	44.0
Lignin	6.4	7.4
Ash	5.8	6.5
Gross Energy, Kcal/g DM	4.11	3.96

[1]Gamba hay = Andropogon gayanus
[2]Values expressed on as fed basis
[3]Zoodry VM 701, product of F. Hoffman La Roche and Co. Ltd. (See Appendix table 19 for composition).
[4]Values expressed on dry matter basis.

were weighed before the morning feeding. Weights taken at beginning and end of each study period were after a 24 hour feed and 12 nour water withdrawal.

At the end of each 90-day period, the animals were scored for body condition. Linear body measurements were taken every two weeks. This was done by moving animals from the feeding pens to a cattle crush and chest girth and wither height measurements taken according to proecedures described by Buvanendran et al. (1980).

(c) Blood sampling

The bulls were bled every two weeks at the time linear body measurements were taken. Blood samples were collected via jugular vein puncture into vacutainer tubes. At each sampling two 5 ml - samples were obtained from each animal, one into a tube containing an anticoagulant, disodium salt of ethylene diaminetetracetic acid (EDTA) and the other into a tube without an anticoagulant. The sample without an anticoagulant was centrifuged about 5 hours after collection and the serum was frozen for thyroxine determination. A portion of the sample with anticoagulant was used to measure haemoglobin (Hb), packed cell volume (PCV) and total protein. The rest was spun and the plasma stored in a freezer for the eventual analysis of plasma urea nitrogen.

2.3. Digestibility trials

Three digestibility trials on the ration used were carried out separately for the two age groups. The trials were conducted at the end of the mid period (180-day of trial), midway through final period (125-day of trial) and at the end of the final period (270-day of trial). Three bulls from each treatment category were used in the trials. The animals were restrained in individual metabolism crates and fed the diets twice daily at 08.00 and 16.00 hr. Orts were weighed and recorded daily before the morning feeding.

Each digestibility trial consisted of a 7 day adjustment period followed by a 5 day period of total collection of faeces and urine. During collection, faeces were mixed thoroughly and a 10% aliquot sample was taken daily and oven dried at $80^{o}C$ for 2 days. At the end of the collection period, the 5 day samples were bulked. Urine was collected daily in plastic tubs containing 100 ml of concentrated Hydrochloric acid (HCL). Ten percent of daily urine was saved in composite bottle containing 50 ml of conc. HCL for further analysis. Samples of Gamba hay, concentrate mixture and feed residues were taken daily and composited at the end of each collection period. Dried samples of feed and faeces were ground through 1 mm screen and stored for subsequent analysis.

2.4. Carcass compositional study

The comparative slaughter technique (Lofgreen and Garrett, 1968) was used to determine composition of carcass gain.

2.4.1. Slaughter procedures and processing

The plan of slaughter is presented in Table 3. For each age group three bulls were intended for slaughter at the beginning and end of the designated early period to determine initial body composition. At the end of each subsequent period three bulls per treatments were intended for slaughter. However, because of death losses over the early and mid periods there were reductions in the actual numbers slaughtered (Table 3). In all slaughter periods, animals were killed after a 24 hour feed and water withdrawal.

Following slaughter, the skin was removed and weighed. After severing the head, the tongue was removed and weighed. The rest of the head was weighed, the tail, front and back legs were removed and weighed separately. After evisceration, the heart, liver and spleen were removed and weighed. The gall and urinary bladders were weighed full, emptied of their contents and reweighed. The rest of the urinogenital tract and the respiratory tract were weighed. The gastrointestinal tract was ligatured at the abomaso-duodenal junction and the reticulum, rumen, omasum and abomasum (hereafter referred to as the "rumen") cut off from the small and large intestine. The rumen and the small and large intestine were weighed separately with the adhering fat tissues, emptied of their contents and reweighed. Thereafter, the adhering omental and mesentery fats were removed and weighed separately.

The carcass was sawn down the dorsal mid line into two sides. Both sides including the kidneys were weighed, chilled

Table 3: Number of animals slaughtered per period.

Slaughter Period	Treatment	Number of Animals		
		Young	Old	Total
Beginning of early period	Initial body composition	2	3	5
End of Early period	Initial body composition	3	2	5
End of Mid period	LHH	2	3	5
	LMH	3	3	6
	LLH	2	3	5
End of final period	LHH	3	3	6
	LMH	3	3	6
	LLH	3	3	6

for 24 hours at 3-4°C and reweighed. The kidneys were removed and the weights of kidneys and kidney fat were recorded separately. The left half of the carcass was then divided into ten wholesale cuts (Fig. 1) as described by Buvanendran et al. (1983). The 9-10-11th rib section was separated from the rib cut as described by Hankins and Howe (1946) and saved for separate study not within the scope of the present thesis. Rib eye area was measured by means of tracing on acetate paper over the 12th rib. A plastic overlay grid lined off in ten squares per square inch was used to measure the traced area. The values were converted to cm^2 by multiplying by 6.45.

2.4.2. Physical and Chemical composition

The wholesale cuts and the 9-10-11th rib were weighed and physically separated into lean, fat, bone and connective tissues. The lean and fat were weighed separately while the bone and connective tissues were weighed together. The lean and fat from the wholesale cuts were bulked, labelled "side boneless carcass" and stored in freezer for further processing. The lean and fat from the 9-10-11th rib were combined, labelled "9-10-11th rib boneless carcass" and similarly handled.

The frozen side and 9-10-11th rib boneless carcass were cut into small pieces, followed by grinding in a 1 1/2 horsepower (HP) Cripto meat mincer, model AE 22 (Crypto-Peerless Limited, London), using a 0.32 cm plate once. During grinding small aliquot samples were removed as the minced meat passed through the plate. To ensure representative sampling, the samples were taken throughout the entire grinding period. Approximately 600-

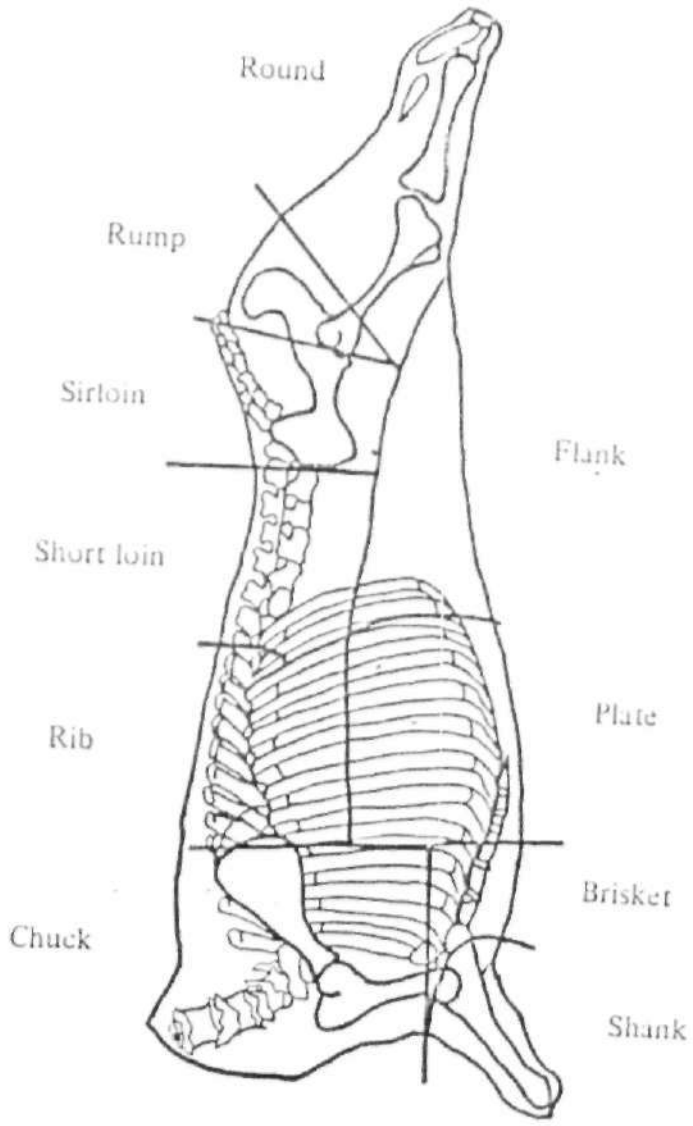


Fig. 1. Carcass wholesale cuts.

800 gm samples were taken, thoroughly mixed by hand, labelled and stored for freeze-drying. The mincer was cleaned in between samples to prevent sample contamination.

Freeze-dried samples were crushed and broken into smaller pieces by hand and thoroughly mixed. Small quantities of sample were put in a kitchen blender and ground into fine powder. During grinding chips of dry ice were added to facilitate the grinding process and reduce frictional heating of sample which might result in loss of energy. The ground samples were stored in labelled plastic bottles, tightly capped and kept in a freezer for proximate analysis. Chemical composition was based on boneless carcass partly because of the physical limitation of grinding whole carcass and partly because boneless meat is the most valuable portion of carcass.

2.5. Analytical procedures

2.5.1. Chemical analysis

Pre-dried ($80^{o}C$) feed and faecal samples were subjected to a second stage drying at $100^{o}C$ to determine the true dry matter (DM) of samples. Moisture content of meat samples was determined by freezer-drying. All subsequent chemical analysis were done on the pre-dried samples.

Ash was determined by heating in a muffle furnace at $550^{o}C$ for 5 hours (AOAC, 1975). Nitrogen in feed, faeces, urine and meat samples was determined by the Kjeldahl procedure (AOAC, 1975). Feed and faecal samples were analysed for neutral detergent fibre (NDF), acid detergent fibre (ADF), cellulose and

lignin by the procedures of Goering and Van Soest (1970), the gross energy of the feed, meat and faecal samples was determined by combusting 1.2 gm sample in a Gallenkamp (Gallenkamp, P.O. Box 290, London, E.C 2PER U.K) adiabatic autobomb calorimeter. Meat samples were analysed for ether extract according to AOAC (1975).

Haemoglobin (Hb), packed cell volume (PCV) and total protein (TP) in blood samples were determined using routine laboratory procedures (Coles, 1967). Plasma urea nitrogen (PUN) was determined using the method of Natelson (151). The procedures is outlined in Appendix Table 17. The concentrations of tetraiodothyronine (T_4) in the serum samples were determined by radioimmunoassay, using appropriate Amerlex RIA Kit from Radiochemical Centre, Amersham, England. The detailed procedure for this is described in Appendix Table 18.

2.5.2. Calculations

Feed intake values were calculated from the difference between feed offered and feed refused. These differences were also taken on a DM basis to arrive at the appropriate DM intake values. Daily gain was computed from the difference between initial and final body weights divided by the number of days on feed. Feed conversion efficiency was calculated from the ratio of DM intake to body weight gain. Index of compensation was calculated from the difference in weight existing between the control group (LHH) and the treatment groups (LMH and LLH) at the end of mid period minus the difference existing after

realimentation in final period, divided by the original difference at the end of mid period (Wilson and Osbourn, 1960).

DM digestibility was calculated from the difference between DM intake and faecal DM output, expressed as a percent of DM intake. Crude protein (CP) digestibility was computed from the difference between CP intake and CP output in faeces, expressed as a percent of CP intake. Digestible crude protein (DCP) percent was calculated by multiplying CP digestibility by CP content of diet. Daily DCP intake was obtained by multiplying DCP percent by daily DM intake. Digestible energy (DE) was calculated from gross energy intake minus faecal gross energy, divided by DM intake. Metabolizable energy (ME) intake was determined by multiplying DE by a factor of 0.82 (A.R.C., 1980).

Empty body weight was obtained by subtracting the weights of gut contents and the bladders from the shrunk body weight. Empty body weight gain was computed from the difference between initial empty body weight and the final empty body weight divided by the number of days on feed. Initial empty body weight of surviving bulls was determined by means of a regression equation generated from ten bulls slaughtered at the beginning of the trial (early period). The equation was $Y = 27.02 + 0.65X$ ($r^2 = 0.97$, C.V. = 16.2%) where Y is the initial empty body weight, kg and X is the initial full body weight, kg.

Dressing percent was obtained by dividing warm carcass weight by the slaughter weight. Carcass gain was computed from the difference between initial carcass weight and the final carcass weight. Initial carcass weight of surviving bulls was determined by means of a regression equation generated from the

ten initial slaughter bulls. The equation was Y = 18.53 + 0.34X (r^2 = 0.93, C.V. = 15.8%) where Y is the initial warm carcass weight, kg and X is the initial full body weight, kg.

Energy and protein efficiencies of utilization were calculated from the ratio of ME intake to boneless carcass energy gain, and the ratio of DCP intake to protein gain in boneless carcass, respectively. Daily protein, fat and energy gain were determined from the differences between initial and final boneless carcass protein, fat and energy values. Boneless carcass protein, fat and energy values were obtained by multiplying boneless carcass weight by carcass concentrations of protein, fat and energy. Initial boneless carcass weight and initial carcass concentrations of protein fat and energy were derived from the ten initial slaughter group (Lofgreen and Garrett, 1968).

Economics of feeding was determined for bulls previously subjected to varying degrees of undernutrition. Factors considered in the relative cost calculations included live weight gain, carcass weight gain, quantity of feed consumed and cost of feed consumed. Input costs such as capital required for construction of feeding pens, depreciation, purchase of stock, and labour were not considered as such costs were the ones likely to be exaggerated by the special high demands of research inputs. Furthermore, since feed costs were generally considered to be the greatest input costs per unit throughout of feeder cattle and the ones closely monitored in the study, these were the production costs considered in the computations.

In determining the economics of feeding, only the final feeding phase (180-270 days) was considered. The value of economic analysis of the other feeding periods, 0-270 and 90-270 days, is doubttul since no feedlot operator will subject animals to early (L) period of feeding. The mid period feeding regimes was to create three different types of feedlot animals for fattening in the final feeding phase.

2.5.3. Statistical Analysis

Data were analyzed for a randomized block design with feeding regime and age of animal as the criteria of classification. Analysis of variance procedure was used to study the effects of diet restriction and age of animals on the various parameters. Treatment means were compared using Duncan's Multiple Range Test (Steel and Torrie, 1960). All statistical tests were done at the 5% probability level.

Table 4 Continued.

Feeding Regime	181 to 225 Days				226 to 270 Days				0 to 270 Days			
	Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
LHH	7.33	7.50	7.42[a]		6.97	8.00	7.49		5.49	6.37	5.94[a]	
LMH	6.20	7.17	6.69[b]	0.10	6.78	8.38	7.59	0.22	4.60	5.26	4.94[b]	0.08
LLH	6.72	6.93	6.83[b]		7.94	8.28	8.11		4.82	4.86	4.84[b]	
Means	6.76[c]	7.20[d]		0.08	7.24[c]	8.22[d]		0.18	4.97[c]	5.51[d]		0.06

S.E.M	91 to 180 Days	0 to 270 Days
Feeding Regime x Age =	±0.07	±0.11

[a,b]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$)

[c,d]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$)

animals on LLH feeding regime and lowest for LHH animals, though these differences were not significant.

Over the entire experimental period (0 to 270 days), significant interaction occurred between feeding regime and age of animal. In younger group, DM intake was significantly higher for LHH animals than LLH or LMH animals, while differences between animals on LMH and LLH feeding regimes were not significant. In the older group, DM intake was significantly higher in LHH than LMH which had higher DM intake than LLH animals.

At all stages of the trial, the older, heavier bulls had greater DM intakes than the younger, lighter bulls.

The body weight gain of bulls at the respective trial stages are presented in Table 5. The dietary treatment imposed in the early period to simulate poor dry season feeding conditions resulted in weight losses for all treatment groups. In general, younger bulls lost an average of 0.32 kg per day while the mean daily weight loss in the older bulls was 0.46 kg. Total body weight loss at the end of the period as percent of the initial body weight averaged 19.6 and 17.0 for the younger and older bulls, respectively.

The objective of the mid period was to create differences in body weight and/or composition due to dietary treatment in order to determine their influence on performance of bulls during the subsequent full feeding period. Daily gains during this mid period directly reflected the feeding levels as the LHH animals which were full fed gained significantly higher than the the LMH and LLH animals in both age groups.

Table 5: Means for full body weight gain (kg/day) by feeding regime and age of animal at various trial periods.

Feeding Regime	0 to 90 Days				91 to 180 Days				181 to 270 Days			
	Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
LHH	-0.31	-0.49	-0.41		0.60	0.90	0.76[a]		0.67	0.38	0.53[a]	
LMH	-0.31	-0.43	-0.37	0.03	0.10	0.05	0.07[b]	0.02	0.70	0.63	0.67[b]	0.04
LLH	-0.34	-0.43	-0.39		-0.01	-0.11	-0.07[b]		0.88	0.70	0.79[b]	
Means	-0.32[d]	-0.45[e]		0.02	0.22	0.28		0.02	0.75[d]	0.57[e]		0.03

Table 5 Continued.

Feeding Regime	181 to 225 Days				226 to 270 Days				0 to 270 Days			
	Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
LMH	0.93	0.49	0.66		0.49	0.28	0.39[a]		0.37	0.34	0.36[a]	
LMH	0.73	0.81	0.77	0.07	0.67	0.46	0.57[b]	0.04	0.20	0.14	0.17[b]	0.01
LLH	0.93	0.78	0.85		0.82	0.61	0.72[c]		0.25	0.11	0.18[b]	
Means	0.83	0.69		0.06	0.67[d]	0.45[e]			0.28[d]	0.20[e]		0.01

S.E.M.	91 to 180 Days	0 to 270 Days
Feeding Regime x Age =	±0.04	±0.02

[a,b,c] Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$)

[d,e] Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

The mean daily gains during the first half of the final period (181-225 days) were greater for animals on LLH and LMH feeding regimes than those of the control LHH animals. These differences were, however, not significant. In the second half of the final period (226-270 days), gains were highest for LLH animals, lowest for LHH animals and intermediate for animals on LMH feeding regime. Overall daily gain during the final period was significantly lower in LHH animals while differences between LMH and LLH animals were not significant.

Table 5 shows that during the final period, the younger bulls gained significantly faster than the older bulls. Over the entire experimental period, significant interaction occurred between feeding regime and age of animal (Appendix Table 3). In younger bulls, daily gains were significantly higher in LHH than LMH which gained significantly higher than LLH animals. In the older group, daily gains were significantly higher in LHH controls while differences between LMH and LLH animals were not significant.

