A STUDY OF SOME FACTORS AFFECTING FEED INTAKE AND PERFORMANCE OF STEERS

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INTRODUCTION

Adequate feed consumption is essential for satisfactory animal performance and is, therefore, one of the primary considerations of all livestock producers. Many times the genetic potential for production is not utilized due to sub-optimum levels of feed intake. The exact physiological mechanisms involved in voluntary feed consumption are not clearly defined, but research in this area has included neurological, chemical, thermostatic and physical factors. Much of the research to date has been conducted with mono-gastric animals. Due to the physiological differences between monogastric and ruminant animals and the wide differences in diets fed these two types of animals, it may be hazardous to transpose the experimental conclusions to ruminants.

Several theories concerning regulation of feed intake in ruminants have been proposed. British workers have suggested that when ruminants are fed an all-roughage diet, the voluntary intake is limited by capacity of the gastro-intestinal tract. However, when high concentrate rations are fed, there is a characteristic reduction in total feed intake and, in some cases, a reduction in caloric intake when compared with conventional roughage-containing rations. It is doubtful if capacity of the digestive tract is the factor limiting intake in the case of ruminants fed high concentrate rations. Chemostatic factors, thermostatic factors or a combination of factors may regulate food intake when rumen load or fill is not of primary importance.

Animals have an energy requirement for maintenance which must be met before energy can be used for production. Therefore, as animals increase feed intake above maintenance, total production also increases. If the mechanisms controlling feed intake could be determined, proper alterations in the diet and feeding practices could possibly result in increased feed consumption and greater total animal production as well as improved efficiency of feed utilization.

These experiments were conducted to determine some of the factors affecting feed intake and performance of steers when fed *ad libitum* rations varying in bulk, density, caloric source and energy concentration.

REVIEW OF LITERATURE

General

Recently the number of studies concerned with voluntary feed intake of animals has increased substantially. Previously it was thought that feed intake was largely a reflection of palatability. Now, more research emphasis is being placed on the physical and chemical characteristics of rations since these factors may be associated with voluntary intake of dietary ingredients or complete rations. Much of the research concerned with factors affecting feed intake of ruminants has been based on similar work with monogastric animals. For this reason, results from experiments with laboratory animals have been included in this review. However, the widely different diets fed to ruminants and the characteristics of ruminant digestion must be considered in any attempt to transpose information obtained from experiments with mongastric animals.

Animals which have access to their natural foods do not normally starve or overeat to a harmful extent. This provides evidence for regulatory mechanisms which ensure that animals eat when food is required and stop eating when enough has been consumed. Grossman (1955) stated that the body's content of nutrients is the main item maintained relatively constant by regulation of food intake.

The process which tends to regulate body stores of nutrients to a great extent involves hunger and appetite. Hunger, as defined by Grossman (1955), is the complex of sensations evoked by depletion of body nutrient stores; and appetite is the desire to consume food. Fullness designates the complex of sensations associated with repletion of body nutrient stores, and satiety is the corresponding affective state of repletion signifying a lack of desire to eat. Brobeck (1955) stated that "the regulation of food intake is not an isolated phenomenon, but is an intimate part of the regulation of energy exchange involving heat production and heat loss, the expenditure of energy for activity and the storage of energy as protein, carbohydrate, and fat."

Some of the theories advanced to explain the regulation of food intake are regulation by the central nervous system (Anand, 1961), thermostatic regulation (Brobeck, 1955), glucostatic regulation (Mayer, 1955), lipostatic regulation (Kennedy, 1953) and gastric distention (Janowitz and Grossman, 1949; Blaxter _et al_., 1961). Additional factors which may influence voluntary feed intake in ruminants are body weight, level of production, rate of ingesta passage, type and quality of feed and frequency of feeding (Mather, 1959; Conrad _et al_., 1964). These theories and other factors will be discussed in this review.

Role of the Central Nervous System in Regulation of Food Intake

It has been demonstrated that the hypothalamus contains nuclei which are active in initiating and halting food consumption (Anand and Brobeck, 1951; Brobeck, 1955; Anand, 1961). Kennedy (1950) observed that lesions in the region of the ventromedial nuclei produce hyperphagia and obesity in rats. Electrical or other stimulation of this same area produces hypophagia; thus, the area has been called the "satiety center" (Wyrwicka and Dobrzecka, 1960; Anand, 1961; Andersson and Larsson, 1961b). Bilateral lesions in the lateral hypothalamus cause temporary or permanent aphagia (Anand and Brobeck, 1951; Mayer and Sudsaneh, 1959). This anatomical region of the hypothalamus has been called the "feeding center" since stimulation results in hyperphagia (Andersson and Larsson, 1961b; Anand, 1961).

Anand (1961) stated that the mechanisms for regulation of feeding and locomotion to food are integrated in the hypothalamic region. Brobeck (1955) suggested that the role of the hypothalamus in regulating food intake could be expressed in two types of activity--facilitation or inhibition, with the lateral hypothalamus acting as a facilitatory area and the medial region acting as an inhibitory area for feeding reflexes.

There is evidence to indicate that "higher" nervous centers are also involved in the regulation of food intake. Bruce and Kennedy (1951) suggested two distinct urges to eat; hunger, the central regulator of which is located in the hypothalamus; and appetite, the central regulator of which is situated in the cerebral cortex. Anand _et al_. (1958) noted that frontal lobe lesions restricted to the posterior orbital cortex led to a decrease in food intake, and that lesions sparing this area were followed by an increase in intake. The effects were more pronounced in monkeys than in cats, indicating a possibility of species differences. These workers concluded that the frontal and temporal lobe structures modify food intake through a discriminating mechanism (appetite) which also influences the primative urge (hunger). Bell and Lawn (1955) found that the electrical stimulation of certain loci in the medulla oblongata of sheep produced physiological responses associated with eating. These workers obtained reticuloruminal, oesophageal, laryngeal and respiratory responses. However, Clark (1953) reported that the medulla does not contain the center for control of rumination or motility of the reticulo-rumen.

Chemostatic Regulation of Food Intake

Glucostatic Regulation

For short-term regulation of energy exchange in monogastric animals, Mayer (1955) proposed the "glucostatic" theory. This theory postulates that "glucoreceptors" in the hypothalamus are sensitive to the rate of glucose utilization. Using human subjects, Van Itallie _et al_. (1953) reported that the arteriovenous (A-V) glucose difference (Δ-glucose), rather than blood glucose concentration, is important in regulating food intake. Values for Δ-glucose throughout the day generally reflected the previous dietary intake. When values for Δ-glucose remained appreciable (greater than 15 mg. per cent) hunger was not reported; but Δ-glucose values approaching zero were associated with hunger. Anand _et al_. (1961) obtained similar results with cats and monkeys. It has been observed in monkeys, cats, and dogs that electrical activity of satiety centers shows marked increase after feeding and this is accompanied by a simultaneous drop in electrical activity of feeding centers (Anand _et al_., 1961; Anand _et al_., 1962).

Further evidence for the "glucostatic" theory and the presence of "glucoreceptors" in the hypothalamus has been reported by Marshall _et al_. (1955) and Debons _et al_. (1962). In these experiments, injections of goldthioglucose produced obesity in mice and caused extensive damage in ventromedial nuclei of the hypothalamus. However, in human subjects, Grossman (1955) found that hyperglycemia with an elevated A-V glucose difference did not significantly decrease hunger sensations, appetite, or food consumption. He felt that his findings constituted crucial evidence against the glucostatic hypothesis.

Although it is possible that there is some form of chemoregulatory control of food intake in the ruminant, Manning _et al_. (1959) considered it unlikely that the metabolite is glucose. Intravenous infusions from 1.67 to 8.3 gm. glucose per kg. body weight were made over a 2-hour period and did not affect food consumption or feeding behavior of ewes. Similar observations were made by Holder (1963) with sheep and by Dowden and Jacobson (1960) using cattle. Ulyatt (1965) found no significant effect on the feed intake of sheep when glucose was administered intra-ruminally at the rate of 1 gm. per kg. body weight. Reid (1950a, 1950b) presented further evidence which tends to eliminate blood glucose *per se* as a regulating metabolite in ruminants. He reported no appreciable rise in blood glucose levels in response to feed consumption in sheep. He also found low A-V differences and only slight variation in blood glucose levels. However, McClymont and Setchell (1956) reported considerable glucose uptake by tissues located in the head of sheep.

Lipostatic Regulation

Kennedy (1953) suggested that the hypothalamic satiety mechanism is concerned only in the prevention of an overall surplus of energy intake over expenditure, which would cause the deposition of adipose tissue. His proposed method for this lipostasis is based on the sensitivity of the satiety center to the concentration of circulating metabolites and the level of these blood metabolites in turn being influenced by the amount of fat in depots. The fact that wide variations in the chemical composition of the diet were without effect on the caloric intake of rats suggested to him that control of intake is influenced by a complex of metabolites in the blood stream rather than by glucose alone.

Mayer (1955) supported the "lipostatic" theory as a possible means of long-term regulation of body reserves. He proposed a modified theory based on mobilization each day of a quantity of fat proportional to the total fat content of the body with any increase in fat content being followed by increased availability of readily utilizable fat. In contrast to the "lipostatic" theory, Mayer and Bates (1952) reported that the intravenous infusion of fat did not reduce feed intake of rats when the caloric equivalent of the injected fat was taken into account.

Presently in ruminants, there is no direct evidence for the operation of a mechanism conforming to the lipostatic hypothesis of Kennedy (1953).

Regulation by Dietary Protein and Serum Amino Acids

Dietary protein and serum amino acid concentration are two other possible regulatory factors. Mellingkoff et al. (1956) found that appetite was inversely correlated with serum amino acid concentration in human subjects. Using rats, Sanahuja and Harper (1962, 1963) stated that both food intake and food selection are influenced by the amino acid pattern of the diet. They concluded that a depression in food intake resulting from feeding imbalanced diets and diets totally deficient in one amino acid could be produced by an altered blood amino acid pattern.

Due to the unique protein metabolism in ruminants, very few specific studies on the influence of protein and amino acids on feed intake have been reported. However, Campling et al. (1961) recognized that the introduction of urea into the rumen of cattle increased both digestibility and intake of oat straw. Hemsley and Moir (1963) also obtained increased intake when urea was fed with oat hay. Raleigh and Wallace (1963) observed that steers consumed significantly more meadow hay supplemented with urea and/or cottonseed meal at the 9 and 12 per cent crude protein levels than at lower levels. Preston and Burroughs (1958) reported that protein level affected both feed intake and the serum amino acid nitrogen level of lambs. Thus, in some way, protein may also play a role in chemostatic regulation.

Most workers feel that protein exerts its influence on feed intake by affecting the rate of food digestion. The importance of this factor will be discussed in another section.

Regulation by Other Metabolites

In contradiction to a report by McClymont and Setchell (1956), Reid (1950b) stated that the A-V difference in volatile fatty acids was considerable in sheep. Since the carotid artery was used as the source of arterial blood, the A-V difference indicated removal of acetic acid by tissues in the head. Dowden and Jacobson (1960) administered sodium acetate, glucose, and acetic, propionic, valeric, hexanoic and lactic acids to dairy cattle by intravenous drip. Only acetic and propionic acids resulted in significant reductions in feed intake. These results further suggested the existence of a chemoreceptor response to changes in concentration of blood constituents in ruminants. Little and Hawkins (1963) found that feed intake by steers (per eating interval per 100 lbs. of body weight) was not related to starting and finishing levels of blood acetic acid *per se*; however, the change in acetic acid level from initiation to termination of feeding intervals was highly significant.

Farhan's (1965) work showed no consistent linear relationship between blood concentration of acetate and feed intake by young dairy calves. Significant correlations were not found between rate of utilization of blood acetate by body tissues and feed intake, nor was there evidence of a threshold level for blood acetate with respect to feed intake. Holder (1963) noted that intravenous infusions of acetate which resulted in higher than normal post-prandial blood acetate levels in sheep did not affect feed intake.

Ulyatt (1965) stated that peripheral intravenous infusions bypass the rumen epithelium and the liver, both sites of metabolism of volatile fatty acids. He pointed out that experiments in which propionic and butyric acids are administered in this fashion must be considered unsatisfactory in view of the low concentration of these acids normally present in the blood.

