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THE EFFECT OF DIETARY PROTEIN LEVEL ON RATE, EFFICIENCY AND COMPOSITION OF GAIN AND RELATED ENDOCRINE FACTORS OF GROWING BEEF BULLS

By

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ABSTRACT

THE EFFECT OF DIETARY PROTEIN LEVEL ON RATE, EFFICIENCY AND COMPOSITION OF GAIN AND RELATED ENDOCRINE FACTORS OF GROWING BEEF BULLS

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The effect of diets containing 10, 12 or 14% crude protein (CP) on performance of bulls was examined. In experiment 1, bulls fed 12 or 14% CP for 140 d gained faster ($P<.05$) than those fed 10%. Bulls fed 12% CP were fatter ($P<.05$) than those fed the other diets.

In experiment 2, bulls fed 10% CP for 136 d had suppressed ($P<.05$) liveweight gain, protein gain and fat gain compared to bulls fed 12 or 14%. From 137 d to 202 d no differences were observed. Serum growth hormone and unbound somatomedin-C were correlated negatively with fatness; somatomedin-C means paralleled protein gain. Circulating cortisol, insulin, testosterone, thyroxine and triiodothyronine were unrelated to performance.

In experiment 3, bulls and steers were fed to equal weight or age. Bulls gained faster and more efficiently, were leaner, and deposited more carcass protein per d (all $P<.001$) with no difference in feed intake (expressed per unit of body weight) or carcass fat gain per d.

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INTRODUCTION

Castration of male calves is a common management practice in United States beef production. Castrated males (steers) are easier to manage than gonadally intact males (bulls) and steers produce carcasses that have higher quality grades and more predictable palatability. Employment of this traditional management practice continues despite knowledge that bulls grow faster and more efficiently and produce leaner carcasses than steers.

Potential exists for increased beef production from young bulls. The American public has become increasingly health conscious and many consider consumption of the quantity and type of fat contained within traditional beef products a threat to their health. These perceived threats, along with other factors, have caused a decrease in per capita beef consumption. The industry is striving to produce beef that is both lean and palatable enough to ensure consumer acceptance in this age of new attitudes. Most major beef packers are now trimming beef cuts more closely than before. While this reduces the quantity of fat shipped to retailers and presented to consumers, this practice is inefficient. The goal of animal scientists and beef producers must be to find methods to produce palatable beef without the waste fat that now accompanies the product. With proper management, beef production from young bulls, may provide one means of attaining this goal.

Nutritional requirements of growing bulls have not been thoroughly studied. The increased growth rate and the greater quantity of lean in the carcasses of bulls suggest that their nutrient requirements may differ from those of steers. Hormonal control of growth and metabolism of bulls is also not well defined. If efficiency of beef production is to be improved through feeding of bulls, these areas must be investigated further.

A REVIEW OF LITERATURE

The Effect of Castration

Most differences between bulls and steers are well known and many have long been quantified. Field (1971) reviewed 14 studies and concluded that bulls grew 17% faster than steers, converted feed to live weight 13% more efficiently, and produced carcasses with 35% lower fat thickness measurements. These classic differences were supported in a more recent review by Seideman et al. (1982). Table 1 summarizes a number of bull/steer comparisons. It is generally accepted that bulls have larger rib eye areas, more muscular chucks and forequarters, equal dressing percentages, and higher percentages of any measure of retail yield when compared to steers. Field noted that 39% and 53% of all cattle slaughtered in West Germany (Boyazoglu and Massmann, 1967) and 53% in Sweden, respectively, (Brannang, 1969) are bulls and concluded that "an increase in the U.S. in the production of meat from bulls approximately 12 to 16 months of age appears to be in the best interest of the beef industry".

Palatability

The U.S. beef industry has been reluctant to accept beef from bulls because palatability and quality factors of bull beef are considered to be lower and more variable than beef from steers. Nichols et al. (1964) reported that carcasses from bulls had less marbling than carcasses from steers

TABLE 1. SUMMARY OF COMPARISONS OF BULLS AND STEERS: AVERAGE DAILY GAIN, FEED TO GAIN RATIO, AND FAT THICKNESS [a]

Reference	Endpoint [b]	ADG of bulls St = 100	F/G of bulls St = 100	Fat Th. of bulls St = 100
Brown et al. 1962	UK	127	70	--
Matsushima and Sprague, 1963	UK	107	--	82
Matsushima et al. 1964	UK	117	85	59
Field et al. 1964	UK	112	--	51
Nichols et al. 1964	WT	110	92	74
Anthony and Starling, 1966	UK	111	96	49
Martin et al. 1966	UK	115	--	66
Brannang, 1966	UK	109	92	--
Bailey et al. 1969	WT	112	84	--
Bailey and Hironacka, 1969	WT	120	96	69
Watson, 1969	UK	106	--	41
Arthaud et al. 1969	TOF	118	89	64
Hedrick et al. 1969	WT	142	89	67
Hedrick et al. 1969	TOF	115	94	89
Champagne et al. 1969	TOF	123	85	63
Bidart et al. 1970	TOF	119	86	--
Galbraith et al. 1976	TOF	124	83	--
Arthaud et al. 1977	TOF	110	94	73
Arthaud et al. 1977	TOF	120	86	78
Webster et al. 1977	TOF	118	88	--
Ntunde et al. 1977	Fat Th.	111	--	86
Landon et al. 1978	WT	108	--	57
Price et al. 1980	WT	111	92	82
Price et al. 1980	WT	132	77	54
Price et al. 1980	WT	120	84	68
Ford and Gregory, 1983 [c]	TOF	124	78	59
Jones et al. 1984	Fat Th.	108	95	90
Crouse et al. 1985 [d]	Age	---	85	--
Crouse et al. 1985	Comp.	---	105	129
Vanderwert et al. 1985	Fat Th.	118	86	90

[a] Partially adapted from Field, 1971.
[b] WT = Weight, Fat Th. = Fat Thickness, TOF = Time on Feed, Comp. = Chemical Composition, UK = Unknown
[c] Implanted steers.
[d] Steers castrated at 400 d.

and Hedrick et al. (1969) showed that tenderness, although not juiciness or flavor, was inferior in bull beef. The difference in tenderness was only noticeable when bulls were more than 16 months of age. Hunsley et al. (1971) indicated that increases in age had a more detrimental effect on tenderness of bull beef than steer beef.

The study of Boccard et al. (1979) compared bulls and steers of two breeds from birth to 24 months of age. At all ages, bull muscle had higher collagen content than steer muscle, and collagen solubility of bulls decreased markedly between 12 and 16 months of age. Collagen content of bull muscle peaked at 12 months of age (excluding measurements taken at birth) (Boccard et al., 1979, Cross et al., 1984). Because the increase in collagen coincides with sexual development and differs in breeds with different patterns of sexual maturity, the above authors suggested that this increase may be related to endocrine regulation of puberty. In contrast, Dikeman et al. (1986) found collagen content to be unaffected by age and Unruh et al. (1986) found collagen content to be higher in bulls at 17.4 months of age than at 12.0 or 13.8 months. This incongruity must be considered with care, because Unruh et al. (1986) used bulls implanted with estrogenic compounds and it is not clear how administration of exogenous sex hormones affects collagen content or maturity pattern. Dikeman et al. (1986) also indicated that bulls to have higher collagen content than steers; however, cattle fed low energy diets had higher percentages of collagen than

those fed high energy diets. Since collagen content is expressed as a percentage of total weight, or total surface area in the histological examinations of Dikeman et al. (1986), it is possible that some of the difference due to sex, age or energy density of the diet may be partially explained by a difference in fat content of the tissue sample.

Bull beef may also be darker and more variable in color than steer beef and often has coarser texture (Seideman et al.,1982). The aggressive manner and social behavior of bulls can lead to preslaughter glycogen depletion and an increase in the incidence of dark cutting carcasses. Care must be taken prior to slaughter of bulls. Price and Tennesson (1981) concluded that mixing and regrouping unfamiliar bulls increased the incidence of dark cutting carcasses from 2 to 73%. Because of their aggressiveness, bulls are also noted for destruction of facilities and difficulty of handling but the number of bulls fed for slaughter in other countries suggests that this management problem can be overcome.

It can be concluded that beef from young bulls may be slightly lower in palatability than beef from steers but will be acceptable if the cattle are fed and handled properly.

Energy Utilization

Bidart et al. (1970) was the first to examine comparative dietary energy use of bulls and steers. With partial regression techniques they estimated that bulls required 6.0 Mcal of DE to accrue 1 kg of edible carcass while steers required 12.8

Mcal. Bulls required 338% more DE (20.3 Mcal) to produce 1 kg of carcass trim (predominately fat) while steers required 15.3 Mcal (120% of that required for edible product gain). The authors concluded that bulls gained edible carcass weight more efficiently than steers because of the higher proportion of lean in the tissue gain of bulls. No explanation was given for the higher requirement of bulls for carcass trim gain but this may be reflective of the difference in fat deposition pattern as bulls did not begin to gain appreciable amounts of carcass trim until they were very heavy, whereas steers gained both trim and edible product constantly. Thus, the heavier bulls may have had greater maintenance costs per unit of trim than the steers. In this study bulls produced 20% more protein per day per unit of DE consumed than steers and 38% more edible product per Mcal of DE. This study showed no difference in the percentage of consumed DE that was retained as calories though the source of the calories (protein or fat) was very different.

In the same study, estimates of maintenance requirements of bulls and steers were not different. This is unusual because the greater lean body mass of bulls at equal weights as well as their higher thyroid hormone levels would indicate that both quantity and fractional rate of protein turnover, an energetically expensive process, would be higher in bulls. With more intense methods, Webster et al. (1977) showed that bulls had 20% higher basal metabolism. Although this finding is shaded by the fact that the bulls were consuming more feed

prior to the start of the study, most feel that this is an accurate reflection of the maintenance requirements of bulls and steers. In the same study, and in the work of Price et al. (1980), no differences were found in digestibility between the two sex conditions, ruling out one partial explanation for the difference in feed conversion.

Energy Density of the Diet

All studies listed thus far involve bulls and steers fed high energy diets to either weight or time constant endpoints and have very similar results. With lower energy diets or under grazing conditions, the advantages of bulls may be lessened or removed (Cobic, 1968; Price and Yeates, 1969).

Slaughter Endpoint

Choice of a different slaughter endpoint can also affect results. Ntunde et al. (1977) were the first to compare sex condition effects when cattle were slaughtered at similar fat thickness (.76 cm). Bulls required more days on feed to reach the endpoint, had higher carcass weights, greater percentage of lean, greater percentage of trimmed chuck, lower percentage of fat and higher lean to fat ratios but the advantage of bulls in feed conversion, although still evident, was lowered to nonsignificance. The work of Jones et al. (1984a) also indicates a slight, nonsignificant difference in efficiency when cattle were fed to a constant fat thickness. Due to greater musculature of bulls, a fat thickness endpoint cannot

be considered composition constant. Crouse et al. (1985a) adjusted their results to a constant percentage of extractable rib fat and found no difference in efficiency due to sex condition. Their selected endpoint of 33.5% fat in the 9-10-11 rib section may be too high to accurately compare bulls and steers.

Composition of Gain

It is unclear from these studies whether the leanness of bull carcasses is due to greater rates of lean gain, lowered rates of fat gain, or both. Vanderwert et al. (1985) were the first to address this and found that bulls were equal to steers in the rate of fat deposition in the 9-10-11 rib section while bulls had greater rates of lean tissue accretion than steers.

Circulating Hormones and Metabolites

Few studies have been done to compare endocrine profiles of bulls and steers. Obviously, the primary difference is testosterone production. While the adrenal cortex can produce minute quantities of the sex steroid, circulating levels of testosterone in steers are usually too low for detection. Clearly, this is the basis for the differences between bulls and steers, through both direct and indirect effects.

Afinson et al.(1975) were the first to investigate the difference between the growth hormone profiles of bulls and steers. These workers sampled blood from five bulls and seven

steers at 15 min intervals over a 24 h period. The 24 h mean of plasma GH was higher in bulls (7.0 ng/ml) than in steers (5.7 ng/ml) while baseline values were not different (5.6 for bulls, 5.1 for steers). The difference in mean GH is due to greater magnitude of GH peaks (defined as the mean + four standard deviations) in bulls (22.1 ng) compared to 11.0 ng in steers. Bulls had five peaks per 24 h, while steers had 2.7, but this difference was not significant. No information is given in their abstract regarding origin, age, breed or growth rate of the cattle.

The most complete report on this topic is that of Galbraith et al. (1978) who compared Friesian bulls and steers for 21 wk beginning when the cattle were ten mo of age. With single blood samples taken at weekly intervals, they found that bulls had higher GH and prolactin and lower serum albumin and plasma urea. No difference was found in insulin, serum total protein, plasma glucose or plasma free fatty acids. The higher GH of bulls agrees with the data of Afinson et al. (1975) but must be considered with care because of infrequent sampling. The increased plasma prolactin of bulls may also account for some of the anabolic advantages of bulls. Bulls had lower concentrations of blood urea possibly due to decreased breakdown of protein (possibly due to lower cortisol, which was not measured). Serum somatomedin activity was not measured.

Endocrine Influence on Growth

Growth is a complex process that involves increases in cell number and size and the deposition of substances within these cells. These processes are interrelated and the extent to which each is carried out depends on an intricate balance between factors such as the environment, nutrient supply, hormones and hormone receptors. Age and sex further determine the upper limit of growth of an animal. While environment will place limits on animal growth in practical situations, the factors listed above are ultimately limited by the genotype of the animal. A major area of current research is that of altering the genotype through methods other than selection which would improve the upper limit of growth rate.

Hormones are the ultimate mediators of growth and metabolism, both long and short term. It is the interaction of hormones that allows growth, but for any hormone to be effective it must exert its influence through receptors. Thus two items are of critical importance: 1) the interaction between circulating hormones and their receptors, including regulation of receptor numbers, and 2) the interrelationship between hormones. Future research will also likely clarify understanding of clearance rates of hormones, tissue sensitivity and alteration of such, and the effects of fragments or metabolites of protein or peptide hormones.