The respective daily gains of animals on LHH, LMH and LLH feeding regimes during early, mid and final periods created differences in body condition score at the various stages of the trial. At the initial stage, body condition score of all animals average 3.0 to 3.5 on the scale of 1 = very lean to 6 = very fat (Table 6). Following feed restriction in early period, the bulls lost condition and were characterized by marked emaciation. At the end of the mid period, animals on LLH and LMH feeding regimes which were further restricted, were significantly poorer in body

Table 6: Means for body condition score by feeding regime and age of animal at various trial stages

Feeding Regime	Day 0				Day 90				Day 180				Day 270			
	Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
LHH	2.7	3.3	3.0		1.0	1.5	1.3[a]		4.0	4.5	4.3[a]		5.0	5.7	5.3[a]	
LMH	3.2	4.0	3.6	1.19	1.3	2.8	2.1[b]	0.13	2.0	2.3	2.2[b]	0.19	4.3	4.7	4.5[b]	0.22
LLH	3.0	4.0	3.5		1.8	2.7	2.3[b]		1.2	1.7	1.5[b]		4.7	4.3	4.5[b]	
Means	3.0[c]	3.8[d]		0.15	1.4[c]	2.3[d]		0.11	2.4	2.8		0.15	4.7	4.9		0.18

[a,b]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$)

[c,d]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$)

*The interactions between feeding regime and age of animal were consistently non-significant in all the parameters measured in this study, and so are henceforth being excluded.

condition compared to full-fed LHH animals. Although LLH and LMH animals rapidly improved in condition upon refeeding, the control LHH animals maintained significantly superior body condition at the end of the final period.

During the final full feeding period, animals on the LLH feeding regime recorded higher rates of empty body weight gain (Table 7), which failed to reach statistical significance than LMH animals which had non-significantly higher empty body weight gains than LHH controls. Gains in empty body weight were greater in the younger bulls than in older bulls during the final full feeding period, though the differences were non-significant.

Efficiency of DM utilization for empty body weight gain during the first half of the full feeding period (Table 7) followed the same trend as did DM efficiency for full body weight gain (Appendix Table 4). The bulls on LLH and LMH feeding regimes required significantly less DM per unit of empty body weight gain during that period than the control LHH bulls. During the second half of the full feeding period, LLH animals were more efficient than LHH animals which were more efficient than LMH animals in coverting DM into empty body weight gain (Table 7). These differences were, however, not significant. Overall, DM efficiency for empty body gain during the final full feeding period was better, though not significantly in LLH than in LMH and LHH treatment groups. Younger bulls were significantly more efficient than older bulls in DM conversion to empty body gain at all stages of the full feeding period.

Table 7: Influence of feeding regime and age of animal on empty body weight gain and feed conversion efficiency during the full feeding period.

Item	Feeding Regime	181 to 270 Days				181 to 225 Days				226 to 270 Days			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
Empty body gain, kg/day	LHH	0.64	0.58	0.61		0.54	0.32	0.43		0.75	0.84	0.79	
	LMH	0.64	0.57	0.61	0.04	0.47	0.52	0.49	0.04	0.82	0.62	0.72	0.06
	LLH	0.79	0.65	0.72		0.60	0.51	0.55		0.98	0.80	0.89	
	Means	0.69	0.60		0.03	0.53	0.45		0.04	0.85	0.75		0.05
Kg DM/kg Empty body gain	LHH	11.23	13.29	12.26		13.74	24.08	18.91[a]		9.48	9.51	9.49	
	LMH	10.32	14.14	12.23	0.88	13.37	14.07	13.72[b]	1.25	8.47	14.27	11.37	0.93
	LLH	9.39	12.05	10.72		11.48	14.83	13.15[b]		8.10	10.79	9.44	
	Means	10.31[c]	13.16[d]		0.72	12.86[c]	17.66[d]		1.02	8.68[c]	11.52[d]		0.76

[a,b]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$).

[c,d]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

3.1.2. Body measurement changes

The changes in heart girth and height at withers during various stages of the trial are given in Table 8. At the end of the early period when all animals were restricted in feed intake, negative changes in heart girth but positive changes in height at withers were shown by all treatment groups. In mid period, changes in heart girth were negative and significantly lower in LLH and LMH animals than LHH controls. Changes in height at withers were positive and non-significantly different between feeding regimes. All treatment groups exhibited positive changes in heart girth during the final period but values for LHH animals were significantly higher than those of LMH and LLH animals which were not significantly different from each other. There were no significant differences between treatments in height at withers during the final period.

During feed restriction, older bulls showed greater resistance to decreased heart girth than younger bulls. During the full feeding period, however, the younger bulls showed significantly higher changes in both heart girth and height at withers.

3.2. Digestibility and Nitrogen balance

3.2.1. Digestibility of nutrients

The digestibility of nutrients and metabolizable energy content of diet determined at different phases of the study are presented in Table 9. The two age groups, being mature ruminants, would not differ in digestibility given the same

Table 8: Changes (cm) in heart girth and height at withers during various stages of trial.

Item	Feeding Regime	0 to 90 Days[1] Young	Old	Means	±SEM	91 to 180 Days[2] Young	Old	Means	±SEM	181 to 270 Days[3] Young	Old	Means	±SEM
Heart girth	LHH	-2.94	-2.37	-2.66		2.38	11.08	6.73[a]		20.77	13.53	17.15[a]	
	LMH	-1.96	-2.13	-2.01	0.24	0.65	-0.84	-0.10[b]	0.38	8.30	9.77	9.03[b]	0.74
	LLH	-2.37	-2.44	-2.40		-0.90	-2.10	-1.50[b]		8.73	6.40	7.57[b]	
	Means	-2.42	-2.31		0.20	0.71[c]	2.71[d]		0.31	12.60[c]	9.90[d]		0.61
Height at withers	LHH	1.46	1.34	1.40		2.23	1.90	2.07		5.03	0.87	2.95	
	LMH	1.05	1.26	1.15	0.33	0.61	1.38	1.00	0.42	2.40	0.74	1.57	
	LLH	1.21	1.40	1.30		1.73	1.18	1.46		1.40	0.67	1.04	
	Means	1.24	1.33		0.28	1.52	1.49		0.34	2.94[c]	0.76[d]		0.44

[1]Body measurement at the end of early period less initial body measurement.

[2]Body measurement at the end of mid period less body measurement at the end of the early period.

[3]Body measurement at the end of the trial period less body measurement at the end of the mid period.

[a,b]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$)

[c,d]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

diets, hence only feeding regimes were considered in the study. In the first trial conducted at the end of the mid period, the digestibility coefficients of dry matter, crude protein and gross energy were significantly lower when determined on LLH compared to LMH and LHH bulls. There were no significant differences between treatment groups in the digestibility of neutral detergent fibre at this period, although lower values were recorded for animals on LLH feeding regime. The content of metabolizable energy (ME) was significantly depressed in LLH bulls compared to bulls on LMH and LHH feeding regimes at that period.

Data obtained half way into the final period showed marked improvement in the digestibility of nutrients by the most severely restricted LLH bulls as the study progressed. Thus, no significant differences were detected between treatment groups in the digestibilities of dry matter, energy, crude protein and neutral detergent fibre, and in the ME content of diets at this period, although the values were lower in LLH bulls than in LMH and LHH bulls.

The results obtained at the end of the second half of the final period (Table 9) showed that the differences between feeding regimes in the coefficients of dry matter, crude protein, energy and neutral detergent fibre digestibility and in the ME content of the diet were minor and non-significant.

3.2.2. Nitrogen balance

The data in Table 10 indicate that nitrogen intake at the end of the mid period was highest in full fed control bulls,

Table 9: Digestibility of nutrients and contents of metabolizable energy (ME) in the diet according to feeding regime within stage of trial.

Item	91 to 180 Days				181 to 225 Days				226 to 270 Days			
	LLH	LMH	LLH	±SEM	LHH	LMH	LLH	±SEM	LHH	LMH	LLH	±SEM
Digestibility Coefficient %												
Dry matter	56.9[a]	59.3[a]	49.5[b]	1.33	67.8	65.4	61.0	3.41	68.4	69.1	67.8	1.67
Crude protein	65.6[a]	68.1[a]	47.3[b]	2.43	73.6	69.3	66.0	3.09	71.2	70.6	69.8	2.79
Neutral detergent fibre	54.6	56.6	50.2	2.49	63.4	62.0	56.4	3.16	65.8	67.1	66.0	1.57
ME, Mcal/kg DM	2.10[a]	2.11[a]	1.83[b]	0.06	2.21	2.18	2.03	0.09	2.30	2.33	2.29	0.06

[a,b]Means in a row within a trial stage with different superscripts are significantly different ($P<0.05$).

Table 10: Nitrogen intake, losses and retention according to feeding regime within stage of trial.

Item	91 to 180 Days				181 to 225 Days				226 to 270 Days			
	LHH	LMH	LLH	±SEM	LHH	LMH	LLH	±SEM	LHH	LMH	LLH	±SEM
Nitrogen intake, g/day	134.0[a]	60.7[b]	30.9[c]	4.87	138.5	126.3	138.8	8.52	132.1	134.4	147.8	10.19
Faecal Nitrogen, g/day	48.1[a]	20.2[b]	15.2[b]	2.59	36.6	38.9	45.7	4.30	36.9	38.5	44.0	3.11
Urinary Nitrogen, g/day	22.5[a]	14.9[b]	9.2[b]	2.21	21.1[a]	13.7[b]	10.8[b]	1.83	22.0	18.1	21.8	4.06
Nitrogen retained, g/day	62.1[a]	25.5[b]	6.6[c]	4.02	80.5	74.6	81.5	7.55	73.3	77.9	81.9	9.89

[a,b,c]Means in a row within a trial stage with different superscripts are significantly different ($P<0.05$).

lowest in severely restricted LLH bulls and intermediate in moderately restricted LMH bulls. Nitrogen losses in faeces and urine were significantly lower in LLH and LMH bulls compared to the controls. Retained nitrogen per day was significantly lower in LLH bulls than in LMH bulls which in turn had lower values than the LHH controls.

During the first half of the final feeding phase, animals on LMH feeding regime consumed less nitrogen per day than did animals on LLH and LHH feeding regimes. The differences were, however, not significant. No significant differences existed between feeding regimes in faecal nitrogen output. Urinary nitrogen loss was significantly less in LMH and LLH bulls than in LHH controls. There were no significant differences in nitrogen retention between treatment groups.

During the second half of the final feeding period no significant differences were observed across feeding regimes in nitrogen intake, and in faecal and urinary nitrogen output. However, from the start of realimentation to end of final period, nitrogen retention progressively increased in LLH and LMH bulls but declined in LHH bulls. Consequently nitrogen retention at the end of the final period was higher, though not significantly, in LLH and LMH animals compared to LHH control animals.

3.3. Physiological changes

In order to determine the role of physiological changes in compensatory growth, haemotalogic parameters, serum thyroxine and plasma urea nitrogen levels were measured during feed restriction

and full feeding periods.

3.3.1. Haematologic parameters

Means for packed cell volume (PCV), haemoglobin (Hb) and total blood protein (TBP) as affected by feeding regime and age of animals are presented in Table 11. In all the parameters, no significant interactions were noticed between feeding regime and age of animals (Appendix Tables 5-7). Consequently only main effects are considered.

There were generally no significant differences between treatment groups in PCV, and Hb at all stages of the trial. However, PCV values tended to decline during mid and final periods for animals on LMH and LLH feeding regimes while values for LHH animals remained unchanged throughout the periods. The values for Hb tended to decrease during mid period and increase during full feeding period for all treatment groups. During early period, TBP values were similar across feeding regimes. However, in mid period, TBP values were significantly lower in animals on LLH feeding regime than those of the LHH, while differences in TBP between either LMH and LHH or LMH and LLH animals failed to reach significance. In the final period, LHH animals had higher TBP values than LMH and LLH animals which had similar TBP values.

Age of the animal had a significant effect on PCV, Hb and TBP levels during early period, the younger bulls having significantly lower values than the older bulls (Table 11). No significant age effects were detected in PCV, Hb and TBP values during mid and final periods, although the trend for higher

Table 11: Means for packed cell volume (PCV), haemoglobin (Hb) and total blood protein (TBP) by feeding regime and age of animal.

Item	Feeding Regime	0 to 90 Days Young	Old	Means	±SEM	91 to 180 Days Young	Old	Means	±SEM	181 to 270 Days Young	Old	Means	±SEM
PCV(%)	LHH	26.2	29.7	28.1		27.3	28.8	28.0		27.0	29.3	28.1	
	LMH	29.7	30.9	30.3	0.75	27.0	26.4	26.7	0.71	27.2	25.8	26.5	0.64
	LLH	29.4	31.3	30.4		27.0	25.4	26.1		27.1	24.7	25.9	
	Means	28.5[c]	30.6[d]		0.61	27.1	26.8		0.59	27.1	26.6		0.53
Hb(gm/dl)	LHH	8.1	10.1	9.2		8.8	9.5	9.1		9.3	10.2	9.8	
	LMH	9.1	10.3	9.7	0.39	8.8	8.9	8.9	0.28	9.0	9.0	9.0	0.38
	LLH	8.8	10.5	9.7		8.7	8.5	8.6		9.2	8.3	8.8	
	Means	8.7[c]	10.3[d]		0.32	8.8	8.9		0.23	9.2	9.2		0.31
TBP(gm/dl)	LHH	7.1	7.8	7.5		7.5	7.3	7.4[a]		7.4	7.7	7.5[a]	
	LMH	7.2	7.6	7.4	0.15	7.3	6.8	7.1[ab]		7.1	6.8	6.9[b]	0.15
	LLH	7.0	7.8	7.4		7.0	6.7	6.9[b]		6.9	6.6	6.8[b]	
	Means	7.1[c]	7.7[d]		0.12	7.3[c]	6.9[d]		0.12	7.1	7.0		0.12

[a,b]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$).

[c,d]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

values in younger animals was evident in all the parameters.

3.2.2. Serum thyroxine and Plasma urea nitrogen

Serum thyroxine (T_4) levels averaged 6.6, 6.3 and 6.7 ug/100 ml for LHH, LMH and LLH animals, respectively during the early period (0 to 90 days) when all animals were underfed (Table 12). In mid period (91 to 180 days, T_4 levels were greater in LLH than in LMH and LHH bulls. The differences were, however, not significant. Similarly, in the final full feeding period (181 to 270 days), T_4 levels were non-significantly higher in LLH and LMH bulls than in LHH control bulls. Serum T_4 levels were not analysed separately for first and second half of final period because of fewer samplings during that period.

Age had a significant effect on T_4 levels regardless of the feeding regime imposed. Serum T_4 levels were greater in the younger than in the older bulls at all stages of the trial.

Plasma urea nitrogen (PUN) levels were similar across feeding regimes during early period (0 to 90 days), when all the animals received low plane of nutrition (Table 12). During mid period (91 to 180 days), LLH and LMH animals which were fed on low and moderate planes of nutrition respectively, had significantly lower PUN levels than LHH animals which received ad libitum feeding. Differences between LLH and LMH animals were not significant. PUN levels were significantly lower for LLH and LMH bulls during the first part of the final full feeding period but were similar to PUN levels for LHH control bulls during the last part of the full feeding period. Overall PUN levels during the final full feeding period were significantly lower in LLH and

Table 12: Serum thyroxine (T_4) and plasma urea nitrogen (PUN) concentrations in bulls at various trial stages.

Item	Feeding Regime	0 to 90 Days Young	Old	Means	±SEM	91 to 180 Days Young	Old	Means	±SEM	181 to 270 Days Young	Old	Means	±SEM
T_4(ug/100ml)	LHH	8.80	4.35	6.58		7.62	5.76	6.69		11.30	6.83	9.07	
	LMH	8.82	3.75	6.29	0.98	7.87	5.35	6.61	0.84	13.27	6.30	9.79	0.99
	LLH	10.18	3.12	6.65		8.64	6.53	7.59		12.90	7.86	10.38	
	Means	9.27^{c}	3.74^{d}		0.81	8.04^{c}	5.88^{d}		0.69	12.49^{c}	7.00^{d}		0.81
PUN(mg%)	LHH	8.6	10.8	9.8		11.1	13.4	12.3^{a}		15.0	18.4	16.4^{a}	
	LMH	8.8	11.2	10.0	0.23	9.4	11.1	10.2^{b}	0.23	11.2	14.5	12.9^{b}	0.33
	LLH	9.4	11.5	10.5		9.4	11.6	10.3^{b}		11.5	14.1	12.8^{b}	
	Means	8.9^{c}	11.1^{d}		0.19	9.9^{c}	12.0^{d}		0.19	12.6^{c}	15.7^{d}		0.27

Table 12 Continued.

Item	Feeding Regime	181 to 225 Days Young	Old	Means	±SEM	226 to 270 Days Young	Old	Means	±SEM
PUN(mg%)	LHH	15.1	18.4	16.7[a]		15.2	17.1	16.1	
	LMH	9.2	12.9	11.2[b]	0.41	13.8	15.2	14.5	0.35
	LLH	9.4	11.8	10.6[b]		14.0	16.0	15.0	
	Means	11.1[c]	14.3[d]		0.33	14.3[c]	16.1[d]		0.28

[a,b]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$).

[c,d]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

LMH animals than control LHH animals.

Though there was a trend for low PUN levels during feed restriction and increased levels during full feeding in both old and young bulls, the latter group recorded significantly lower PUN values at all stages of the trial.

3.4. Carcass compositional changes

3.4.1. Carcass traits

In all the traits studied there were no significant interactions between feeding regime and age of animal. Consequently, only main effects are presented (Table 13). The data obtained at the end of the mid period (day 180 of trial) show that LHH control animals restricted in early period (0 to 90 days), but full-fed in mid period (91 to 180 days) were significantly heavier at slaughter than LMH and LLH animals restricted in both periods. Similarly, hot carcass weight, dressing percentage, rib eye area and kidney fat were higher in the control animals. There were no significant differences between LMH and LLH animals. At the end of the final, full feeding period, slaughter weight was significantly greater in LHH controls than in animals on LMH feeding regime. However, no significant differences existed between either LLH and LHH or LLH and LMH animals. Hot carcass weight, dressing percentage and rib eye area were significantly lower in bulls on LMH and LLH feeding regimes compared to the controls. There were no significant differences between treatments in kidney fat, although animals on LMH and LLH feeding regimes exhibited lower values.

Table 13: Means for carcass traits by feeding regime and age of animal at various trial stages.

Stage of trial (days)	Feeding Regime	Slaught Wt, Kg			±SEM	Hot Carcass wt, kg			±SEM	Dressing %			±SEM
		Young	Old	Means		Young	Old	Means		Young	Old	Means	
180	LHH	224.0	292.3	258.2[a]		105.9	151.4	128.7[a]		47.4	51.8	49.6[a]	
	LMH	157.6	201.3	179.5[b]	7.01	69.2	96.6	82.9[b]	4.11	44.0	47.7	45.9[b]	1.06
	LLH	147.5	202.3	174.9[b]		63.1	93.2	78.2[b]		42.7	46.0	44.4[b]	
	Means	176.4[c]	232.0[d]		5.74	79.4[c]	113.7[d]		3.36	44.6[c]	48.5[d]		0.87
270	LHH	278.3	348.9	313.6[a]		145.9	186.4	166.2[a]		52.1	53.8	52.8[a]	
	LMH	248.7	287.0	268.0[b]	9.40	122.0	141.6	131.8[b]	5.15	49.2	50.00	49.5[b]	0.57
	LLH	282.3	288.0	285.2[ab]		142.3	136.9	139.6[b]		50.4	49.7	50.1[b]	
	Means	269.8[c]	308.0[d]		7.68	136.7[c]	154.3[d]		4.20	50.7	51.2		0.49

Table 13: Continued.