Several workers have studied the effects of intraruminal infusion of various rumen metabolites. Rook *et al*. (1960) reported that acetic acid introduced into the rumen of heifers reduced appetite. Montgomery *et al*. (1963) discovered that the infusion of acetic acid gave a significant reduction on the daily hay consumption by dairy cows. The sodium salts of acetic acid and lactic acid caused only a slight reduction in hay intake. Propionic acid produced no reduction in intake, and butyric acid caused only a moderate reduction. Simkins et al. (1965b) observed that infusions of propionate and butyrate significantly reduced the 3-hour intake of cows receiving hay, and infusions of acetate and propionate brought about a significant reduction in 3-hour intake of pellets (75% alfalfa and 25% corn). These workers concluded that a chemostatic mechanism elicited by volatile fatty acids is an important component of food intake regulation. Ulyatt (1965) found a linear and inverse relationship between dose rate of acetic acid and feed intake in sheep. With propionic acid, food intake was increased by a 200 calorie dose and was decreased by a 300 calorie dose. The depressing effects of both acids were more pronounced on a low-energy chaff diet than on a concentrate diet. Thus, simple substitution of food calories by acid calories cannot be used to explain the effects of the infusions.

In a study by Hillman et al. (1958), it was evident that cows consumed more dry matter when fed hay than when fed silage. In subsequent trials they found that water content and pH were not the limiting factors. Moore et al. (1960) also stated that water per se was not the reason for reduced dry matter intake by cows fed silage. They further reported that administration of effluent from a silo into the rumen of heifers fed alfalfa hay caused a reduction in dry matter intake. However, intraruminal infusions of lactic, acetic, and propionic acids singly or in combination did not cause a reduction in dry matter intake of alfalfa hay. These workers concluded that the reduction in intake may have been due to a change in the protein fraction of the silage. Campling (1964) contended that there is little evidence to show that any of the previously mentioned compounds administered intraruminally are the natural cause of the reduced dry matter intake when silage is fed. Manning et al. (1959) suggested that a combination of effects by acetate and propionate serving as metabolites may regulate appetite in ruminants.

Thermostatic Regulation of Food Consumption

Strominger and Brobeck (1953) proposed the thermostatic theory in which the day-to-day regulation of food intake is regulated indirectly via the heat liberated during assimilation of the food. These workers concluded that the specific dynamic action (SDA) of a food is more important than its caloric content. The theory is based on the observations that animals reduce their feed intake in warm weather and increase it in cold weather; in other words, "animals eat to keep warm and stop eating to prevent hyperthermia." The proposed mechanism for this regulation is the reaction of the hypothalamus to changes in blood temperature.

Both Kennedy (1953) and Mayer (1955) objected to the thermostatic theory and presented information which tended to minimize its importance as a regulating mechanism.

In support of the thermostatic theory, Andersson and

Larsson (1961a) working with a goat, demonstrated that local cooling of the preoptic area and the rostral hypothalamus induced eating shortly after a meal. The cooling stimulated the animal to eat hay even when the body temperature was greater than 41° C. Warming of the same area inhibited eating in the hungry goat. However, it has not been shown that this mechanism operates under normal conditions.

Hamilton and Brobeck (1964) proposed that the anterior midline portion of the hypothalamus is involved not only with normal regulation of body temperature, but also with food intake and thus, indirectly with internal heat production.

Effects of Caloric Content, Bulk and Density of the Ration on Food Intake

Caloric content, bulk and density (weight per unit volume) of a ration are factors which may affect feed intake. Lepkovsky et al. (1962) summarized that the constancy in energy stores of the body in adult animals is achieved by regulation of energy intake. Kennedy (1953) reported that the caloric content of food seemed to be the main regulator of intake in the rat. When fat, carbohydrate or protein was added to the diets of rats, Strominger et al. (1953) observed that the total grain intake varied inversely with caloric density of the diet; however, in rapidly growing rats, abnormally high caloric intake on high fat diets occurred during a 22-day trial. In an experiment with dogs, Janowitz and Grossman (1949a) studied the effects of a varied caloric content of food on daily intake. They found that even though all dogs made some adjustment in food intake, the tendency to ingest a constant daily volume of food, "eating for bulk", was modified only slowly and incompletely by a tendency to balance caloric deficits, "eating for calories". In another trial with dogs, Janowitz and Hollander (1955) fed rations containing 50, 100 and 175 per cent of the caloric requirements through fistulas. The dogs still ate small amounts of food above the caloric requirement for four to seven weeks; however, at the end of this time, exact caloric intake adjustments had been made. These workers proposed the existance of two regulatory mechanisms--(1) a metabolic device for insuring adequate caloric intake under conditions of varying needs and (2) a neural mechanism tending to maintain the act of ingestion regardless of caloric needs.

Peterson et al. (1954) replaced glucose with wood-pulp cellulose in poultry rations and found that feed intake increased with increasing levels of cellulose. The chickens appeared to be eating for energy. Bolton (1958) found that pullets on a low-energy diet ate more feed than those on a high-energy ration, but daily intakes of digestible protein, digestible energy and metabolizable energy were the same for both groups.

Preston and Burroughs (1958) reported that lambs receiving high and low energy rations (665 and 530 calories of estimated net energy per lb. ration) consumed significantly more of the low-energy ration per day. Blood serum glucose levels were higher in lambs fed the high-energy rations. Therefore, the effects of calories *per se* on intake may have been confounded with the effects of blood metabolites. Church and Ralston (1963) and Erwin *et al*. (1963) also demonstrated a reduction in feed intake with high-energy rations fed to steers. Evidence to support the hypothesis that ruminants will adjust voluntary food intake in relation to physiological demand for energy if fill or rumen load does not limit consumption has been presented by Montgomery and Baumgardt (1965a).

A concept of bulk (indigestible matter) and feed volume (dry matter) was introduced by Tehmann (Fisher and Weiss, 1956) who pointed out their importance in relation to satisfying the animal's needs in two ways--physiological satisfaction and satisfaction of the appetite. The ideal is to have both requirements satisfied at the same time. According to Tehmann, if appetite is satisfied by bulk before physiological needs, the animal will stop eating before it gets all of its requirements; if the reverse happens, then the animal will overeat physiologically. The dry matter content, the amount of ballast or indigestible organic matter, and the fiber content of rations have been considered as important factors affecting feed intake (Makela, 1956).

Makela (1956) quoted Paloheimo as stating that water is not a factor of bulk in ruminants, but that the bulk of the food is increased by circumstances which cause a reduction in food value of the dry matter. He applied the term "bulky" to foods which had a long retention time in the rumen and those which required thorough rumination. Lehmann, cited by Makela

(1956), concluded that the amount of indigestible organic matter, or ballast, determines how much cattle are able to eat. After a thorough review on the effects of bulk, Makela (1956) concluded that the consumption of digestible organic matter did not seem to be as variable with different diets as the amount of consumed ballast, and that neither was as constant as the consumed quantity of dry matter. Thus, he favored dry matter content as the most important factor of bulk affecting feed intake.

Maynard and Loosli (1962) considered crude-fiber content as an important factor governing the bulk of a ration. In poultry, Fisher and Weiss (1956) have found that fiber *per se* is an important factor influencing feed intake independent of energy level of the diet. Using wheat straw meal, Axelson and Eriksson (1953) raised the fiber per cent of dry matter from 4.8 to 9.3 in swine rations. They observed that the feed intake increased slightly with an increased level of fiber and that the intake of metabolizable energy decreased as fiber levels were increased. Eng (1965) fed lambs rations varying in bulk and/or fiber content. At each ambient temperature level below 100° F., the daily intake of digestible dry matter for all rations was approximately the same. According to Blaxter (1950), no factor of bulk present in the ration is alone capable of accounting for the amount of food consumed by cattle when food is fed *ad libitum*.

Results of work by Gordon and Erwin (1960) revealed that steers can be fed like monogastric animals and that roughages play little or no role in steer rations other than by diluting the caloric density of the ration. Carr and Jacobson (1962) concluded that mass or bulk added directly to rumen contents has little effect on maximum voluntary intake of roughage.

Very few experiments designed to study the effects of density *per se* have been conducted. According to Maynard and Loosli (1962), the weight of a given volume of food is an important factor in regard to the properties of bulk of grain mixtures. The pelleting of a ration tends to increase the density of that ration. McCroskey *et al*. (1961) found that pelleting a ration with a concentrate to roughage ratio of 1:4 increased daily consumption by steers, while pelleting a ration with a 4:1 ratio reduced feed intake.

Minson (1963) reported that wafering hay also increased daily consumption. Most workers have found that the pelleting of a high roughage ration results in increased feed intake (Cullison, 1961; Moore, 1964). A possible explanation may be that by increasing the density of the feed, the distention effect of the roughage is reduced. Since pelleting is usually preceded by grinding, the smaller particle size may affect feed intake indirectly by influencing retention time of food particles in the digestive tract.

Density *per se* may also affect the rate of passage of food particles. Hoelzel (1930) found that the rate of passage of inert materials was more or less proportional to the specific gravity of the test materials; the heavier materials passed slower than the lighter materials. When plastic materials were fed to cattle, King and Moore (1957) observed a maximum rate of passage when the density was approximately 1.2 gm. per cubic centimeter. Results of work by Cooley (1963) were in direct contrast with this. In cattle, he found a faster rate of passage of particles with a specific gravity of 1.425 as compared to particles with a specific gravity of 1.14.

Role of the Gastrointestinal Tract in Regulation of Food Intake

Distention and Tract Contents

Janowitz and Grossman (1949b) found that the introduction of food through a fistula into the stomach of dogs immediately prior to offering the regular meal resulted in a decrease in voluntary intake by an equivalent amount. Inert material was just as effective as food, indicating that the effect was a mechanical one due to distention. Janowitz and Grossman (1951) reported that the tendency of the dog to ingest a constant average daily volume of food was not significantly modified in short-term experiments by feeding small portions of sucrose solution, cream, casein, alcohol or bitters 20 minutes before the regular meal. Since considerable time is required for the digestion and assimilation of nutrients following ingestion, Grossman (1955) proposed that mechanisms must exist for sensing the quantity of nutrients ingested before they undergo metabolism and that distention of the stomach is one possible mechanism.

It has been suggested that satiety in cattle is controlled primarily by the filling of the reticulo-rumen, and this in turn depends on the volume of the organ and the time the feed remains in these compartments (Kruger and Muller, 1956). Blaxter *et al*. (1956) concluded that the maximal appetite of animals is determined to a considerable extent by food residues present in the digestive tract. Campling *et al*. (1961) suggested that the voluntary intake of roughage by cattle is regulated by rate of disappearance from the alimentary tract. Furthermore, this is done in such a way as to maintain a constant amount of food residue in the reticulo-rumen immediately before feeding. When cattle were fed either hay or straw *ad libitum*, the daily intake of the two hays was quite different; however, the difference in dry matter content of the rumen was only 0.8 lb. or 6 per cent. Campling and Balch (1961) demonstrated that the removal of hay boluses at the cardia prolonged eating as much as 4 hours and increased total intake by 70-85 per cent in cattle. These workers observed that when 50 lb. of digesta from one cow were added to the rumen of a second cow or when water-filled bladders were placed into the rumen, hay intake decreased; however, 100 lb. of water added directly to the rumen had little effect on feed intake. Veltman and Thomas (1963) obtained a reduction in voluntary feed intake by intraruminal administration of hay, silage or beet pulp.

Since the daily intake of high concentrate rations is usually lower than that observed for rations containing some roughage, it is doubtful that the voluntary intake of high concentrate rations is limited by distention of the digestive tract components (Freer and Campling, 1963). Baile and Pfander (1964) concluded that animals fed roughage rations consume feed until some level of physical distention is reached; and, in the case of high concentrate rations, some mechanism other than physical distention controls intake.

Grossman et al. (1947) showed that the daily food intakes of normal dogs and dogs with denervated stomachs were the same. Thus, the importance of distention in regulating food intake may be questionable.