Cortisol

Cortisol, the primary glucocorticoid in cattle, is a

steroid hormone produced by the cortex of the adrenal gland. Cortisol is catabolic in muscle (Tomas et al.,1979) and is antianabolic in muscle through partial inhibition of insulin mediated amino acid uptake (Bassett et al.,1967; Bassett, 1968; York and Bray, 1972). More recent evidence (Lewis and Goldspink, 1982) suggests that it is hastened efflux of amino acids from cells, not lowered influx that causes this. Thus, through two mechanisms, cortisol increases the amount of amino acids available for gluconeogenesis. After cortisol administration, plasma amino acid concentrations are unaffected but urinary nitrogen increases (Bassett, 1968).

Cortisol and testosterone, a protein anabolic steroid, are known to be antagonistic. Two possible mechanisms for this exist. The first is that of crossreactivity, binding of testosterone to cortisol receptors. Mayer and Rosen (1975) have shown that testosterone can occupy 44% of the available cortisol receptors in skeletal muscle cytosol. The data of Sharpe et al. (1984) also indicate that the anti-anabolic effect of cortisol can be lessened by testosterone binding to cortisol receptors since their evidence suggests some overlap of affinity.

The second possible mechanism has been partially elucidated by the work of Thomas and Rodway (1982a,b,1983a,b) which indicated that exogenous anabolic steroids can lower cortisol concentrations in female rats in vitro and in vivo and in female sheep in vivo and lessen the cortisol response to ACTH injection in in vitro studies with female rat liver cells.

Furthermore, these workers have shown that trenbelone acetate (TBA) can lessen the activity of tyrosine aminotransferase and phosphoenol pyruvate carboxylase, which are glucocorticoid enhanced protein catabolic enzymes. Bukoski et al. (1986) found that testosterone reduced the ACTH stimulated production of cortisol in pigs. Adrenal slices from postpubertal boars produced less cortisol than slices from prepubertal boars or barrows. Bukoski et al. (1986) postulated that this may provide an explanation of the anabolic effect of testosterone on muscle.

It has also been shown that administration of ACTH can inhibit appearance of LH and testosterone in the bloodstream for up to 6 hours (Johnson et al., 1982).

Circulating glucocorticoids have been negatively correlated with rate of gain in cattle (Purchas et al.,1971; VanDerWesthuysen,1973; Obst, 1974; Doornenbal, 1977; Trenkle and Topel, 1978; Purchas et al.,1980) and have been positively correlated with measures of fatness (Cramer and Shahied, 1974; Trenkle and Topel, 1978; Lundstrom et al., 1983; Henricks et al., 1984). Treatment with cortisone acetate or cortisol has increased fatness in cattle and sheep, often at measurable expense of protein (Clegg and Spurlock, 1960; Spurlock and Clegg, 1960; Spurlock and Clegg, 1962; Clark et al., 1963; Carroll et al., 1963). Lundstrom et al. (1983) have observed lower cortisol and lower corticosterone binding globulin in a strain of pigs selected for leanness than in a fat strain.

The most conclusive investigation of sex differences of

cortisol is that of Henricks et al. (1983) who reported that cortisol concentrations were lower in bulls than heifers at 7 mo of age and that the concentrations of bulls remained constant while cortisol concentrations of the slower growing heifers more than doubled from 7 to 12 mo. Steers, however, were reported to have higher cortisol concentrations than heifers at all ages (Cramer and Shahied, 1974).

Growth hormone

Growth hormone (GH) is a peptide hormone released by the anterior pituitary. GH release is induced by growth hormone releasing factor (GRF; growth hormone releasing hormone, GHRH) (Guillemin et al., 1982; Rivier et al., 1982). In the bovine this is pulsatile (Al-Raheem et al., 1984, Wheaton et al., 1986). GRF induced GH release from cultured bovine pituitary cells is modulated by somatostatin (somatotropin release inhibiting factor, SRIF) (Padmanabhan et al., 1984).

It has been known for decades that the pituitary contained a substance that was necessary for growth (Evans and Long, 1922a,b; Evans and Simpson, 1931-cited by Etherton and Kensinger, 1982). Lee and Schaffer (1934) injected rats with an alkaline pituitary extract and found not only increased weight gain, but also an increase in the proportion of muscle compared to fat. This substance of pituitary origin was presumptiously titled growth hormone. It is now known that GH is actually a family of proteins rather than a single entity (Lewis et al., 1980, Nicoll et al., 1986). This knowledge

affects interpretation of early studies and makes comparisons of results from experiments in which different GH assays were used difficult.

GH is known to have marked therapeutic effects in humans or in hypophysectomized laboratory animals but this is of only academic interest to scientists interested in meat animals. In vitro studies with tissues from laboratory animals have shown that addition of GH can also affect normal tissue. Though the primary affects of GH on bone tissues are mediated by somatomedins (Salmon and Daughaday, 1957), Isaksson et al., (1982) have demonstrated that GH can directly stimulate bone growth. GH can bind to chondrocytes isolated from cartilage (Eden et al., 1983) and can stimulate DNA synthesis in the same cells (Madsen et al. 1983).

The effect of GH on muscle cells can be insulin-like. GH directly stimulates amino acid and sugar uptake by muscle cells (Albertsson-Wikland and Isaksson, 1976; Nutting, 1976; Albertsson-Wikland et al., 1980). Schwartz et al. (1982) showed that GH can increase protein synthesis in muscle cells from normal rats. Despite these direct effects of GH, SM are also involved in these actions. GH effects can be pretranslational. Liaw et al. (1983) found mRNA to be altered specifically by GH. Further, GH effects appear strictly confined to hypertrophy of muscle cells, not hyperplasia. Ewton and Florini, (1980, 1981), and Florini (1984) found that proliferation and amino acid uptake of myoblasts were unaffected by GH while SM increased these measures. Actin synthesis of cultured

satellite cell myotubes was not affected by GH treatment (Allen et al., 1983).

While the effects of GH in muscle cells can be termed insulin-like, GH is diabetogenic in adipose tissue. Glucose transport in rat adipocytes depends on GH status. In adipocytes from hypophysectomized rats, basal glucose transport proceeds at a maximum rate and cannot be stimulated by insulin (Schoenle et al., 1979a,b). GH administration to the same rats decreased glucose transport and restored the sensitivity of transport to insulin (Schoenle et al., 1979b). These workers later concluded that the effects of GH must be direct since IGF-I did not affect glucose transport (Schoenle et al., 1983).

Numerous studies have attempted to relate GH status of animals to growth rate. Early workers (Baird et al., 1952, Baker et al., 1956, Nalbandov et al., 1963) suggested that dilution of circulating GH between birth and market weight caused the lowering of growth rate. While too simplistic to completely explain control of metabolism and growth, this theory could also provide one possible explanation for the increase in fat deposition and carcass fatness as animals mature, although the above authors did not address this topic. Later investigators also observed a decrease in the ratio of pituitary weight:body weight and pituitary GH content:body weight (Curl et al., 1968; Purchas et al., 1970) or even a decrease in circulating GH (Trenkle, 1971; Joakimsen and Blom, 1976; Trenkle and Topel, 1978; Keller et al., 1979).

Attempts to correlate circulating GH with performance have been unsuccessful. Purchas et al.(1970), Trenkle, (1970), Purchas et al. (1971a), Keller et al. (1979), Davis et al. (1979) and Klindt et al. (1985) all found plasma GH unrelated to growth rate of ruminants while Purchas et al. (1971b), Joakimsen and Blom (1976) and Trenkle and Topel, (1978) obtained negative correlations.

Several possible explanations exist for this observation. First, simply correlating circulating GH with growth is too simplistic. Despite its name, GH is not the sole hormone responsible for control of growth or metabolism. Homeorhesis is highly complex and is mediated by numerous endocrine factors. Second, many of these early investigators did not take blood samples frequently enough to accurately characterize the GH status of the experimental animals. However, most studies since 1975 have sampled at 30 min intervals or even more frequently and still fail to find significant correlations. Also, simply measuring circulating concentrations of GH gives no insight regarding clearance rates or tissue sensitivity or refractoriness, all of which would affect the impact of a given blood concentration. To accurately assess an animals GH status, receptors must also be measured. Furthermore, these early studies made no attempt to evaluate the existence of the various forms and metabolites of GH.

Another explanation for the inability to relate performance of livestock to their plasma GH concentrations is that the only variable measured usually was rate of gain. Rate of

gain reflects both fat and muscle accretion. In studies with animals in the finishing period, fat deposition is more variable than lean tissue accumulation and accounts for the majority of differences in rate of gain. Given this knowledge, coupled with the lipolytic and anti-lipogenic effects of GH it is not particularly surprising to find GH unrelated to simple weight gain, despite the protein anabolic effects of GH. Indeed, many studies have reported significant negative correlations between GH and carcass fatness (Trenkle, 1970; Purchas et al., 1970; Purchas et al., 1971; Trenkle and Topel, 1978; Keller et al., 1979; Davis et al., 1981; Klindt et al., 1985). GH has been positively correlated to percent muscle in the carcass (Trenkle and Topel, 1978).

Insulin

Insulin is a peptide hormone produced and released by the beta cells of the pancreas. Insulin is a primary regulator of energy and amino acid metabolism which permits increased entry of glucose and amino acids into cells. The importance of insulin in regulation of growth is made apparent by the effects of diabetes. Romsos et al. (1971a) induced diabetes in pigs and observed that body weight of the diabetic pigs was 50% lower than control pigs after 112 d. Growth rate was returned to normal when insulin was administered (Romsos et al., 1971b). There is a marked loss of weight and muscle protein in untreated diabetics, which is suppressed by administration of insulin (Pozefsky et al., 1969; Felig and

Wahren, 1974).

Clearly, insulin is essential for growth but plasma insulin concentration appears to be unrelated to growth rate of meat animals (Trenkle and Topel, 1978; Martin et al.,1979; Etherton, 1982). In fact, Wangsness et al. (1977) reported that a line of pigs selected for slow growth and obesity had higher circulating insulin concentrations than their fast-growing, lean counterparts.

It is reasonable that plasma insulin is not related to growth rate since the concentration varies throughout the day, especially in response to feeding (Trenkle, 1972, 1978; Vasilatos and Wangsness, 1981). Also, measuring circulating plasma concentration gives no evidence of differences in secretion or clearance rates and the biological effects of insulin may be a function of changes in tissue sensitivity (Etherton, 1982).

Although plasma insulin seems unrelated to growth rate, it has been strongly correlated with carcass fatness (Trenkle, 1970; Trenkle and Irvin, 1970) and observed to be higher in bulls fed diets containing excess protein which resulted in fatter carcasses than lower protein diets (Martin et al., 1979c). This observation is reasonable because of the role of insulin in energy metabolism, even in the metabolism of ruminants in which glucose plays less of a part than in non-ruminants. These relations seemed paradoxical in light of data which indicated that insulin does not stimulate synthesis of fatty acids from acetate or glucose in in vitro studies with

bovine adipose tissue (Vernon, 1977, 1980; Prior and Smith, 1982; Vasilatos et al., 1983; Vernon et al., 1985). A recent report (Etherton and Adcock, 1986) disputes these findings. This latter study indicated that bovine adipocytes are very sensitive to insulin during short term incubation and that insulin plays a predominant role in maintenance of lipogenic activity of cultured bovine adipose tissue. The authors explained the discrepancy between their data and the previous reports by suggesting that the bovine serum albumin (BSA) used in the assays of the others was contaminated when obtained and that the contaminants interfered with the binding of labeled insulin to receptors in the test systems and that the contaminated BSA stimulated lipogenesis. This conclusion is based on the data of Etherton et al.(1984) and Walton et al. (1984). These authors were able to circumvent this possible problem by obtaining more highly purified BSA.

Muscle growth and metabolism are also influenced by insulin status. In insulin deficient rats, muscle cell DNA, RNA and protein synthesis are decreased (Cheek and Hill, 1970; Cheek et al., 1971) and these effects are reversible by insulin administration (Wool, 1972). In normal animals the effects of physiological concentrations of insulin are strictly posttranslational. Florini et al. (1977) have shown no effect of nonpharmacological concentrations of insulin on proliferation of myogenic cells. Insulin can enhance myoblast proliferation when added to cell culture at concentrations that are several orders of magnitude higher than circulating

concentrations (Florini and Ewton, 1981; Dodson et al., 1985). This effect is likely due to insulin crossreaction with SM receptors instead of a direct effect of insulin. Insulin does facilitate uptake of glucose (Jarrett et al., 1974; Hay et al., 1984) and amino acids (Ahmed et al. 1982) by muscle tissue.

Somatomedins

The somatomedins (SM) are a family of insulin-like peptide growth factors. Salmon and Daughaday (1957) first observed that incorporation of labeled sulfate into cartilage explants was not increased during in vitro incubation with GH or with serum from hypophysectomized rats. Uptake of labeled sulfate was, however, increased by addition of serum from normal or GH treated hypophysectomized rats. Because GH was inactive in this system, it was postulated that the growth promoting actions of GH on the skeleton are mediated through a "sulfation factor" that is found in serum and induced in vivo by GH. After these classical experiments other physiological roles were discovered for the "sulfation factor" and Daughaday et al. (1972) proposed the more general name of somatomedins.

The family of SM includes SM-C, a basic, 70 amino acid peptide, and SM-A, a neutral peptide with 67 amino acids. SM-C is also called insulin-like growth factor I (IGF-I) because of its structural homology with pro-insulin. SM-A may be similar to a compound known as IGF II (known as multiplication stimulating activity; MSA, in rats). Both show insulin-like

activity. Early workers (Van Wyk et al., 1974) felt that the liver was the sole site of SM synthesis. It is now known that the liver does produce the majority of SM although other tissues, such as fibroblasts, also produce SM (Underwood et al., 1985). Somatomedins can have autocrine, paracrine, or endocrine actions.

It has long been thought that much of the growth promoting action of GH could be attributed to, or mediated by, SM. Direct evidence that this is true was provided by Schoenle et al. (1982). They infused IGF-I into hypophysectomized rats and demonstrated that growth rate and tibial cartilage growth were restored to rates comparable to that observed with GH administration. To underscore their importance, Spencer (1984) called SM the ultimate mediators of growth.