Stage of trial (days)	Feeding Regime	Rib eye area, cm^2				Kidney fat, kg			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	33.75	56.56	45.16		1.14	1.67	1.41[a]	
	LMH	32.20	37.73	35.00	4.78	0.10	0.37	0.24[b]	0.21
	LLH	27.65	33.60	30.63		0.09	0.27	0.18[b]	
	Means	31.20	42.63		3.99	0.44	0.77		0.18
270	LHH	49.47	68.60	59.04[a]		2.27	1.65	1.96	
	LMH	39.03	49.10	44.07[b]	1.22	1.40	1.30	1.35	0.22
	LLH	42.57	48.80	45.69[b]		1.70	1.50	1.60	
	Means	43.69[c]	55.50[d]		1.05	1.79	1.48		0.19

[a,b]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$).

[c,d]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

Age had a significant effect on dressing percentage at the end of the mid period, the younger animals dressing lower than the older bulls. Rib eye area and kidney fat were also higher in favour of the older animals. From the end of the period of feed restriction to the end of the full feeding period, dressing percentage increased by 6.1% units in younger bulls and 2.7% units in older bulls. At the end of the final (full feeding) period no significant differences occurred between younger and older bulls in dressing percentage and kidney fat, but the latter group significantly exceeded in rib eye area.

3.4.2. Offals and by-products

(a) Hide and other by-products

Table 14 shows hide and other by-products expressed as percentages of the empty body weight. At the end of the mid period, hide percentage was not significantly different between treatment groups. However, animals fed on low plane during mid period tended to have higher percentage hide than those fed on moderate level which had greater values than animals on full feeding. Head percentage followed similar trend, with LLH animals showing significantly higher values than LMH animals which yielded significantly higher head percentage than did the controls.

Compared to the controls, front and back feet percentages were significantly greater at the end of the mid period in LMH and LLH bulls. In absolute terms the weights of hide, head, tail and feet were significantly depressed by feed restriction

Table 14: Hide and other by-products expressed as percentages of the empty body weight of bulls.

Stage of trial(days)	Feeding Regime	Hide				Head				Tail			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	10.9	11.2	11.1		6.8	6.0	6.4[a]		0.7	0.7	0.7	
	LMH	11.3	11.9	11.6	0.50	7.6	6.7	7.2[b]	0.14	0.8	0.8	0.8	0.03
	LLH	11.7	12.8	12.3		8.8	7.3	7.9[c]		0.7	0.7	0.7	
	Means	11.3	12.0		0.42	7.8[d]	6.7[e]		0.12	0.8	0.7		0.03
270	LHH	12.7	10.6	11.6		5.9	5.2	5.6		0.6	0.6	0.6	
	LMH	10.8	12.3	11.5	0.71	6.0	5.8	5.9	0.22	0.7	0.6	0.6	0.04
	LLH	12.1	11.1	11.6		5.8	5.9	5.8		0.7	0.7	0.7	
	Means	11.8	11.3		0.58	5.9	5.6		0.19	0.7	0.7		0.04

Table 14 Continued.

Stage of trial(days)	Feeding Regime	Front feet				Back feet			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	1.5	1.4	1.4[a]		1.6	1.4	1.5[a]	
	LMH	2.0	1.8	1.9[b]	0.06	2.0	1.8	1.9[b]	0.07
	LLH	1.9	1.9	1.9[b]		1.9	1.8	1.9[b]	
	Means	1.8	1.7		0.05	1.8	1.7		0.06
270	LHH	1.3	1.2	1.3[a]		1.3	1.1	1.2[a]	
	LMH	1.6	1.5	1.6[b]	0.07	1.5	1.5	1.5[b]	0.06
	LLH	1.4	1.5	1.5[ab]		1.4	1.5	1.5[b]	
	Means	1.4	1.4		0.06	1.4	1.4		0.05

[a,b] Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$)

[d,e] Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

(Appendix Table 11).

From mid to final period, hide and tail percentages did not change appreciably in all the treatment groups. Consequently, the percentages of these by-products were not significantly different between treatments at the end of the final period. Similarly, the head as percentage of the empty body weight was not significantly different, although LLH and LMH animals tended to have greater values. At the end of the final period, relative percentage of both front and back feet were depressed in all treatments, but values were higher in LLH and LMH animals than in the LHH group. The actual weights of the by-products were not significantly different between treatment groups at the end of the full feeding period (Appendix Table 11).

At the end of the mid period, the head represented a higher percentage of the empty body weight in younger bulls than in older bulls. No significant differences between age groups in percentages of hide, tail, front and back feet were found, although younger animals exhibited higher values for all parameters except in hide percentage. At the end of final full feeding period, younger animals maintained higher percentages of hide, head, front and back feet, but the differences were all not significant.

(b) Components of gut tissue

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Gut tissue components expressed as percentages of the empty body weight are given in Table 15. During feed restriction, the percentage of full rumen was significantly higher in LLH animals,

Table 15: Components of gut tissue expressed as percentages of empty body weight of bulls.

Stage of trial (days)	Feeding Regime	Rumen[1], Full				Rumen[1], Empty				Omental fat			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	17.8	14.9	16.3[a]		4.5	3.8	4.1		0.8	0.7	0.8[a]	
	LMH	19.6	18.0	18.8[a]	**2.03**	4.1	4.1	4.1	0.20	0.4	0.3	0.3[b]	0.19
	LLH	29.0	26.3	27.6[b]		4.5	4.4	4.4		0.4	0.3	0.3[b]	
	Means	22.1	19.7		1.66	4.3	4.1		0.17	0.6	0.4		0.16
270	LHH	14.8	13.0	13.9[a]		4.3	3.7	4.0		1.1	1.1	1.1	
	LMH	16.0	19.6	17.8[b]	1.06	4.5	4.6	4.5	0.18	0.9	1.0	0.9	0.08
	LLH	15.5	18.9	17.2[b]		4.1	4.3	4.2		0.8	0.9	0.8	
	Means	15.4	17.2		0.86	4.3	4.2		0.15	0.9	1.0		0.06

Table 15 Continued.

Stage of trial (days)	Feeding Regime	Intestine[2], Full				Intestine[2], Empty				Mesenteric fat			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	6.8	3.8	5.3[a]		4.3	3.4	3.8		0.6	0.4	0.5	
	LMH	6.5	6.7	6.6[b]	0.25	4.3	4.4	4.3	0.35	0.4	0.4	0.4	0.05
	LLH	9.5	7.4	8.4[c]		5.2	5.0	5.1		0.7	0.3	0.5	
	Means	7.7[d]	6.0[e]		0.21	4.6	4.3		0.04	0.6[d]	0.4[e]		0.04
270	LHH	5.1	4.7	4.9[a]		4.2	3.3	3.7		1.0	0.9	1.0	
	LMH	6.3	6.4	6.4[b]	0.28	4.2	4.5	4.3	0.32	0.9	0.9	0.9	0.11
	LLH	5.4	6.1	5.7[ab]		4.3	4.1	4.2		0.7	0.8	0.8	
	Means	5.6	5.7		0.23	4.2	3.9		0.26	0.9	0.9		0.09

[1]Includes reticulum, rumen, omasum and abomasum

[2]Includes small and large intestine

[a,b,c]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$)

[d,e]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

while differences between LMH and LHH treatment groups were not significant. Similarly, the full intestine expressed as percentage of the empty body weight was highest in LLH animals, lowest in LHH control group and intermediate in LMH animals. The percentages of empty rumen and empty intestine did not differ significantly between treatment groups. However, the absolute weights of the empty rumen, but not the empty intestine, were significantly lower in LLH and LMH bulls (Appendix Table 12). The percentage of omental fat was significantly lower at the end of mid period in LLH and LMH animals than in LHH treatment group while no significant differences existed between the treatments in the percentage of mesenteric fat.

In general, the proportions of rumen and intestine decreased from mid to final period in all the treatments while those of omental fat and mesenteric fat increased. At the end of the full feeding period, animals on LMH and LLH feeding regimes had significantly higher full rumen and intestine percentages than animals on LHH feeding regime. Empty rumen and intestine percentages were also higher in favour of LLH and LMH animals, but the differences were not significant. In contrast, omental and mesenteric fat percentages were greater for the control LHH animals than in LMH and LLH animals though the differences were not significant. Also, there were no significant differences between groups in the absolute weights of tissue components (Appendix Table 12). In mid period, younger bulls had significantly higher proportions of full intestine and mesenteric fat than the older bulls. The percentages of full rumen, empty rumen, omental fat and empty intestine were also greater in the

younger than in older bulls. The differences were, however, not significant. At the end of the full feeding period, no significant differences attributable to age of animals were evident in the components of gut tissue. However, younger bulls tended to have greater proportions of empty rumen and empty intestine while older animals exceeded in percentages of full rumen, full intestine and omental fat.

(c) Internal organs

Data are presented in Table 16 on the internal organs other than gut tissue, expressed as percentages of the empty body weight. The results show that no significant differences due to feeding regime were detected in the percentages of liver, heart and kidney during the mid period. The percentages of these organs tended to decline from feed restriction period to full feeding period except in liver where LMH animals showed an increase. The spleen represented significantly higher percentage of the empty body weight in control LHH animals than in LMH and LLH animals at the end of the mid period. Spleen percentages increased from mid to final period in LMH and LLH animals, but decreased in the LHH group. At the end of the full feeding period, there were no significant differences between treatment groups in the proportions of internal organs. In absolute terms, the weights of liver, heart and spleen were significantly depressed in LLH and LMH bulls at the end of the mid period while differences between treatment groups were not significant at the end of full feeding (Appendix Table 13).

Table 16: Influence of feeding regime and age of animal on some internal organs expressed as percentages of the empty body weight.

Stage of trial (days)	Feeding Regime	Liver				Heart				Spleen				Kidney			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	1.50	1.31	1.41		0.44	0.37	0.40		0.37	0.28	0.32[a]		0.24	0.22	0.23	
	LMH	1.30	1.19	1.24	0.05	0.47	0.40	0.43	0.03	0.29	0.21	0.24[b]	0.01	0.29	0.21	0.25	0.03
	LLH	1.31	1.30	1.30		0.46	0.40	0.43		0.28	0.24	0.26[b]		0.28	0.23	0.26	
	Means	1.36	1.27		0.05	0.46	0.40		0.02	0.31[c]	0.25[d]		0.01	0.27	0.22		0.03
270	LHH	1.31	1.12	1.22		0.37	0.32	0.35		0.31	0.27	0.29		0.21	0.18	0.20	
	LMH	1.44	1.40	1.42	0.07	0.35	0.32	0.34	0.02	0.33	0.28	0.30	0.02	0.22	0.20	0.21	0.01
	LLH	1.21	1.17	1.19		0.33	0.38	0.36		0.29	0.28	0.28		0.20	0.22	0.21	
	Means	1.32	1.22		0.06	0.35	0.34		0.02	0.31	0.27		0.01	0.21	0.20		0.01

[a,b] Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$)

[c,d] Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

Liver, heart and kidney percentages did not differ significantly between age groups although younger bulls tended to have higher values at both slaughter periods. Younger animals had significantly higher spleen percentage at the end of the mid period while the difference between age groups in spleen percentage at the end of the full feeding period was not significant.

3.4.3. Physical composition

(a) Carcass lean, bone and fat percentages

The effect of feeding regime on carcass physical composition is shown in Table 17. The results obtained at the end of the mid period indicate that full fed LHH animals produced significantly greater proportions of lean, fat and muscle than LMH and LLH animals fed moderate and low planes of nutrition, respectively. The differences between LMH and LLH treatment groups were not significant. In contrast, LMH and LLH bulls yielded significantly higher bone percentage compared to LHH animals at the end of the mid period.

From mid to final period, lean percentage increased in LMH and LLH animals but decreased in LHH animals. Consequently, the percentage of lean in carcass was significantly greater in LMH and LLH animals compared to the controls at the end of the full feeding period. Carcass fat percentage increased from mid to final period for all treatment groups, the control group yielding significantly greater values at the end of final full feeding period. From mid to final period, bone percentage was depressed

Table 17 Physical composition (%) of the carcass of bulls according to various slaughter criteria.

Stage of trial (days)	Feeding Regime	Lean				Fat				Bone				Muscle[1]			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	68.5	68.9	68.7[a]		7.9	7.2	7.5[a]		23.7	23.9	23.8[a]		76.3	76.1	76.2[a]	
	LMH	66.9	66.3	66.6[b]	0.25	4.2	4.1	4.2[b]	0.14	28.3	29.6	29.0[b]	0.35	71.1	70.4	70.8[b]	0.35
	LLH	65.9	66.3	66.1[b]		4.4	3.9	4.1[b]		29.8	29.8	29.8[b]		70.3	70.2	70.2[b]	
	Means	67.1	67.2		0.21	5.5	5.1		0.12	27.3	27.8		0.29	72.5	72.2		0.29
270	LHH	67.9	67.4	67.7[a]		12.1	11.6	11.9[a]		20.0	21.2	20.6[a]		79.9	78.9	79.4[a]	
	LMH	69.7	68.8	69.3[b]	0.33	8.4	9.1	8.7[b]	0.41	22.0	22.1	22.0[b]	0.32	78.0	77.9	78.0[b]	0.32
	LLH	69.5	68.2	68.9[b]		8.7	8.9	8.8[b]		21.8	22.7	22.3[b]		78.2	77.3	77.8[b]	
	Means	69.0	68.1		0.28	9.7	9.9		0.35	21.3	22.0		0.27	78.7	78.0		0.27

[1] Muscle = Lean + Fat.

[a,b] Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$).

by 6.0% units in both LMH and LLH animals while a decrease of about 3.0% units was noted in LHH animals. Despite these differential rates of decrease, LMH and LLH animals exhibited significantly greater values of bone percentage at the end of the full feeding period.

Across treatment groups and during both slaughter periods, no significant differences due to age of animals were evident for lean, bone, fat and muscle percentages. However, at the end of the final period, younger bulls tended to have higher percentages of lean but lower fat percentages than their older counterparts.

During the mid period, full fed LHH bulls recorded significantly higher lean to bone, fat to bone and muscle to bone ratios than restricted LMH and LLH animals (Table 18). In contrast, lean to fat ratio was significantly higher in LMH and LLH animals compared to the controls. At the end of the full feeding period, lean to bone ratio was not significantly affected by feeding regimes while lean to fat ratio was significantly higher in favour of animals on LMH and LLH feeding regimes compared to control animals on LHH feeding regime. The control group showed significantly higher fat to bone, and muscle to bone ratios than animals on LMH and LLH feeding regimes which were not significantly different from each other.

During both slaughter periods, the ratios between various carcass components were not significantly influenced by age of animals (Table 18). However, younger bulls yielded slightly higher lean to bone and lean to fat ratios than older bulls at the end of the full feeding period.

Table 18: Ratios between carcass components according to various slaughter criteria.

Stage of trial (days)	Feeding Regime	Lean: Bone				Fat: Bone				Lean: Fat				Muscle[1]: Bone			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	2.89	2.89	2.89[a]		0.33	0.30	0.32[a]		8.69	9.56	9.13[a]		3.22	3.19	3.21[a]	
	LMH	2.31	2.24	2.28[b]	0.04	0.15	0.14	0.15[b]	0.04	16.02	16.03	16.03[b]	0.48	2.46	2.38	2.42[b]	0.05
	LLH	2.21	2.22	2.22[b]		0.15	0.13	0.14[b]		15.23	16.95	16.09[b]		2.36	2.35	2.36[b]	
	Means	2.47	2.45		0.03	0.21	0.19		0.03	13.31	14.18		0.39	2.68	2.64		0.04
270	LHH	3.39	3.19	3.29		0.60	0.54	0.57[a]		5.61	5.88	5.74[a]		3.99	3.73	3.86[a]	
	LMH	3.18	3.11	3.15	0.05	0.38	0.41	0.39[b]	0.03	8.53	7.55	8.04[b]	0.42	3.56	3.52	3.54[b]	0.07
	LLH	3.18	3.01	3.10		0.39	0.40	0.40[b]		8.03	7.49	7.76[b]		3.58	3.41	3.50[b]	
	Means	3.25	3.11		0.05	0.46	0.45		0.02	7.40	6.97		0.36	3.71	3.55		0.06

[1] Muscle = Lean + Fat.

[a,b] Means in a column **within a stage of trial** with different superscripts are significantly different ($P<0.05$).

(b) Wholesale cut percentages

Data are presented in Table 19 relevant to the wholesale cuts from left side of the carcass expressed as percentages of side weight. During mid period, restricted LMH and LLH animals had significantly higher percentage in shank but a significantly lower percentage in shortloin than full-fed LHH control animals. No significant differences existed between LMH and LLH animals in these two cuts. Animals on LMH and LLH feeding regimes also had higher percentages in round but lower percentages in plate, brisket, rump and flank than control animals on LHH feeding regime. The differences were, however, not significant. There were no definite trends at the end of the mid period in percentages of chuck, rib and sirloin although LLH animals tended to yield higher proportions of chuck but lower values in rib and sirloin than LHH controls. Among wholesale cuts within treatments, side proportion ranged from approximately 25.0% in round to 4.0% in flank.

From mid to final full feeding period, the proportions of chuck round and sirloin did not change appreciably in all the treatments. Rib and plate percentages increased in all treatment groups except LMH group, where a decrease in rib percentage was noted. Animals on LMH and LLH feeding regimes exhibited increases in brisket and flank percentages while no changes were apparent in LHH animals. Shank percentage declined by about 3.0% in LMH and LLH animals and by about 0.8% in LHH animals. The percentages of rump and shortloin decreased in LHH animals but increased in LMH and LLH treatment groups.

Table 19: Means of carcass wholesale cuts (%) by feeding regime and age of animal at various trial stages.

Stage of trial (days)	Feeding Regime	Chuck				Rib[1]				Plate			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	19.7	21.4	20.6		5.9	7.6	6.8		4.9	5.2	5.1	
	LMH	19.6	20.7	20.2	0.71	8.4	6.9	7.7	0.35	4.3	5.7	5.0	0.34
	LLH	20.6	22.0	21.3		6.1	7.1	6.6		5.3	4.5	4.9	
	Means	19.9	21.4		0.58	6.8	7.2		0.29	4.8	5.1		0.28
270	LHH	21.0	20.8	20.9		8.2	8.2	8.2		5.7	5.9	5.8	
	LMH	19.0	19.4	19.2	0.92	6.7	6.5	6.6	0.52	5.6	5.9	5.7	0.36
	LLH	21.5	18.9	20.2		7.0	7.0	7.0		5.5	6.0	5.7	
	Means	20.5	19.7		0.79	7.3	7.2		0.44	5.6	5.9		0.31

Table 19 Continued.