Rate of Digestion and Rate of Passage of Food Particles

Rate of digestion and rate of passage are very closely associated with distention of the tract and food residues present in the tract. Blaxter et al. (1956) observed that animals given highly digestible forages which passed through the tract rapidly had larger appetites than those given foods of low digestibility and slow passage. From studies with sheep, Crampton (1957) concluded that the extent of voluntary consumption of a forage is limited primarily by the rate of digestion of cellulose and hemicellulose. Conrad et al. (1960) found that daily silage intake by cattle was reduced and required 2-4 weeks to reach a new maximum whenever the dry matter digestibility was suppressed by sudden changes in the type of silage fed. Campling et al. (1961) suggested that the reason for a low intake of straw relative to hay was a slower breakdown of straw to optimum size for passage from the rumen. Freer _et al_. (1962) reached a similar conclusion. Campling _et al_. (1962) found that the administration of urea into the rumen increased rate of digestion and in turn increased the daily intake of straw.

Ewing and Smith (1917) and Blaxter _et al_. (1956) found that an increase in the quantity of feed consumed by steers was associated with a faster rate of passage. However, whether a short retention time is caused by or is the cause of a high voluntary intake remains to be determined. Crampton (1957) concluded that the more quickly ingesta moves out of the gastric structures, the sooner hunger recurs; and thus, more food is eaten over a given period of time.

With regard to the role of the digestive tract in regulating food intake, there are distinct differences between the effects of roughage rations and concentrate rations. Freer and Campling (1963) reported that with hay and dried grass, the mean retention times in the tract were inversely related to the amount of food consumed, while retention times for concentrates were not related to amounts eaten. With roughages, there was a constant amount of digesta dry matter present immediately before the next meal; however, with concentrates, the amount of digesta dry matter did not approach this level before or after feeding.

Rodrique and Allen (1960) ground hay to various degrees of fineness and reported that the finer the grind, the greater the depression in digestibility of the ration and the faster the rate of excretion in lactating cows. Thus, the effects of rate of digestion and rate of passage may influence the level of blood metabolites and, in turn, entail both physical and chemical regulating mechanisms.

Gastric Motility and Contractions

Several studies concerning the role of gastric contractions and motility have been reported (Schalk and Amadon, 1928; Phillipson, 1952; Hogan and Phillipson, 1960). Quigley (1955) stated that, in man, the desire to eat is a response to specialized hunger contractions of the stomach. Although stomach contractions seem to be associated with the sensation of hunger in man, it appears that their role in regulating food intake is only secondary (Grossman, 1955; Anand, 1961).

Constriction of the Tract

Some workers feel that constriction of the digestive tract by internal fat or the gravid uterus may inhibit feed intake. Blaxter (1957) cited results which indicated that, in ruminants, voluntary feed intake dropped during the last one-fifth of pregnancy. He also observed that excessively fat cows reduced feed intake greatly during pregnancy. Taylor (1959) reported that fill weights were lower in steers carrying more internal fat.

Effects of Environmental Temperature on Food Consumption

Acute exposure to heat brought about a decrease in food intake in rats (Mayer, 1955). After a short period of exposure to cold, food intake increased. Wayman *et al*. (1962) reported that when the environmental temperature of cows was increased to 88° F. or above, daily feed intake decreased. Eng (1965) observed a decline in digestible dry matter intake by sheep as the temperature was increased above 55° F. Garrett *et al*. (1960) demonstrated that shade or shade and fans would increase feed consumption by steers during hot weather.

Other Factors Associated with Regulation of Food Intake

Hormones

Janowitz and Grossman (1951) reported that the physiological release of enterogastrone was apparently not involved in the production of satiety in dogs. Insulin has been found to stimulate the appetite in monogastric animals (Grossman *et al*., 1947). These workers suggested that insulin-induced hypoglycemia may act directly upon the brain to excite hunger. Meites and Turner (1948) reported that large doses of estrogen reduced food and water intake by goats. Anand (1961) stated that treatment of animals with hormones will influence the energy requirement and thus, indirectly alter the long-term regulation of food intake.

Frequency of Feeding

Frequency of feeding and time of access to feed appears to influence feed intake. Mohrman *et al*. (1959) reported that cattle fed a 35 per cent roughage ration six times per day consumed 17 per cent more feed than cattle fed two times per day. Campbell and Merilan (1961) found that feed intake (alfalfa hay, beet pulp, grain) by dairy cows increased as frequency of feeding was increased from two to four or seven times per day. When cows were fed concentrates, feed intake was 84 per cent greater on an ad libitum regime as compared to a daily feed access of 5 hours (Freer and Campling, 1963). On the other hand, Rhodes and Wood (1962) found no significant differences in feed intake when lambs were fed two, four or six times daily. Blaxter et al. (1961) reported similar results with two and four feedings for lambs. Murdock (1964) reported that the intake of unwilted silage by sheep increased significantly when access was allowed for 24 hours instead of 3 hours.

Putnam et al. (1961) indicated that the total VFA concentration in rumen fluid was greater in heifer calves fed ten times per day than in those fed only twice daily. Thus, frequency of feeding could be involved in both physical and chemical regulating mechanisms.

Oropharyngeal Regulation

Janowitz and Grossman (1949b) found that in esophagostomized dogs, sham feeding resulted in the consumption of greater quantities of food than in intact animals. Grossman (1955) concluded that the oropharyngeal component is weak when acting alone and potent when acting with the gastrointestinal component in monogastric animals. Since Campling and Balch (1961) reported that removal of boluses at the cardia in ruminants led to an increased feed intake and feeding time, it appears that oropharyngeal regulation is likely to be only a minor factor influencing feed intake of ruminants.

TRIAL 1

Materials and Methods

This trial, initiated in the fall of 1962, was conducted to obtain preliminary information concerning the effects of ration bulk, ration density (weight per unit of volume), caloric source and energy concentration on feed intake and performance of steers. After having been fed a standard ration for 2 weeks, 30 yearling Hereford steers with an average weight of 760 lb. were allotted on the basis of 12-hour shrunk weight and feeder grade to five groups of six steers each. During this 173-day trial, the cattle were housed in sheds which opened to paved lots. Five experimental rations were randomly assigned to the groups and were fed *ad libitum* from self-feeders. To insure freshness of feed, the self-feeders were maintained at one-half their capacity, and feed in the troughs was rotated back into the feeders each day. Water and a salt-mineral mixture (2 parts salt, 1 part steamed bone meal) were available *ad libitum*.

Experimental ration composition and proximate analysis values determined by the methods of A.O.A.C. (1960) are shown in Table I. The experimental rations contained steam-rolled milo as the grain source and cottonseed hulls served as a roughage source. The rations used are described below.

TABLE I

COMPOSITION OF RATIONS FED IN TRIAL 1

Ration Type	Conventional	High Concentrate	Conventional + Fat	Conventional + Sand	High Concentrate + Inert Bulk
Ration Designation	A	B	C	D	E
Ingredient, %					
Steam rolled milo	51.40	83.90	46.40	Same as A plus 500 lb. sand added to 1 ton feed	Same as B plus 400 lb. inert bulk[d] added to 1 ton feed
Cottonseed meal[a]	8.00	5.00	8.00		
Dehydrated alfalfa meal[a]	5.00	5.00	5.00		
Urea	1.50	1.50	1.50		
Molasses	3.00	3.00	3.00		
Stabilized animal tallow	-	-	5.00		
Cottonseed hulls	30.00	-	30.00		
Salt	0.50	0.50	0.50		
Calcium carbonate	0.50	1.00	0.50		
Vitamin A premix[b]	0.05	0.06	0.05		
Trace minerals[c]	0.05	0.04	0.05		
Chemical composition, %					
Dry matter	92.93	92.73	92.32	93.74	93.74
Ash	4.18	4.23	4.27	23.56	3.64
Crude protein	13.39	14.90	13.73	11.46	12.32
Fat	2.83	3.28	6.87	2.17	2.71
Fiber	14.66	3.17	16.15	11.84	22.62
N.F.E.	57.87	67.15	51.30	44.71	52.18

[a]Crude protein: cottonseed meal, 41%, alfalfa meal, 17%

[b]10,000 I.U. of Vitamin A per gram

[c]Minimum per cent: Mn, 10.0; Fe, 10.0; Ca, 10.0; Cu, 1.0; Zn, 10.0; I, 0.3; Co, 0.1

[d]Polyethylene resin (Alathon), E. I. du Pont de Nemours Co., Inc., Wilmington, Delaware

Ration A - A conventional ration containing 30 per cent hulls.

Ration B - A high concentrate ration.

Ration C - A conventional ration containing 30 per cent cottonseed hulls and 5 per cent stabilized animal tallow which replaced a like quantity of milo.

Ration D - Ration A with an addition of 500 lb. sand per ton of nutrient-containing material to increase ration density.

Ration E - Ration B with an addition of 400 lb. inert polyethylene resin per ton of nutrient-containing material to reduce ration density. The polyethylene utilized was of a very fine granular form and mixed easily with the nutrient material.

Ration density was determined by the use of a small-grain weight tester. Average density values, estimated net energy (ENE) values and calculated total digestible nutrient (TDN) values appear in Table II. ENE and TDN values for these rations and rations used in subsequent trials were calculated from values reported by Morrison (1959).

Response criteria observed were rate of gain; daily feed consumption; daily feed volume consumption; ENE intake; expressions of feed efficiency including pounds of ration, nutrient-containing material, concentrate and calculated TDN per pound of gain; and carcass merit including dressing

TABLE II

ENERGY CONTENT AND DENSITY OF RATIONS FED IN TRIAL 1

Ration Type	Conventional	High Concentrate	Conventional + Fat	Conventional + Sand	High Concentrate + Inert Bulk
Ration Designation	A	B	C	D	E
Energy					
TDN, %	64.0	74.5	70.1	51.2	62.1
ENE, megcal./lb.	0.57	0.71	0.63	0.46	0.59
Density, gm./liter[a]	405.48	572.82	411.9	489.15	431.23

[a]Average of three determinations

percentage, carcass grade, marbling score, rib eye area and fat thickness at the 12th rib. Other measurements included reticulo-rumen weight and weight of reticulo-rumen contents.

Feedlot activity of the steers was determined by observing all pens at 30-minute intervals during five separate 12-hour periods during the trial. Activity observations made during each interval included the number of steers idle, eating and ruminating.

Initial and final weights were taken after steers had been without feed and water for 12 hours. Average daily feed intake was determined for each 28-day period during the trial on the basis of total feed consumption for that particular period. Immediately following slaughter, the rumen epithelium was inspected, and full and empty reticulo-rumen weights were recorded. Weight of reticulo-rumen contents was obtained by difference. Calculations involving carcass weight were based on hot carcass weight with a standard 2 per cent calculated cooler shrink.

Analyses of variance and calculation of standard errors were conducted according to the methods outlined by Steel and Torrie (1960). Duncan's new multiple range test was used to make comparisons among treatment means. Mean comparisons were conducted only when analysis of variance for the various criteria were significant ($P<.10$).

Results and Discussion

The results of this trial with respect to daily gain, feed intake and feed efficiency are summarized in Table III. Since treatments were not replicated, statistical analyses could not be made on feed intake and efficiency data. Average daily gains were quite variable within treatments, and treatment means did not differ significantly (P>.05). Daily gains tended to parallel estimated net energy intake for all the experimental rations with the exception of Ration A. The average daily ration weight intake for Ration B, the high concentrate ration, was 23 per cent less than the intake for Ration A, the conventional ration. Gordon and Erwin (1960) and Davis _et al_. (1963) reported reductions in feed intake when high concentrate rations were compared with conventional rations for cattle.

The addition of sand to the conventional ration to increase ration density and the addition of polyethylene to the high concentrate ration to reduce density resulted in increased total daily ration weight intake. Eng (1965) observed that sheep increased consumption of total ration when polyethylene cubes were added to the feed. Cooley (1963) found that when 2 per cent sand was added to cattle finishing rations, daily consumption of total ration increased; however, in general there was no change in the daily consumption of nutrient material.