Underwood (1985) summarized data from studies involving human SM by listing four cardinal properties that characterize SM: 1) they promote incorporation of sulfate into proteoglycans of cartilage; 2) their concentrations in serum are GH dependant; 3) they possess insulin-like action in extraskeletal tissues; and 4) they stimulate DNA synthesis and cell multiplication in certain types of cells such as fibroblasts, fetal liver cells and pituitary tumor cells.

Very few studies have evaluated the SM status of meat animals. To date, no commercially available radioimunnoassay procedures have been validated for SM-A or SM-C in bovine, porcine or ovine serum. Bioassay procedures do exist but they are time consuming and are labor intensive. Ringberg Lund-

larsen and Bakke (1975) first adapted the bioassay of Hall (1970) for use with porcine instead of human serum. This assay measures total somatomedin activity and does not differentiate between SM-A and SM-C. These workers compared three lines of pigs; one selected for high rate of gain and low backfat (HP), one selected for low rate of gain and high backfat (LP), and one line was unselected (CP). The pigs from the HP line had higher SM and GH as well as longer carcasses than the pigs from the LP line. This agrees with the findings of Hall and Luft (1974) and Hall and Filipson (1975) who found positive correlations between growth rate and SM in normal children. The finding that the lean pigs had higher SM than the obese pigs is confusing since Underwood et al. (1972) showed that, while not lipogenic, SM paralleled insulin in antilipolytic effect. While circulating SM levels were not positively correlated with individual rate of gain (Underwood et al., 1972), they were related to body length. These workers also reported no difference in circulating SM concentration between barrows and gilts.

These Norwegian workers used the same bioassay to measure SM in Red Danish bulls and found circulating SM to be positively correlated with rate of gain and linear growth and negatively correlated to feed/gain ratios (Ringberg Lund-Larsen et al., 1977). This study reported no relationship between SM and cross sectional muscle area.

In the discussion of both of these papers, the authors suggested that diurnal variation of circulating SM was minimal

and proposed that one blood sample could be taken from young bulls and the SM concentration used to predict subsequent performance. This was then investigated by Ringberg (1979). Bulls from a high weight gain group (HG) had higher SM concentrations than bulls from a low weight gain group (LG). While the author observed a clear trend toward higher SM concentrations in young bulls that subsequently had a high rate of gain, the correlation between weight gain and serum SM was too weak to consider serum SM a reliable indicator of prospective performance. The author also concluded that only slight diurnal variation was evident in seven samples taken over a 14 h period. It is interesting to note that HG bulls showed more variation during the 14 h period than LG bulls.

Olsen et al. (1981) measured serum SM-like activity (SM-A) in serum samples taken from sheep at two week intervals from 2 to 18 wk of age. SM-A was related to relative growth rate (R=.84) but not to absolute growth rate and the authors could only suggest that SM-like activity may be important in the regulation of growth in sheep. These same workers (Wangsness et al., 1981) found higher SM-A in Suffolk sired lambs than in lambs sired by Finnsheep, which grew slower. They reported that zeranol implantation, which raises GH and insulin in sheep (Olsen et al., 1981), did not affect SM-A.

Thyroid Hormones

Thyroxine (T4) and Triiodothyronine (T3) are amine hormones produced and released by the thyroid gland. The

thyroid hormones are iodinated derivatives of paired tyrosine molecules with the subscript indicating the number of iodine atoms per molecule. Thyroid hormones have two major effects: 1) increasing metabolic rate, and 2) permitting normal growth.

After entering the bloodstream, all but minute quantities of the thyroid hormones bind immediately to plasma proteins, primarily thyroxine binding globulin, a glycoprotein. Due to a greater affinity for the binding proteins, T4 has a longer half-life than T3. Because of extrathyroidal conversion of T4 to T3, some have speculated that, in humans at least, bound T4 may act as a storage form for the more biologically active T3 (Vander, 1985)

In cattle, circulating concentrations of T4 and protein bound iodine (PBI, a thyroid hormone index) are very high at birth, decline rapidly and then increase steadily from 3 wk of age until 3 yr (Anderson et al., 1973; Kahl et al., 1977; Fabry, 1983). Hart et al. (1981) found that T4 decreased during and just after the weaning phase of dairy calves but terminated the study at 110 d so these results are not necessarily inconsistent with the others.

Experiments have not been designed specifically to compare sexes. However, Kahl et al.(1977) and Kahl and Bitman (1983) found that bulls had higher T4 and T3 than heifers between 6 and 22 wk of age. No difference was found in younger calves and older calves were not studied. This is in direct contrast to Anderson et al. (1973) who found no difference between growing Jersey bulls and heifers. He

compared means of samples taken from cattle 1 wk to 3 yr of age, perhaps during some portion of that period the sexes did differ.

Kunkel et al. (1953) were the first to compare circulating concentrations of PBI with weight gain of Hereford bulls and found a negative correlation. Bogart (1975) observed that thyroid gland weight (indicative of thyroid hormone production (Curl et al., 1968)) was positively correlated with average daily gain and proportion of lean in the carcass.

Gashaw et al. (1974) suggested that blood T3 concentrations at the beginning of a postweaning performance test may be useful to predict subsequent rate of gain. Fabry (1983) obtained significant correlations between T4 levels of bulls 8 to 10 d old or 66 to 95 d old and resultant weight gain. In bulls 96 to 125 d old or 126 to 155 d old T3 uptake (T3U) was correlated to live weight gain. The author speculated that the interaction between T4 and T3U is important in controlling growth, supporting the hypothesis of Vander (1985).

Attempts to relate circulating levels of thyroid hormones to weight gain are difficult to interpret. Trenkle (1970) found no relationship between PBI and weight gain while Kahl and Bitman (1983) reported a positive correlation between T3, T4 and weight gain in growing dairy calves. In direct contrast, Fabry (1983) indicated that the correlations between T4 and ADG and PBI and ADG were significant and negative. In discussion, he supported the theory first proposed by Kunkel et al. (1953) that growth is slowed above or below an optimal

level of T4.

T3 and T4 synthesis and release are stimulated by thyroid stimulating hormone (TSH, thyrotropin) an anterior pituitary glycoprotein that is regulated by the hypothalamic tripeptide amide thyrotropin releasing hormone (TRH).

Protein Nutrition of Ruminants

Protein nutrition of ruminants is made complex by the symbiosis between rumen microorganisms and their host. Dietary nitrogen is ingested as preformed protein or nonprotein nitrogen (NPN), urea is the most common form of NPN. Dietary proteins are subject to varying degrees of microbial proteolysis which produces peptides and free amino acids. Microbial deamination of these products produces carbon skeletons and ammonia. Bacterial urease also produces ammonia from urea. Ruminal microbes then synthesize microbial crude protein (MCP) from these substrates. MCP is continually washed into the lower gut where it is digested as are rumen undegraded proteins.

The conversion of plant nitrogen to microbial nitrogen has a major impact on nitrogen metabolism of the ruminant and the extent of this conversion has been examined extensively. Weller et al. (1957) examined rumen contents of sheep and found that 63 to 82% of the nitrogen present in the rumen was microbial nitrogen. By examining omasal contents, these same scientists estimated that 60 to 82% of dietary plant nitrogen is converted to microbial nitrogen. In a review, Owens and

Bergen (1983) stated that 40 to 80% of the protein that reaches the duodenum is MCP, the amount depends on several dietary and animal factors. MCP has a high but not ideal protein quality with a biological value of from 66 to 87 (Bergen et al., 1967, 1968).

Protozoa and fungi are present in the rumen but MCP synthesis and flow depend primarily on bacteria (Bergen and Yokoyama, 1977). Many rumen bacteria prefer ammonia as their nitrogen substrate (Bryant and Robinson, 1963), but more recent evidence indicates that some species of rumen bacteria incorporate amino acids and possibly small peptides (McMeniman et al., 1976; Salter et al., 1979).

MCP synthesis has potential to sustain the animal. Protein free diets have been shown to support growth in sheep (Loosli et al., 1949) and milk production in dairy cows (Virtanen,1966). Rumen microbes can synthesize all essential and nonessential amino acids from ammonia (Loosli et al.1949).

Despite the fact that lower gut digestion of microbially produced amino acids can support the animal, feeding only NPN is not necessarily the optimal method. While NPN is consistently the lowest cost supplemental nitrogen source, growth of cattle on high NPN diets seldom equals that of cattle fed the majority of their nitrogen in the form of preformed protein. Also, Huber and Kung (1981) have shown that the yield of ruminal MCP may not meet the needs of high producing ruminants. Thus, the goal of those balancing diets for ruminants is to strike the most cost effective balance between utilization

of low cost NPN and the performance advantages of preformed protein.

Early diet formulation involved simply balancing diets for the required amount or percentage of crude or digestible protein. This approach was too simplistic. "It is clear that the traditional use of crude or digestible protein must be modified to reflect the intervention of rumen microbes in the digestive process and to recognize the contribution of endogenous nitrogen and microbial residues to fecal output" (Satter, 1982).

Several researchers have developed models to meet this need. The first is the metabolizable protein (MP) system developed at Iowa State University (Burroughs et al., 1971, Trenkle, 1982). Use of this system involves two estimates; metabolizable protein (MP) and urea fermentation potential (UFP). MP is defined as the quantity of protein digested or the quantity of amino acids absorbed in the postruminal portion of the digestive tract. Obviously there are two sources of MP; feed proteins which are not degraded in the rumen and MCP. MP is calculated by summing digestible undegraded protein and digestible microbial protein, after adjusting for metabolic fecal protein. UFP is the quantity of urea (or other NPN) that can be used to supply additional MP with given amounts of a feedstuff or combination of feedstuffs. UFP can be positive or negative and is calculated as:

((10.44 * TDN/kg) - (g of protein degraded/kg))/2.81

This is based on the standard value of 10.44% of TDN converted

to MCP. A positive UFP indicates the amount of urea that can be used to produce additional MP. Negative values indicate that NPN use has been maximized.

Satter and Roffler (1975) concur that use of MP is a valid concept but claim that the Iowa system is vulnerable to additive error due to variation in estimates of MP synthesis and uncertainty regarding the extent of protein degradability of some feedstuffs (Satter, 1982). The Wisconsin system takes into account the fact that dietary or recycled nitrogen will only be available in a form absorbable by the lower gut when ammonia production does not exceed the ability of the rumen bacteria to convert ammonia to microbial protein.

Calculation of the point of excess or "ammonia overflow" requires knowledge of the concentration of rumen ammonia necessary to support maximum growth of rumen bacteria. The conditions in the rumen under the feeding and management conditions in question must also be known. This system is predicated on the assumption that NPN has no value in ruminants unless it is converted into MP and reflects the unstated theory that the Iowa system can overestimate the value of NPN in some feeding systems. The Wisconsin system sidesteps the need for determining the degradability of most low protein feedstuffs and does not depend on an estimate of MP. Instead it is based largely on rumen ammonia concentration, which reflects protein degradation and microbial protein synthesis.

Another system is the Nebraska growth system (Rock et al., 1981; Klopfenstein, 1982). This system was designed to

evaluate protein sources for growing cattle. The protein sources are compared to a control diet in which urea is the only supplemental protein source. The feedstuff, or combination of feedstuffs in question is added incrementally to replace urea in the diet. It is assumed that MP synthesis will be maximized in the urea control diet and any improvement in gain on the treatment diets will be a result of increased MP presented to the lower gut or an improved amino acid balance.

Protein efficiency is defined as the daily gain observed above the control cattle per unit of natural protein supplemented. All supplemental protein sources are then compared to soybean meal and diet formulation is based on soybean meal equivalent values.

Michigan investigators introduced a series of models summarized by Waller et al. (1982). The models described included three in effect and two proposed that range from a rather simple, static model to complex, dynamic models. Model 1 is a static model based on net protein estimates derived from balance studies, thus, no consideration is given to paths of nitrogen metabolism. These net protein values are only of use if the supply of ammonia does not exceed the capacity of the rumen microflora to utilize it. Model 2, also static, includes protein degradation rates, digestion of microbial and rumen undegraded protein and absorption. Model 3 is similar and focuses on amino acid metabolism instead of net protein metabolism. Proposed models 4 and 5 are the dynamic counterparts of models 2 and 3.

Features of the Michigan systems include:

-calculation of ammonia utilization potential (AUP) which is similar to UFP

-inclusion of an acid detergent insoluble nitrogen (ADIN) component which reflects the rumen undegraded protein that cannot be digested in the lower tract

-least cost analyses built into each model

-safety factors which allow for adequate animal performance despite typical variability of feedstuffs and animal factors

-partial consideration of composition of gain as it relates to rate of gain

Dietary Protein Levels for Bulls

Few studies have been designed to evaluate the effect of varying dietary protein levels on bulls. The first is that of Kay and Macdearmid (1969). These Scottish workers fed Friesian bull calves from 100 to 450 kg. They compared four dietary combinations including 12, 14.5, or 17% crude protein for bulls 100 to 250 kg with protein lowered 2.5 or 5% when the bulls reached 250 kg. At weights less than 250 kg, 12% protein was too low to sustain maximum rates of growth, 14.5 and 17% produced similar results. When bulls were heavier than 250 kg, 12% was adequate while 9.5% depressed performance.

No difference was observed in DMI between treatments so feed conversion was inversely related to rate of gain. This

study also reported no difference due to treatment in the chemical composition of the 8-9-10 rib section. The authors attribute this lack of effect to too few cattle per treatment; but means were similar.

Williams et al.(1975a) included early weaning and diethylstilbestrol implantation as main effects in a study that compared protein levels in a 90% concentrate diet. They compared 14% CP vs 12% in bulls that weighed less than 182 kg, 13% vs 11% for bulls between 182 and 364 kg, and 12% vs 10% for bulls heavier than 364 kg. These workers found a slight, nonsignificant advantage for higher CP in early weaned calves and no difference between CP levels for standard weaned calves with no difference in DMI due to CP level. In this study, high protein resulted in fatter carcasses and had no effect on palatability.

These same workers evaluated the NRC recommendations using Holstein bulls (Williams et al., 1975b). When bulls were between 150 and 325 kg, the NRC recommended value (12%) produced gains as rapidly as a higher value (14%). Growth was impaired in bulls fed a lower value (10%). When bulls weighed more than 325 kg, 9% CP (below NRC values) was adequate with no advantage shown for higher protein levels.