Stage of trial(days)	Feeding Regime	Brisket Young	Old	Means	±SEM	Shank Young	Old	Means	±SEM	Round Young	Old	Means	±SEM
180	LHH	5.9	6.7	6.3		11.0	10.9	10.9[a]		25.0	23.9	24.4	
	LMH	5.2	6.1	5.7	0.51	14.3	12.1	13.2[b]	0.29	26.3	25.1	25.7	0.36
	LLH	5.6	5.7	5.7		14.7	12.4	13.6[b]		25.3	25.3	25.3	
	Means	5.5	6.2		0.41	13.3[c]	11.8[d]		0.23	25.5	24.8		0.29
270	LHH	6.1	7.0	6.5		9.7	10.6	10.1		23.9	21.6	22.8	
	LMH	6.7	7.2	6.9	0.43	10.7	10.7	10.7	0.21	24.5	24.3	24.4	0.78
	LLH	7.0	7.2	7.1		10.0	11.3	10.7		23.4	22.8	23.1	
	Means	6.6	7.1		0.37	10.1[c]	10.9[d]		0.18	23.9	23.0		0.67

Table 19 Continued.

Stage of trial (days)	Feeding Regime	Rump Young	Rump Old	Rump Means	Rump ±SEM	Sirloin Young	Sirloin Old	Sirloin Means	Sirloin ±SEM	Shortloin Young	Shortloin Old	Shortloin Means	Shortloin ±SEM	Flank Young	Flank Old	Flank Means	Flank ±SEM
180	LHH	6.1	5.1	5.6		8.0	4.8	6.4		8.1	7.0	7.6[a]		4.3	4.7	4.5	
	LMH	5.4	5.1	5.2	0.39	5.8	5.7	5.8	0.25	5.9	6.9	6.4[b]	0.28	3.5	3.7	3.6	0.35
	LLH	5.0	4.8	4.9		6.5	6.0	6.2		6.5	6.2	6.3[b]		3.8	4.2	4.0	
	Means	5.5	5.0		0.32	6.8[c]	5.5[d]		0.21	6.8	6.7		0.23	3.9	4.2		0.28
270	LHH	5.0	4.7	4.9		5.8	6.8	6.3		7.2	6.4	6.8		4.4	4.8	4.6	
	LMH	5.6	5.2	5.4	0.16	7.2	6.6	6.9	0.43	6.7	5.6	6.2	0.22	5.7	4.9	5.3	0.24
	LLH	4.9	5.1	5.0		6.2	6.9	6.6		6.9	7.8	7.4		5.0	5.1	5.1	
	Means	5.2	5.0		0.14	6.4	6.8		0.37	6.9	6.6		0.19	5.1	4.9		0.21

[1]Less 9-10-11 Rib cut

[a,b]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$)

[c,d]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

At the end of the full feeding period, there were no significant differences between treatments in the percentages of all wholesale cuts. Differences between controls and LMH or LLH bulls were very minor.

Among age groups, younger animals had significantly greater proportions of shank and sirloin at the end of the mid period than older bulls. The older animals showed greater percentages in chuck, rib, plate, brisket and flank but lower values in round and rump compared to younger bulls. The differences were, however, not significant. The data obtained at the end of the full feeding period indicate that differences between age groups in the percentages of all cuts were not significant except in shank percentage, where younger bulls had significantly lower values than older ones. The younger bulls also tended to have lower percentages of their sides in plate, brisket and sirloin but higher values in chuck, round, rump, shortloin and flank compared to the older bulls.

(c) Lean, bone and fat in wholesale cuts

Changes were also observed with respect to lean, bone and fat proportions in the different wholesale cuts.

(i) Lean percentage

During the mid period, separable lean percentages in plate and shank were significantly greater in control LHH bulls than in restricted LMH and LLH bulls (Table 20). Lean percentages in chuck, rib, shortloin and flank were also higher, though not significantly, in LHH controls. In sirloin cut, lean percentage

Table 20: Means for percent separable lean in each wholesale cut by feeding regime and age of animal at various trial stages.

Stage of trial (days)	Feeding Regime	Chuck				Rib[1]				Plate			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	70.1	72.8	71.5		69.9	71.2	70.6		65.8	70.3	68.1[a]	
	LMH	70.2	71.1	70.7	0.71	62.7	64.6	63.7	2.82	55.0	58.6	56.8[b]	2.95
	LLH	70.4	69.3	69.8		62.6	67.7	65.2		50.2	54.5	52.4[b]	
	Means	70.2	71.1		0.58	65.1	67.8		2.31	57.0	61.1		2.41
270	LHH	72.2	74.7	73.5		71.1	67.2	69.2		62.5	57.0	59.8	
	LMH	72.6	74.8	73.7	1.70	72.3	63.9	68.1	1.92	71.1	63.5	67.3	1.17
	LLH	74.7	73.3	74.0		69.6	60.4	65.0		62.4	69.1	65.8	
	Means	73.2	74.3		1.45	71.0[c]	63.8[d]		1.64	65.3[c]	63.2[d]		1.01

Table 20 Continued.

Stage of trial (days)	Feeding Regime	Brisket Young	Brisket Old	Brisket Means	Brisket ±SEM	Shank Young	Shank Old	Shank Means	Shank ±SEM	Round Young	Round Old	Round Means	Round ±SEM
180	LHH	58.8	54.1	56.5		64.7	61.1	62.9[a]		74.6	73.5	74.1	
	LMH	60.6	55.1	57.9	1.61	59.8	55.1	57.5[b]	0.92	72.4	73.8	73.1	0.63
	LLH	52.8	53.4	53.1		58.2	54.0	56.1[b]		72.5	71.9	72.2	
	Means	57.4	54.2		1.32	60.9[c]	56.7[d]		0.75	73.2	73.1		0.51
270	LHH	53.9	53.9	53.9		63.3	62.6	63.0		75.4	76.9	76.2	
	LMH	53.7	55.4	54.6	1.55	63.2	60.8	62.0	1.40	74.9	74.9	74.9	0.67
	LLH	51.4	55.9	53.7		62.6	61.5	62.1		77.7	74.7	76.2	
	Means	53.0	55.1		1.33	63.0	61.6		1.20	76.0	75.5		0.58

Table 20 Continued.

Stage of trial (days)	Feeding Regime	Rump Young	Old	Means	±SEM	Sirloin Young	Old	Means	±SEM	Shortloin Young	Old	Means	±SEM	Flank Young	Old	Means	±SEM
180	LHH	61.4	60.8	61.1		62.1	66.1	64.1		61.7	69.3	65.5		64.8	68.6	66.7	
	LMH	59.8	59.9	59.9	1.41	65.1	67.8	66.5	2.45	65.4	62.5	64.0	1.56	66.1	60.7	63.4	2.51
	LLH	57.1	64.6	60.9		67.7	70.7	69.2		59.1	62.6	60.9		62.1	66.5	64.3	
	Means	59.4	61.8		1.16	65.0	68.2		1.98	62.1	64.8		1.27	64.3	65.3		2.06
270	LHH	63.5	61.7	62.6		64.4	61.4	62.9		61.6	56.4	59.0		53.6	51.2	51.4[a]	
	LMH	65.8	61.3	63.6	1.86	66.3	70.1	68.2	2.05	66.5	63.8	65.2	2.47	65.7	67.8	66.8[b]	3.16
	LLH	63.8	51.4	57.6		67.3	70.8	69.1		64.9	66.7	65.8		63.0	71.4	67.2[b]	
	Means	64.4[c]	58.1[d]		1.59	66.0	67.4		1.76	64.3	62.3		2.12	60.8	63.5		2.71

[1]Less 9-10-11 Rib cut

[a,b]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$)

[c,d]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

was lower in LHH controls than in LMH and LLH animals while no definite trends were observed for brisket and rump lean proportions.

As feeding progressed from the mid period, changes in lean percentages were variable among wholesale cuts. In chuck, round, rump and shank all treatment groups showed increases in lean percentage. Lean percentages in rib, plate, sirloin, shortloin and flank were depressed in LHH control animals but increased in LMH and LLH treatment groups. Lean percentage in brisket declined from mid period to final full feeding period in all feeding regimes.

Data obtained at the end of the study show that lean percentage was not significantly different between feeding regimes in all the wholesale cuts except in flank, where animals on LMH and LLH feeding regimes significantly exceeded in muscling of the cut. However, LLH animals tended to have higher lean percentages in sirloin and shortloin, but lower values in rib and shank compared to the control animals on LHH feeding regime.

Among wholesale cuts, within feeding regimes, round and chuck had the greatest percentages of lean while brisket and flank had the lowest lean percentages at the end of full feeding period.

In mid period, younger bulls tended to yield lower lean percentages in chuck rib, plate, rump, sirloin, shortloin and flank but higher lean proportions in brisket and shank than older bulls. These differences were, however, not significant except

in shank, where younger bulls significantly exceeded in lean percentage.

At the end of the final period, lean percentages in rib, plate and rump were significantly higher in favour of the younger animals. They also yielded higher lean percentages in shank, round and shortloin, though the differences were not significant. In contrast, lean percentages in chuck, brisket, sirloin and flank were non-significantly greater in the older bulls.

(ii) Bone percentage

Among wholesale cuts, separable bone percentages ranged from approximately 38.0% mean across feeding regimes in shank to 22.0% mean across these regimes in the flank at the end of the mid period. At the end of the full feeding period, these mean values ranged from about 32.0% in the shank to 17.0% in the flank.

Compared to LHH control animals, restricted LMH and LLH animals had significantly higher bone percentages in chuck, plate, brisket, shank and shortloin at the end of mid period (Table 21). Bone percentages in rib, round, rump, sirloin and flank were also greater in favour of LMH and LHH bulls but the differences were not significant (Table 21).

As feeding progressed from mid period to final full feeding period the proportions of bone in all wholesale cuts were depressed for all treatment groups, the rates of decrease being greater in animals on LMH and LLH feeding regimes than in LHH control bulls. Consequently, at the end of full feeding period no significant differences existed between feeding regimes in proportions of bone in all cuts except chuck, where LMH animals

Table 21: Means for percent separable bone in each wholesale cut by feeding regime and age of animal at various trial stages.

Stage of trial (days)	Feeding Regime	Chuck				Rib[1]				Plate			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	21.5	21.7	21.6[a]		24.5	23.1	23.8		29.6	21.7	25.7[a]	
	LMH	27.0	26.1	26.6[b]	0.84	33.4	31.4	32.4	2.92	37.4	37.4	37.4[b]	2.45
	LLH	25.2	28.3	26.8[b]		31.2	27.8	29.6		42.7	36.1	39.4[b]	
	Means	24.6	25.4		0.09	29.7	27.4		2.39	36.6	31.7		2.00
270	LHH	17.5	17.5	17.5[a]		20.5	23.0	21.8		26.6	24.1	25.4	
	LMH	21.4	19.8	20.6[b]	0.72	22.3	25.8	24.1	1.34	20.4	23.6	22.0	0.91
	LLH	19.6	19.9	19.7[ab]		21.0	25.0	23.0		24.8	24.8	24.8	
	Means	19.5	19.1		0.62	21.3	24.6		1.15	23.9	24.2		0.78

Table 21 Continued.

Stage of trial (days)	Feeding Regime	Brisket Young	Brisket Old	Brisket Means	Brisket ±SEM	Shank Young	Shank Old	Shank Means	Shank ±SEM	Round Young	Round Old	Round Means	Round ±SEM
180	LHH	22.5	25.5	24.0[a]		31.3	35.0	33.2[a]		20.9	22.9	21.9	
	LMH	30.4	35.5	33.0[b]	1.68	37.1	41.2	39.2[b]	**1.04**	23.9	23.9	23.9	**0.73**
	LLH	31.7	35.0	33.4[b]		35.9	42.9	39.4[b]		24.7	25.4	24.3	
	Means	28.2	32.0		1.38	34.8[c]	39.7[d]		0.85	23.2	24.1		0.60
270	LHH	19.1	22.5	20.8		31.9	32.4	32.2		16.9	18.2	17.6	
	LMH	20.9	24.3	22.6	1.67	31.8	36.6	34.2	**1.46**	20.7	18.9	19.8	**0.66**
	LLH	29.8	20.0	24.9		33.3	34.6	34.0		17.8	19.0	18.4	
	Means	23.3	22.3		1.43	32.3	34.4		1.25	18.5	18.7		0.56

Table 21 Continued.

Stage of trial (days)	Feeding Regime	Rump Young	Rump Old	Rump Means	Rump ±SEM	Sirloin Young	Sirloin Old	Sirloin Means	Sirloin ±SEM	Shortloin Young	Shortloin Old	Shortloin Means	Shortloin ±SEM	Flank Young	Flank Old	Flank Means	Flank ±SEM
180	LHH	28.0	24.5	26.3		25.2	23.1	24.2		27.3	23.7	25.5[a]		18.9	17.8	18.4	
	LMH	28.6	34.3	31.5	2.51	25.8	24.1	25.0	1.93	29.1	32.5	30.8[b]	1.80	18.3	29.7	24.0	2.18
	LLH	35.7	30.3	33.0		26.8	24.2	25.5		33.0	33.5	33.3[b]		25.7	24.9	25.3	
	Means	30.8	29.7		2.05	25.9	23.8		1.58	29.7	29.9		1.47	21.0	24.1		1.78
270	LHH	25.6	23.9	24.8		17.9	20.6	19.3		19.5	20.8	20.2		16.4	18.3	17.4	
	LMH	24.5	26.7	25.6	1.71	21.0	17.2	19.1	1.71	22.8	23.6	23.2	1.93	11.7	11.0	11.4	2.27
	LLH	24.0	28.0	26.0		18.9	20.8	19.9		22.0	20.4	21.2		19.1	17.2	18.2	
	Means	24.7	26.2		1.46	19.3	19.5		1.46	21.4	21.6		1.66	15.7	15.5		2.38

[1]Less 9-10-11 Rib cut

[a,b]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$).

[c,d]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

had significantly higher values than controls (Table 21). Animals on LLH feeding regime showed a trend for higher bone percentages in the remaining cuts compared to the control LHH group.

Among age groups, younger animals yielded significantly lower shank bone percentage during mid period than older animals. Younger bulls also had lower bone percentage in brisket, round, and flank but higher values in rib, plate, rump and sirloin at the end of mid period. These differences, however, did not reach significance. Similarly, at the end of the full feeding period, no significant differences in bone percentage was found between age groups for all cuts.

(iii) Separable fat percentage

At the end of the mid period (day 180 of trial), animals on LMH and LLH feeding regimes had significantly less fat percentages in chuck, brisket, round, rump and shortloin than control animals on LHH feeding regime (Table 22). In sirloin cut, significant differences in fat percentage were apparent between LLH and LMH or LHH, but not between LMH and LHH treatment groups. Fat percentages in rib, plate, shank and flank were lower in LMH and LLH animals compared to LHH animals, but the differences did not reach significant level. Across feeding regimes, at the end of the mid period, flank tended to be fattest (12.5% mean) followed by brisket (11.0% mean) and rump (9.2% mean). Shank had the least fat percentage (3.5% mean).

As feeding progressed from the mid period into full feeding

Table 22: Means for percent separable fat in each wholesale cut by feeding regime and age of animal at various trial stages.

Stage of trial (days)	Feeding Regime	Chuck				Rib[1]				Plate			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	8.4	5.5	6.9[a]		5.6	5.6	5.6		4.6	8.0	6.3	
	LMH	2.8	2.8	2.8[b]	0.44	3.9	4.1	4.0	0.63	7.6	4.0	5.8	1.11
	LLH	4.4	2.5	3.5[b]		6.1	4.5	5.3		7.0	4.8	5.9	
	Means	5.2[c]	3.6[d]		0.36	5.2	4.7		0.52	6.4	5.6		0.91
270	LHH	10.3	7.8	9.1		8.5	9.7	9.1		10.9	17.0	13.9[a]	
	LMH	6.1	5.4	5.8	1.26	5.3	10.3	7.8	1.14	8.5	13.0	10.7[b]	0.63
	LLH	5.7	6.9	6.3		9.4	12.0	10.7		12.8	7.1	10.0[b]	
	Means	7.4	6.7		1.08	7.7[c]	10.6[d]		0.97	10.7[c]	12.4[d]		0.54

Table 22 Continued.

Stage of trial (days)	Feeding Regime	Brisket Young	Brisket Old	Brisket Means	Brisket ±SEM	Shank Young	Shank Old	Shank Means	Shank ±SEM	Round Young	Round Old	Round Means	Round ±SEM
180	LHH	18.7	20.4	19.6[a]		4.0	3.9	4.0		4.5	3.6	4.1[a]	
	LMH	9.0	9.4	9.2[b]	1.68	3.1	3.6	3.3	0.33	3.7	2.3	3.0[b]	0.20
	LLH	15.5	11.6	13.6[b]		5.9	3.1	4.5		2.8	2.7	2.8[b]	
	Means	14.4	13.8		1.37	4.3	3.5		0.27	3.7[c]	2.9[d]		0.16
270	LHH	27.0	23.6	25.3[a]		4.9	5.0	5.0		7.8	4.9	6.4	
	LMH	25.5	20.3	22.9[ab]	1.05	5.1	4.6	4.9	0.84	4.3	6.2	5.3	0.85
	LLH	18.8	24.0	21.4[b]		4.1	3.9	4.0		4.6	6.3	5.5	
	Means	23.8	22.6		0.90	4.7	4.5		0.72	5.6	5.8		0.73

Table 22 Continued.

Stage of trial (days)	Feeding Regime	Rump Young	Rump Old	Means	±SEM	Sirloin Young	Sirloin Old	Means	±SEM	Shortloin Young	Shortloin Old	Means	±SEM	Flank Young	Flank Old	Means	±SEM
180	LHH	10.6	14.7	12.7[a]		12.7	10.8	11.8[a]		11.0	7.0	9.0[a]		16.4	13.6	15.0	
	LMH	11.6	5.8	8.7[b]	1.46	9.2	8.9	9.1[a]	1.12	5.5	5.1	5.3[b]	0.80	15.6	9.7	12.7	1.68
	LLH	7.1	5.1	6.1[b]		5.5	5.1	5.3[b]		7.9	3.9	5.9[b]		12.1	8.7	10.4	
	Means	9.8	8.5		1.19	9.1	8.3		0.92	8.1[c]	5.3[d]		0.66	14.7	10.7		1.37
270	LHH	10.9	14.4	12.7		17.6	18.0	17.8[a]		18.9	22.8	20.9[a]		30.0	30.5	30.2[a]	
	LMH	9.7	12.0	10.9	1.45	12.6	12.7	12.7[b]	1.08	10.7	12.6	11.7[b]	1.32	22.5	21.2	21.9[ab]	2.55
	LLH	10.2	13.5	11.9		13.8	8.3	11.1[b]		13.2	13.0	13.1[b]		18.0	11.4	14.7[b]	
	Means	10.3	13.3		1.24	14.7	13.0		0.93	14.3	16.1		1.13	23.5	21.0		2.19

[1]Less 9-10-11 Rib cut

[a,b]Means in a column within a stage of trial with different superscripts are significantly different (P<0.05)

[c,d]Means in a row within a stage of trial with different superscripts are significantly different (P<0.05).

in the final period, fat percentage increased in all cuts, with LMH and LLH animals exhibiting higher rates of increase in chuck, brisket and rump but lower rates in plate, shank, round, shortloin and flank than did LHH control animals. In rib and sirloin cuts, LLH bulls showed higher rates of increase in fat percentage than did LHH controls which had faster rates of increase than LMH animals. Across feeding regimes, fat percentage increased in all wholesale cuts, but the mean increase in percentage units was greatest in flank (10.3%), followed by brisket (9.0%), shortloin (2.4%), rump (2.2%) and shank (1.4%).