The daily concentrate intake was similar for all rations fed in this trial; however, cattle fed Ration E tended to overcompensate for the nutrient dilution. The reason for the overcompensation noted is difficult to explain. Wise

TABLE III

EFFECTS OF RATION BULK, DENSITY AND ENERGY CONCENTRATION ON FEED INTAKE AND PERFORMANCE OF STEERS: TRIAL 1

Ration Type	Conventional	High Concentrate	Conventional + Fat	Conventional + Sand	High Concentrate + Inert Bulk
Ration Designation	A	B	C	D	E
Number of steers	6	6	6	6	6
Average daily gain, lb.	2.17	2.30	2.81	2.33	2.52
Average daily intake, lb.					
Total ration	28.73	21.46	29.59	33.12	27.94
Nutrient material	28.73	21.46	29.59	26.50	23.28
Concentrate	20.11	21.46	20.71	18.55	23.28
TDN	18.39	15.99	20.74	16.96	17.35
Estimated daily net energy, megcal.	16.38	15.24	18.64	15.23	16.48
Average daily volume intake, liter	32.14	16.99	32.59	30.71	29.42
Feed conversion					
Lb. ration/lb. gain	13.24	9.33	10.53	14.21	11.09
Lb. nutrient material/ lb. gain	13.24	9.33	10.53	11.37	9.24
Lb. concentrate/lb. gain	9.27	9.33	7.37	7.96	9.24
Lb. TDN/lb. gain	8.47	6.95	7.38	7.28	6.88

et al. (1961) and Wise *et al*. (1965) reported only a slight increase in consumption of all-concentrate rations when hay was added in limited amounts or fed *ad libitum* to steers.

The response, with respect to ration weight intake, observed in this trial was apparently an attempt on the part of the steers to consume an amount of nutrient-containing material similar to that consumed by cattle receiving rations without inert material additions. The addition of sand resulted in a reduction in calculated energy intake; however, daily gain was improved slightly when compared with the conventional ration (2.17 vs. 2.33 lb.). This suggests that the calculated energy intake values were not accurate measures of ration performance. The addition of polyethylene to the high concentrate ration resulted in a slight increase in calculated net energy intake (15.24 vs. 16.48 megcal.) which was reflected in a trend toward increased daily gain (2.17 vs. 2.52 lb.). Thus the cattle consuming the ration containing polyethylene were able to compensate fully for the energy dilution and actually consumed slightly more ENE than cattle receiving a similar ration without polyethylene.

When average daily energy intake was measured as pounds of TDN or megacalories of ENE, the highest consumption was obtained with Ration C which contained 5 per cent added fat. Hale (1965) indicated that steers did not reduce feed intake when 4 per cent tallow was included in a conventional finishing ration; thus a higher level of calculated energy intake was obtained with tallow additions.

The role of energy in regulating feed intake is difficult to determine from these data. Even though consumption of feed weight increased when inert materials were added, TDN and ENE intakes were quite variable. Montgomery and Baumgardt (1965a) concluded that ruminants will adjust voluntary intake in relation to physiological demand for energy if fill or rumen load does not limit consumption. Eng (1965) also observed that sheep consuming rations varying in inert bulk and fiber tended to consume similar levels of digestible energy.

The average daily volume intake (liters/day) of Ration B was approximately half as great as the volume intakes of the other rations; while volume intakes of Rations A, C, D and E were very similar. Freer and Campling (1963) proposed that the intake of rations containing considerable roughage is regulated so as to maintain a constant fill just prior to the next meal and that consumption of rations made up largely of concentrates is limited by the end products of digestion. Since the volume intakes of rations containing natural or inert bulk (Rations A, C, D and E) were similar, distention of the digestive tract may have been a factor in limiting intake of these rations. It is apparent that rumen load or fill was not the limiting factor with Ration B.

Feed efficiency expressed as pounds of ration weight required per pound of gain favored Ration B and represented 29 per cent and 11 per cent improvement over Rations A and C, respectively. When efficiency was expressed as pounds of nutrient material or pounds of TDN required per pound of gain, Rations B and E were of almost equal value and excelled the other experimental rations. Gordon and Erwin (1960), Anthony *et al*. (1961), and Davis *et al*. (1963) reported improved feed efficiency with high concentrate rations for steers in comparison to rations containing roughage. Pounds of concentrate per pound of gain for Rations A and B were very similar (9.27 vs. 9.33 lb.) which suggests that the roughage used in this case was of little value in terms of energy contributed for maintenance and gain. Wise *et al*. (1965) reported that when limited or *ad libitum* hay was added to an all-concentrate ration, cattle ate more feed; however, performance was not significantly influenced by the added hay. The concentrate portion from Ration C was more efficiently utilized than the concentrate from Ration A (7.37 vs. 9.27 lb.). Hale *et al*. (1965) reported improved feed efficiency when 4 per cent tallow was included in a conventional finishing ration. The poor performance of steers consuming Ration A cannot be explained. The use of this ration in a subsequent trial resulted in much higher average daily gains.

Carcass and rumen data are presented in Table IV. Dressing per cent of cattle fed Ration D was significantly ($P<.05$) lower than that of cattle fed Ration C (62.7 vs. 64.6%). Steers fed Ration D had more reticulo-rumen contents than steers fed the other experimental rations; however, the differences were not statistically significant ($P>.05$). The

TABLE IV

CARCASS AND RUMEN DATA FROM STEERS FED RATIONS VARYING IN BULK, DENSITY AND ENERGY CONCENTRATION: TRIAL 1

Ration Type	Conventional	High Concentrate	Conventional + Fat	Conventional + Sand	High Concentrate + Inert Bulk	Standard Error of Treatment Means
Ration Designation	A	B	C	D	E	
Carcass data						
Dressing per cent[a]	63.6	64.6	65.4	62.7	63.5	0.68
Carcass grade[b]	9.5	9.7	9.8	9.5	9.2	0.45
Rib-eye area, sq. in.	11.49	11.56	11.78	11.36	11.83	
Rib-eye area/ cwt. carcass, sq. in.	1.61	1.56	1.45	1.56	1.56	0.06
Fat thickness, in.	0.81	0.90	1.01	0.84	0.93	
Fat thickness/ cwt. carcass, in.	0.11	0.12	0.12	0.11	0.12	0.01
Rumen data						
Empty reticulo-rumen, lb.	16.58	20.29	18.67	18.04	21.79	1.46
Reticulo-rumen contents, lb.	46.96	42.33	48.92	58.75	44.46	4.94

[a]Dressing per cent, D<C (P<.05). All other treatment differences non-significant (P>.05)

[b]7 = low good, 9 = high good, 11 = average choice

portion of the contents comprised of sand is not known. Empty reticulo-rumen weights were similar for all treatments.

Results of observations on feedlot behavior of steers, expressed as per cent of total time from 6 a.m. to 6 p.m., are shown in Table V. Steers consuming Rations C, D, and E spent more time at the feeders than those consuming Rations A or B. It is not clear why eating time was less for Ration A than for Rations C and E (10.1 vs. 11.9 and 14.7%) since daily ration weight and volume intakes were similar for all three rations. The presence of hulls, sand or polyethylene in the ration resulted in increased rumination time when compared with that observed for the high concentrate ration. Putnam and Davis (1963) conducted feeding pattern studies with steers fed *ad libitum*. They reported a 21 per cent reduction in time spent at the feeders when high concentrate rations were offered in contrast to a high roughage ration (25% vs. 89% hay). Average daily time at the feeder was 324 minutes in the first observation period and 228 minutes in the second period. This corresponded to approximately 22 and 15 per cent of the total time, respectively.

TABLE V

FEEDLOT ACTIVITY OF STEERS EXPRESSED AS PER CENT OF TOTAL TIME FROM 6 A.M. to 6 P.M.: TRIAL 1

Ration	Observation			
	Idle	Eating	Ruminating	Other
A	65.4	10.1	14.0	10.5
B	67.7	10.8	11.4	10.1
C	60.0	11.9	15.9	12.2
D	61.1	12.8	14.2	11.8
E	59.5	14.7	15.1	10.7

TRIAL 2

Materials and Methods

Trial 2, a 110-day feeding trial, was conducted during the summer of 1963 to further evaluate some of the effects of ration density on feed intake and performance of steers. Twenty-seven yearling Hereford steers with an average weight of 680 lb. were allotted to nine groups on the basis of 12-hour shrunk weights. This provided three replicate lots of three steers for each of three experimental rations. The rations were randomly assigned to the groups of steers and were fed *ad libitum* from self-feeders. The treatments used in this study were as follows:

Ration A - A conventional finishing ration containing 20 per cent cottonseed hulls.

Ration B - Ration A with an addition of 400 lb. sand per ton of nutrient-containing material to increase density.

Ration C - Ration A with an addition of 300 lb. inert polyethylene resin per ton of nutrient-containing material to reduce ration density.

Experimental ration composition and proximate analysis values, as determined by methods of A.O.A.C. (1960), are shown in Table VI. Ration density was determined by the method described in Trial 1. Gross energy determinations for each ration were made with a Parr oxygen bomb and adiabatic calorimeter. Density and energy values for the rations appear in Table VII.

Experimental procedure, including management, measurements and analyses were as described for Trial 1 with the exception of feedlot activity studies, which were not conducted in this trial.

Results and Discussion

Feed intake and performance data are summarized in Table VIII. The average daily gains for steers receiving Rations A, B, and C were 2.65, 2.41, and 2.48 lb., respectively. The average daily intake of ration weight was higher for Rations B and C than for Ration A (31.07 and 27.10 vs. 26.70 lb.); however, only the intake noted for Ration B was significantly ($P<.05$) higher than that for the control ration (Ration A).

Daily consumption of nutrient-containing material (exclusive of inert additions), ENE and concentrate portion was significantly depressed by polyethylene additions in this trial. Even though daily intake of total ration weight was higher for Ration C as compared with Ration A (27.10 vs. 26.70 lb.), the steers consuming the ration containing added inert bulk were not able to completely compensate for the energy dilution. This conclusion is supported by the

TABLE VI

COMPOSITION OF RATIONS FED IN TRIAL 2

Ration Type	Conventional	Conventional + Sand	Conventional + Inert Bulk
Ration Designation	A	B	C
Ingredient, %			
Steam rolled milo	60.15	Same as A plus 400 lb. sand added to 1 ton feed.	Same as A plus 300 lb. inert bulk[e] added to 1 ton feed.
Cottonseed meal[a]	8.00		
Dehydrated alfalfa meal[b]	6.00		
Urea	1.00		
Molasses	3.00		
Cottonseed hulls	20.00		
Salt	1.00		
Calcium carbonate	0.80		
Vitamin A premix[c]	0.03		
Trace mineral[d]	0.02		
Chemical composition, %			
Dry matter	89.50	91.07	91.26
Ash	4.88	21.37	4.18
Crude protein	12.30	11.57	11.60
Fat	2.58	1.49	1.91
Fiber	9.66	7.87	21.74
N.F.E.	60.08	48.77	51.83

[a]Crude protein, 41%

[b]Crude protein, 17%

[c]10,000 I.U. of Vitamin A per gram

[d]Minimum per cent: Mn, 10.0; Fe, 10.0; Ca, 10.0; Cu, 1.0; Zn, 10.0; I, 0.3; Co, 0.1

[e]Polyethylene resin (Alathon), E. I. du Pont de Nemours Co., Inc., Wilmington, Delaware

TABLE VII

ENERGY CONTENT AND DENSITY OF RATIONS
FED IN TRIAL 2

Ration Type Ration Designation	Conventional A	Conventional + Sand B	Conventional + Inert Bulk C
Energy			
TDN, %	67.1	55.9	58.3
Gross energy, cal./gm.[a]	3707.3	2965.8	5056.2 (3223.9)[c]
Estimated net energy, megcal./lb.	0.62	0.52	0.54
Density, gm./liter[b]	444.10	505.00	424.79

[a]Average of two determinations

[b]Average of three determinations

[c]Value corrected for polyethylene content of ration

TABLE VIII

EFFECTS OF RATION BULK AND DENSITY ON FEED INTAKE
AND PERFORMANCE OF STEERS: TRIAL 2

Ration Type Ration Designation	Conventional A	Conventional + Sand B	Conventional + Inert Bulk C	Standard Error of Treatment Means	Significant Differences[a]
Number of steers	9	9	9		
Average daily gain, lb.	2.65	2.41	2.48	0.13	NS
Average daily intake, lb.					
Total ration	26.70	31.07	27.10	0.72	B>(A+C)*
Nutrient material	26.70	25.89	23.57	0.63	A>C*
Concentrate	21.36	20.71	18.85	0.50	A>C*
TDN	17.92	17.36	15.80	0.42	A>C*
Estimated daily net energy, megcal.	16.56	16.15	14.63	0.39	A>C*
Gross energy intake, megcal.	44.94	41.82	39.67[b]	1.04	A>C*
Daily volume intake, liter	27.27	27.91	28.95	0.71	NS
Feed conversion					
Lb. ration/lb. gain	10.07	13.03	10.91	0.63	A<B*
Lb. nutrient material/lb. gain	10.07	10.86	9.49	0.44	NS
Lb. concentrate/lb. gain	8.06	8.69	7.59	0.36	NS
Lb. TDN/lb. gain	6.76	7.28	6.36	0.36	NS

[a] *P<.05, NS = non-significant (P>.05)

[b] Adjusted for polyethylene content

similarity in daily volume intake for the three rations. Since daily volume intake was similar for all rations, it is possible that the 12 per cent reduction in nutrient portion intake observed for Ration C as compared with Ration A was due to limited volume capacity of the digestive tract. Since this trial was conducted during the hot summer months, the added bulk may have added to the heat load of the animal as has been noted in the case of natural roughage additions (Wayman _et al_., 1962). However, Eng (1965) concluded that at ambient temperatures above 85° F., the end products of digestion and not bulk _per se_ limit intake.