Researchers at Purdue University have conducted the most extensive studies to evaluate protein levels for bulls. Martin et al. (1978) fed 141 purebred Angus bulls three continuous levels of dietary protein, 11.1, 13.3 and 15.5%. The 168 d trial simulated performance testing station conditions. The

bulls were started on feed soon after weaning at an average weight of 223 kg. Bulls fed the lowest level of CP gained slower for the first 56 d of the trial but compensated so that there were no treatment differences over the entire trial. Bulls fed the two higher protein levels had fatter carcasses than bulls fed the lowest level. The authors stated that protein efficiency favored the bulls fed the lowest level. They concluded that "continuous levels of dietary protein higher than 11% cannot be justified for bulls."

These results may have limited interpretational value because of the type of cattle used. The mean 12th rib fat thickness for all treatments was 1.26 cm for bulls that were less than 13 mo old and weighed 411 kg. These data indicate that the bulls were very small in frame size. The overall mean ADG of 1.12 kg (<1 kg for the last 28 d) is very low for bulls fed a high energy diet and supports the contention that the cattle studied were smaller than most modern cattle.

The above study was followed by another in which the authors fed 153 Angus bull calves .23, .41, .59 or .77 kg of SBM per head per day in moderate energy corn:corn silage diets (Martin et al., 1979a). During the first 56 d of the trial there was a positive linear response to added SBM. For the entire trial bulls fed the lowest SBM level grew 22% slower than the others which were not different. This is due in part to the fact that bulls fed the lowest CP level consumed 6% less feed than the other bulls. The authors observed that carcass fat thickness increased linearly as protein supplemen-

tation increased but ribeye area was unaffected by SBM addition. From this work the authors concluded that 11.5% CP was the minimum dietary level that would sustain maximum growth in bulls with body weights from 220 to 300 kg. For bulls from 300 to 400 kg, they recommended 10.5% (compared to a recommendation of 11.1% in their previous work, this discrepancy was not explained).

Martin et al. (1979b) investigated the reproductive ability and some circulating endocrine factors of these bulls. They found no effect of dietary protein level on six measures of reproductive ability: masculinity score, scrotal circumference, testicular consistency, sperm motility, sperm concentration, or percentage of normal sperm.

In the first of the 2 yr represented in this study the bulls fed the highest level of dietary protein had the highest circulating testosterone concentrations with no difference in the second year. This resulted in a CP level x year interaction that is difficult to interpret. One possible explanation is that these results reflect only one blood sample per bull per bleeding date (bulls were sampled on d0, 28, 92 and 140 of the 140 d study) which is probably not enough to accurately characterize the testosterone status of these bulls. This detail clouds many of the conclusions of this study. Despite this, the authors reported a significant correlation of .225 between testosterone level and 140 d ADG and concluded that the data suggest a positive association between testosterone and dietary CP level.

The same serum samples were also assayed for insulin and growth hormone (Martin et al., 1979c). Insulin was directly related to CP level at every bleeding date with bulls fed the highest CP level having significantly higher insulin concentrations and the bulls fed the lowest CP level having the lowest insulin. This agrees with the data of Bassett et al. (1971) and Borger et al. (1973) who reported that low protein depressed circulating insulin concentrations in steers. This could well explain the effect of excess dietary protein on carcass fatness. The lipogenic effects of insulin are well known and amino acids not needed for protein synthesis would be deaminated and directed to energy storage as fat.

Growth hormone means were consistently higher in the bulls fed a diet inadequate in protein. This is consistent with the hypothesis of Trenkle (1978) who suggested that in the nutritionally deprived state GH would be elevated to ensure adequate protein anabolism and that the antilipogenic effects of GH would be evident.

OBJECTIVES

TRIAL 1. THE EFFECT OF DIETARY PROTEIN LEVEL ON RATE AND COMPOSITION OF GAIN OF GROWING BEEF BULLS.

Due to a paucity of data in this field of study, and, as part of a cooperative NCR 132 committee project, this experiment represents a preliminary investigation of the effect of dietary protein levels on young, growing bulls. Medium frame British breed bulls of high genetic merit were selected for the study because of their availability and because they may represent the most ideal type of cattle for profitable beef production from young bulls (Able, 1982). The primary objective of this experiment was to examine the effect of dietary crude protein level on feedlot performance of bulls in a study designed to mimic the standard 140 d performance test commonly used to evaluate the performance of bulls. Three experimental diets were chosen. A diet containing 12% crude protein was fed since that was near the level recommended by NRC. A diet containing 14% was chosen to determine if dietary crude protein in excess of recommended levels would result in improved performance. A diet containing 10% crude protein was fed with the expectation that growth would be limited.

A second objective was to examine the effect of dietary protein level on rates of carcass protein and fat accretion. This approach was intended to detect influences of

dietary protein level that would not be discerned by simply evaluating live weight gain and carcass data.

With these objectives in mind, an experiment was designed with the following null hypothesis:

> Dietary crude protein levels of 10,12 and 14% will not affect rate, efficiency, or composition of gain of growing beef bulls in a simulated performance test.

TRIAL 2. COMPARISON OF DRY MATTER INTAKE, COMPOSITION OF GAIN AND OTHER MEASURES OF SIMMENTAL BULLS AND STEERS FED TO EQUAL WEIGHT OR AGE.

While numerous experiments have adequately described most production differences between bulls and steers, some specific questions still remain. This experiment was designed to provide answers to questions about feed intake and composition of gain of bulls and steers. In order to meet the objectives of this study, it was critical that the experimental bulls and steers be of equal genetic merit.

It is commonly reported that bulls consume more feed than steers. On a per head basis this is true. Diet formulation, however, is based on estimates of feed intake that consider body weight. All studies reported compare bulls to steers with lower body weights. It is unclear whether the greater feed intake of bulls that has been reported reflects greater appetite of bulls or simply greater body weights under all

experimental conditions. An objective of this study was to examine feed consumption of bulls and steers after mathematically eliminating the traditional bias of greater body weights of bulls.

Carcass composition was the other area of most interest. It is clear that bulls produce leaner carcasses than steers. It is not clear, however, whether this is due to a greater rate of lean tissue deposition, reduced fat accretion, or a combination of both. An objective of this experiment was to compare composition of gain of bulls and steers fed to two endpoints, equal age and weight.

With these objectives in mind, an experiment was designed with the following null hypothesis:

> Neither feed consumption (expressed per unit of body weight or unit of metabolic body weight), nor composition of gain differ between bulls and steers of equal genetic merit fed to similar weights or ages.

TRIAL 3. THE EFFECT OF DIETARY PROTEIN LEVEL ON RATE, EFFICIENCY AND COMPOSITION OF GAIN AND RELATED ENDOCRINE FACTORS OF GROWING BEEF BULLS.

Data obtained from trial 1 indicated that dietary crude protein level could affect both rate and composition of gain. Further, it was noted, not unexpectedly, that the response of growing bulls to a given dietary protein level

changed as the weight of the bulls increased. Trial 3 represented a more ambitious attempt to evaluate the effect of dietary crude protein level on rate and composition of gain. Trial 3 included four slaughter dates in order to monitor changes in body composition over time.

An additional objective of trial 3 was that of obtaining an endocrine profile of the growing beef bull. Analysis of blood samples collected on four dates allowed examination of the level and nature of seven critical hormones. The relationship of these hormones to various measures of rate and composition of gain was also intended.

With this in mind, an experiment was designed with the following null hypotheses:

> Rate, efficiency and composition of gain of growing beef bulls, as examined over a range of weights, will be unaffected by dietary crude protein level.

and

> Circulating hormone concentrations of growing beef bulls will be unaffected by dietary crude protein level and age and will be unrelated to rate or composition of gain.

MATERIALS AND METHODS

TRIAL 1. THE EFFECT OF DIETARY PROTEIN LEVEL ON RATE AND COMPOSITION OF GAIN OF GROWING BEEF BULLS.

Cattle and Management

Fifty-nine Angus and Polled Hereford bulls were utilized in a 2 yr study to determine the effects of three levels of dietary protein on rate, efficiency and composition of gain and carcass characteristics. In year 1, 19 Angus and 11 Polled Hereford bulls were used and in year 2, 13 Angus and 16 Polled Hereford bulls were used. Calves were blocked by weight within breed and 8 bulls per year were randomly assigned to one of three treatment groups (10, 12 or 14% crude protein) or to initial slaughter to determine initial body composition. Preformed protein (soybean meal) was used as the supplemental protein source, experimental diets are given in table 2. No growth implants were used. In yr 1, bulls were fed from November 9, 1983 to April 3, 1984 (146 d) and slaughtered at an average age of 406 d. In yr 2, bulls were fed from November 24, 1984 to April 8, 1985 (136 d) and slaughtered at an average age of 402 d.

The average initial weight of all bulls was 333 kg, all weights reported are the average of weights taken before feeding on 2 consecutive d. Initial and final hip heights and scrotal circumferences were recorded for each bull. The average frame score was 5. Bulls were housed on the south side

TABLE 2. EXPERIMENTAL DIETS FED TO PUREBRED ANGUS AND POLLED HEREFORD BULLS

	Dietary crude protein level		
	10%	12%	14%
Component	Percentage of dry matter		
High moisture corn	75.5	70.8	65.5
Corn silage	20.6	19.8	20.0
Soybean meal	2.4	8.0	13.1
Mineral/vitamin supplement	1.5	1.4	1.4

Diets were formulated to provide 1.32 MCal NEg/kg.

of an open front, partial roof building with a cement floor.

Bulls were fed ad libitum once daily. Refused feed was collected and weighed weekly. Dry matter content of the refused feed was determined if the refused feed seemed to differ from the fresh feed.

Initial slaughter cattle were slaughtered on d 1, all others immediately after the feeding period. On the day of slaughter, bulls were loaded in the early morning, transported 114 km to a commercial slaughter facility, and slaughtered immediately after unloading. Testicles were collected on the kill floor and placed in plastic bags immediately. After the final bull was slaughtered, all testicles were trimmed uniformly and paired weights were recorded.

Carcass Composition

Carcass data were collected after a 24 h chill period. The 9-10-11 rib section was removed as described by Hankins and Howe (1946), boned and ground three times. Soft tissues were mixed thoroughly by hand between grindings.
After grinding, a 300g sample was collected, placed in a Whirlpack bag and stored at -30C until analysis. Dry matter content of the samples was determined by drying duplicate samples in aluminum pans for 48 h at 60C. Percentage crude protein of duplicate samples was calculated from total N as determined by a Technicon auto-Kjeldahl system and percentage fat was determined by ether extraction of triplicate samples for 5 h in a Goldfisch apparatus. Percentage carcass fat and

protein were estimated from rib fat and protein using the equations of Hankins and Howe (1946). Because of variation of body composition among initial slaughter cattle apparently due to differences in weight, initial body composition of those calves placed on trial was estimated by linear regression with body weight as the dependant variable. Accretion rates of carcass tissues were then calculated using the equation:

$$a = ((bc) - (def))/g$$

where:

a = accretion rate of fat or protein (g/d) for a particular bull

b = carcass weight (kg)

c = estimated carcass percentage fat or protein

d = initial live weight (kg)

e = average dressing percentage of initial slaughter group

f = initial percentage protein or fat, estimated by regression

g = number of days on feed

Statistical Analysis

Statistical analyses were conducted on a personal computer using MSUSTAT (Montana State University) based on Snedecor and Cochrane (1967). Data were analyzed by two way analysis of variance with year and treatment as the main effects. Students t tests were used for mean separation.

TRIAL 2. COMPARISON OF DRY MATTER INTAKE, COMPOSITION OF GAIN AND OTHER MEASURES OF SIMMENTAL BULLS AND STEERS FED TO EQUAL WEIGHT OR AGE.

Cattle and Management

Seventy Simmental bulls and steers (35 of each) were purchased from one large herd in South Dakota and obtained just after weaning. All calves were selected by the breeder with uniformity of growth potential, frame size and age the primary criteria. Steer calves had been castrated at 2-3 mo of age. Average birth date of both groups was within 6d. The average frame score of the bulls was 6.03 at the start of the trial. Since the effect of the gonad on pre-pubertal long bone growth is thought to be minimal, the steers were considered to be the same frame score as the bulls.

The cattle were blocked by weight and 5 of each gonadal status were selected for initial slaughter to determine initial body composition. The remaining calves were randomly assigned to pens (5 pens of 6 head of each gonadal status). They were fed on the north side of an open front, slotted floor barn and moved to the south side of an open front, partial roof, cement floor barn after four months on feed.

The average starting on feed weight of bulls was 313 kg., of steers, 289 kg. Weights reported are the average of weights taken before feeding on 2 consecutive d. Against the request of the experimenters, the steers had received a growth implant 3 d prior to shipping. All implants were surgically

removed, pellets were counted to insure completeness of removal. The cattle were started on a predominately corn silage diet and switched, over a 19 d adaption period, to experimental diets (table 3). Due to a shortage of corn silage, diets were reformulated to include dry ground hay instead of silage for the final 100 d.

Carcass Composition

Initial slaughter cattle were slaughtered on d 1. All bulls and a random half of the steers (StI) were slaughtered when it was deemed that the steers had reached the peak of their average daily gain curve (167 d). The remaining steers (StII) were slaughtered when they attained the final slaughter weight of the bulls (224 d). On the day of slaughter, cattle were loaded in the early morning, transported 114 km to a commercial slaughter facility, and slaughtered immediately to avoid the problem of dark cutting bulls. Carcass data were obtained after a 24 h chill period. The 9-10-11 rib section was removed according to Hankins and Howe (1946) boned and ground to obtain a representative sample of the soft tissues. These samples were frozen and stored at -30C until further preparation. Samples were powdered with dry ice at -30C in a Tech-mar industrial strength blender. After evaporation of CO2 at -30C, samples were thawed in beakers sealed with Parafilm. Samples were dried in aluminum pans for 48h at 60C to determine dry matter content. Percentage fat of the sample was determined by soxhlet ether extraction and percent-

TABLE 3. EXPERIMENTAL DIETS FED TO SIMMENTAL BULLS AND STEERS

Component	Percentage of dry matter
High moisture corn	68.0
Corn silage	18.0
SBM/vit/min supplement	14.0

Diets were formulated to provide: 13.14% Crude protein
1.35 MCal NEg/kg
.60% Ca.
.40% P.

age crude protein was calculated from total N as determined by a Technicon auto-Kjeldahl system. Percentage carcass fat and protein were estimated from rib fat and protein using the equations of Hankins and Howe (1946). Accretion rates of carcass tissues were estimated using the equation as in trial 1. Initial dressing percentage and composition of all cattle was assumed to be equal.