Data obtained at the end of the full feeding period show that the proportion of fat in plate, sirloins and shortloin was significantly less in LMH and LLH treatment groups than in LHH control group. Also, in chuck, shank, and rump, fat percentage was lower in LMH and LLH animals compared to LHH animals, but the differences were not significant. In brisket and flank, fat percentage was significantly less in LLH animals than in LHH controls while differences between either LLH and LMH or LMH and LLH were not significant. Among wholesale cuts, across feeding regimes, fat percentage ranged from approximately 23.0% mean in the brisket and flank to less than 5.0% mean in the shank.

Fat percentages in chuck, round and shortloin were significantly greater in younger than in older bulls at the end of the mid period (Table 22). Younger animals also yielded higher fat percentages in the rib, plate, brisket, shank, rump, sirloin and flank, but the differences were not significant. At the end of the full feeding period, older bulls significantly exceeded in rib and plate fat proportions. Fat percentages in

other cuts were not significantly different between age groups.

3.4.4. Chemical composition, components of carcass gain and efficiencies of protein and energy utilization

(a) Chemical composition

At the end of mid period, animals on LLH feeding regime had significantly higher water percentage than those on LMH feeding regime, which in turn, had significantly higher percentage of water in their carcasses than control animals on LHH feeding regime (Table 23). Chemical fat percentage followed a reverse trend, the control group exhibiting significantly higher values than LMH and LLH groups. Gross energy was also significantly greater in favour of the LHH control group. Differences in protein and ash percentages were small and non-significant (Table 23).

As feeding progressed from the restricted feeding stage to full feeding in final period, carcass water percentage decreased, while fat percentage increased in all treatment groups, the rates of increase or decrease being faster in LMH and LLH groups than in LHH animals (Table 23). An increasing trend was also evident in the gross energy content of boneless carcass of all treatment groups, with LMH and LLH animals showing higher rates of increase. Protein and ash percentages decreased slightly from mid to final period in all groups except in LLH treatment group where the percentage of ash increased slightly (Table 23).

At final slaughter, little differences occurred between treatments in carcass chemical composition. However, animals on LLH feeding regime tended to have higher water, protein and ash

Table 23: Mean chemical composition[1] of the boneless carcass of bulls according to various slaughter criteria.

Stage of trial (days)	Feeding Regime	Water, % Young	Old	Means	±SEM	Protein, % Young	Old	Means	±SEM	Fat, % Young	Old	Means	±SEM
180	LHH	66.4	66.1	66.3[a]		23.9	21.9	22.9		10.7	12.2	11.5[a]	
	LMH	71.1	72.6	71.9[b]	0.64	25.8	23.1	24.5	0.68	4.3	4.9	4.6[b]	0.64
	LLH	72.7	75.6	74.2[c]		24.5	20.6	22.6		3.3	3.9	3.6[b]	
	Means	70.1	71.4		0.52	24.7[d]	21.9[e]		0.55	6.1	7.0		0.52
270	LHH	62.9	65.0	63.9		22.2	19.7	21.0		16.9	14.9	15.9	
	LMH	64.6	63.8	64.2	0.98	20.9	19.2	20.1	0.51	15.8	17.4	16.6	0.95
	LLH	67.4	66.8	67.1		22.2	20.6	21.4		12.1	15.2	13.7	
	Means	65.0	65.2		0.84	21.8[d]	19.8[e]		0.44	14.9	15.8		0.82

Table 23 Continued.

Stage of trial (days)	Feeding Regime	Ash, % Young	Old	Means	±SEM	Gross Energy, Kcal/gDM Young	Old	Means	±SEM
180	LHH	1.2	0.9	1.1		6.3	6.4	6.4[a]	
	LMH	1.0	1.1	1.1	0.09	5.6	5.7	5.6[b]	0.06
	LLH	1.1	1.0	1.0		5.5	5.5	5.5[b]	
	Means	1.1	1.0		0.07	5.8	5.9		0.05
270	LHH	0.9	1.0	1.0		6.8	6.8	6.8	
	LMH	1.0	0.9	1.0	0.07	6.7	7.0	6.9	0.07
	LLH	1.2	0.9	1.1		6.5	6.9	6.7	
	Means	1.0	0.9		0.06	6.7[d]	6.9[e]		0.06

[1]Dry matter basis

[a,b,c]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$).

[d,e]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

percentages, but lower values of fat and energy than those on either LMH or LHH feeding regimes.

During mid period, younger bulls had greater protein and ash percentages but less water, fat and energy values compared to older bulls (Table 23). The differences were all non-significant except for protein. At the end of the final period, younger bulls yielded significantly higher boneless carcass protein percentage but significantly less energy value than older bulls. Water• and fat percentages were slightly greater in older bulls while ash percentage tended to be higher in younger animals. These differences were, however, non-significant.

(b) Components of carcass gain

During the mid period, boneless carcass weight increased at an estimated rate of 64.8 g/day for full fed animals, but decreased at the rates of 10.0 and 22.0 g/day for restricted LMH and LLH animals respectively. Thus, the rate of carcass growth in full fed animals was significantly higher than in restricted animals (Table 24). Similarly, the rates of protein, fat and energy gains were significantly greater in control LHH animals than in LMH and LLH animals. No significant differences were found between LMH and LLH treatment groups (Table 24).

Animals underfed in the mid period showed great increases in carcass, protein, fat and energy in the final period. Although the absolute weights of boneless carcass, crude protein and fat and the energy content of the carcass were significantly higher in the control animals than in the restricted animals at the end

Table 24: Components of boneless carcass gain at various trial stage.

Stage of trial (days)	Feeding Regime	Carcass gain, g/day Young	Old	Means	±SEM	Protein gain, g/day Young	Old	Means	±SEM
0-180	LHH	20.1	109.4	64.8[a]		2.7	18.6	10.7[a]	
	LMH	-33.0	12.6	-10.2[b]	7.52	-8.4	-0.7	-4.6[b]	1.74
	LLH	-47.0	3.0	-22.0[b]		-13.2	-6.5	-9.9[b]	
	Means	20.0[c]	41.7[d]		6.16	-6.3[c]	3.8[d]		1.43
181-270	LHH	58.1	146.5	102.3[a]		12.2	19.8	16.0[a]	
	LMH	108.2	194.3	151.3[b]	9.45	16.8	28.3	22.6[a]	2.60
	LLH	164.1	184.5	174.3[b]		37.4	29.9	33.7[b]	
	Means	110.1[c]	175.1[d]		9.04	22.1	26.0		2.21

Table 24 Continued.

Stage trial (days)	Feeding Regime	Fat gain, g/day Young	Old	Means	±SEM	Energy gain, Mcal/day Young	Old	Means	±SEM
0-180	LHH	10.9	24.6	17.8[a]		0.92	1.57	1.25[a]	
	LMH	-1.0	1.9	0.5[b]	1.23	0.52	0.84	0.68[b]	0.04
	LLH	-2.4	0.3	-1.1[b]		0.51	0.77	0.64[b]	
	Means	2.5[c]	8.9[d]		1.01	0.65[c]	1.06[d]		0.03
181-270	LHH	25.2	31.4	28.3[a]		2.41	3.11	2.76[a]	
	LMH	37.2	57.3	47.3[b]	3.66	1.91	2.66	2.29[b]	0.07
	LLH	33.6	48.1	40.9[b]		2.16	2.51	2.34[b]	
	Means	32.0[c]	45.6[d]		3.12	2.16[c]	2.76[d]		0.06

[a,b]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$).

[c,d]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

of this period (Appendix Table 14), the latter group showed greater improvement in the rates of gain during the period. Thus, LLH and LMH bulls had significantly higher rates of boneless carcass gain compared to LHH bulls (Table 24). Daily crude protein gain was significantly higher in LLH bulls than in LMH and LHH bulls which had similar values. Daily fat gain was significantly higher in LLH and LMH groups compared to LHH control group. The control LHH bulls maintained significantly higher energy gain than LMH and LLH bulls.

Age of the animal had a significant influence on the components of carcass gain (Table 24). During the mid period, gains in boneless carcass, protein, fat and energy were significantly lower in the younger bulls compared to the older bulls. At the end of the trial, older bulls maintained significantly higher rates of daily carcass, fat and energy gain. There were no significant differences between age groups in crude protein gain during the final period.

(c) Efficiency of energy and protein utilization

Metabolizable energy (ME) intake was similar across treatments during the full feeding period (Table 25). The bulls on LLH feeding regime were significantly more efficient in utilizing ME for empty body weight gain than the bulls on LMH and LHH feeding regimes. No significant differences existed between LMH and LHH animals in ME required per unit of empty body weight gain. The differences between age groups in either ME intake or efficiency of ME utilization for empty body weight gain were small and non-significant.

Table 25: Efficiency of energy and protein utilization during the full feeding period.

Feeding Regime	MEI[1], Mcal/day Young	Old	Means	±SEM	MEI/kg Empty body wt. gain Young	Old	Means	±SEM	MEI/Mcal Carcass[3] energy gain Young	Old	Means	±SEM
LHH	16.28	16.38	16.33		25.60	27.77	26.68[a]		6.72	5.38	6.05[a]	
LMH	14.88	16.85	15.87	0.48	23.43	26.47	24.95[a]	1.01	7.81	6.40	7.11[b]	0.17
LLH	15.64	15.00	15.32		20.10	20.80	20.45[b]		7.22	6.09	7.66[b]	
Means	15.60	16.08		0.39	23.04	25.01		0.82	7.25[d]	5.96[e]		0.14

Table 25 Continued.

Feeding Regime	DCP[2], g/day Young	Old	Means	±SEM	DCP/g Carcass[3] protein gain Young	Old	Means	±SEM
LHH	563.0	671.3	617.2		36.37	34.40	35.39[a]	
LMH	487.7	658.7	573.2	23.51	30.47	21.90	26.19[b]	1.65
LLH	611.0	614.0	612.5		16.70	18.40	17.55[c]	
Means	553.9[d]	648.0[e]		46.34	27.85	24.90		1.35

[1]Metabolizable energy intake

[2]Digestible crude protein intake

[3]Boneless carcass basis

[a,b,c]Means in a column with different superscripts are significantly different ($P<0.05$)

[d,e]Means in a row with different superscripts are significantly different ($P<0.05$).

There were no significant differences between the LMH and LLH treatment groups in efficiency of ME utilization for carcass energy gain. Both groups were, however, less efficient than control bulls on LHH feeding regime in converting ME intake to boneless carcass energy gain. Older bulls required significantly less ME per unit of boneless carcass energy gain than the younger bulls.

Daily digestible crude protein intake during the final full feeding period was higher in the control LHH animals than in LMH and LLH treatment groups though the differences were non-significant. Animals on LLH feeding regime were significantly more efficient in utilizing digestible crude protein for boneless carcass protein gain than LMH animals which in turn were more efficient than LHH controls. The older bulls consumed significantly more digestible crude protein than the younger bulls during the final period (Table 25), but there were no significant differences between age groups in efficiency of digestible crude protein utilization for boneless carcass protein gain.

3.5. Economics of feeding

During realimentation (181 to 270 days), total feed consumed was slightly higher in animals on the LLH feeding regime, followed by the control animals on the LHH feeding regime and least in LMH bulls (Table 26). Differences in this aspect were, however, non-significant. The cost of feed consumed was similar for LHH and LLH treatment groups but lower in LMH group by about

Table 26: Economics of feeding during the final full feeding period.

Feeding Regime	Total feed consumed, kg				Cost of feed consumed, ₦				Total liveweight gained, kg			
	Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
LHH	1244.4	1298.3	1271.3		161.7	164.5	163.1		103.0	56.7	79.8	
LMH	1129.7	1304.6	1217.2		147.5	165.0	156.2		108.3	93.7	101.0	
LLH	1275.0	1276.0	1275.5		165.9	162.0	164.0		135.0	99.7	117.3	
Means	1216.3	1293.0			158.4	163.8			115.4	83.3		

Table 26 Continued.

Feeding Regime	Total carcass[1] wt. gained, kg				Feed Cost/Kg liveweight gain, ₦				Feed Cost/Kg Carcass[1] wt. gain, ₦			
	Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
LHH	60.6	60.7	60.6		1.57	2.93	2.25[a]		2.68	2.74	2.71	
LMH	54.4	58.0	56.2		1.37	1.79	1.58[b]	0.13	2.74	2.87	2.80	0.10
LLH	68.8	59.5	64.1		1.24	1.66	1.45[b]		2.44	2.72	2.58	
Means	61.3	59.4			1.39[c]	2.12[d]		0.11	2.62	2.78		0.08

[1]Bone-in-carcass basis

[a,b]Means in a column with different superscripts are significantly different ($P<0.05$).

[c,d]Means in a row with different superscripts are significantly different ($P<0.05$).

5.0%. The cost of producing 1 kg liveweight gain was significantly lower in LLH and LMH treatment groups than in the control group. The saving in feed cost per kg liveweight gain was approximately 35.5 and 30.0% in LLH and LMH animals respectively, compared to the controls.

There were no significant differences between feeding regimes in the cost of producing 1 kg carcass weight gain. However, animals on LLH feeding regime gained 1 kg carcass weight at about 5.0% less cost than the control bulls on LHH feeding regime.

During the final full feeding period, younger bulls consumed less feed and recorded higher total liveweight gains than the older bulls (Table 26). Consequently, the cost of producing 1 kg liveweight gain was significantly lower in younger bulls by about =NO.7 Differences between age groups in feed cost per kg carcass weight gain were small and non-significant.

CHAPTER IV

DISCUSSION

4.1. Feed intake, growth and feed conversion efficiency

Evidence has been presented which appear to indicate that the feedlot performance of severely restricted and realimented animals may be different from those of their counterparts which have been subjected to less feed restriction.

(a) Feed intake

During early period when all animals were fed low plane of nutrition, total dry matter (DM) intake was approximately 1.2% of initial body weight. In mid period this amount had to be reduced for animals on LLH feeding regime to induce further weight losses, suggesting that the animals became increasingly more efficient in utilizing feed. Ledger and Sayers (1977) noted that in groups of Boran and Hereford x Boran steers kept at constant liveweights for periods up to 24 weeks, less of the diet had to be fed daily as time progressed.

The lack of a significant improvement in feed intake in previously restricted fed animals (LMH and LLH) over their unrestricted counterparts (LHH) during the final full feeding phase (Table 4) is at variance with other results in cattle (Meyer et al., 1965; O'Dovonan et al., 1972; Horton and Holmes, 1978) and in sheep (Allden and Young 1964; McManus et al., 1972; Graham and Searle, 1975; Lakpini et al., 1982) which indicated

that previously underfed animals consumed more feed when realimented than unrestricted animals. However, the current result is supported by other studies involving cattle (Hironaka and Kozub, 1973; Saubidet and Verde, 1976) and sheep (Meyer and Clawson, 1964; Murray and Slezacek, 1980b). The lack of significant differences in intake observed at full feeding may be attributed to gut capacity which was similar among treatment groups (Table 15). The decrease in DM intake during the first half of realimentation observed in this study is in agreement with the results of Keenan et al. (1970) who found that voluntary intake of feed increased only slowly after restrictions were removed. Similarly, Buttler-Hogg and Tulloh (1982) reported that after weight loss in sheep, ad libitum dry matter intake was significantly lower during the first 10 kg of gain during realimentation but similar to those of full fed controls when the complete recovery period was considered.

(b) Growth and feed efficiency

During the early trial period when all animals were placed on low plane of nutrition to simulate the natural dry season environment, animals lost approximately 17.0 to 20.0% of their body weight similar to the values reported by de Leeuw (1971) for cattle on natural grazing during the dry season. In mid period, continued restriction resulted in further loss in body weight (Table 5) and body condition (Table 6) but the rates of loss in both cases were lower than in early period. This indicates that the animals progressively became more efficient in feed utilization as the period of undernutrition was increased.

The bulls on LLH and LMH feeding regimes exhibited compensatory growth during the final period of full feeding (Table 5). They were, respectively, 83.0 and 79.0 kg lighter than the control bulls on LHH feeding regime at the end of mid period (Appendix Table 4). By the end of the final period, LLH and LMH animals had recovered 45.0 and 24.0 kg (Appendix Table 4) respectively, resulting in indices of compensation (Wilson and Osbourn, 1960) of 0.54 and 0.30. Thus, animals on LLH feeding regime which were more severely restricted had more rapid gains during realimentation than the bulls on LMH feeding regime. In support of the present findings, Ledger (1973), who imposed restrictions of 15-25 per cent liveweight loss on boran Zebu steers over 12-24 weeks, found that the longer the period of restriction the greater the compensatory growth. In sheep, Buttler-Hogg and Tulloh (1982) observed that greater weight loss was associated with higher and more persistent growth rates during realimentation. The lack of significant differences between treatment groups in empty body weight gains at the end of full-feeding period (Table 7) when such differences existed on full body weight basis (Table 5) would suggest that part of the higher liveweight gains of the restricted but recovered bulls was attributed to increased gut contents observed in these animals (Table 15). This observation is supported by the results of Broadbent et al. (1969) who indicated that part of the compensation for previously restricted cattle was achieved as a result of a change in gut fill at turn out to grazing. Similarly, the higher initial weight gains of cull cows were

attributed to gut fill (Graham and Price, 1982).

Feed efficiency determined at the end of the full feeding period (Table 7) showed that animals on LLH and LMH feeding regimes were significantly more efficient in converting DM into empty body weight gain at the early part of the full feeding period. This superiority greatly diminished at the later part of full feeding phase. There are conflicting reports on the relationship between undernutrition and efficiency of feed utilization during subsequent full feeding. Tudor and O'Rourke (1980) found that, during the recovery period, restricted calves were more efficient in converting feed into liveweight gain than unrestricted calves. In sheep there is evidence of improved efficiency of feed utilization during realimentation (Murray and Slezacek, 1980a; Buttler-Hogg and Tulloh, 1982). In contrast sheep that lost weight and then recovered it were only about 86% as efficient in feed utilization as those which maintained weight (Keenan et al., 1969).

At all stages of realimentation, younger bulls were more efficient than older bulls in converting DM into empty body weight gain. Coleman and Evans (1982), who studied the effect of age on the feedlot performance of Angus and Charolais steers following two planes of nutrition, found that younger steers were more efficient in the conversion of DM and ME into liveweight gain than older steers.