Daily gains were similar for all three rations; however, a lower daily consumption of nutrient-containing material was observed with Ration C. Thus, it is apparent that cattle consuming this ration were utilizing nutrient-containing material more efficiently than cattle receiving Rations A or B. This conclusion is substantiated by the comparative efficiency values of 10.07 and 9.49 lb. of nutritive material per pound of gain for Rations A and C, respectively. Feed efficiency expressed as pounds of concentrate or pounds of TDN required per pound of gain also favored Ration C; however, treatment differences were not statistically significant ($P>.05$). The improved efficiency could have resulted from several influences of the inert bulk. The added polyethylene may have affected rate of passage and/or stimulated the rumen epithelium. The latter influence, however, would appear doubtful in this case since all rations contained cottonseed hulls at conventional levels. If rate of passage was affected, then end products of digestion may have been altered. A more detailed discussion concerning the effects of inert bulk will be presented in a later section.

Carcass data and rumen characteristics observed are shown in Table IX. Similarity in weights of rumen contents adds some support to the rumen fill theory of Campling *et al.* (1962) which states that cattle regulate intake so as to maintain a constant amount of dry matter within the rumen prior to each meal. However, the rumen fill weights reported in this trial represent contents after 90 minutes in transit and do not necessarily represent conditions prior to a meal. Rib eye area per hundredweight of carcass was greater in steers which had been fed Ration C than in cattle fed Ration B ($P<.05$). No other significant carcass or rumen differences were noted.

TABLE IX

CARCASS AND RUMEN DATA FROM STEERS FED RATIONS VARYING IN BULK AND DENSITY: TRIAL 2

Ration Type Ration Designation	Conventional A	Conventional + Sand B	Conventional + Inert Bulk C	Standard Error of Treatment Means	Significant Differences[a]
Carcass data					
Dressing per cent	60.0	59.9	59.4	0.44	NS
Carcass grade[b]	9.0	9.0	9.2	0.24	NS
Rib-eye area, sq. in.	10.98	10.36	11.16		
Rib-eye area/cwt. carcass, sq. in.	1.89	1.83	1.96	0.04	C>B*
Rumen data					
Empty reticulo-rumen, lb.	16.2	16.7	16.5	0.37	NS
Reticulo-rumen contents, lb.	40.5	41.8	44.7	1.20	NS

[a] *P<.05, NS = non-significant (P>.05)

[b] 7 = low good, 9 = high good, 11 = average choice

TRIAL 3

Materials and Methods

Trial 3 was conducted during the fall of 1963 to determine some of the effects of conventional and high concentrate rations on rumen fluid pH and volatile fatty acid (VFA) concentration. Eight yearling Hereford steers averaging 750 lb. in weight were randomly allotted to two groups of four steers each. Treatments were then randomly assigned to groups. One group was fed a conventional ration containing 30 per cent cottonseed hulls, and the other group was fed a high concentrate ration (Ration A and Ration B, respectively, Table I). The experimental rations were fed *ad libitum* in each case.

Response criteria included total VFA concentration in rumen fluid; the molar percentage of acetic, propionic, butyric, and valeric acids; and rumen fluid pH.

After a period of 14 days, rumen fluid samples were collected from each steer by a modification of the procedure described by Raun and Burroughs (1962). The groups were then reversed with respect to treatment and after a second 14-day period, rumen fluid samples were again obtained from each steer. Rumen fluid pH was determined with a Beckman Zeromatic pH meter immediately after the rumen fluid sample had been obtained. Microbial action in the fluid was stopped by quick-freezing with an acetone-ice mixture. Samples were then stored at -10° C. Volatile fatty acid analyses were later conducted according to the procedure of Erwin et al. (1961). An Aerograph Hy-Fi Model A-600 B gas chromatograph and a Sargent recorder were utilized in the determinations.

Animal facilities and management practices were as described for Trial 1. Statistical analyses were conducted according to the method described by Brandt (1938) for simple change-over designs.

Results and Discussion

Results of the rumen volatile fatty acid (VFA) analyses and pH determinations are presented in Table X. A significantly ($P<.02$) higher concentration of total VFA's was observed for rumen fluid samples collected from steers receiving Ration A as compared with samples from steers fed Ration B (114.45 vs. 99.19 mM/liter). Thompson et al. (1965) found that the addition of hay to all-concentrate rations resulted in a reduction in total VFA concentration in rumen fluid. However, Bath and Rook (1963) stated that changing the hay:concentrate ratio from 1:0 to 1:3 had little influence on total VFA concentration. Ration A produced significantly higher molar proportions of acetic ($P<.05$), butyric ($P<.01$), and valeric ($P<.05$) acids than did Ration B. At the same time, steers consuming Ration B had a significantly ($P<.01$) higher molar percentage of propionic acid and a significantly

TABLE X

EFFECTS OF CONVENTIONAL AND HIGH CONCENTRATE RATIONS ON RUMEN pH AND VOLATILE FATTY ACID CONCENTRATION: TRIAL 3

Ration Type Ration Designation	Conventional A	High Concentrate B	Standard Error of Treatment Means	Level of Significance
VFA concentration, mM/l.[a]	114.45	99.19	4.67	P<.02
VFA concentration, molar %				
Acetic	51.51	46.11	1.97	P<.05
Propionic	33.44	45.95	1.76	P<.01
Butyric	11.04	6.41	0.56	P<.01
Valeric	2.02	1.53	0.14	P<.05
Acetic/propionic	1.51	1.01	0.10	P<.01
Rumen fluid pH	6.64	6.21	0.20	NS

[a]Including acetic, propionic, butyric, and valeric acids

(P<.01) lower acetic:propionic ratio. Most workers report that as the proportion of concentrate in the ration increases, the molar percentages of propionic and butyric acids increase and the molar percentage of acetic acid decreases (Eusebio *et al*., 1959; Elliot and Loosli, 1959; Bath and Rook, 1963).

Even though treatment means were not significantly (P>.05) different, consumption of Ration A resulted in a higher average rumen pH value (6.64 vs. 6.21). The presence of cottonseed hulls in Ration A possibly stimulated rumination and secretion of more saliva which in turn could have increased the pH level of rumen fluid.

TRIAL 4

Materials and Methods

This trial was conducted during the winter of 1963 to observe the influences of ration energy concentration, fat as a caloric source and inert bulk additions on feed consumption by steers. Thirty-five yearling Hereford steers averaging 750 lb. were stratified on the basis of shrunk weight and were assigned to five groups of seven steers each. Five experimental rations were assigned at random to the five groups for the initial test period. The rations were fed *ad libitum* from self-feeders during five 25-day test periods. A 5 x 5 Latin square design permitted all groups of steers to receive each ration for one test period. A 7-day preliminary feeding period preceded each 25-day test. The five rations utilized in this trial are described as follows:

Ration A - A conventional ration containing 20 per cent cottonseed hulls.

Ration B - A high concentrate ration.

Ration C - A conventional ration containing 20 per cent cottonseed hulls and 5 per cent stabilized animal tallow.

Ration D - A high concentrate ration containing

5 per cent stabilized animal tallow.

Ration E - Ration D with an addition of 300 lb. inert polyethylene resin per ton of nutrient-containing material to reduce density.

Percentage composition and proximate analysis values are presented in Table XI. Ration density and gross energy values were determined by methods stated for Trial 1 and Trial 2, and average values for each ration are shown in Table XII.

Response criteria were daily feed volume consumption; daily feed consumption including pounds of feed, pounds of nutrient-containing material, pounds of concentrates and pounds of TDN; and megacalories of estimated net energy. Other observations included rumen fluid pH, total concentration of volatile fatty acids and molar percentages of acetic, propionic, butyric, and valeric acids.

Midway through each 25-day test period, rumen fluid samples were taken from two randomly selected steers in each group. Procedures for obtaining the samples and determining pH values and volatile fatty acid concentrations were as outlined for Trial 3.

Physical facilities, management practices, and statistical analyses were as described for Trial 1.

Results and Discussion

The results of this trial with respect to feed

TABLE XI

COMPOSITION OF RATIONS FED IN TRIAL 4

Ration Type	Conventional	High Concentrate	Conventional + Fat	High Concentrate + Fat	High Concentrate + Fat + Inert Bulk
Ration Designation	A	B	C	D	E
Ingredient, %					
Steam cracked milo	60.85	83.95	55.85	78.95	Same as D plus 300 lb. inert bulk[d] added to 1 ton feed
Cottonseed meal[a]	8.00	5.00	8.00	5.00	
Dehydrated alfalfa meal[a]	6.00	5.00	6.00	5.00	
Urea	1.00	1.50	1.00	1.50	
Molasses	3.00	3.00	3.00	3.00	
Stabilized animal tallow	-	-	5.00	5.00	
Cottonseed hulls	20.00	-	20.00	-	
Salt	0.50	0.50	0.50	0.50	
Calcium carbonate	0.60	1.00	0.60	1.00	
Vitamin A premix[b]	0.03	0.03	0.03	0.03	
Trace minerals[c]	0.02	0.02	0.02	0.02	
Chemical composition, %					
Dry matter	91.5	91.4	92.2	91.8	93.1
Ash	4.2	3.9	4.0	3.3	3.4
Crude protein	13.4	15.3	13.6	15.1	12.5
Fat	3.1	3.8	8.0	8.6	7.5
Fiber	9.7	2.8	8.4	2.6	13.7
N.F.E.	61.1	65.6	58.1	62.2	56.0

[a]Crude protein: cottonseed meal, 41%; alfalfa meal, 17%

[b]10,000 I.U. of Vitamin A per gram

[c]Minimum per cent: Mn, 10.0; Fe, 10.0; Ca, 10.0; Cu, 1.0; Zn, 10.0; I, 0.3; Co, 0.1

[d]Polyethylene resin (Alathon), E. I. du Pont de Nemours Co., Inc., Wilmington, Delaware

TABLE XII

ENERGY CONTENT AND DENSITY OF RATIONS FED IN TRIAL 4

Ration Type Ration Designation	Conventional A	High Concentrate B	Conventional + Fat C	High Concentrate + Fat D	High Concentrate + Fat + Inert Bulk E
Energy					
TDN, %	67.7	74.6	73.8	80.7	70.2
Gross energy, cal./gm.[a]	3948.0	4006.4	4243.4	4238.7	5118.2 (3686.0)[c]
ENE, megcal./lb.	0.62	0.72	0.69	0.78	0.68
Density, gm./liter[b]	443.8	570.6	457.6	586.8	495.6

[a]Average of two determinations

[b]Average of three determinations

[c]Value corrected for polyethylene content of ration

consumption, energy intake and volume intake are shown in Table XIII. Steers receiving Ration A consumed significantly ($P<.05$) more daily ration weight than steers fed Rations B or D (26.19 vs. 21.31 and 20.60 lb.). When the intakes of actual nutrient-containing material, exclusive of inert additions, were compared, daily consumption was significantly ($P<.05$) higher for Ration A than for Rations B, D, and E. No significant treatment differences were noted in daily intakes of concentrate portion, TDN or ENE; however, the TDN and ENE values tended to be lowest for Ration B. It appeared that the steers were regulating daily consumption of the experimental rations so as to maintain a relatively constant energy intake.