Other Measures

At the slaughter facility, immediately after exsanguination, the right front knee was severed and the foot and leg bone collected. Within 24 h the pastern joint was severed and the metacarpus (cannon) bone was skinned, scraped of all soft tissue, measured and weighed.

Immediately after evisceration the liver was weighed wet and returned.

Statistical Analysis

Stastical analysis were conducted using a microcomputer and MSUSTAT. Data were analyzed by one-way analysis of variance, means of both steer groups were compared to bulls with students t test statistics.

TRIAL 3. THE EFFECT OF DIETARY PROTEIN LEVEL ON RATE, EFFICIENCY AND COMPOSITION OF GAIN AND RELATED ENDOCRINE FACTORS OF GROWING BEEF BULLS.

Cattle and Management

Seventy Simmental x Angus and Simmental x Hereford bull calves, selected for uniformity, were obtained from the Roman L. Hruska U.S. Meat Animal Research Center, Clay Center, Nebraska, after they were weaned. During a 30 d adaptation period, 21 randomly selected calves were tamed and halter broken. Following the adaptation period, an additional 39 calves were selected for the study. Both groups were blocked by weight and breed of dam and were randomly assigned to one of three dietary treatments (10, 12 or 14% crude protein) or to initial slaughter (6 bulls). Preformed protein (soybean meal) was the supplemental protein source, experimental diets are listed in table 4. No growth implants were used. Bulls were placed in 2 pens of 9 bulls per treatment and housed, with treatments randomized within the facility, on the south side of a covered, open front, slotted floor facility.

Average initial weight of all bulls was 318 kg. All weights reported are the average of weights taken before feeding on 2 consecutive days. Hip height and scrotal circumference were recorded for each bull remaining prior to each slaughter date. Their average frame score was 5.

TABLE 4. EXPERIMENTAL DIETS FED TO CROSSBRED BULLS

Component	Dietary crude protein level		
	10%	12%	14%
	Percentage of dry matter		
High moisture corn	50.0	50.0	44.0
Corn silage	46.0	41.1	42.1
SBM/vit/min suppl	4.0	8.9	13.9

Diets were formulated to provide 1.26 Mcal NEg/kg of dry matter

Carcass Composition

Initial slaughter cattle were slaughtered on d 2. Three bulls from each pen were slaughtered on d 66, d 136, and d 202. Bulls were transported 114 km to a commercial slaughter facility and slaughtered immediately after unloading. Testicles were collected and weighed as in trial 1. Carcass data and 9-10-11 rib section analyses were similar to trial 2. All carcasses from the d 66 slaughter were processed at the slaughter facility before carcass data or rib sections were collected thus, no data are available from this slaughter group.

Blood Collection and Hormone Assays

Prior to the initiation of the study, 21 bulls were tamed and halter broken. Seven of these bulls were assigned to each treatment group and five of those seven per treatment group were selected for blood sample collection based on disposition. Blood samples were collected from each of these bulls on d 2, d 64, d 137 and d 198. These dates were selected to correspond with the slaughter dates (d 0, 66, 136 and 202). On the day before each blood collection date, bulls to be sampled were removed from their pens 3 h after they were fed. Bulls were fitted with a polyvinyl cannula in the jugular vein and placed in individual stalls in the metabolism room at the MSU beef cattle research center. The next day, beginning at 0800 h, blood samples were taken from each bull every 30 min for 12 h. Bulls were fed at the same time as they had been when in

TABLE 5. SLAUGHTER SCHEDULE OF CROSSBRED BULLS FED THREE PROTEIN LEVELS

	Slaughter date		
	66d	136d	202d
Treatment	Number of bulls slaughtered		
10% CP	6	6	6
12% CP	6	6	6
14% CP	6	6	6

6 bulls slaughtered on 0 d to determine initial body composition.

their pens and fresh water was available constantly. Blood samples designated to provide serum were stored at 20 C for 2 to 4 hours, and then stored overnight at 4 C. The next day, sera were obtained by centrifugation at 2000 x g for 25 min. Sera were decanted and stored at -20 C. Blood samples designated to provide plasma were collected in tubes coated with EDTA and were placed on ice immediately. Within 30 min these tubes were spun at 2000 x g for 20 min and plasma was decanted and stored at -20 C.

Sera were analyzed for cortisol (Purchas et al., 1985), growth hormone (Purchas et al., 1970), insulin (Micro-medic), and testosterone (Kiser et al., 1978). Plasma samples were analyzed for unbound Somatomedin-C (Nichols Institute, Etherton et al., 1987), thyroxine and triiodothyronine (Refsal et al., 1984).

Statistical Analysis

Data were analyzed by two-way analysis of variance with treatment and slaughter date or sampling date as the main effects. Means were compared by students t or Bonferroni test statistics.

RESULTS

TRIAL 1. THE EFFECT OF DIETARY PROTEIN LEVEL ON RATE AND COMPOSITION OF GAIN OF GROWING BEEF BULLS.

No significant treatment x year interactions were observed for any variables ($P>.1$), thus data from both years were pooled and analyzed by one way analysis of variance, with protein level as the single classification in the analysis. Students t tests were used for mean separation.

Feedlot Performance

Feedlot performance data are shown in table 6. Bulls fed 10% CP gained slower ($P<.05$) than bulls fed 12% or 14%, which were not different. The suppression of gain in the bulls fed 10% was most severe over the first 84 d of the trial. Bulls fed 12% CP grew slower ($P<.05$) over the first 56 d of the trial than bulls fed 14% (1.63 vs 1.82 kg/d).

Carcass Measurements

Treatment group means of carcass measurements are shown in table 7. Carcass weights parallel live weights and there were no differences in dressing percentage due to treatment. Carcasses from bulls fed 12% CP had greater adjusted 12th rib fat thickness ($P<.05$) than those from bulls fed the other diets. There were no treatment effects on KPH%, or intra-

TABLE 6. FEEDLOT PERFORMANCE OF PUREBRED ANGUS AND POLLED HEREFORD BULLS FED THREE PROTEIN LEVELS

Item	Dietary crude protein level			MSE
	10%	12%	14%	
Number of bulls	16	16	15	
Initial weight, kg	334	332	333	558
Final weight, kg	537.5	549.4	548.4	802
Average daily gain, kg/d	1.45[a]	1.54[b]	1.53[b]	.01

[a,b]Means within rows without common superscripts differ ($P<.05$).

TABLE 7. CARCASS MEASUREMENTS OF PUREBRED ANGUS AND POLLED HEREFORD BULLS FED THREE PROTEIN LEVELS

Item	Dietary crude protein level			MSE
	10%	12%	14%	
Carcass weight, kg	326.5	331.1	334.8	355.9
Fat thickness, cm	1.12[a]	1.44[b]	1.07[a]	.01
Ribeye area, cm^2	94.2	89.7	96.1	2.30
Dressing percentage	60.7	60.2	61.0	.21
KPH, %	2.16	2.22	2.10	.02
Quality grade [c]	10.5	10.4	10.5	.14
Marbling[d]	452	438	442	460.1
Yield grade	2.10[a]	2.67[b]	2.05[a]	.05

[a,b] Means within rows without common superscripts differ ($P<.05$).

[c] 10.0 = good+, 11.0 = choice-, etc.

[d] 400 = slight, 500 = small, etc.

muscular fat. Two bulls from each treatment graded choice. Ribeye area means did not differ between treatments.

Carcass Composition and Composition of Gain

Carcasses of bulls fed 12% CP had a greater percentage of fat than carcasses of bulls fed 14% ($P<.05$), with carcasses of bulls fed 10% intermediate (table 8). Bulls fed 12% CP also gained more fat per day than bulls fed 10%. Carcass protein percentage estimates did not differ between treatments but bulls fed 14% CP deposited 11% more carcass protein per day than bulls fed the other diets. This difference approached significance ($P<.1$).

TRIAL 2. COMPARISON OF DRY MATTER INTAKE, COMPOSITION OF GAIN AND OTHER MEASURES OF SIMMENTAL BULLS AND STEERS FED TO EQUAL WEIGHT OR AGE.

Feedlot Performance

Bulls gained 18% faster ($P<.001$) and 13% more efficiently ($P<.01$) than StI (table 9). Bulls gained 25% faster ($P<.001$) and 23% more efficiently ($P<.01$) than StII.

Feed Consumption

Group means of various measures of feed consumption are shown in table 10. All values represent pen means for feed consumption and of body weights when appropriate. As is commonly reported, bulls tended to have higher average daily

TABLE 8. CARCASS COMPOSITION AND COMPOSITION OF GAIN OF PUREBRED ANGUS AND POLLED HEREFORD BULLS FED THREE PROTEIN LEVELS

Item	Dietary crude protein level			MSE
	10%	12%	14%	
Carcass fat, %	28.32[ab]	30.69[b]	28.18[a]	.14
Carcass fat gain, g/d	437.7[a]	504.0[b]	452.1[ab]	1077
Carcass protein, %	16.21	15.67	16.31	.002
Carcass protein gain, g/d	158.3[c]	152.5[c]	172.6[d]	209
Protein gain, % of dm	26.98	23.64	27.90	4.93

[a,b]Means within rows without a common superscript differ (P<.05).

[c,d]Means within rows without a common superscript tend to differ (P<.1).

TABLE 9. FEEDLOT PERFORMANCE OF SIMMENTAL BULLS AND STEERS

Item	Bulls	St I	St II	MSE
Number of animals	30	15	14	
Start weight, kg	313.4	289.4[a]		
Days on feed	167	167	224	
Slaughter weight, kg	621.1	549.4[a]	618.2	3787
Average daily gain, kg/d	1.84	1.56[a]	1.47[a]	.10
Feed conversion, f/g	4.57	5.24[a]	5.94[a]	.25

[a] Mean differs from bulls (P<.001)

TABLE 10. DRY MATTER INTAKE OF SIMMENTAL BULLS AND STEERS

Feed intake	Bulls	St I	St II	MSE
kg/head/d	8.42	8.15[a]	8.54	.889
kg/45.5 kg body wt/d	.818	.883[b]	.849[a]	.075
kg/metabolic body wt/d	.084	.088	.082	.002

[a] Mean tends to differ from bulls (P<.1).
[b] Mean differs from bulls (P<.01).

feed intake than steers when fed to the same age. When intake is expressed per 45.5 kg of body weight instead of per head, StI had greater intake than bulls ($P<.01$) and StII showed a similar trend ($P<.1$). When expressed per unit of metabolic body weight there was no difference between groups.

Carcass Measurements

Bulls had higher carcass weights than StI ($P<.001$), reflective of higher live weights (table 11). Bulls had less internal, external and intramuscular fat than StI ($P<.001$) and these differences were magnified when compared to StII. Bulls also had larger ribeye areas than both steer groups ($P<.001$ vs StI; $P<.01$ vs StII) and greater ribeye area per 100 kg of carcass weight than StII ($P<.05$).

Carcass Composition and Composition of Gain

Group means of carcass composition, as estimated from 9-10-11 rib section composition, are presented in table 12. Carcasses from bulls had a lower percentage of fat ($P<.001$) and a higher percentage of protein ($P<.001$). Bulls also had less total fat and more total protein (85.99, 92.64, and 118.4 kg : 62.71, 51.26, and 54.15 kg of fat and protein for bulls, StI, and StII, respectively). All groups had similar fat accretion rates, with an average of 459 g/d.

Other Measures

Bulls had heavier ($P<.1$, $P<.001$) livers than both steer

TABLE 11. CARCASS MEASUREMENTS OF SIMMENTAL BULLS AND STEERS

Item	Bulls	St I	St II	MSE
Carcass weight, kg	378.3	329.6d	369.9	1409
Dressing percentage	60.9	60.1[a]	59.8[c]	1.65
Fat thickness, cm	.58	.76[b]	1.12[d]	.03
Ribeye area, cm^2	102.6	88.6[d]	95.1[b]	13.01
REA/100kg carcass	27.1	26.9	25.8[b]	6.46
KPH, %	1.58	1.97[c]	3.21[d]	.15
Yield grade	1.47	2.01[c]	2.62[d]	.29
Marbling score [e]	228	266[c]	448[d]	2527

[a] Mean tends to differ from bulls (P<.1).
[b] Mean differs from bulls (P<.05).
[c] Mean differs from bulls (P<.01).
[d] Mean differs from bulls (P<.001).
[e] 200 = slight, 300 = small, etc.

TABLE 12. CARCASS COMPOSITION AND COMPOSITION OF GAIN OF SIMMENTAL BULLS AND STEERS

Item	Bulls	St I	St II	MSE
Carcass fat, %	22.67	28.13[a]	32.08[a]	13.29
Carcass protein, %	16.59	15.53[a]	14.67[a]	.48
Carcass fat gain, g/d	437.5	471.8	467.7	7736
Carcass protein gain, g/d	198.7	152.3[a]	127.6[a]	646
Protein gain, % of dm gain	32.1	24.6[a]	21.4[a]	30.5

[a] Mean differs from bulls (P<.001).

TABLE 13. OTHER COMPARISONS OF SIMMENTAL BULLS AND STEERS

Item	Bulls	St I	St II	MSE
Liver weight, g	7684	7182[a]	6903[c]	70310
Liver wt/carcass wt, g/kg	20.3	21.8[b]	18.7[c]	.65
Cannon bone length, cm	22.3	22.4	23.1[d]	.39
Cannon bone weight, g	647.4	612.7[a]	672.1	3224
Cannon bone density, g/cm	29.1	27.4[b]	29.1	5.16

[a] Mean tends to differ from bulls (P<.1).
[b] Mean differs from bulls (P<.05).
[c] Mean differs from bulls (P<.01).
[d] Mean differs from bulls (P<.001).

groups (table 13) but were intermediate between steer groups when liver weight was expressed per unit of carcass weight.