(c) Body measurements

The fact that bulls on LLH and LMH regimes showed decreases in heart girth but increases in wither height during the early

and mid feeding periods (Table 8) shows that heart girth was more severely affected than height measurement by restricted feeding. Thus, some skeletal growth, as represented by height at withers, did take place in LLH and LMH animals although at a lower rate compared to the control LHH animals. Lawrence and Pearce (1964a) reported that the early maturing height measurements were least affected, while circumference at navel and chest girth considered as late maturing were much more severely affected by low levels of nutrition in beef cattle. In sheep, Meyer et al. (1962) found that height at withers was not influenced by a reduction in protein or total feed intake, but reduced energy intake decreased height at withers.

The results obtained at the end of the full feeding period indicated that heart girth measurement which was more severely retarded during feed restriction showed greater growth rates upon realimentation than height at withers. Also, younger bulls showed greater increases in both heart girth and wither height than the older bulls, indicating superior response to liberal feeding in the former group.

4.2. The role of feed digestibility

Digestibility coefficients of DM, crude protein and energy were significantly lower at the end of mid period in LLH bulls fed at low level compared to LMH and LHH bulls which received moderates and high levels of nutrition, respectively (Table 9). This is contrary to the generally observed effect of level of feeding on digestibility. In ruminants the digestibility of

organic nutrients would normally be higher at lower levels of intake and decline as intake increases due to more rapid passage through the gut and therefore less time for rumen micro-organisms to ferment the feed (Church, 1976; A.R.C., 1980).

The digestibility of nutrients progressively improved as realimentation commenced. Thomson et al. (1982) also noted an improvement in the digestibility of diets in lambs as the trial progressed from feed restriction phase to realimentation. The lack of significant differences in digestibility of nutrients between feeding regimes during both phases of the full feeding period suggests that feed digestibility is not an important factor in compensatory growth. Other workers have similarly observed no change in feed or energy digestibility during realimentation in cattle (Foot and Tulloh, 1977; Horton and Holmes, 1978) and in sheep (Allden and Young, 1964; Graham, 1964). In contrast, reduced digestibilities during compensatory growth have been reported in lambs (McManus et al., 1972; Drew and Reid, 1975c) and in steers (Thomson et al., 1982). The depression in digestibility observed at the beginning of realimentation (Thomson et al., 1982) was attributed to increased rate of passage associated with elevated appetite of the compensatory animals.

4.3. The role of physiological changes in compensatory growth

The results on haematologic parameters show that apart from T8P feed restriction causes no appreciable reduction in PCV and Hb in Sokoto Gudali bulls while realimentation has no noticeable effect on these blood parameters. Saror and Coles (1975) and

Oyedipe et al. (1984) showed that lower nutritional status or a reduction in the protein content of feed resulted in depressed PCV, Hb and serum protein values of Zebu cattle. The results obtained in the present study do not support those of Norman and Evan (1972) who reported that PCV was raised in growing steers by increasing the level of nitrogen intake. During realimentation, serum T_4 levels were increased in all treatment groups. The results, however, indicated that feeding regimes imposed in this study had no significant influence on serum T_4 levels. This later observation is at variance with the reports by Fox et al. (1974) who attributed lower thyroid secretion rates in compensatory steers to reduced metabolic rate and concluded that a lower metabolic rate during the recovery period would contribute to an increase in efficiency of energy utilization. In general, T_4 values obtained in the present study are higher than the values reported for Sokoto Gudali females (Kumaresan et al., 1983).

The lower PUN values observed in LLH and LMH bulls, during feed restriction in mid period were carried over to the first part of the full feeding period. Consequently, PUN values were lower in LLH and LMH animals during the first half of the full feeding period but similar to PUN values for control LHH animals during the last half of the full feeding period (Table 12). These results suggest that LLH and LMH animals had more rapid rates of protein deposition during the first part of the recovery period, resulting in lower circulatory levels of urea nitrogen. This observation is supported by the findings of Fox (1970) and

Asplund et al., 1975), who attributed lower PUN values during the first part of realimentation to higher rates of protein retention.

The data showed that PUN levels were lower in younger bulls than in older bulls during feed restriction and realimentation, suggesting higher rates of tissue nitrogen retention in younger animals during the recovery period.

4.4. Carcass composition

The results of the present study indicate that undernutrition affects carcass components and composition. In addition, evidence has been presented that show that the degree of feed restriction and subsequent realimentation contribute to carcass compositional changes in cattle.

4.4.1. Carcass traits, by-products and organ components

The animals on LLH and LMH feeding regimes which were on low plane feeding in early and mid periods but realimented on high plane feeding were lighter at slaughter and had lower carcass weights than LHH controls which were on high plane feeding during mid and final period (Table 13). This would indicate that complete compensation was not accomplished in the previously restricted fed animals.

Kidney fat measure which may be used as an indication of fat deposition shows that restricted animals on LMH and LLH feeding regimes lost fat in mid period while the full-fed controls deposited fat. However, during realimentation in the final period, LMH and LLH animals tended to gain fat at a much more

rapid rate than the controls.

The dressing percentage was reduced in restricted LMH and LLH animals slaughtered at the end of the mid period by 4.1 and 5.3% respectively, compared to full-fed LHH bulls. During realimentation, there was an improvement in the dressing percentage of LMH and LLH animals although values were still lower by about 3.0% compared to the controls. The reduction in dresing percentage may be due largely to higher gut contents observed in these animals (Table 15). Several reports in the literature support this finding. Butterfield (1966) found that dressing percentage was lower in nutritionally stressed and recovered cattle compared to cattle fed on an uninterrupted high plane of nutrition. Similarly, Hironaka and Kozub (1973) observed a lower dressing percentage for restricted and realimented steers. In sheep, the apparent dressing percent was reduced by 2% during compensatory growth (Winter et al., 1976). Likewise, Lakpini et al. (1983) reported that the dressing percentage of Yankasa lambs previously fed low protein ration was 4.5% lower after realimentation on high protein diet compared to control lambs fed high protein ration throughout.

(c) By-products and organ components

Although the absolute weights of the hide and other external by-products were significantly lower in LLH and LMH bulls than LHH controls at the end of mid period, when expressed as a percentage of the empty body weight (Table 14), the results showed that feed restriction significantly increased the

proportions of head, front and back feet while the hide and tail proportions were not significantly affected. This indicates that the head and feet lost very little weight during feed restriction relative to the empty body weight probably because of their higher bone content. This, observation is in agreement with the reports by Seebeck (1973a) who found that weight loss in Brahman cross and Afrikander cross steers increased the proportions of head, tail and feet.

Data on gut tissue components showed that feed restriction followed by full feeding had no significant influence on the proportion of empty rumen and empty intestine in the empty body (Table 15), indicating that gut capacity was not altered. The proportions of full rumen and full intestine were, however, higher in restricted and realimented animals on LLH and LMH feeding regimes than in controls on LHH feeding regime. This suggests that undernutrition followed by full feeding results in increased gut contents. In sheep, Burton et al. (1974) observed an average increase of over 56% in gastrointestinal tract contents in the realimented animals. The increase in gut contents despite no change in gut capacity observed in this study may be due to accumulation of water in the gut of the previously restricted animals. Keenan et al. (1970) noted increased water retention in the gut of sheep following feed restriction.

The lack of significant differences in the proportions of liver, heart and kidney between treatment groups during both mid and final periods (Table 16) suggests that the level of feeding has no major influence on the proportions of these vital organs. This observation is consistent with the report by Leche (1973)

who found that though bulls reared on a high plane of nutrition had higher absolute weights of livers than low plane animals of the same empty body weight, the level of nutrition had no significant effect on the proportions of offal components in the empty body.

4.4.2. Changes in carcass physical composition

The results presented in this study seem to indicate that changes do occur in the physical composition of carcass during growth retardation and later recovery.

(a) Carcass lean, bone and fat proportions

The lean, bone and fat components expressed as percentages of the carcass showed that at the end of the mid period, animals on LMH and LLH feeding regimes had lower lean and fat but higher bone proportions than the control animals on LHH feeding regime (Table 17). This indicates that feed restriction decreases lean and fat but has no effect on bone deposition, confirming the earlier observation that skeletal development, as represented by height at withers, was not significantly influenced by undernutrition. It would seem therefore, that bone growth is more of a function of age than the level of feeding. This observation is in close agreement with the reports by Murray *et al.* (1974) who found that at the same dissected side weight, growth restriction tended to increase carcass bone percentage and concluded that bone development was related to both age and carcass weight. Similarly, Seebeck (1973b) reported that body

weight loss in Brahman cross and Afrikander cross steers resulted in muscle and fat approximately reversing the path of development, while bone, fascia and tendons remained approximately constant.

Results obtained at the end of full feeding period showed that LMH and LLH animals had higher lean percentages than LHH animals, suggesting that feed restriction followed by realimentation on high plane diet increases lean proportions in cattle. Carroll et al. (1963) noted that realimentation resulted in greater lean growth by steers previously unsupplemented. In a relatively recent study, Hironaka et al. (1984) similarly found that previously restricted steers had leaner carcasses during recovery than those that were given the diet ad libitum throughout.

The results further revealed that fat percentages increased during full feeding in LLH and LMH animals, but the values did not reach up to the levels of the control LHH animals. This observation is supported by the results of Drew and Reid (1975b) who indicated that realimentation in sheep produced a lower fat concentration than during normal growth.

The decrease in bone percentages observed in LLH and LMH bulls compared to LHH control bulls during full feeding may be due to dilution effect of fat during realimentation in LLH and LMH bulls, resulting in lower proportions of bone.

In general, the results obtained in the present study support the observation that feed restriction and realimentation affect the growth of major carcass tissues. On the contrary, Lawrence and Pearce (1946b) found that cattle realimented after

various degrees of feed restriction had similar carcass composition. Likewise, Murray and Slezacek (1976) observed that at the same dissected side weight, the amount of muscle, bone and fat was similar in sheep grown along three growth paths.

The higher muscle to bone and lean to fat ratios in LLH and LMH bulls compared to LHH control bulls at the end of the full feeding period (Table 18) is a reflection of the higher rates of lean deposition, but lower rates of fat deposition in the LLH and LMH treatment groups in this period. The economic value of carcass is considered maximal when it has the highest lean to bone ratio and a desirable percentage of fat as dictated by consumer preference (Berg and Butterfield, 1976). The present results suggest that animals restricted in food intake for longer periods and exhibiting compensatory growth produce carcasses of higher quality than animals that are full-fed for longer periods and not exhibiting this compensatory growth phenomenon.

(b) The proportions of wholesale cuts

The results on wholesale cuts (Table 19) showed that, expressed as percentages of carcass, the shank, chuck, rib and round tended to increase while the shortloin, flank, rump, brisket and plate tended to decrease for LMH and LLH animals slaughtered at the end of the mid period, compared to those of LHH animals. The changes in the relative proportions of these cuts is attributable to the fact that they conform to the known differential growth patterns (Palsson, 1955; Butterfield, 1966; Seebeck and Tulloh, 1968a). The shank, chuck, rib and round are in the early maturing regions of the body while the loins

(shortloin and sirloin), flank, rump, brisket and plate are in the late maturing regions. The late maturing tissues are more affected by nutrient deprivation than early maturing tissues. During realimentation, these late maturing tissues show a greater growth impetus than the early maturing ones (Butterfield, 1966; Berg and Butterfield, 1976). Thus for LMH and LLH bulls, especially as plane of nutrition advanced from the mid to the final full-feeding period, there was increase, albeit slight, in proportions of the loin cuts, flank, rump, brisket and plate but decrease in proportions of the chuck, rib, shank and round. These results are in general agreement with those of Dockerty (1970) who found that the percentages of plate, shortloin and flank increased uniformly to final weights following a decrease during the period of maintanance.

(c) Lean, bone and fat percentages in wholesale cuts

The decline in the per cent lean of plate, shortloin and flank of LMH and LLH bulls observed at the end of the mid period compared to values from LHH bulls may be attributed to the fact that muscles from these cuts are late-maturing (Butterfield and Berg, 1966; Seebeck and Tulloh, 1968a,b) and would be more severely affected by feed restriction. This observation is supported by the results of Seebeck (1973b) who indicated that body weight loss affected muscle weight distribution, the most marked effect being the decline in the relative proportion of the late-maturing abdominal muscle. Similarly Murray et al. (1974) found that the proportion of abdominal muscle was higher and the proportion of distal muscle of the fore-leg was lower in steers

maintained in high plane diet than in those on low plane diet.

At the end of the full feeding period, little differences existed between treatment groups in lean distribution except in plate sirloin, shortloin and flank, where LMH and LLH animals had consistently greater lean percentages though only flank percentages were significant. These results demonstrate the ability of the musculature to recover. The significantly higher lean proportions in the flank cut exhibited by the more severely restricted and now recovered animals is striking. It supports the contention that the abdominal muscle is late-maturing (Butterfield and Berg, 1966; Seebeck and Tulloh, 1968b) and therefore more likely to respond more positively to improved nutrition later in life.

The data on bone distribution (Table 21) showed that, at the end of the mid period, LMH and LLH animals tended to increase the proportion of bone deposited in all the ten wholesale cuts than LHH control animals, indicating that feed restriction results in increased bone proportions. At the end of full feeding period, little differences occurred between treatment groups in the proportions of bone in the wholesale cuts. These changes are a reflection of the rates of tissue maturity and indicate that bone matures early and is related more to age than to nutritional differences.

The results of fat distribution (Table 22) indicated that at the end of the mid period, animals on LHH feeding regime had higher percentages of fat in all the cuts than restricted LMH and LLH animals. This suggests that the deposition of fat and bone

tend to follow an inverse relationship. This observation is in close agreement with the results of Buvanendran et al. (1983) who found that while lean percentage was relatively constant for cattle slaughtered at different weights, the bone and fat percentage changes were inversely related, with those carcass parts showing the greatest increase in fat percentage undergoing the largest decrease in bone percentage. These changes are larrgely attributed to the dilution effect of fat.

At the end of full feeding period, the differences in fat percentages were markedly reduced. However, fat content significantly favoured LHH control bulls in the late-maturing cuts of plate, brisket, sirloin, shortloin and compared to LLH bulls.

4.4.3. Chemical composition, components of carcass gain and efficieny of energy and protein utilization.

(a) Chemical composition

Chemical analysis of the boneless carcass showed that at the end of the mid period, restricted LMH and LLH bulls had more water, less fat and similar proportions of protein and ash compared to the full-fed LHH control bulls (Table 23). The lack of significant differences in protein percentage may be related to differences between groups in body composition at the end of the early period. The bulls on LHH feeding regime were in poorer condition at this period (Table 6). In general, however, the present results are in agreement with several other reports. Coleman et al. (1982) fed Angus and Charolais steers either a control or restricted growing ration followed by a high energy

finishing ration. These authors (Coleman et al., 1982) found that at the end of the growing phase, restricted steers tended to have more moisture and protein, less fat and similar proportions of ash, compared to the controls. Seebeck and Tulloh (1969) determined chemical components of carcasses from Angus steers which grew either continuously or which were subjected to a period of weight loss before slaughter. They (Seebeck and Tulloh, 1969) found that as the carcass weight increased, the proportion in the carcass of protein, water and ash decreased while the proportion of chemical fat increased. When the two groups of animals were compared at the same carcass weight, Seebeck and Tulloh (1969) noted that weight loss led to a significant increase in the proportion of ash and a significant decrease in that of protein. In contrast, Buttler-Hogg (1984) reported that at the same empty body weight, the carcass of weight loss sheep contained more fat and protein and less water than full-fed control sheep. Buttler-Hogg (1984) further showed that the rate at which water was lost decreased while fat and protein loss increased as undernutrition progressed. Thus, the differences in composition observed at the early stage of undernutrition would be expected to be altered at a later stage of undernutrition.

Following realimentation in the final period, there were little differences between treatments in the chemical composition of carcass. However, restricted LLH bulls tended to have higher proportions of water, protein and ash but lower fat and energy values compared to LHH controls. This finding is in close

agreement with several other reports. Thus, Reid et al. (1968) found that partial fasting followed by refeeding resulted in a little more protein, considerably more water, but musch less fat and energy at a given body weight than did an energy intake that produced a steady, positive body-energy gain. Burton et al. (1974) reported that sheep which had undergone weight loss and then recovered weight retained more water and less energy, and tended to deposit less fat and more protein than normally grown controls. Similarly, Drew and Reid (1975a) observed that sheep realimented after losing 25% empty body contained more water and protein and less fat and energy than continuously full-fed animals.

The results on chemical composition further revealed that during both feed restriction and realimentation, younger bulls had higher protein and ash percentages but lower water, fat and energy values than the older bulls. This is probably a reflection of weight differences as the younger animals were lighter at both periods than older bulls.

(b) Component of gain in the boneless carcass

There were considerable differences between treatment groups in the composition of gains made during the period of feed restriction (Table 24). Although the more severely restricted LLH and LMH bulls were in positive energy balance during this period, the control LHH bulls gained considerably more protein and fat in boneless carcass than the LMH and LLH bulls which did not differ significantly from each other. These results indicate that body fat and protein are mobilized during nutritional stress

to meet the maintenance requirements of the animal. Although the relative contributions of protein and fat to energy gain were not calculated, the results suggest that protein makes up a smaller fraction and fat a correspondingly larger fraction of the energy balance during weight loss. This observation is consistent with the reports by Searle et al. (1979) who found that the composition of weight change during the later stage of weight loss in sheep consisted of less protein and more fat, and those of Graham and Searle (1979) who noted a diminishing protein contribution to energy balance during prolonged weight loss.

During the full feeding period, the control LHH animals gained significantly lower boneless carcass than the more severely restricted and now recovered LLH and LMH animals (Table 24). The composition of the gain varied considerably between treatment groups. The gain contained approximately 21.0, 15.0, 18.5% protein and 22.0, 31.0, 29.6% fat, respectively for LLH, LMH and LHH bulls. Thus, the boneless carcass weight gains made by the most severely restricted and realimented LLH bulls were higher in protein and lower in fat compared with the LHH control bulls. This result is supported by the findings of Baker et al. (1985) who found that steer calves realimented on pasture following a low plane of nutrition gained more protein and water, but less energy and ash than those of continuously full-fed group. Similarly, Swingle et al. (1979) observed that although the estimated carcass gains were higher for cows on moderate energy diet than for those on the low energy diet, the latter tended to gain more protein and moisture but less lipid as

percentage of carcass gain. In the study by Fox (1970), weight gains made by compensatory steers during the first part of the full feeding period were higher in protein and lower in fat than full-fed controls but were higher in fat and lower in protein than controls during the last part of the full feeding.

Daily protein, fat and energy gains in the carcass were greater for the older bulls than for the younger bulls at the end of the mid period (Table 24). Following realimentation in final period, daily fat and energy gains were higher in the older bulls than younger bulls while protein deposition (g/day) was similar for the two age groups. These results support, in part, the data of Coleman et al. (1982) who indicated that during finishing phase, daily protein, fat and energy gains in the carcass were higher in favour of older steers.