The daily consumption of concentrate portion was similar for all rations and corresponded to the concentrate intake pattern observed in Trial 1. Wise _et al_. (1965) observed that when hay was fed with an all-concentrate ration, daily consumption of total ration increased while intake of concentrates remained about the same.

Daily feed volume intakes were significantly ($P<.01$) higher for the bulk-containing rations (A, C, and E) when compared with those observed for the high concentrate rations (B and D). The volume intake of Ration A was also significantly ($P<.05$) greater than that of Ration E (26.77 vs. 21.89 lb.). Rumen fill and distention of the digestive tract may have been primary factors in limiting consumption of Ration A; however, it is unlikely that these were

TABLE XIII

EFFECTS OF RATION BULK, DENSITY AND ENERGY CONCENTRATION ON FEED AND ENERGY INTAKE OF STEERS: TRIAL 4

Ration Type Ration Designation	Conventional A	High Concentrate B	Conventional + Fat C	High Concentrate + Fat D	High Concentrate + Fat + Inert Bulk E	Standard Error of Treatment Means	Significant Differences[a]
Average daily intake, lb.							
Total ration	26.19	21.31	24.09	20.60	23.93	1.10	A>(B&D)*
Nutrient material	26.19	21.31	24.09	20.60	20.80	1.09	A>(B,D&E)*
Concentrate	20.95	21.31	19.27	20.60	20.80	0.92	NS
TDN	17.73	15.90	17.78	16.51	16.79	0.78	NS
Estimated daily net energy, megcal.	16.24	15.35	16.62	16.11	16.26	0.72	NS
Daily gross energy, megcal.	46.93	38.77	46.41	39.63	40.01[b]	2.00	(A&C)>(B,D&E)*
Daily volume intake, liter	26.77	16.94	23.88	15.92	21.89	1.09	(A,C&E)>(B&D)** A>E*

[a] *P<.05, **P<.01, NS = non-significant (P>.05)

[b] Adjusted for polyethylene content

important factors in limiting the consumption of the high concentrate rations (B and D). Freer and Campling (1963) concluded that the intake of a roughage ration by ruminants was directly related to the rate of digestion and inversely related to the mean retention time of food residues. The content of cottonseed hulls in Rations A and C may have been great enough to result in a limited intake due to slower rates of digestion and ingesta passage.

Values for rumen fluid pH and VFA concentrations are presented in Table XIV. Rumen fluid collected from steers receiving Ration A had a significantly ($P<.05$) higher average pH value than that obtained from steers fed Rations B or E (6.28 vs. 5.85). In this trial the inclusion of cottonseed hulls in the ration tended to elevate rumen fluid pH values. Since a greater volume of intake was obtained with Ration A, additional saliva flow may have resulted from the presence of roughage; and this, in turn, may have elevated rumen pH. Bailey and Balch (1960) found that the rate of parotid saliva secretion was two to two and one-half times greater during rumination and eating than during rest.

No significant ($P>.05$) treatment differences were noted in total ruminal VFA concentration. The molar percentage of acetic acid was significantly ($P<.01$) higher in steers fed Ration A than in steers fed Rations B, D, or E (60.55 vs. 47.38, 50.46 and 46.45%). A trend toward a higher molar percentage of propionic acid in rumen fluid was observed with rations without cottonseed hulls. A higher molar percentage

TABLE XIV

EFFECTS OF RATION BULK, DENSITY AND ENERGY CONCENTRATION ON RUMEN pH AND VOLATILE FATTY ACID CONCENTRATION: TRIAL 4

Ration Type	Conventional	High Concentrate	Conventional + Fat	High Concentrate + Fat	High Concentrate + Fat + Inert Bulk	Standard Error of Treatment Means	Significant Differences[a]
Ration Designation	A	B	C	D	E		
Rumen pH	6.28	5.85	6.23	6.02	5.85	0.12	A>(B&E)*
VFA concentration, mM/l.[b]	115.67	125.62	114.36	110.31	134.75	9.49	NS
Acetic/Propionic	2.30	1.11	1.75	1.26	1.04	0.25	A>(E&B)** A>D*
VFA concentration, molar %							
Acetic	60.55	47.38	53.24	50.46	46.45	1.94	A>(B,D&E)** A>C* C>E*
Propionic	29.06	44.50	35.06	41.95	45.75	2.96	(E&B)>A** E>C* D>A*
Butyric	8.96	6.29	10.09	5.97	6.26	1.30	NS
Valeric	1.43	1.63	1.60	1.62	1.54	0.18	NS

[a]*P<.05, **P<.01, NS = non-significant (P>.05)

[b]Acetic, propionic, butyric and valeric acids

of propionic acid was also found in rumen fluid from steers fed the ration containing polyethylene (E) when compared with that from steers fed Ration D (45.75 vs. 41.95%); however, the difference was not statistically significant ($P>.05$). No significant treatment differences were observed in molar percentages of butyric and valeric acids.

When the concentrations of the respective ruminal VFA from steers fed Rations B and D were compared, no significant ($P>.05$) treatment differences were found due to the fat addition. However, the addition of tallow to the conventional ration significantly ($P<.05$) decreased the proportion of acetic acid and tended to increase the proportion of propionic acid in rumen fluid (Ration A vs. C). Several researchers have reported variable results with respect to the effects of added dietary fat on VFA patterns in ruminants. Esplin et al. (1963) reported that the addition of fat to a conventional cattle finishing ration tended to increase total VFA concentration, but had no effect on molar percentage concentration. Shaw and Ensor (1959) observed that the addition of cod liver oil or unsaturated fatty acids to rations for dairy cows decreased the molar percentage of acetic acid and increased the molar percentage of propionic acid.

The acetic:propionic ratio was significantly higher for rumen fluid samples from steers receiving Ration A as compared with samples from steers fed Rations B, D, or E. Elliot and Loosli (1959), Raun et al. (1962) and Erwin et al. (1963) also reported an increase in acetic:propionic ratios as the portion of roughage in the ration increased.

Several workers have proposed that VFA may serve as regulating metabolites in chemostatic regulation of food intake by ruminants (Dowden and Jacobson, 1960; Little and Hawkins, 1963; Simkins et al., 1965a; Ulyatt, 1965). Simkins et al. (1965b) concluded that acetic, propionic, or butyric acids could act as a satiety signal compound. They further concluded that acetic acid would be the most likely VFA that could serve as a circulating metabolite in regulation of food intake. The data presented in Trial 4 reveal that higher daily consumption of nutrient material occurred with rations producing the higher molar percentages of acetic acid (Rations A and C), yet total VFA concentrations were not significantly different. With the previously discussed research in mind, it would appear that the concentration of propionic acid in the rumen could be a more important factor than acetic acid in regulating intake of rations used in this trial. However, these data do not show a cause and effect relationship between concentration of VFA and intake. Information concerning rumen volume, rate of VFA production and absorption at various times after feeding and rate of blood flow must be evaluated prior to making conclusions concerning the role of VFA concentration in regulation of food intake.

The exact mode of action of VFA in regulating food consumption has not been elucidated. VFA may act on receptors in the rumen wall, the portal system, the liver, or the brain (Simkins et al., 1965b). Since VFA comprise a major portion of the end products of digestion in the ruminant, it may be that the animal is able to "meter" energy through the influence of these end products.

TRIAL 5

Materials and Methods

Trial 5 was conducted during the summer of 1964 to study some of the effects of ration bulk, energy concentration, and caloric source on feed consumption and performance of steers fed during periods of high environmental temperature. Fifty yearling Hereford steers averaging 700 lb. were fed a standard ration for two weeks. Twelve-hour shrunk weights were taken, and the steers were randomly assigned to ten groups of five steers each to provide replicate lots for five randomly assigned treatments. The experimental rations (Table XV) utilized in this trial were similar to those used in Trial 4 and were fed *ad libitum* from self-feeders. Ration density and gross energy determinations were conducted by methods previously cited, and average values for each ration are presented in Table XVI.

Response criteria included all of those measurements and observations listed for previous trials with the exception of reticulo-rumen weight, reticulo-rumen content weight and feed-lot activity. Additional measurements included blood sugar level, rectal temperature, rumen and liver condition, and carcass cutability (Murphey *et al.*, 1960).

TABLE XV

COMPOSITION OF RATIONS FED IN TRIAL 5

Ration Type	Conventional	High Concentrate	Conventional + Fat	High Concentrate + Fat	High Concentrate + Fat + Inert Bulk
Ration Designation	A	B	C	D	E
Ingredient, %					
Steam cracked milo	62.15	84.55	56.95	79.55	Same as D plus 300 lb. inert bulk[d] added to 1 ton feed
Cottonseed meal[a]	8.00	5.00	8.00	5.00	
Dehydrated alfalfa meal[a]	5.00	5.00	5.00	5.00	
Urea	1.00	1.50	1.20	1.50	
Molasses	3.00	3.00	3.00	3.00	
Stabilized animal tallow	-	-	5.00	5.00	
Cottonseed hulls	20.00	-	20.00	-	
Salt	0.50	0.50	0.50	0.50	
Calcium carbonate	0.30	0.40	0.30	0.40	
Vitamin A premix[b]	0.03	0.03	0.03	0.03	
Trace minerals[c]	0.02	0.02	0.02	0.02	
Chemical composition, %					
Dry matter	96.8	96.3	96.6	95.1	97.9
Ash	3.8	3.5	3.7	3.4	2.8
Crude protein	14.7	15.6	14.5	15.1	13.2
Fat	3.1	3.5	7.9	8.5	7.6
Fiber	10.0	2.8	10.1	2.9	17.4
N.F.E.	65.2	70.9	60.4	65.2	49.7

[a]Crude protein: cottonseed meal, 41%; alfalfa meal, 17%

[b]10,000 I.U. of Vitamin A per gram

[c]Minimum per cent: Mn, 10.0; Fe, 10.0; Ca, 10.0; Cu, 1.0; Zn, 10.0; I, 0.3; Co, 0.1

[d]Polyethylene resin (Alathon), E. I. du Pont de Nemours Co., Inc., Wilmington, Delaware

TABLE XVI

ENERGY CONTENT AND DENSITY OF RATIONS FED IN TRIAL 5

Ration Type Ration Designation	Conventional A	High Concentrate B	Conventional + Fat C	High Concentrate + Fat D	High Concentrate + Fat + Inert Bulk E
Energy					
TDN, %	68.2	75.0	74.2	81.2	71.2
Gross energy, cal./gm.[a]	3993.9	3855.3	4213.4	4221.0	5167.8 (3670.6)[c]
ENE, megcal./lb.	0.63	0.73	0.69	0.79	0.69
Density, gm./liter[b]	434.4	603.8	438.4	583.6	488.0

[a]Average of two determinations

[b]Average of three determinations

[c]Value corrected for polyethylene content of ration

Steers were weighed at 21-day intervals throughout the 132-day trial. Final weights were determined after a 12-hour shrink period without feed and water. Average daily feed consumption was also determined for 21-day intervals throughout the trial.

Rumen fluid samples were taken from two randomly selected steers in each lot at the end of each 25-day interval by the method previously cited. Analyses for volatile fatty acids were conducted by the procedure stated for Trial 3. Blood samples were obtained from the same steers by jugular puncture. Blood sugar concentration was determined by the method of Colvin _et al_. (1961). Rectal temperatures of two steers in each lot were determined on five different days during the trial. A daily record of feedlot and shed ambient temperatures was also maintained.