At the same age, bulls had heavier ($P<.1$), denser ($P<.01$) bones than steers with no difference in length. StII had longer bones than bulls ($P<.05$) with identical ratios of weight to height.

TRIAL 3. THE EFFECT OF DIETARY PROTEIN LEVEL ON RATE, EFFICIENCY AND COMPOSITION OF GAIN AND RELATED ENDOCRINE FACTORS OF GROWING BEEF BULLS.

Feedlot Performance

Weight gain, dry matter intake and feed conversion data are shown in table 14. Bulls fed 10% CP grew slower ($P<.05$) from d 0 to 66, d 67 to 136 and over the entire trial than bulls fed 12% or 14% CP. Growth of bulls fed 12% CP did not differ from that of bulls fed 14% CP during any period. No treatment differences were noted from d 137 to 202. Apparently, 10% dietary CP was adequate to sustain maximum growth of bulls when their live weights exceeded 500kg.

Since dietary CP level did not significantly affect DMI, feed conversion ratios reflect differences in ADG. Bulls fed 10% CP required more ($P<.05$) feed per unit of gain from d 0 to 66 and d 67 to 136 and tended ($P<.1$) to utilize feed less efficiently over the entire trial.

TABLE 14. FEEDLOT PERFORMANCE DATA OF CROSSBRED BULLS FED THREE PROTEIN LEVELS

	Dietary crude protein level			
	10%	12%	14%	SEM
Day 0 to 66				
Number of bulls	17	18	18	
Average daily gain, kg/d	0.99[a]	1.42[b]	1.50[b]	.02
Dry matter intake, kg	8.03	8.21	8.12	.19
DMI/Gain	8.09[a]	5.79[b]	5.37[b]	.2
Day 67 to 136				
Number of bulls	12	12	12	
Average daily gain, kg/d	1.25[a]	1.51[b]	1.50[b]	.02
Dry matter intake, kg	9.25	9.93	10.16	.40
DMI/Gain	7.42	6.59	7.33	.19
Day 137 to 202				
Number of bulls	6	6	6	
Average daily gain, kg/d	0.98	0.87	0.93	.08
Dry matter intake, kg	8.85	8.98	9.16	.42
DMI/Gain	8.99	10.40	9.85	.43
Day 0 to 136				
Number of bulls	12	12	12	
Average daily gain, kg/d	1.13[a]	1.47[b]	1.50[b]	.05
Dry matter intake, kg	8.62	9.07	9.16	.19
DMI/Gain	7.76[a]	6.69[b]	6.35[b]	.15
Day 0 to 202				
Number of bulls	6	6	6	
Average daily gain, kg/d	1.11[a]	1.25[b]	1.27[b]	.04
Dry matter intake, kg	8.71	9.03	9.16	.25
DMI/Gain	8.17[c]	7.62[d]	7.53[d]	.11

Dry matter intake and DMI/Gain were calculated from pen averages.

a,b Means in a common row without a common superscript differ (P<.05).

c,d Means in a common row without a common superscript tend to differ (P<.1).

Carcass Measurements

Group means of carcass measurements are presented in table 15. There were no significant differences due to treatment. Ribeye area means were greater ($P<.05$) for bulls slaughtered on d 202 while fat thickness did not differ between slaughter groups.

Carcass Composition

Dietary CP level did not significantly affect the percentage of fat or protein in the carcass ($P>.05$), as estimated from 9-10-11 rib section composition, (table 16), nor did any differences exist between carcasses from bulls slaughtered on d 136 and those slaughtered on d 202. Bulls fed 14% CP had numerically greater percentages of fat and lower percentages of protein than bulls fed the other treatments after 136 d of feed. This difference approached statistical significance.

Composition of Gain

Estimated carcass fat deposition rate increased incrementally with higher dietary CP from d 0 to 136 (table 17). Carcass fat gain did not differ between treatment groups for d 0 to 202 although bulls fed 10% CP seemed to have a somewhat lower mean.

No significant treatment differences were observed for the d 137 to 202 period despite the fact that bulls fed 14% CP deposited 54% less fat per day than the mean of the other two treatments.

TABLE 15. CARCASS MEASUREMENTS OF CROSSBRED BULLS FED THREE DIETARY PROTEIN LEVELS AND SLAUGHTERED AFTER 136 OR 202 d ON FEED

	Slaughter date						
Item	136 d			202 d			SEM
Protein level	10%	12%	14%	10%	12%	14%	
No. of bulls	6	6	6	6	6	6	
Fat thickness, cm	.8	.8	1.0	.8	1.0	.9	.03
Ribeye area cm^2	84.5	91.0	90.0	103.2	103.9	99.4	6.2
Marbling[a]	470	434	468	507	497	523	36
No. USDA choice	2	0	1	3	2	3	

[a]400 = slight, 500 = small, etc.

TABLE 16. CARCASS COMPOSITION OF CROSSBRED BULLS FED THREE DIETARY PROTEIN LEVELS AND SLAUGHTERED AFTER 136 OR 202 d ON EXPERIMENTAL DIETS

	% Carcass fat		% Carcass protein	
	Slaughter date		Slaughter date	
PROTEIN LEVEL	136 d	202 d	136 d	202 d
10%	22.04	24.40	16.04	16.11
12%	22.49	26.07	16.14	15.73
14%	25.90	25.63	15.70	15.89
MSE	8.28		.264	

TABLE 17. CARCASS FAT ACCRETION RATES (g/d) OF CROSSBRED BULLS FED THREE DIETARY PROTEIN LEVELS AND SLAUGHTERED AFTER 136 OR 202 d ON EXPERIMENTAL DIETS

Protein Level	Period		
	0 to 136 d	0 to 202 d	137 to 202 d
10%	310.0 [a]	331.2	371.7
12%	390.2 [ab]	383.7	374.4
14%	478.4 [b]	376.3	173.3
MSE	8490	3138	48820

[a,b] Means within columns without common superscripts differ (P<.05).

TABLE 18. CARCASS PROTEIN ACCRETION RATES (g/d) OF CROSSBRED BULLS FED THREE DIETARY PROTEIN LEVELS AND SLAUGHTERED AFTER 136 OR 202 d ON EXPERIMENTAL DIETS

Protein Level	Period		
	0 to 136 d	0 to 202 d	137 to 202 d
10%	93.2 [a]	122.7 [a]	183.9
12%	141.8 [b]	131.7 [ab]	98.2
14%	136.8 [b]	136.5 [b]	154.0
MSE	414	119	7357

[a,b] Means within a column without common superscripts differ (P<.05).

Bulls fed 10% CP gained less ($P<.05$) carcass protein per day than the other treatments from d 0 to 136 (table 18). Over the entire trial, bulls fed 10% CP had lower rates of carcass protein deposition than bulls fed 14% CP, bulls fed 12% CP were intermediate. Although no significant differences were observed from d 137 to 202, bulls in the 10% treatment group did exhibit nonsignificant compensatory protein gain when their body weights were high enough that 10% CP met their requirement and maximum growth was sustained.

Serum Cortisol

Mean serum cortisol concentrations represent the mean of 13 samples taken at 30 min intervals from 1400 h until 2000 h from each of 5 bulls per treatment and are presented in table 19. No significant treatment x sampling date interaction was observed so main effect means were analyzed separately. Dietary crude protein level did not significantly affect cortisol concentrations. Circulating cortisol increased over time ($P<.05$). Mean cortisol concentrations of samples taken on d 0 and d 66 did not differ. The mean of samples taken on d 136 was greater ($P<.05$) than the mean of the first two sampling dates and the mean of samples collected on d 202 was greater ($P<.05$) than the others.

Growth Hormone

Each GH value shown in table 20 represents the mean of 25 serum samples from each of 5 bulls per treatment group. At

TABLE 19. SERUM CORTISOL MEANS (pg/ml) OF SAMPLES TAKEN AT 30 MIN INTERVALS FROM 1400 H UNTIL 2000 H FROM CROSS-BRED BULLS FED THREE DIETARY PROTEIN LEVELS AND SAMPLED ON FOUR DATES (5 BULLS PER TREATMENT GROUP)

Protein Level	Cortisol	Sampling date	Cortisol
10%	1543	0 d	1209 [a]
12%	1506	66 d	1018 [a]
14%	1508	136 d	1681 [b]
		202 d	2168 [c]
SEM	40.4		39.4

[a,b,c] Means within a column without a common superscript differ ($P<.05$).

TABLE 20. SERUM GROWTH HORMONE (ng/ml) MEANS OF SAMPLES TAKEN AT 30 MIN INTERVALS FROM 0800 H UNTIL 2000 H FROM CROSSBRED BULLS FED THREE DIETARY PROTEIN LEVELS AND SAMPLED ON FOUR DATES (FIVE BULLS PER TREATMENT GROUP)

Protein Level	Sampling date [a]			
	0 d	66 d	136 d	202 d
10%	6.3	6.8	6.1	5.7
12%	6.4	6.5	5.1	5.4
14% [b]	6.9	6.4	6.0	4.7

[a] Within all treatment groups GH means declined over time.

[b] The decline between d 136 and d 202 was greatest ($P<.05$) for bulls fed 14% dietary crude protein.

least two nonconsecutive samples from each bull on each sampling date exceeded twice the mean of all samples from that bull on that day, indicative of the pulsatile nature of GH.

Dietary crude protein level did not affect GH means ($P>.05$). The effect of sampling date was significant but due to the existence of a significant treatment x sampling date interaction ($P<.05$), interaction means were analyzed separately. Treatment means within a sampling date were separated using a Bonferroni t test statistic and bull x treatment residual error as the error term. Sampling date means were compared with a Bonferroni t test statistic and MSE as the error term.

GH means declined over time ($P<.05$) and from d 136 to 202 bulls fed 14% CP showed a greater ($P<.05$) decline than bulls fed the other diets.

Insulin

Quantification of insulin was conducted on 18 serum samples per bull per sampling date. All samples taken at 30 min intervals from 0800 h until 2000 h were assayed with the exception of samples collected at 0830, 0930, 1530,1630, 1730,1830 and 1930 h. Interaction means are shown in table 21.

Serum from bulls fed 12% crude protein had significantly higher ($P<.001$) insulin concentrations than serum from bulls fed 10% or 14% crude protein. This difference was significant on each sampling date, including the baseline, d 0. Consequently, serum insulin values were converted to differences by

TABLE 21. MEAN SERUM INSULIN CONCENTRATION (U/ML) OF SAMPLES TAKEN AT 30 OR 60 MIN INTERVALS FROM 0800 UNTIL 2000 FROM CROSSBRED BULLS FED THREE LEVELS OF PROTEIN AND SAMPLED ON FOUR DATES (5 BULLS PER TREATMENT GROUP)

Protein Level [b,c]	Sampling Date [a]			
	0 d	66 d	136 d	202 d
10%	8.3	9.3	10.1	8.7
12%	14.0	12.5	15.2	12.4
14%	8.1	7.8	10.2	10.2

[a] The effect of sampling date was significant ($P<.001$).
[b] The effect of protein level was significant ($P<.001$), on each sampling date, the bulls fed 12% CP had higher insulin concentrations than bulls fed the other diets ($P<.01$).
[c] The protein level x sampling date interaction was significant ($P<.01$).

TABLE 22. MEAN SERUM INSULIN REPORTED AS DIFFERENCE FROM BASELINE (D 0) OF CROSSBRED BULLS FED THREE PROTEIN LEVELS AND SAMPLED ON FOUR DATES (FIVE BULLS PER TREATMENT GROUP)

Protein Level	Difference [a]	Sampling date	Difference
10%	1.01 [c]	66 d [b]	-.25
12%	-.60 [b]	136 d [c]	1.67
14%	1.26 [c]	202 d [b]	-.25
SEM	.01		.01

[a] Serum collected from bulls fed 12% protein had significantly greater ($P<.001$) concentrations of insulin at each sampling date, including 0 d. Because of this observation, serum insulin values were subtracted from the 0 d mean of the bull from which the sample was taken.

[b,c] Means within a column without a common superscript differ ($P<.05$).

subtracting the mean d 0 insulin concentration of each bull from each assay value. Statistical analysis of these differences revealed no significant treatment x sampling date interaction so main effect means are presented.

Circulating insulin concentrations of bulls fed 12% crude protein decreased from their d 0 values. This change from baseline was different ($P<.05$) than the change of the bulls fed the other treatments, which had statistically similar increases from their d 0 means.

Across treatments, the greatest increase in circulating insulin from d 0 was observed on d 136 when the mean of all samples was 1.67 ng/ml greater than the mean on d 0. The means of samples collected on d 66 and d 202 had statistically similar changes from d 0 and both were lower ($P<.05$) than the change of the d 136 samples.

Somatomedin-C

All SM-C values represent the mean of one sample taken at 1000 h and one sample taken at 1800 h from each of 5 bulls per treatment, data are shown in table 22. Dietary CP level affected SM-C ($P<.05$). Bulls fed 14% dietary CP had lower concentrations of SM-C than bulls fed 10%, with bulls fed 12% CP intermediate. Mean SM-C was lower ($P<.05$) on d 0 than the other sampling dates.

Due to unexpected variation in SM-C content between morning and afternoon samples, an attempt was made to characterize the pattern of circulating SM-C in the bull. In order

TABLE 23. PLASMA SOMATOMEDIN-C MEANS (MICRO IU/ ML) OF SAMPLES TAKEN AT 1000 H AND 1400 H FROM CROSSBRED BULLS FED THREE PROTEIN LEVELS AND SAMPLED ON FOUR DATES (FIVE BULLS PER TREATMENT GROUP)

Protein Level	SM-C	Sampling date	SM-C
10%	289.0 [b]	0 d	195.5 [a]
12%	266.6 [ab]	66 d	277.5 [b]
14%	239.3 [a]	136 d	296.9 [b]
		202 d	289.9 [b]
SEM	9.7		11.9

[a,b] Means within a column without a common superscript differ ($P<.05$).