(c) Efficiency of energy and protein utilization

The significant improvement in efficiency of ME conversion to empty body weight gain during the final full feeding period in LLH bulls compared to LMH and LHH bulls (Table 25) is a reflection of the higher, though not significantly, empty body weight gain in the LLH animals at this period (Table 7). Similarly, the significantly greater efficiency of ME utilization for carcass energy gain in the control LHH animals compared to LMH and LLH animals may be attributed to the higher energy gain in the controls during this period (Table 24). These results support the findings of Fox (1970) who noted a greater increase in efficiency of ME utilization for growth in compensatory steers than full-fed controls, but not those of Coleman et al. (1982)

and Baker et al. (1985) who reported similarity in energy efficiency for carcass energy deposition between normal and compensatory growth.

Animals on LLH feeding regime which were the most severely restricted were the most efficient in converting digestible crude protein to carcass protein gain during the full feeding period. This is probably because in LHH and LMH animals where a relatively greater proportion of the gain is fat, dietary nitrogen is utilized less efficiently due to greater nitrogen loss in deamination of the amino acids. Improved efficiency of protein utilization for carcass protein retention during compensatory growth has been reported by other workers (Fox, 1970; Graham and Searle, (1979) and Baker et al., 1985).

Younger bulls were less efficient in ME utilization for carcass energy gain than older bulls at the end of the full feeding period (Table 25). This may be due to the fact that the gain of the younger bulls contained less energy at this period (Table 24). The lack of significant difference between the younger and older bulls in efficiency of digestible crude protein utilization for carcass protein gain supports the results of Coleman et al. (1982) who found no difference in protein efficiency attributable to age of steers. However, the present results do not agree with the similarity in ME efficiency for carcass energy gain between younger and older steers reported by Coleman et al. (1982).

The results of this section indicate that increased efficiency of protein utilization for protein gain is largely

responsible for compensatory growth response in Sokoto Gudali bulls.

4.5. Economics of feeding

The cost of producing 1 kg liveweight gain during the full feeding period was significantly lower in LLH and LMH bulls that were restricted in feed intake for six months than in LHH bulls which were underfed for three months prior to full feeding (Table 26). This is due to the higher liveweight gains relative to feed intake exhibited by LLH and LMH animals at this period. It was also cheaper, though non-significantly, to produce 1 kg of carcass weight gain in LLH bulls that were underfed for longer period than in LHH controls that experienced shorter and less severe undernutrition. The significantly lower cost of liveweight gain in younger bulls compared to the older bulls may be due to the greater feed conversion efficiency in the former group.

The natural effects of nutrition on animals in the drier parts of Nigeria caused by seasonal fluctuations in forage availability are similar to the different planes of nutrition imposed on animals in this study. Hence these results have practical implications for cattle fattening practices as they provide information on the degree and duration of under-nutrition, and age of animals in relation to their ability to respond profitably to improved nutritional plane in the feedlot.

During the dry season, cattle raised on poor quality, overgrazed range are undernourished. When these animals are transferred to feedlot and finished on high plane of nutrition,

their level of performance varies, depending on the age and degree of starvation before fattening. In terms of feed costs, it will be advantageous to select younger animals that commenced the period of underfeeding at 12-18 months of age and with a body condition score of 1.5-2.0 since they are more likely to achieve liveweight gains in the feedlot at a cheaper cost than older animals. Similarly, animals that were restricted of feed for six or more months prior to fattening would be economically more efficient than those that experienced shorter period of feed restriction. Thus, a farmer who purchased his cattle at the end of the dry season after six or more months of feed restriction, and fattened them would benefit from reduced cost of production primarily because of compensatory growth. Besides, the farmer would have paid less for the cattle since they weighed much less and were in poorer condition, thus enhancing his overall profit margin.

CHAPTER V

SUMMARY AND CONCLUSION

The study was carried out to examine the factors influencing compensatory growth responses of Sokoto Gudali bulls. Forty-eight Sokoto Gudali bulls belonging to two age groups were used in a randomized block design with feeding regime and age as the criteria of classification. The animals were on either low (L), moderate (M) or high (H) level of nutrition during three periods. The feeding periods which lasted 90 days each were arranged to give LLH, LMH and LHH feeding regimes. Animals on the LHH feeding regime served as the control.

Data were obtained on growth, feed intake, efficiency of feed conversion, serum thyroxine and plasma urea nitrogen levels. Nutrient digestibility and nitrogen balance were estimated at different phases of the study. Representative bulls were slaughtered at the beginning of the study and at the end of each feeding period to determine carcass components, composition of carcass gain and efficiency of energy and protein utilization.

During early period when all animals were fed low plane of nutrition, total dry matter intake was approximately 1.2% of initial body weight and the animals lost about 17.0 to 20.0% of their body weight at the end of this period. Dry matter intake during the full feeding period was similar across feeding regimes, indicating that enhanced appetite during realimentation was not an important factor in compensatory growth.

Average daily liveweight gains during the full feeding period were 0.53, 0.67, and 0.79 kg/day respectively for LHH, LMH and LLH groups and were significantly higher in LMH and LLH animals than in LHH controls. On an empty body weight basis, however, no significant differences in gains were recorded. These empty body weight gains were 0.61, 0.61, and 0.72 kg/day respectively for LHH, LMH and LLH animals.

Efficiency of feed utilization for empty body weight gain (feed/gain) during the full feeding period was better in animals on LLH and LMH feeding regimes than the controls on LHH feeding regime. These efficiency figures were 10.72, 12.23 and 12.26 kg DM/kg empty body gain respectively for LLH, LMH and LHH treatment groups.

Younger bulls consumed less feed and grew faster during realimentation than older bulls. Feed efficiencies for empty body weight gain were 10.31 and 13.16 for younger and older bulls respectively, and were significantly higher for the younger bulls.

The bulls on LLH and LMH feeding regimes which were restricted in intake during early and mid feeding periods showed decreases in heart girth but increases in wither height during these periods, showing that skeletal development was related more to animal age and duration of feeding time than to the nutritional regimes imposed.

Nutrient digestibility coefficients were depressed during feed restriction. There were, however, no significant differences between feeding regimes in digestibility coefficients determined during the full feeding period, suggesting that

improved digestibility during realimentation was not responsible for compensatory growth.

Serum T_4 levels were lower during feed restriction than during full feeding. At feed restriction, T_4 values were 6.65, 6.29 and 6.58 ug/100 ml respectively for LLH, LMH and LHH bulls. Comparable values at full feeding phase were 10.38, 9.79 and 9.07 ug/100 ml respectively for LLH, LMH and LHH bulls. There was, however, no significant treatment effect on serum T_4 levels.

Plasma urea nitrogen values were consistently lower in LLH and LMH animals during feed restriction and during the first part of the full feeding period, but increased to the level of controls during the last part of the full feeding period. Overall, PUN values during the full feeding period were 12.8, 12.9 and 16.4 mg % respectively for LLH, LMH and LHH bulls and were significantly lower in LLH and LMH than in LHH bulls. These results indicate that bulls on LLH and LMH feeding regimes had a more rapid rate of protein deposition during the first part of recovery than the controls on LHH feeding regime.

At final slaughter, LHH control bulls had significantly higher carcass weight (166.2 kg), dressing percent (52.8%) and rib eye area (57.12 cm^2) than LLH (139.6 kg carcass weight, 50.1 dressing %, 44.13 cm^2 rib eye area) and LMH (131.8 kg carcass weight, 49.5 dressing %, 43.60 cm^2 rib eye area) animals.

The head, front and back feet, expressed as percentages of empty body weight, were significantly increased in LLH and LMH bulls at the end of the mid period, showing that these bony structures, lost very little during feed restriction relative to

the empty body weight. At the end of the full feeding period, the proportions of full rumen and full intestine were significantly higher in LLH and LMH bulls than in LHH controls while differences between feeding regimes in the proportions of empty rumen and empty intestine were not significant. These results suggest that increased gut contents, but not gut capacity, was an important feature of compensatory growth.

During mid period, animals on LLH and LMH feeding regimes had significantly lower lean and fat percentages but higher bone percentage than the bulls on LHH feeding regime. At the end of the full feeding period, lean percentage values were 69.2, 69.3 and 67.7% respectively for LLH, LMH and LHH bulls and were significantly higher in LLH and LMH than in LHH bulls.

At the end of full feeding period, there were no significant differences between feeding regimes in the proportions of wholesale cuts. Similarly, little differences existed between treatment groups in bone or lean distribution except in flank where animals on LLH and LMH feeding regimes exhibited significantly greater lean percentages than LHH control animals. There were, however, considerable differences between feeding regimes and among wholesale cuts in fat distribution. The proportion of fat in plate, brisket, sirloin, shortloin and flank was significantly less in LLH bulls than in LHH bulls at the end of the full feeding period. Among wholesale cuts across feeding regimes, mean fat percentage ranged from approximately 23.0% in the brisket and flank to less than 5.0% in the shank.

At final slaughter the bulls on LLH feeding regime had higher percentages of water (67.2%) and protein (21.4%) but lower

fat percentage (13.7%) than control bulls (63.9%) water, 21.0% protein, 15.9% fat) on LHH feeding regime.

Efficiency of ME utilization for empty body weight gain during the final full feeding period was significantly better in LLH than in LMH and LHH bulls. These efficiency values were 20.45, 24.95 and 26.68 Mcal/kg empty body weight gain respectively for LLH, LMH and LHH bulls. The control LHH bulls were, however, more efficient in converting ME to carcass energy gain than LLH and LMH animals. Digestible crude protein efficiencies for carcass protein gain were 17.55, 26.19 and 35.39 g DCP/g protein gain respectively for LLH, LMH and LHH bulls and were significantly better in LLH and LMH than in LHH animals. These results and those of PUN values suggest that increased efficiency of protein utilization during the first half of the full feeding period was largely responsible for compensatory growth in Sokoto Gudali bulls.

Estimates of cost of feeding during the final full feeding period showed that animals on LLH and LMH feeding regimes gained 1 kg liveweight at significantly lower cost than the control bulls on LHH feeding regime. Younger bulls were economically more efficient in liveweight gains than older bulls. The results of this study have practical implications on cattle fattening practices in Nigeria as they provide information on the performance of animals that pass through varying degrees of starvation under natural grazing before fattening.

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Appendix Table 1: Concentrate and Hay intake (kg/day) according to feeding regime and age of animal.

Feeding Regime	0 to 90 Days								91 to 180 Days							
	Conc.				Hay				Conc.				Hay			
	Young	Old	Means	±S.D.	Young	Old	Means	±S.D.	Young	Old	Means	±S.D.	Young	Old	Means	±S.D.
LHH	0.7	2.5	1.7	±0.91	2.4	1.1	1.8	±0.70	5.2	4.8	5.0	±0.34	1.2	4.1	2.7	±1.51
LMH	0.7	2.5	1.6	±0.91	2.4	1.0	1.7	±0.70	2.9	1.6	2.3	±0.65	0.8	1.7	1.3	±0.52
LLH	0.7	2.5	1.7	±0.91	2.3	1.0	1.6	±0.69	1.9	0.7	1.3	±0.60	0.7	1.1	0.9	±0.18
Means ±S.D	0.7 ±0.04	2.5 ±0.01			2.4 ±0.11	1.0 ±0.06			3.3 ±1.44	2.4 ±1.80			0.9 ±0.25	2.3 ±1.36		

Appendix Table 1 Continued

Feeding Regime	181 to 270 Days								181 to 225 Days							
	Conc.				Hay				Conc.				Hay			
	Young	Old	Means	±S.D	Young	Old	Means	±S.D	Young	Old	Means	±S.D	Young	Old	Means	±S.D
LHH	4.3	4.5	4.4	±0.22	3.8	4.3	4.1	±0.47	4.5	4.2	4.4	±0.19	3.7	4.1	3.9	±0.36
LMH	3.9	4.5	4.2	±0.33	3.4	4.3	3.9	±0.52	3.8	4.1	4.0	±0.21	3.1	3.8	3.5	±0.43
LLH	4.4	4.4	4.4	±0.04	3.9	4.2	4.1	±0.23	4.2	4.0	4.1	±0.11	3.3	3.7	3.5	±0.23
Means	4.2	4.5			3.7	4.3			4.2	4.1			3.4	3.9		
±S.D	±0.27	±0.07			±0.40	±0.10			±0.32	±0.13			±0.33	±0.20		

Appendix Table 1 Continued

Feeding Regime	226 to 270 Days								0 to 270 Days							
	Conc.				Hay				Conc.				Hay			
	Young	Old	Means	±S.D	Young	Old	Means	±S.D	Young	Old	Means	±S.D.	Young	Old	Means	±S.D
LHH	4.1	4.8	4.5	±0.44	3.9	4.5	4.2	±0.59	3.6	4.1	3.9	±0.26	2.6	3.4	3.0	±0.49
LMH	4.1	4.9	4.5	±0.50	3.7	4.7	4.2	±0.61	2.7	3.0	2.9	±0.16	2.2	2.6	2.4	±0.21
LLH	4.7	4.8	4.8	±0.09	4.4	4.7	4.6	±0.30	2.6	2.7	2.6	±0.05	2.4	2.3	2.4	±0.08
Means	4.3	4.8			4.0	4.6			3.0	3.3			2.4	2.8		
±S.D.	±0.40	±0.11			±0.58	±0.17			±0.48	±0.63			±0.21	±0.49		

Appendix Table 2: Summary of Analysis of variance for dry matter intake.

Source of Variation	Degrees of Freedom	Mean Squares			
		0-90	91-180	181-270	0-270
Treatment	2	0.05	63.71*	0.21	2.19*
Age	1	1.31*	1.06*	2.32*	1.28*
Treatment x Age	2	0.02	5.44*	0.40	0.28*
Error+		0.04	0.02	0.13	0.04

+Degrees of freedom for error are 28, 28, 12 and 12 for 0-90, 91-180, 181-270 and 0-270 days respectively.
*(P<0.05).

Appendix Table 3: Summary of Analysis of Variance for full body weight gain.

Source of Variation	Degrees of Freedom	Mean Squares			
		0-90	91-180	181-270	0-270
Treatment	2	0.004	2.179*	0.102*	0.066*
Age	1	0.157*	0.016	0.144*	0.023*
Treatment x Age	2	0.006	0.128*	0.017	0.005*
Error[+]		0.010	0.007	0.009	0.001

[+]Degrees of freedom for error are 28, 28, 12 and 12 for 0-90, 91-180, 181-270 and 0-270 days respectively.
*($P<0.05$).

Appendix Table 4: Means for full body weight and feed conversion efficiency at various trial stages.

Item	Feeding Regime	Day 0 Young	Old	Means	±SEM	Day 90 Young	Old	Means	±SEM	Day 180 Young	Old	Means	±SEM
Body wt, kg	LHH	159.0	239.3	199.2		126.6	193.5	160.1		204.2	305.5	254.9	
	LMH	171.7	242.8	207.3	5.57	139.5	203.2	171.4	3.79	152.3	209.2	180.8	4.69
	LLH	188.0	251.0	219.5		154.4	211.0	182.7		152.8	196.8	174.8	
	Means	172.9	244.4		4.58	140.2	202.6		3.11	169.8	237.2		3.85

Appendix Table 4 Continued.

Item	Feeding Regime	Day 225 Young	Old	Means	±SEM	Day 270 Young	Old	Means	±SEM
Body wt., kg	LHH	257.0	347.3	302.2		294.0	368.3	331.2	
	LMH	200.7	266.0	233.4	7.07	251.3	300.7	276.0	9.97
	LLH	232.0	247.0	239.5		293.7	293.0	293.4	
	Means	229.9	286.8	5.77		279.7	320.7	6.51	

Appendix Table 4 Continued.

Item	Feeding Regime	181 to 225 Days Young	Old	Means	±SEM	226 to 270 Days Young	Old	Means	±SEM	181 to 270 Days Young	Old	Means	±SEM
Kg DM/kg Full	LHH	8.89	15.59	12.24[a]		14.25	30.60	22.43[a]		10.69	20.42	15.56[a]	
Body wt.gain	LMH	8.65	9.10	8.88[b]	0.81	10.12	20.25	15.19[b]	2.28	9.32	12.48	10.90[b]	0.64
	LLH	7.42	9.60	8.51[b]		9.74	13.53	11.64[b]		8.41	11.26	9.84[b]	
Means		8.32[c]	11.43[d]		0.66	11.37[c]	21.46[d]		1.86	9.47[c]	14.71[d]		0.53

[a,b]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$).
[c,d]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

Appendix Table 5: Means for heart girth (HG) and height at withers (WH) during various stages of trial.

Item	Feeding Regime	Day 90 Young	Old	Means	±SEM	Day 180 Young	Old	Means	±SEM	Day 270 Young	Old	Means	±SEM
HG, cm	LHH	124.2	141.8	133.0		126.6	152.9	139.8		145.7	166.2	156.0	
	LMH	124.8	142.6	133.7	1.31	125.5	141.7	133.6	1.36	132.0	150.2	141.1	1.76
	LLH	131.6	141.5	136.6		130.7	139.4	135.1		142.0	144.6	143.3	
	Means	126.9	142.0		1.07	127.6	144.7		1.12	139.9	153.7		1.44
WH, cm	LHH	112.2	124.7	118.5		114.4	126.6	120.5		118.1	125.1	121.6	
	LMH	112.3	123.9	118.1	1.01	113.0	125.2	119.1	1.06	115.7	125.1	120.4	1.27
	LLH	114.4	121.9	118.2		116.1	123.0	119.6		120.2	123.3	121.8	
	Means	112.9	123.5		0.82	114.5	124.9		0.87	118.0	124.5		1.04

Appendix Table 6: Summary of Analysis of Variance for packed cell volume (PCV).

Source of Variation	Degrees of Freedom	Mean Squares		
		0-90	91-180	181-270
Treatment	2	19.20	11.58	8.02
Age	1	39.65*	0.62	1.03
Treatment x Age	2	3.98	6.62	9.06
Error[+]		6.33	5.79	4.81

[+]Degrees of freedom for Error are 28, 28, and 12 for 0-90, 91-180 and 181-270 days respectively.
*(P<0.05)

Appendix Table 7: Summary of Analysis of variance for Haemoglobin (Hb).

Source of variation	Degrees of freedom	Mean Squares		
		0-90	91-180	181-270
Treatment	2	1.42	0.85	1.66
Age	1	23.00*	0.25	0.001
Treatment x Age	2	0.37	0.66	1.31
Error+		1.77	0.91	0.88

+Degrees of freedom for Error are 28, 28 and 12 for 0-90, 91-180 and 181-270 days respectively.
*(P<0.05).

Appendix Table 8: Summary of Analysis of variance for total blood protein (TBP).

Source of variation	Degrees of freedom	Mean Squares		
		0-90	91-180	181-270
Treatment	2	0.01	0.84*	0.96*
Age	1	3.03*	0.91*	0.04
Treatment x Age	2	0.17	0.11	0.17
Error+		0.25	0.19	0.13

+Degrees of freedom for error are 28, 28 and 12 for 0-90, 91-180 and 181-270 days respectively.
*($P<0.05$)

Appendix Table 9: Summary of Analysis of variance for serum thyroxine (T_4).