Upon slaughter, the rumen lining was scored by visual appraisal for color, papillae condition and erosion, and the presence of hair trapped among papillae. Carcass cutability scores were calculated by the method of Murphey _et al_. (1960).

Physical facilities, management practices and statistical analyses were as described for Trial 1.

Results and Discussion

The results of this trial with respect to gain, feed intake and feed efficiency are summarized in Table XVII. Rations containing natural roughage or inert bulk (Rations A, C, and E) produced faster ($P<.05$) rates of gain than the

TABLE XVII

EFFECTS OF RATION BULK, DENSITY AND ENERGY CONCENTRATION ON FEED INTAKE AND PERFORMANCE OF STEERS: TRIAL 5

Ration Type	Conventional	High Concentrate	Conventional + Fat	High Concentrate + Fat	High Concentrate + Fat + Inert Bulk	Standard Error of Treatment Means	Significant Differences[a]
Ration Designation	A	B	C	D	E		
Number of steers	10	10	10	10	9[b]		
Average daily gain, lb.	2.56	2.21	2.60	2.10	2.60	0.07	(A,E&C)>(B&D)*
Average daily intake, lb.							
Total ration	27.44	22.26	25.65	19.40	22.54	0.48	(A)>(B,D&E)** C>(B&D)** E* (E&B)>D*
Nutrient material	27.44	22.26	25.65	19.40	19.60	0.48	(A&C)>(B,D&E)** B>(D&E)*
Concentrate	21.95	22.26	20.50	19.40	19.60	0.48	(A&B)>(D&E)*
TDN	18.71	16.70	19.03	15.76	16.05	0.37	(A&C)>(B,D&E)*
Estimated daily net energy, megal.	17.28	16.25	17.70	15.33	15.56	0.36	C>(B,D&E)* A>(D&E)*
Gross energy intake, megcal.	49.74	38.96	49.07	37.18	37.56[c]	0.86	(A&C)>(B,D&E)**
Daily volume intake, liter	28.64	16.72	26.54	15.08	20.96	0.39	(A>C>E>B>D)*
Feed conversion							
Lb. ration/lb. gain	10.70	10.05	9.90	9.22	8.70	0.40	E<A*
Lb. nutrient material/ lb. gain	10.70	10.05	9.90	9.22	7.57	0.39	E<(A,B,C&D)*
Lb. concentrate/lb. gain	8.56	10.05	7.92	9.22	7.57	0.36	(A,E&C)<B* E<D*
Lb. TDN/lb. gain	7.29	7.54	7.35	7.48	6.20	0.30	E<(B&D)*

[a]*P<.05, **P<.01

[b]Twenty-eight days after initiation of feeding, one steer died due to abscessed kidney.

[c]Adjusted for polyethylene content

high concentrate rations (Rations B and D). Steers consuming rations containing cottonseed hulls (Rations A and C) had significantly higher daily intakes of ration weight ($P<.01$), nutrient material ($P<.01$), TDN ($P<.05$) and gross energy ($P<.01$) than steers fed Rations B, D, or E. Steers fed Rations A or B consumed significantly ($P<.05$) larger quantities of concentrates than steers which received Rations C, D, or E, the rations with added fat.

In comparing the intake criteria values for Rations A vs. C and Rations B vs. D, the addition of fat to either the conventional or the high concentrate ration resulted in a reduction in ration weight intake. Possibly, the steers were able to meter energy content and reacted by reducing intake. This reduction in intake of ration weight was greater when fat was added to the high concentrate ration than when added to the conventional ration (12.8 vs. 6.5%). Erwin _et al_. (1963) reported reduced feed intake when fat was added to cattle finishing rations. Wise _et al_. (1963) reported no change in feed consumption by steers when 2 per cent animal fat was deleted from an all-concentrate ration. Gordon and Erwin (1960) observed a greater reduction in pounds of feed required per pound of gain when fat was added to a ration containing 30 per cent alfalfa hay than when it was added to an all-concentrate ration for steers.

Greater ($P<.05$) intakes of TDN and ENE were obtained with the rations containing hulls (A and C) than with the high concentrate rations (B and D) or the ration containing inert bulk (E). Treatment differences in energy intake were greater in this trial than in Trial 4. The pattern observed in the change-over trial (Trial 4) may suggest that capacity of the digestive tract is not reduced by deleting roughage for a period of 25 days as compared with longer feeding periods.

As noted in previous trials, the daily volume intakes of Rations A and C were higher than those of Rations B, D, or E. From the data available, it appears that distention may have been a limiting factor in the intake of Ration A; however, it is doubtful if this factor limited the consumption of Rations B, D, or E. In comparing consumption of nutrient material for Rations D and E, steers may have been able to meter energy intake to a rather exact degree since nutrient material intake values for these two rations were similar (19.40 vs. 19.60 lb.).

The comparisons of feed efficiency values for Rations A vs. C and Rations B vs. D indicate that fat additions reduced pounds of ration weight required per pound of gain. The degree of improvement in feed efficiency resulting from the 5 per cent fat additions was similar for both conventional and high concentrate rations (6.1 vs. 6.9%). When cottonseed hulls were added to the high concentrate rations with and without animal tallow, one pound of cottonseed hulls replaced 0.66 pounds and 0.70 pounds of concentrates, respectively. One pound of polyethylene replaced 1.46 pounds of concentrates when polyethylene was added to the high concentrate ration containing tallow. Thus, from an efficiency standpoint, the beneficial effects of added bulk were greater with the inert source than with the natural source.

Feed efficiency expressed as ration weight per pound of gain favored Ration E, the polyethylene-containing ration. Utilization of the nutrient-containing material was also significantly ($P<.05$) greater for Ration E. It appears that polyethylene exerted some influence on utilization of the nutrient portion of the ration. This conclusion is supported by the comparison of nutrient material required per pound of gain for Rations D and E (9.22 vs. 7.57 lb.). The reasons for this influence are not clear. Polyethylene may have stimulated the rumen epithelium and, in turn, improved VFA absorption. Polyethylene may also have reduced rate of passage of feed materials. This could have resulted in more complete digestion of the nutrient material consumed.

VFA data and pH values obtained from rumen fluid samples are shown in Table XVIII. Rumen fluid pH values were significantly ($P<.01$) higher for steers fed Rations A or C as compared with those resulting from Rations B, D, or E. The possible effects of roughage on rumen pH were discussed in Trial 3. The role of rumen pH in regulation of food intake has not been determined. Bhattacharya (1966) reported a reduction in consumption of an all-hay ration by steers when rumen pH was reduced to approximately 6.0 by ruminal infusions of phosphoric, lactic and citric acids.

TABLE XVIII

EFFECTS OF RATION BULK, DENSITY AND ENERGY CONCENTRATION ON RUMEN CONDITION, pH AND VOLATILE FATTY ACID CONCENTRATIONS: TRIAL 5

Ration Type	Conventional	High Concentrate	Conventional + Fat	High Concentrate + Fat	High Concentrate + Fat + Inert Bulk	Significant Differences[a]
Ration Designation	A	B	C	D	E	
Rumen pH	6.30	5.89	6.42	5.78	5.72	C>(A,B,D&E)** A>(B,D&E)**
VFA concentration, mM/l.	105.09±5.18[b]	107.18±5.63	96.24±4.40	104.87±4.67	106.42±4.53	NS
VFA concentration, molar %						
Acetic	57.76±1.55[b]	49.76±1.68	57.02±1.32	50.08±1.40	49.44±1.36	(A&C)>(B,D&E)**
Propionic	30.19±1.66[b]	40.61±1.81	30.23±1.42	38.54±1.50	42.35±1.46	(B,D&E)>(A&C)**
Butyric	12.05±1.14[b]	9.63±1.24	12.76±0.96	11.39±1.02	8.21±0.99	E<(A,B,C&D)**
Acetic/Propionic	2.04±0.20[b]	1.26±0.21	2.14±0.17	1.41±0.18	1.19±0.17	A>(B,E&D)* C>(B,D&E)**
Rumen condition						
Color[c]	1.4	2.0	1.0	1.6	1.7	
Erosion[d]	2.1	2.6	1.9	2.6	2.0	
Matted papillae[d]	1.4	1.8	1.0	1.6	2.5	
Entrapped hair[d]	1.4	1.8	1.2	2.0	1.5	

[a] *P<.05, **P<.01, NS = non-significant (P>.05)
[b] Standard error of treatment mean
[c] 1 = normal, 2 = slightly dark, 3 = dark
[d] 1 = normal, 2 = slight, 3 = moderate, 4 = severe

No significant (P>.05) differences were noted among treatments with respect to total VFA concentration in rumen fluid samples. Steers consuming Rations A and C had significantly (P<.01) higher proportions of ruminal acetic acid than those consuming Rations B, D, or E. Higher (P<.01) proportions of propionic acid were noted for steers receiving Rations B, D, or E than for those fed the rations containing cottonseed hulls (A and C). The molar percentage of butyric acid was lowest (P<.05) for steers receiving Ration E. Rations A (P<.05) and C (P<.01) produced significantly higher acetic: propionic ratios than did Rations B, D, and E. In comparing VFA data from steers fed Rations D and E, polyethylene appeared to produce a minor reduction in the acetic:propionic ratio.

Blood glucose levels did not appear to be related to feed consumption. Several workers (Dowden and Jacobson, 1960; Holder, 1963; and Simkins et al. 1965b) concluded that blood glucose is not a prime regulatory metabolite with respect to food consumption by ruminants.

Scores assigned to relate rumen condition are shown in Table XVIII. Reductions in the incidences of papillae erosion and hair trapped among papillae were noted with Ration E in comparison with Ration D. However, the cases of matted papillae were more frequent when Ration E was fed. When compared with the high concentrate rations (B and D), the use of rations containing cottonseed hulls (A and C) resulted in a more desirable rumen condition as measured by color, papillae erosion, matted papillae and trapped hair.

Apparently steers consuming Rations B or D had a craving for roughage and sought to satisfy this craving by licking themselves and other steers as evidenced by the amount of hair found in the rumen. This was also evident in day to day visual observations of the animals. The relationship of rumen condition to performance in this trial is not known. Oltjen and Davis (1965) reported dark rumen epithelial color and matted papillae when all-concentrate rations were fed to cattle.

No significant differences in carcass criteria were observed among the various treatment groups (Table XIX). The incidence of abscessed livers was similar for all rations. Wise et al. (1963) reported 40 per cent condemned livers in cattle fed all-concentrate diets, and Durham et al. (1963) found a 74 per cent incidence of abscessed livers in cattle fed a milo-cottonseed meal ration.

Average rectal temperatures ranged from 104.50° F to 102.19° F and tended to parallel ambient temperatures, which ranged from 106° F to 75° F. No consistent patterns due to roughage, inert bulk and fat additions were noted. Average rectal temperatures for steers fed the five experimental ration were A, 103.04° F; B, 102.76° F; C, 102.76° F; D, 103.21° F; and E, 102.94° F.

TABLE XIX

CARCASS AND LIVER DATA FROM STEERS FED RATIONS VARYING IN BULK, DENSITY AND ENERGY CONCENTRATION: TRIAL 5

Ration Type	Conventional	High Concentrate	Conventional + Fat	High Concentrate + Fat	High Concentrate + Fat + Inert Bulk	Standard Error of Treatment Means	Significant Differences[a]
Ration Designation	A	B	C	D	E		
Carcass data							
Dressing per cent	62.7	62.8	62.4	63.2	60.6	0.18	NS
Carcass grade[b]	9.6	9.8	9.7	9.4	10.2	0.20	NS
Marbling score[c]	9.1	8.8	8.7	8.1	9.3	0.37	NS
Rib-eye area, sq. in.	10.54	10.88	11.17	10.94	10.47		
Rib-eye area/ cwt. carcass, sq. in.	1.61	1.75	1.69	1.77	1.68	0.08	NS
Fat thickness, in.	0.83	0.68	0.78	0.68	0.81		
Fat thickness/ cwt. carcass, in.	0.13	0.11	0.12	0.11	0.13	0.02	NS
Boneless retail cuts, %	47.88	49.24	48.02	49.22	48.61	0.78	NS
Abscessed livers	4	4	3	5	4		

[a]NS = non-significant (P>.05)

[b]7 = low good, 9 = high good, 11 = average choice

[c]Slight - = 4, slight = 5, slight + = 6, small - = 7

TRIAL 6

Materials and Methods

The final trial in the study was initiated in the spring of 1965 to further investigate the effects of bulk *per se* and caloric source on feed intake and performance of steers. Forty yearling Hereford steers averaging 680 lb. were fed a standard ration for two weeks. Shrunk weights were taken after the steers had been without feed and water for 12 hours. Cattle were assigned to blocks on basis of source, and steers within blocks were randomly assigned to groups with four groups per block and five steers per group. Groups within blocks were randomly assigned to treatments.