TABLE 24. SERUM TESTOSTERONE MEANS (ng/ml) OF SAMPLES TAKEN AT 30 MIN INTERVALS FROM 1400 H UNTIL 2000 H FROM CROSSBRED BULLS FED THREE PROTEIN LEVELS AND SAMPLED ON FOUR DATES (FIVE BULLS PER TREATMENT GROUP)

Protein Level	Testosterone	Sampling date	Testosterone
10%	12.93	0 d	10.68 [a]
12%	13.49	66 d	16.33 [c]
14%	12.41	136 d	12.52 [b]
		202 d	12.13 [b]
SEM	.53		.61

[a,b,c] Means within a column without a common superscript differ ($P<.05$).

to pursue this observation, 4 bulls were selected each to represent a different sampling date. The SM-C content of all samples collected from each bull on his designated sampling date were determined.

Results of these 12 h windows are depicted graphically in figures 1-4. GH concentrations are plotted with SM-C concentrations to observe the relationship between the two hormones.

Figure 1 illustrates the SM-C and GH content of samples collected from bull no 9 on d 0. This bull had the highest circulating level of GH. He was a member of the 12% treatment group. These samples had a mean SM-C content of 212.8 micro IU/ml and a mean GH content of 9.41 ng/ml. The simple correlation between SM-C and GH for these samples was not significant ($R=.28$; $P>.05$).

Figure 2 depicts samples from bull no 20, collected on d 66. This bull was in the 14% treatment group and was the fastest growing bull from d 0 to 66. These samples had a mean SM-C content of 360.3 micro IU/ml and mean GH of 6.90 ng/ml. The simple correlation between the SM-C and GH concentrations was not significant ($R= -.111$; $P>.05$).

Figure 3 depicts samples from bull no 15, d 136. This bull was in the 12% treatment group and had the leanest carcass. The mean SM-C content of these samples was 414.5 micro IU/ml, mean GH was 4.07 ng/ml. The correlation between the 25 SM-C concentrations and the 25 GH concentrations approached significance ($R=.397$; $P<.1$).

Figure 4. Growth hormone and Somatomedin-C concentration of samples collected every 30 min from 0800 h to 2000 h from a 15 mo old crossbred bull.

Bull #9 Bleed 1
Growth Hormone
SM-C
SM-C (Micro Units/ml)
Growth Hormone (ng/ml)
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
2000
1930
1900
1830
1800
1730
1700
1630
1600
1530
1500
1430
1400
1330
1300
1230
1200
1130
1100
1030
1000
0930
0900
0830
0800

Figure 3. Growth hormone and Somatomedin-C concentration of samples collected every 30 min from 0800 h to 2000 h from a 13 mo old crossbred bull.

Bull #20 Bleed 2

Figure 2. Growth hormone and Somatomedin-C concentration of samples collected every 30 min from 0800 h to 2000 h from an 11 mo old crossbred bull.

Bull #15 Bleed 3
Growth Hormone
SM-C
SM-C (Micro Units/ml)
Growth Hormone (ng/ml)
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0800
0830
0900
0930
1000
1030
1100
1130
1200
1230
1300
1330
1400
1430
1500
1530
1600
1630
1700
1730
1800
1830
1900
1930
2000

Figure 1. Growth hormone and Somatomedin-C concentration of samples collected every 30 min from 0800 h to 2000 h from a nine mo old crossbred bull.

Bull #16 Bleed 4
Growth Hormone
SM-C
SM-C (Micro Units/ml)
Growth Hormone (ng/ml)
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0800
0830
0900
0930
1000
1030
1100
1130
1200
1230
1300
1330
1400
1430
1500
1530
1600
1630
1700
1730
1800
1830
1900
1930
2000

Figure 4 depicts samples from bull no 16, d 202. The fastest growing bull in the study, he was in the 14% treatment group. Mean SM-C was 201.5 micro IU/ml, mean GH was 5.32 ng/ml. The correlation between GH and SM-C content was significant (R=.513; P<.05).

Testosterone

Testosterone analysis was conducted on all serum samples collected between 1400 h and 2000 h. No significant treatment x sampling date interaction was observed so main effect means are presented in table 23. Dietary crude protein level had no effect on circulating testosterone values. The effect of sampling date was significant (P<.05). Samples collected on d 66 had the highest testosterone values. Samples taken on d 136 had higher values than those taken on d 0, with samples taken on d 202 intermediate.

Thyroid Hormones

Main effect means for triiodothyronine (T3) and thyroxine (T4) are presented in table 24 since the treatment x sampling date interaction was not significant. Samples from bulls fed 12% crude protein had lower (P<.05) T3 values than samples from bulls fed 14% CP, with samples from bulls fed 10% CP intermediate. Samples collected on d 0 had lower (P<.05) T3 values than samples collected on d 66, d 136, or d 202, which did not differ.

T4 values did not differ due to dietary treatment. T4

TABLE 25. PLASMA T3 AND T4 MEANS (ng/ml) OF SAMPLES TAKEN AT 1000 H AND 1400 H FROM CROSSBRED BULLS FED THREE PROTEIN LEVELS AND SAMPLED ON FOUR DATES (FIVE BULLS PER TREATMENT GROUP)

Protein Level	T3	T4	Sampling date	T3	T4
10%	1.51 [ab]	67.0	0 d	1.25 [a]	48.3 [a]
12%	1.46 [a]	62.5	66 d	1.71 [b]	60.4 [b]
14%	1.60 [b]	65.8	136 d	1.57 [b]	76.0 [c]
			202 d	1.57 [b]	76.6 [c]
SEM	.037	1.38		.046	1.69

[a,b,c] Means within a column without a common superscript differ ($P<.05$)

values did increase with time. Samples collected on d 0 had the lowest concentration of T4, samples collected on d 66 contained more T4 than samples collected on d 0 ($P<.05$) but less than samples collected on d 136 and samples collected on d 202, which did not differ from each other.

TABLE 26. CORRELATIONS BETWEEN GROWTH HORMONE AND SOMATOMEDIN-C AND MEASURES OF CARCASS COMPOSITION OF CROSSBRED BULLS

	Growth Hormone	Somatomedin-C
Percentage carcass fat	NS [a]	-.60 [c]
Carcass fat accretion rate	-.25 [b]	-.57 [c]
Total carcass fat	NS	-.52 [c]
Fat thickness	-.19 [b]	-.73 [c]
Percentage carcass protein	NS	.60 [c]

[a] NS = Not significant (P>.1).
[b] P<.1.
[c] P<.05.

DISCUSSION

TRIAL 1. THE EFFECT OF DIETARY PROTEIN LEVEL ON RATE AND COMPOSITION OF GAIN OF GROWING BEEF BULLS.

The suppression of gain shown by the bulls fed 10% CP was most severe during the first 84 d of the trial. When these bulls neared 450 kg, their performance was similar to bulls fed the other diets. NRC (1984) does not provide recommended protein levels for bulls of this frame size and weight gaining at rates greater than 1.36 kg/d but they can be estimated. The estimated requirement for bulls gaining 1.58 kg/d does not decrease to 10% until the bulls weighed 450 kg, thus, the performance of the bulls in this study supports the equations used by NRC to calculate recommended dietary crude protein levels.

The reduced performance of bulls fed 10% CP compared to those fed higher levels was similar to that found by Williams et al. (1975) and Martin et al. (1979a). This differs from the results of Kay and MacDearmid (1969) but their bulls grew at slower rates so it is difficult to compare the results.

Bulls fed 12% CP grew slower (1.63 kg/d) over the first 56 d of the trial than bulls fed 14% CP (1.82 kg/d). This agrees with the estimated NRC guidelines. This difference, followed by compensatory gain that resulted in no treatment difference over the entire trial, is parallel to the data of Martin et al. (1978) who fed 1% lower protein levels to bulls

that were smaller framed and grew slower than the bulls in this study.

The difference in ADG cannot be attributed to differences in DMI as the means were not statistically different though bulls fed 10% CP consumed slightly less feed. Feed conversion ratios were similar among treatments. This implies that protein efficiency, if calculated simply as weight gain per unit of dietary protein consumed, would favor bulls fed the lowest dietary level, a result supported by Martin et al. (1978).

Carcasses from bulls fed 12% CP were fatter than from bulls fed the other diets. It is possible that their pattern of growth, slowed during the early part of the trial followed by rapid compensation may result in increased fat deposition. Bulls fed 14% CP, allowed to grow maximally, had leaner carcasses, as did bulls fed 10% CP which were inhibited early with less dramatic compensation later. There was no treatment effect on internal fatness, as indicated by KPH%, or intramuscular fat. Thus, the primary difference in fat deposition due to treatment was in the quantity of subcutaneous fat. Two bulls from each treatment graded USDA choice.

Ribeye area means did not differ between treatments. This agrees with all previous reports. Apparently dietary protein deprivation must be severe to have a noticeable effect on muscle growth of growing bulls. This could reflect the fact that bulls utilize dietary nitrogen very efficiently. It is possible that restriction of dietary protein earlier in the

life of the bulls would have slowed the growth of muscle which is intermediate in maturity pattern. The report of Kay and MacDearmid (1969) involved bulls that were restricted in growth due to protein deprivation at 175 kg, although their age was not reported. These workers showed no difference in the weight of lean tissues in the 8-9-10 rib section of light weight bulls under conditions of minor dietary protein restriction.

Carcass composition data are somewhat perplexing. The increased fat deposition of bulls fed 12% CP, when compared to bulls fed 10% CP, could be easily explained by their higher rates of gain and by assuming that excess dietary protein was utilized as energy. This is theoretically sound and has been observed before (Martin et al., 1978; Martin et al., 1979a) but does not explain the difference in fatness between the 12% and 14% treatments groups. Possibly, the ability to accrue carcass protein was hindered during the early part of the trial and the gain during compensation was primarily fat due to the high energy density of the diet. It is unlikely, however, that 10% dietary CP would result in an effect that severe. The tendency for greater rates of carcass protein deposition by the bulls fed 14% CP could be a result of their faster early gain, during the portion of the trial when lean tissue deposition would be expected to be the greatest. As discussed, however, this has not been observed in other studies and, if valid, makes it difficult to explain that 10% and 12% treatment groups did not differ.

If the increased fatness of bulls fed 12% CP compared to those fed 14% CP is repeatable, there are obvious implications for bull performance testing stations. These programs are often run with tight profit margins and managers continually seek to reduce expenses. Lowering the protein level in the diets of the bulls would reduce costs. These data would indicate that diets containing 12% CP and 14% CP would produce similar gains over a 140 d test period. One common and serious criticism of bull testing programs is that they encourage fattening of the bulls beyond ideal breeding condition. Lowering the protein level of the diet may increase fat deposition of bulls without affecting performance, exacerbating this problem. This could, however, be an advantage in a system of feeding bulls for slaughter. Certainly one of the primary advantages of feeding bulls is their leaner carcasses but some fat is necessary for palatability and to insulate carcasses to protect against cold shortening and evaporative loss.

TRIAL 2. COMPARISON OF DRY MATTER INTAKE, COMPOSITION OF GAIN AND OTHER MEASURES OF SIMMENTAL BULLS AND STEERS FED TO EQUAL WEIGHT OR AGE.

The higher starting weight of bulls reflects higher preweaning gain since birth dates of bulls and steers were similar. Bulls gained 18% faster and 13% more efficiently than StI. Bulls gained 25% faster and 23% more efficiently than StII. The existence and magnitude of these differences was

expected and agrees with most reported values. Although a statistical comparison would not be valid it is interesting to note that from d 168 to 224 growth of StII was slower (1.20 kg/d) and less efficient (f/g = 8.01) than from d 0 to 167, indicating that the objective of slaughtering steers at the peak of the daily gain curve was met. The increase in magnitude of the performance difference between bulls and steers when steers were fed to weights equal to the bulls reflects the greater lean body mass of the bulls. Although bulls and StI were the same height at slaughter, bulls weighed more due to greater lean body mass. Steers required feeding to a greater calendar age and a larger frame size to equal the weight of the bulls. Because the steers were in the fattening phase after d 167, bone growth was very slow, lean gain was minimal (14.9 g/d of carcass protein accretion), carcass fat gain was high (385 g/d) and weight gain was inefficient.

As is commonly reported, bulls tended to have higher average daily feed intakes than steers when fed to the same age. The higher average intake of StII reflects the 57 d at high body weights and rates of intake. When intake is expressed per 45.5 kg of body weight instead of per head, StI had higher intake than bulls and StII showed a similar trend. When expressed per unit of metabolic body weight there was no difference between groups.

When the same calculations are performed on means of other studies, the results are similar. These data indicate that reports that bulls consume more feed than steers simply

reflect higher body weights of bulls, rather than a difference in appetite and that similar estimates of intake may be used when formulating diets for bulls and steers.

Bulls had higher carcass weights than StI, reflective of higher live weights. The trend toward higher dressing percentage of bulls is apparently a result of increased musculature because of the typically leaner carcasses, heavier hides and equal or greater gut fill of bulls, factors that would tend to favor dressing percentage of steers. The lower dressing percentage of StII is inexplicable, perhaps a function of gut fill. Bulls had less internal, external and intramuscular fat than StI and these differences were magnified when compared to StII. Bulls also had larger ribeye areas than both steer groups and greater ribeye area per 100 kg of carcass weight than StII. The incremental increase in yield grade in the order of bulls, StI, StII indicates the differences in fatness and muscling but also points out that even StII were of acceptable composition for current market conditions.

Marbling scores point out one drawback of bull beef production. The average USDA quality grade of these bulls was low good with high carcass weights. Clearly it would be impractical to feed bulls of this type to the choice grade, this topic was discussed by Able (1982). Smaller frame bulls may be able to reach the choice grade at acceptable weights. Profitable bull beef production is limited by the current marketing system which relies on USDA grades to group carcasses for price determination.

Carcasses from bulls had a lower percentage of fat and a higher percentage of protein. Bulls also had less total carcass fat and more total carcass protein. All groups had similar carcass fat accretion rates, with an average of 459 g/d. Thus, even the lean bulls in this study had considerable rates of fat deposition. These values are comparable to those of Spivey (1980) who reported carcass fat accretion rates of up to 570 g/d in Angus and Simmental bulls fed high energy diets. The higher rates of protein accretion of bulls indicate that the leanness of bull carcasses in this study was not due to slower fat accretion than steers, but rather results from greater lean tissue accretion. This concurs with the data of Vanderwert et al. (1985) who observed equal fat gain but significantly different rates of lean gain in the 9-10-11 rib section of Angus and Limousin bulls and steers. The lower percentage of fat in the bull carcasses reflects a similar amount of fat within a heavier carcass with more total lean. Protein gain as a percentage of dry matter greatly favors bulls.