Source of variation	Degrees of freedom	Mean Squares		
		0-90	91-180	181-270
Treatment	2	0.54	3.27	3.22
Age	1	236.53*	39.83*	119.61*
Treatment x Age	2	4.62	0.32	0.86
Error+		9.77	8.03	5.88

+Degrees of freedom for error are 28, 28 and 12 for 0-90, 91-180 and 181-270 days respectively.
*(P<0.05)

Appendix Table 10: Summary of Analysis of variance for plasma urea nitrogen (PUN).

Source of variation	Degrees of freedom	Mean Squares		
		0-90	91-180	181-270
Treatment	1	2.80	13.04*	31.27*
Age	2	36.36*	34.42*	42.47*
Treatment x Age	2	0.34	0.38	0.24
Error+		0.60	0.61	0.67

+Degrees of freedom for error are 28, 28 and 12 for 0-90, 91-180 and 181-270 days respectively.
*(P<0.05)

Appendix Table 11: Influence of feeding regime and age of animal on weights (kg) of hide and other by-products

Stage of trial (days)	Feeding Regime	Hide				Head				Tail			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	20.85	29.28	25.07[a]		13.00	15.60	14.30[a]		1.35	1.70	1.53[a]	
	LMH	15.30	20.64	17.97[b]	1.17	10.13	11.74	10.94[b]	0.42	1.07	1.30	1.19[b]	0.07
	LLH	13.25	20.84	17.05[b]		10.00	11.87	10.93[b]		0.85	1.10	0.98[b]	
	Means	16.47[c]	21.43[d]		0.97	11.04[c]	13.07[d]		0.35	1.09[c]	1.37[d]		0.06
270	LHH	31.05	34.23	32.64		14.63	16.80	15.72		1.65	2.0	1.82	
	LMH	23.84	28.70	26.27	1.87	13.10	15.00	14.05	0.50	1.53	1.45	1.49	0.11
	LLH	30.50	27.46	28.98		14.53	15.27	14.90		1.83	1.83	1.83	
	Means	28.46	30.13		1.54	14.09	15.69		0.40	1.67	1.76		0.09

Appendix Table 11 Continued.

Stage of trial (days)	Feeding Regime	Front feet				Back feet			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	2.83	3.68	3.26[a]		3.00	3.57	3.29[a]	
	LMH	2.67	3.20	2.94[b]	0.09	2.60	3.07	2.84[b]	0.09
	LLH	2.15	3.03	2.59[b]		2.15	2.96	2.56[b]	
	Means	2.55[c]	3.30[d]		0.08	2.58[c]	3.20[d]		0.08
270	LHH	3.21	3.70	3.46		3.10	3.60	3.35	
	LMH	3.44	3.60	3.52	0.16	3.27	3.55	3.41	0.14
	LLH	3.44	3.60	3.52		3.47	3.56	3.52	
	Means	3.36	3.63		0.13	3.23	3.57		0.12

[a,b]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$)

[c,d]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$)

Appendix Table 12: Effect of feeding regime and age of animal on weights (kg) of gut tissue components

Stage of trial (days)	Feeding Regime	Rumen, Full				Rumen, empty				Omental fat			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	35.15	38.97	37.06		8.55	10.04	9.30[a]		1.50	1.86	1.68[a]	
	LMH	25.84	31.17	28.51	3.17	5.43	7.10	6.27[b]	0.40	0.57	0.46	0.52[b]	0.08
	LLH	33.50	42.54	38.02		5.15	7.07	6.11[b]		0.45	0.46	0.46[b]	
	Means	31.50	37.56		2.62	6.38[c]	8.07[d]		0.33	0.84	0.93		0.07
270	LHH	36.93	40.96	38.95		10.63	11.12	11.12		2.63	3.43	3.03	
	LMH	34.83	48.36	41.60	2.78	9.83	11.14	10.49	0.53	2.03	2.33	2.18	0.21
	LLH	38.70	46.40	42.55		10.26	10.50	10.38		1.97	2.13	2.05	
	Means	36.82[c]	45.24[d]		2.27	10.24	11.08		0.44	2.21	2.63		0.17

Appendix Table 12 Continued.

Stage of trial (days)	Feeding Regime	Intestine, full				Intestine, empty				Mesenteric fat			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	14.05	10.10	12.08		8.00	8.87	8.44		1.05	1.06	1.06[a]	
	LMH	8.66	11.60	10.13	0.48	5.70	7.67	6.69	0.50	0.53	0.63	0.58[b]	0.10
	LLH	11.25	12.00	11.63		5.95	8.07	7.01		0.85	0.53	0.69[b]	
	Means	11.32	11.23		0.40	6.55[c]	8.20[d]		0.42	0.81	0.74		0.08
270	LHH	12.73	14.90	13.82		10.40	10.43	10.42		2.54	2.97	2.76	
	LMH	13.73	15.76	14.75	0.52	9.06	10.87	9.97	0.58	1.94	2.23	2.09	0.31
	LLH	13.50	14.73	14.12		10.66	9.87	10.27		1.79	2.03	1.90	
	Means	13.32[c]	15.13[d]		0.42	10.04	10.39		0.49	2.08	2.41		0.25

[a,b]Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$)

[c,d]Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$).

Appendix Table 13: Effect of feeding regime and age of animal on weights (kg) of some internal organs

Stage of trial (days)	Feeding Regime	Liver				Heart				Spleen				Kidney			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM	Young	Old	Means	±SEM
180	LHH	2.85	3.54	3.20[a]		0.85	0.97	0.91[a]		0.71	0.77	0.74[a]		0.46	0.56	0.51	
	LMH	1.85	2.06	1.96[b]	0.10	0.65	0.70	0.68[b]	0.05	0.41	0.37	0.39[b]	0.02	0.41	0.36	0.39	0.05
	LLH	1.30	2.10	1.70[b]		0.50	0.67	0.59[b]		0.31	0.40	0.36[b]		0.31	0.36	0.34	
	Means	2.00[c]	2.57[d]		0.09	0.67	0.78		0.04	0.48	0.51		0.02	0.39	0.43		0.04
270	LHH	3.40	3.67	3.54		0.93	1.03	0.98		0.76	0.90	0.83		0.53	0.56	0.55	
	LMH	3.13	3.30	3.22	0.17	0.76	0.80	0.78	0.06	0.70	0.66	0.68	0.05	0.50	0.50	0.50	0.02
	LLH	3.03	2.90	2.97		0.83	0.93	0.88		0.73	0.66	0.70		0.50	0.50	0.50	
	Means	3.19	3.29		0.14	0.84	0.92		0.05	0.73	0.75		0.04	0.51	0.52		0.02

[a,b] Means in a column within a stage of trial with different superscripts are significantly different ($P<0.05$)

[c,d] Means in a row within a stage of trial with different superscripts are significantly different ($P<0.05$)

Appendix Table 14: Mean weights of boneless carcass, protein and fat and energy values in the boneless carcass at various trial stages

Stage of trial (days)	Feeding Regime	Carcass weight, kg				Crude protein, kg			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM
0	Initial	27.5	31.9	29.7		7.64	7.61	7.63	
180	LHH	34.0	53.4	43.7		8.2	11.7	10.0	
	LMH	22.0	32.4	27.2	1.57	5.7	7.6	6.7	0.36
	LLH	20.0	30.3	25.2		4.9	6.2	5.6	
	Means	25.3	38.7		1.28	6.3	8.5		0.29
270	LHH	54.8	68.5	61.7		12.1	13.2	12.7	
	LMH	43.9	56.0	50.0	1.44	9.1	10.7	9.9	0.40
	LLH	51.5	52.3	51.9		11.4	10.1	10.8	
	Means	50.1	58.9		1.22	10.9	11.3		0.34

Appendix Table 14 Continued.

Stage of trial (days)	Feeding Regime	Fat, kg				Energy, (Mcal/total Carcass weight)			
		Young	Old	Means	±SEM	Young	Old	Means	±SEM
0	Initial	0.93	1.48	1.21		156.2	175.8	165.9	
180	LHH	3.7	6.5	5.1		216.7	341.6	279.2	
	LMH	1.0	1.6	1.3	0.27	122.0	184.0	153.0	9.77
	LLH	0.9	1.2	1.0		109.5	166.9	138.2	
	Means	1.9	3.1		0.22	149.4	230.8		8.01
270	LHH	9.3	10.0	9.7		372.9	460.9	416.9	
	LMH	7.0	9.6	8.3	0.50	294.3	392.9	343.6	10.28
	LLH	6.2	8.1	7.2		333.5	370.8	352.2	
	Means	7.5	9.2		0.48	333.6	408.2		8.74

Appendix Table 15: Cost and Sources of major ingredients.

Ingrdients	=N/Metric tonne*	Source
Molasses	115.00	National Livestock Project Unit, Kaduna.
Cottonseed cake	210.00	F.C.C.C., Funtua
Wheat bran	220.00	Flour Mill, Kaduna
Palm kernel cake	120.00	Vegetable Oils (Nig) Ltd., Ikeja, Lagos.

*Cost based on 1984/85 year.

Appendix Table 16: Format for slaughter floor data collection.

Animal No._____ Group_____

Date of slaughter_____ Date cut-up_____

Weight at slaughter_____ Approx. Age_____

Empty body weight at slaughter_____

Hot carcass weight: Chilled carcass weight:

Left side_____ Left side_____

Right side_____ Right side_____

Dressing %_____

Weight of reticulo-rumen, omasum and abomasum:

Full_____ Empty_____

Ingesta_____ Omentum fat_____

Weight of Small and large intestine:

Full_____ Empty_____

Ingesta_____ Mesentery fat_____

Weight of offals:

Head_____ Tail_____

Hide_____ Blood_____

Foreshank_____ Rearshank_____

Tongue_____ Heart_____

Liver_____ Spleen_____

Respiratory tract_____ Urinogenital tract_____

Bladder: Gall bladder:

Full_____ Full_____

Empty_____ Empty_____

Kidneys_____ Kidney fat_____

Rib eye area_____

Appendix Table 17: Procedure for determination of Plasma Urea (Diacetyl Monoxime Method Using Thiosemicarbazide).

Principle

When urea is heated in strongly acidic conditions with substance such as diacetyl, $CH_3COCOCH_3$, containing two adjacent carbonyl groups or its monoxime: $CH_3Co.C = NoH$, yellow condenstation compounds are formed. The reaction is intensified by the presence of polyvalentions such as ferricions. And then a red coloured complex is formed - which is more linear with concentration than the yellow one. The intensity of the red complex is measured colorimetically and its intensity is proportional to the concentrations of Urea in sample.

Technique	Test ml.	Standard ml.	Blank ml.
Distilled water	10	10	-
Plasma	0.1	-	-
Standard (10mmol/l)	-	0.1	-
Mix thoroughly:-			
Pipette	1.0	1.0	-
Distilled water	1.0	1.0	2.0
Working Colour reagent	2.0	2.0	2.0
Mixed Acid reagent	2.0	2.0	2.0

Mix thoroughly then place the tubes in a boiling water or an incubator at 100°C for 20 minutes. Cool, and Read the O.D. at 520mm.

Circulation

$$\text{Urea mmol/L} = \frac{T - B}{S - B} \times 10$$

Normal Value 2.5 - 6.5 mmol/L

Repeat all values below 10 mg % (1.66 mmol/) and those above 40 mg % (6.64 mmol/L).

Reagents

Acid reagent - Stock A

Dissolve 5 g of ferric chloride ($Fecl_3,6H_20$) in about 20 ml of water. Transfer this to a graduated cylinder and add 100 ml of 85% phosphoric acid - slowly and with swirling. Make the volume to 250 ml with distilled water.

Appendix Table 17 Contd.

Acid Reagent - Stock B

Add 300 ml of concentrated sulphuric acid to 700 ml of distilled water in a 2 litre conical flask - slowly, with swirling and cooling in a bath of ice water.

Mixed Acid Reagent - or - Working Acid Reagent

Add 0.5 ml of solution A to 1 litre of solution B.

Colour Reagent - Stock A: Dissolve 20 g of diacetyl

Monoxime per litre in distilled water. And Filter.

Colour Reagent - Stock B: Dissolve 5 g of thio-semicarbazide per litre in distilled water.

Mixed Colour Reagent - or - Working Colour Reagent

Mix 67 ml of solution A with 67 ml of solution B and make to 1 litre with distilled water.

Preservative, diluent for standards

Dissolve 40 mg of phenylmercuric acetate in about 250 ml of water with heating. Transfer the solution to a measuring cylinder. Add 0.3 ml of concentrated sulphuric acid and make the volume to 1 litre with distilled water and mix.

Appendix Table 18: Radioimmunoassay of Serum Thyroxine

Thyroxine concentrations were determined using a commercially available diagnostic kit (Amerlex T_4 RIA Kit, Amersham U.K. Ltd). The assay procedure was as follows: 25 ul aliquotes of standards (0-25 mg T_4/100 ml) and unknown serum samples were added to polystyrene assay tubes (12 x 75 mm) in duplicate. 500 ml 125_I-thyroxine solution was added to each tube. Amerlex specific T_4 antibody (500 ml) was then added rapidly to each tube. All the tubes were then vortex mixed and left to stand at room temperature for 2 hours. All tubes were then centrifuged together for 15 minutes at 1500g. After centrifugation, the tubes were decanted and then inverted in racks over absorbent tissues and drained for 10 minutes. All tubes were then counted for 60 secs in a Gamma 400 counter (Beckman International, Geneva, Switzerland).

Count rates were plotted against T_4 concentration of standards (Fig. 4). Counts for unknowns were averaged and extrapolated from the standard curve.

The antiserum used in the Kit cross-reacts with L-triiodothyronine to the extent of 7.5% and with D-thyroxine approximately 100% by weight. Crossreactivity with the thyroid hormone analoques 3, 5, diiodo-L-tyrosine and 3-iodo-L-tyrosine is negligibly low (0.1%). The within and between assay coefficients of variation were 9% and 12% respectively.

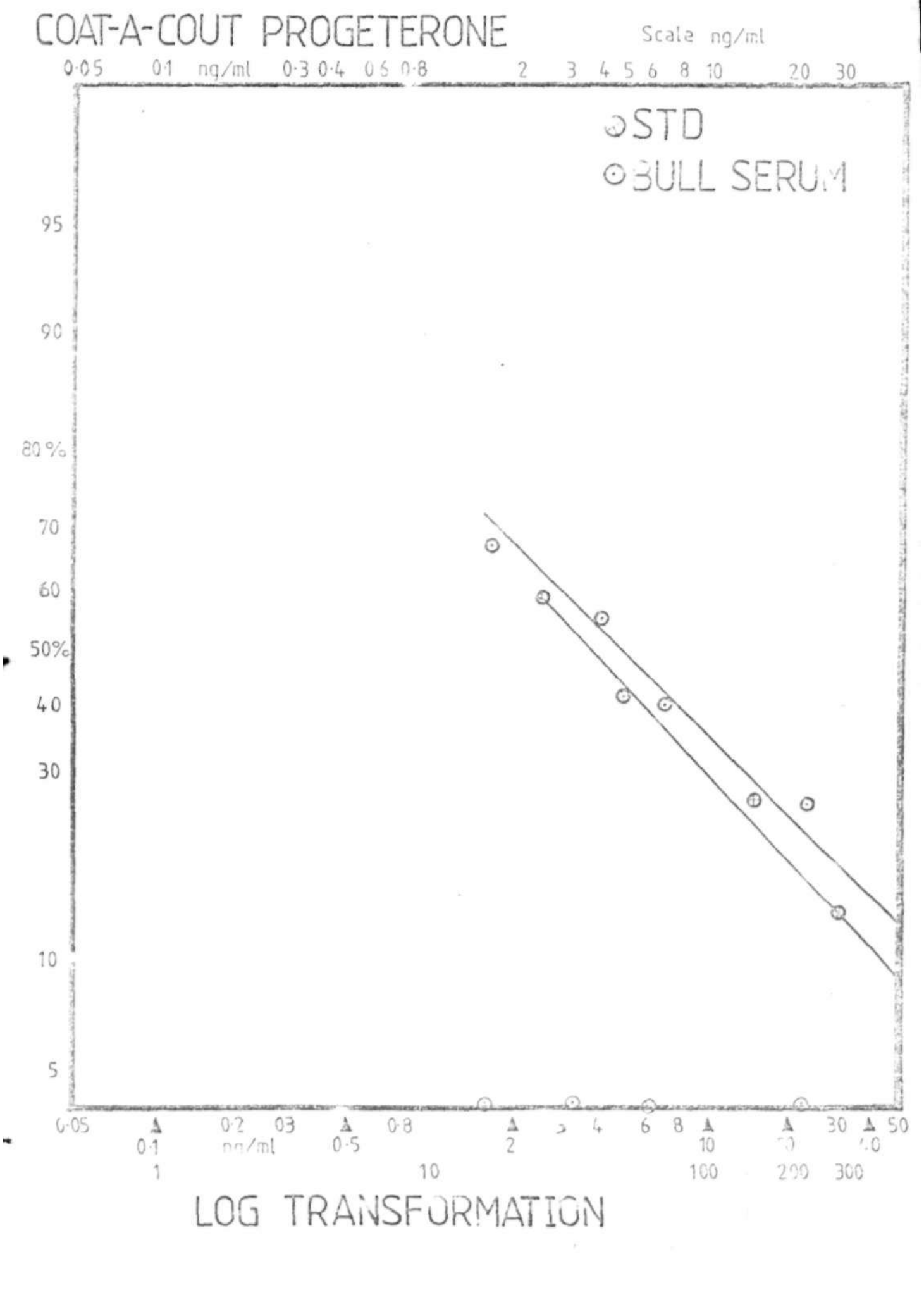
The T_4-kit was manufactured for use with human serum and therefore needed to be validated for bull serum. To achieve this, conventional parallelism tests were run. The top standards

Appendix Table 18 Continued.

of the kit was diluted with T_4-free serum and standards were made serially on 1:1 basis labelled A.B.C.D.

The diluted standards were run with the standards in the kit and both curves were found to be parallel (Fig.4).

Fig.2: Standard curves for serum thyroxine



Appendix Table 19: Composition of Zoodry VM 701

Vitamin A	20,000,000 IU
Vitamin D_3	2,000,000 IU
Vitamin E	40,000 IU
Vitamin B_1	2,000 mg
Vitamin B_2	7,000 mg
Vitamin B_6	2,000 mg
D-pantothenic acid	8,000 mg
Vitamin pp	16,000 mg
Vitamin B_{12}	10 mg
Furazolidone	70,000 mg
Magnesium	120,000 mg
Manganese	60,000 mg
Iron	50,000 mg
Zinc	60,000 mg
Copper	10,000 mg
Iodine	2,000 mg
Cobalt	1,000 mg