Bulls had heavier livers than both steer groups but were intermediate between steer groups when liver weight was expressed per unit of carcass weight. Of interest is the decrease in liver weight shown by StII. This is apparently associated with lower rates of gain as StI were gaining 1.6 kg/d at the time of slaughter and StII only .8 kg/d. Koong et al. (1985) discussed that fasting heat production and maintenance requirements vary with nutritional level and rate of

growth. Several experiments were reviewed in which previous nutritional treatment had a profound effect on estimated maintenance requirements, primarily through altering vital organ mass. Apparently, the diminished rate of growth shown by StII during the final 57 d of the experiment, was accompanied by a reduction in the size of the liver.

At the same age, bulls had heavier, denser bones than steers with no difference in length. Similar results have been seen in pigs (Knudson et al., 1985). Apparently testosterone causes thickening of the diaphysis of long bones. StII had longer bones than bulls with identical ratios of weight to height. Bone density values imply equal skeletal maturity at an older calendar age and that bulls show earlier skeletal maturity.

TRIAL 3. THE EFFECT OF DIETARY PROTEIN LEVEL ON RATE, EFFICIENCY AND COMPOSITION OF GAIN AND RELATED ENDOCRINE FACTORS OF GROWING BEEF BULLS.

Bulls fed 10% CP grew slower from d 0 to 66, d 67 to 136 and over the entire trial than bulls fed 12% or 14%. Growth of bulls fed 12% CP did not differ from growth of bulls fed 14% during any period. No treatment differences were noted from d 137 to 202. Apparently 10% dietary CP was adequate to sustain maximum growth of bulls when their live weights exceeded 500kg. These data support recommendations of Williams et al. (1975), Martin et al. (1978) and Martin et al. (1979) as

well as NRC guidelines.

There were no significant differences in carcass measurements due to treatment. Ribeye area means were greater for bulls slaughtered on d 202 while fat thickness did not differ between slaughter groups. It is assumed that bulls slaughtered on d 202 would have been fatter than those slaughtered on d 136 if the energy density of the diet had been greater and it is possible that differences due to treatment would have been observed as well.

Dietary CP level did not significantly affect the percentage of fat or protein in the carcass, nor did any differences exist between carcasses from bulls slaughtered on d 136 and those slaughtered on d 202. Bulls fed 14% CP had numerically greater percentages of carcass fat and lower percentages of carcass protein than the other treatment groups after 136 d of feed but statistical significance eluded this difference. The grand mean of carcass fat percentage was 24.42%. This value is nearly 5% lower than trial 1, apparently due to lower dietary energy level.

Fat deposition increased incrementally with higher dietary CP over d 0 to 136. This is consistent with the increased fat thickness in bulls fed excess protein noted by Williams et al. (1975) and Martin et al. (1978). In this study, however, fat thickness did not differ, nor did percentage of fat in the carcass. Thus, the differences in fat accretion are a result of both significant differences in ADG and subtle differences in composition. The significant

differences found underline the value of calculating accretion rates of carcass fat and protein rather than simply reporting live weight gain and carcass composition. Fat gain did not differ between treatment groups from d 0 to 202 although bulls fed 10% CP had a lower mean.

No significant treatment differences were observed for the d 137 to 202 period despite the fact that bulls fed 14% CP accrued 54% less fat per day than the mean of the other two treatments. The high error term for this period is a result of the excessive variation found when serial slaughter techniques are used and the cattle do not begin the test period as calves. This drawback of serial slaughter methodology was illustrated by Byers (1979).

Bulls fed 10% CP gained less protein per day than the other treatment groups from d 0 to 136. Over the entire trial, bulls fed 10% CP had lower rates of protein deposition than bulls fed 14% CP, bulls fed 12% CP were intermediate. Although no significant differences were observed for the d 137 to 202 period, bulls in the 10% treatment group did exhibit compensatory protein gain when their body weights were high enough that 10% CP met their requirement and maximum growth was sustained.

Serum Cortisol

The absence of treatment effects on circulating cortisol concentrations implies that the nutritional treatments were not severe enough to affect adrenal function. The increase in

serum cortisol as the bulls in the study aged agrees with the data from growing Jersey bulls of Anderson et al. (1973). The increase in circulating cortisol of growing cattle coincides with the increase in fatness, this could be a causatory effect or a permittent effect. Serum cortisol was not significantly correlated with any measure of fatness in this study. This is surprising in light of the data of Cramer and Shahied (1974), Trenkle and Topel (1978), Lundstrom et al. (1983), and Henricks et al. (1984), all of whom found a positive relationship between cortisol and carcass fatness. The absence of such a relationship in this study may be a result of the low cortisol concentrations and relatively low carcass fatness of the bulls. A relationship between cortisol and carcass fatness may have been observed if the bulls had been fed a higher energy diet and deposited more fat.

Growth Hormone

There was no apparent effect of dietary protein level on GH concentrations. While severe protein malnutrition could theoretically affect circulating GH concentration, apparently the treatments used in this experiment were not extreme enough to elicit this effect.

GH means declined over time. From d 136 to 202 bulls fed 14% CP showed a greater decline than bulls fed the other diets. A decline in circulating GH over time has been observed by workers using cattle of the same age (Trenkle, 1971, Joakimsen and Blom, 1976, Trenkle and Topel, 1978, Keller et

al., 1978). Trenkle and Topel (1978) attributed the decline in rate of gain exhibited by cattle as they approach market weight to a decrease in circulating GH and a profound dilution of GH concentration when expressed as GH concentration per unit of body weight. The decrease in circulating GH concentration from d 136 to 202 did coincide with a dramatic decrease in growth rate of the bulls studied.

GH concentrations were not significantly correlated with ADG during any period. This is consistent with most work in this area. While Trenkle and Topel (1978) obtained significant correlations between plasma GH concentrations and the percentage of muscle in the carcass, GH means were not related to ribeye area, carcass percentage protein or protein deposition rate in this study. Perhaps a more variable group of cattle, such as those used by the Iowa workers, would have exhibited more noticeable relationships between GH and other variables. Negative correlations between GH concentrations and fat deposition rate and fat thickness did approach significance. This has been observed by several workers.

Insulin

The significantly greater insulin concentrations of the bulls fed 12% protein when compared to the other treatment groups mandate that concern be expressed about the other hormone data from this study. No explanation is apparent for the difference between groups on d 0. Bulls were randomized within the facility when blood samples were collected and

samples were randomized within the assay. Thus, this difference cannot be explained by differences in collection or handling of the samples, or by assay error. After the data were analyzed, several samples from bulls fed 12% CP and from other bulls were reassayed and results were similar to the original assay. Consequently, it must be concluded that the five bulls that were randomly assigned to the 12% treatment group each had significantly greater concentrations of serum insulin than the other bulls in this study. While nothing else seemed unusual about these particular bulls, this fact clouds the conclusions that can be drawn.

The high insulin concentrations of the bulls in the 12% treatment group also diminished the opportunity to investigate the relationship between serum insulin concentrations and various measures of carcass composition. Insulin concentrations of the individual bulls in the study were unrelated to any other variable measured. Trenkle and Topel (1978) have shown that insulin was positively related to carcass fatness in a group of cattle with some similarities to the group used in this study. It was expected that serum insulin concentrations would provide insight into the factors that control composition of gain but the difference in baseline concentrations precluded these discoveries. The difference from baseline values reported in table 21 may not accurately represent the insulin status of the bulls or the effect of the dietary treatments on insulin.

Somatomedin-C

Bulls fed 14% dietary CP had lower plasma SM-C concentrations than bulls fed 10%, with bulls fed 12% intermediate. Mean SM-C was lower on d 0 than the other sampling dates. SM-C was negatively correlated with percent carcass fat ($R=-.60$; $P<.05$), carcass fat accretion rate ($R=-.57$; $P<.05$), total carcass fat ($R=-.52$; $P<.05$) and fat thickness ($R=-.73$; $P<.01$). SM-C concentration was positively correlated with the percentage of protein in the carcass ($R=.60$; $P<.05$). While not statistically separable, the highest mean SM-C concentration within each treatment group was observed during the period of greatest protein accretion for that treatment.

Care must be exercised when interpreting these data. The assay used measures total immunoreactive SM-C. This includes free SM-C (less than 1% of circulating SM-C) and may include some of that bound to carrier protein, which constitutes the vast majority. Only free SM-C is biologically active. It has been postulated that bound SM-C serves simply as a reservoir since SM-C is not stored in tissues (Spencer, 1986). If the SM-C carrier protein served as a homeostatic mechanism, the only function of which is to remove SM-C from its active sites, then only the autocrine or paracrine actions of SM-C are of importance. In that case, circulating SM-C concentrations are of questionable importance and may provide only an after the fact measure of SM-C production or activity. In an evolutionary sense, this is unusual. The large quantities of bound SM-C that are found in circulation would represent

inefficient use of protein if the binding proteins serve only to remove SM-C after it has exerted its biological influence. Thus, it seems more plausible that bound SM-C is a storage form that can be used. The value of either total or free SM-C concentration to assess the metabolic state of an animal is yet unclear and this field of study requires further pursuit.

Those investigators who have been able to show significant correlations between somatomedins and growth rate (Ringberg-Lundlarsen et al., 1977; Ringberg et al., 1979), have used bioassays to measure SM activity. Bioassays may measure a different compound than the radioimmunoassays currently available or may measure some other compounds in addition to SM. Further, the time course of a typical bioassay would allow for dissociation of the SM-carrier protein complex during the assay, possibly resulting in a false indication of the physiological state of the animal in question.

The strong negative correlations between SM-C and various measures of fatness may be related to an interaction between SM-C and cortisol. Circulating SM-C was negatively correlated with circulating cortisol level ($R=-.53$; $P<.05$). Phillips et al. (1982) reported that cortisol reduced secretion of somatomedin as well as somatomedin activity in cartilage tissue. If the effect of cortisol on somatomedin is similar in adipose tissue, the low cortisol values of the bulls in this study may explain the relationship between SM-C and measures of fatness by not interfering with SM activity.

Testosterone

Testosterone values, as well as scrotal circumference measurements, indicate that all bulls used in the study were peripuberal or postpuberal at the onset of the study. The fact that dietary crude protein level did not affect the serum testosterone content of the bulls indicates that the treatments were not severe.

Serum testosterone concentrations of the bulls in this study were higher than reported by others for bulls of this age. The bulls also had relatively large scrotal circumference measurements and were very masculine in appearance.

The high testosterone concentrations may account for the leanness of the carcasses of these bulls. Certainly, the presence of testosterone is the ultimate cause for most of the differences between intact males and castrates, which are fatter. Testosterone has been shown to decrease the ACTH stimulated production of cortisol (Thomas and Rodway, 1982a,b; 1983a,b; Bukowski et al. 1986). An animal with high circulating testosterone, an anabolic hormone, would then be expected to have low circulating cortisol, which exerts catabolic effects on protein, is gluconeogenic in effect and usually related to fatness. A high testosterone/cortisol ratio would then seem the ideal physiologic state for maximum lean tissue accretion with minimum fat accumulation. The bulls in this study coupled high testosterone concentrations with unusually low serum cortisol concentrations. This may partially explain the low carcass fatness of these bulls and the high

rates of lean tissue accretion. This is not a cause and effect relationship, however, as the individual testosterone/cortisol ratio of the bulls was not significantly correlated with any measure of composition.

GENERAL DISCUSSION

Data generated in trials 1 and 3 provide support for NRC recommended dietary protein levels. Diets containing 12% dietary crude protein appear adequate to support maximum growth of bulls of the type studied for the experimental period, similar to a typical finishing period in a feedlot. Although bulls fed 14% CP did exhibit superior performance for the first 56 d of trial 1 and for the first 28 d of trial 3 (data not shown), compensation by the 12% treatment group resulted in no statistical significance for the entire trial. A useful experiment to follow this work would include diets that include NRC recommended CP levels. Diets would be reformulated as weight and rate of gain of the bulls changed, and performance compared to a positive control.

The effect of dietary crude protein level on composition of gain has not been fully elucidated. While 12% CP is adequate for beef production from bulls, the cautious manager of a bull testing station should consider slightly higher levels for bulls intended for breeding because of the possibility of over fattening. From the data of trial 2 it is clear that the estimates of feed intake that are currently used to formulate diets for steers would be adequate for bulls.

The administration of the dietary treatments in trial 3 may have interfered with interpretation of results from the hormone analyses. The levels of dietary protein served well to evaluate the protein needs of the bulls studied. They may not have been ideal for the objectives in mind when sampling of the hormones was planned. Few treatment differences in hormone concentration were noted, despite differences in performance of the bulls. Perhaps the dietary treatments were not severe enough to alter the endocrine status of the bulls in a manner that could be observed by the methods employed. At the same time, the dietary treatments may have been sufficiently severe that they masked some relationships between the hormones studied and rate or composition that would otherwise have been observed.

SUMMARY

1. Bulls gained 18% faster and 13% more efficiently than steers for the same time and 25% faster and 23% more efficiently than steers when fed to the same weight.

2. Bulls tended to eat more than steers but on a body weight basis ate less. When intake was expressed per unit of metabolic body size, no differences were observed.

3. Bulls and steers had similar rates of carcass fat accretion. Bulls excelled steers in the rate of carcass protein accretion and in the portion of dry matter gain that was protein.

4. Diets containing 10% crude protein suppressed daily gain and feed conversion efficiency when bulls weighed less than 500 kg. Feed intake was not affected.

5. Bulls fed 12% CP gained slower than bulls fed 14% CP for a brief portion of each trial, but compensated and no significant differences were reported for the entire trial.

6. Growth hormone and SM-C means are correlated negatively with measures of fatness and SM-C means appear to parallel protein accretion.

7. Cortisol, insulin, testosterone, T3 and T4 were not correlated significantly with rate or composition of gain.

8. SM-C was lower in bulls fed 14% CP than in bulls fed 10% CP with bulls fed 12% intermediate.

9. As bulls aged from 9 to 15 months and their weight increased from 350 to 600 kg: testosterone concentrations increased, peaked, then dropped; cortisol reacted inversely; growth hormone declined; Sm-C increased; and T3 and T4 increased.

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