The 2 x 2 factorial arrangement of treatments in this 113-day feeding trial consisted of four experimental rations which were fed *ad libitum* from self-feeders. These rations are described as follows:

Ration B - A high concentrate finishing ration.

Ration C - Ration B with an addition of 300 lb. polyethylene resin per ton of nutrient-containing material to reduce density.

Ration D - A high concentrate ration containing 5 per cent stabilized animal tallow.

Ration E - Ration D with an addition of 300 lb. polyethylene resin per ton of nutrient-containing material to reduce density.

Proximate analysis values as determined by methods of A.O.A.C. (1960) and ration composition are presented in Table XX. Ration density and gross energy were determined by previously described methods, and average values appear in Table XXI.

With the exception of blood sugar concentration, response criteria for Trial 6 were the same as those for Trial 5.

Rumen fluid samples were obtained from two steers in each pen at 21-day intervals throughout the trial. Microbial action was stopped by adding 1 ml. of saturated mercuric chloride to 50 ml. of rumen fluid.

Other details of experimental procedure were as described for Trial 5.

Results and Discussion

The effects of fat and polyethylene additions to high concentrate rations on feedlot performance of steers are shown in Table XXII. Treatment differences in average daily gain were not statistically significant ($P>.05$). The average daily gain of 2.77 lb. obtained with Ration B exceeded all previous performances by cattle fed similar rations (Trials 1 and 5). Significant reductions ($P<.025$) in concentrate portion, TDN, ENE and gross energy intakes were observed as a result of polyethylene additions.

TABLE XX

COMPOSITION OF RATIONS FED IN TRIAL 6

Ration Type	High Concentrate	High Concentrate + Inert Bulk	High Concentrate + Fat	High Concentrate + Fat + Inert Bulk
Ration Designation	B	C	D	E
Ingredient, %				
Steam cracked milo	87.00	Same as B plus 300	80.70	Same as D plus 300
Cottonseed meal[a]	3.00	lb. inert bulk[d]	4.00	lb. inert bulk[d]
Dehydrated alfalfa meal[a]	5.00	added to 1 ton feed	5.00	added to 1 ton feed
Urea	0.80		1.10	
Molasses	3.00		3.00	
Stabilized animal tallow	-		5.00	
Salt	0.50		0.50	
Calcium carbonate	0.65		0.65	
Vitamin A premix[b]	0.03		0.03	
Trace minerals[c]	0.02		0.02	
Chemical composition, %				
Dry matter	92.90	93.72	93.13	94.30
Ash	3.81	3.57	3.90	3.58
Crude protein	13.14	11.81	14.99	12.76
Fat	6.19	5.15	8.85	7.40
Fiber	2.96	16.38	3.28	18.15
N.F.E.	66.80	56.81	62.11	52.41

[a]Crude protein: cottonseed meal, 41%; alfalfa meal, 17%

[b]10,000 I.U. of Vitamin A per gram

[c]Minimum per cent: Mn, 10.0; Fe, 10.0; Ca, 10.0; Cu, 1.0; Zn, 10.0; I, 0.3; Co, 0.1

[d]Polyethylene resin (Alathon), E. I. du Pont de Nemours Co., Inc., Wilmington, Delaware

TABLE XXI

ENERGY CONTENT AND DENSITY OF RATIONS FED IN TRIAL 6

Ration Type	High Concentrate	High Concentrate + Inert Bulk	High Concentrate + Fat	High Concentrate + Fat + Inert Bulk
Ration Designation	B	C	D	E
Energy				
TDN, %	75.5	65.7	81.4	70.8
Gross energy, cal./gm.[a]	3983.4	4948.2 (3464.0)[b]	4191.4	4976.5 (3644.8)[b]
ENE, megcal./lb.	0.73	0.64	0.79	0.69
Density, gm./liter[c]	582.8	552.2	596.4	559.4

[a]Average of two determinations

[b]Value corrected for polyethylene content of ration

[c]Average of three determinations

TABLE XXII

EFFECTS OF FEEDING TWO LEVELS OF ADDED INERT BULK AND TWO LEVELS OF FAT ON FEED INTAKE AND PERFORMANCE OF STEERS: TRIAL 6

Polyethylene Level, %	0	13	0	13	Standard Error of Treatment Means	Significant Differences[a]
Fat Level, %	0	0	5	5		
Ration Designation	B	C	D	E		
Number of steers	9[b]	10	10	10		
Average daily gain, lb.	2.77	2.63	2.56	2.66	.10	NS
Average daily intake, lb.						
Total ration	21.11	21.74	22.56	22.90	.53	NS
Concentrate	21.11	18.90	22.56	19.92	.50	Poly<Fat (P<.025)
TDN	15.94	14.28	18.36	16.22	.42	Poly<Fat (P<.025)
Estimated daily net energy, megcal.	15.41	13.92	17.82	15.80[c]	.41	Poly<Fat (P<.025)
Daily gross energy, megcal.	38.16	34.20	42.94	37.96[c]	.98	Poly<Fat (P<.025)
Daily volume intake, liter	16.43	17.86	17.16	18.58	.41	Poly>Fat (P<.05)
Feed conversion						
Lb. ration/lb. gain	7.62	8.26	8.88	8.60	.45	NS
Lb. concentrate/lb. gain	7.62	7.19	8.88	7.48	.46	NS
Lb. TDN/lb. gain	5.75	5.43	7.22	6.10	.37	Poly<Fat (P<.10)

[a]NS = non-significant (P>.05)

[b]One steer was removed after fourteen days due to chronic stiffness.

[c]Value corrected for polyethylene content

The inclusion of polyethylene resulted in a significant ($P<.05$) increase in daily volume intake. However, it is evident from the concentrate intake values that steers did not overcome the nutrient dilution effect of polyethylene when it was added to high concentrate rations containing zero or 5 per cent added tallow. This is in opposition with results of previous trials. In Trials 4 and 5, complete compensation for polyethylene additions to a high concentrate ration with added fat was obtained.

The fact that fat additions resulted in increased consumption of total ration is difficult to explain. Even though the degree of dustiness of Rations B and C exceeded that of Rations D and E, it was not deemed a problem and did not appear to be more pronounced than that observed in previous trials. A reduction in dry matter digestibility may have influenced consumption of the rations with added fat. Dry matter digestibilities for the rations containing polyethylene were determined by the method of Eudaly (1966). Values for Rations C and E were 70.38 and 63.08%, respectively. This indicates that inclusion of 5 per cent tallow in the concentrate ration with added polyethylene decreased dry matter digestibility by approximately 10 per cent. Chandler _et al_. (1966) also reported a reduction in dry matter digestibility when 10 per cent lard was added to a 70 per cent concentrate ration for dairy calves. However, Esplin _et al_. (1963) found a slight increase in dry matter digestibility when 4 per cent fat was added to a 70 per cent concentrate ration for cattle.

Analysis of the feed efficiency data revealed no significant (P>.05) differences in ration weight or pounds of concentrate required per pound of gain; however, the presence of fat tended to increase these values. This further indicates reduced digestibility with tallow additions. The addition of polyethylene tended to reduce the amount of concentrate required per pound of gain. This reduction was 5.6 per cent when polyethylene was added to the high concentrate ration without fat (B vs. C) and 15.8 per cent when it was added to the high concentrate ration with fat (D vs. E).

Improved digestion due to a reduction in level of nutrient material intake may have contributed to the improved feed efficiency observed with polyethylene additions. Eng and Riewe (1964) reported that level of intake significantly affected dry matter digestibility when rations varying in concentrate:roughage ratios were fed to sheep. Blaxter and Wainman (1964) observed that increasing the feeding level from maintenance to two times maintenance for cattle and sheep caused a reduction in the metabolizable energy of hay but not of flaked maize.

Carcass data and liver condition observations for this trial are presented in Table XXIII. The addition of polyethylene to the rations significantly (P<.05) reduced dressing per cent. This is difficult to explain since all rations produced carcasses with a similar degree of fat thickness. A build-up of polyethylene within the rumen could have influenced dressing per cent; however, no evidence of excess

TABLE XXIII

CARCASS AND LIVER DATA FROM STEERS FED TWO LEVELS OF ADDED INERT BULK AND TWO LEVELS OF FAT: TRIAL 6

Polyethylene Level, % Fat Level, % Ration Designation	0 0 B	13 0 C	0 5 D	13 5 E	Standard Error of Treatment Means	Significant Differences[a]
Carcass data						
Dressing per cent	61.9	60.9	62.1	60.8	.28	Poly<Fat (P<.05)
Carcass grade[b]	9.3	9.2	9.8	9.3	.24	NS
Marbling score[c]	7.5	6.7	7.2	7.3	.46	NS
Rib-eye area, sq. in.	10.93	11.20	11.13	10.60		
Rib-eye area/cwt. carcass, sq. in.	1.78	1.88	1.87	1.80	.03	NS
Fat thickness, in.	.66	.63	.63	.63		
Fat thickness/cwt. carcass, in.	.11	.10	.11	.10	.02	NS
Boneless retail cuts, %	49.50	49.99	49.87	49.60	.45	NS
Abscessed livers	4	6	1	2		

[a]NS = non-significant (P>.05)

[b]7 = low good, 9 = high good, 11 = average choice

[c]Slight = 5, slight + = 6, small - = 7

polyethylene accumulation was observed in rumen fill data for Trials 1 and 2. No other significant differences were noted in carcass measurements. The incidence of abscessed livers was lower for rations containing added fat than for rations without added fat (15 vs. 50%).

Rumen pH values, VFA concentrations, and rumen condition scores are shown in Table XXIV. No significant ($P>.05$) treatment differences were noted among ruminal pH values; however, average values tended to be slightly lower for steers fed rations containing fat (D and E). A significant ($P<.01$) polyethylene x fat interaction was obtained for total VFA concentration. Analysis for simple effects (Steel and Torrie, 1960) revealed that steers fed Ration E had a significantly higher total VFA concentration than did steers fed Rations C ($P<.05$) and D ($P<.01$). Separate statistical analyses for the molar percentages of ruminal acetic, propionic, and butyric acids did not indicate any significant ($P>.05$) treatment differences. It is interesting to note that consumption of rations containing polyethylene (C and E) resulted in higher proportions of ruminal propionic than acetic acid; however, treatment differences in acetic:propionic ratios were not statistically significant ($P>.05$). A slight increase in molar percentage of propionic acid due to polyethylene additions was also noted in Trial 5. Eusebio _et al_. (1959) reported higher proportions of ruminal propionic than acetic when flaked corn was fed to cattle. Information concerning the effects of inert bulk on VFA concentration and feed

TABLE XXIV

EFFECTS OF TWO LEVELS OF ADDED INERT BULK AND TWO LEVELS OF FAT ON RUMEN CONDITION, pH AND VOLATILE FATTY ACID CONCENTRATIONS: TRIAL 6

Polyethylene Level, % Fat Level, % Ration Designation	0 0 B	13 0 C	0 5 D	13 5 E	Standard Error of Treatment Means	Significant Differences[a]
Rumen pH	5.51	5.51	5.40	5.33	0.04	NS
VFA concentration, mM/l.	128.20	121.73	115.39	137.19	4.50	Poly X Fat (P<.01) C vs. E (P<.05) D vs. E (P<.01)
VFA concentration, molar %						
Acetic	45.83	42.58	42.43	39.35	3.63	NS
Propionic	42.24	45.09	42.55	46.02	2.13	NS
Butyric	11.87	12.33	15.01	14.64	2.46	NS
Acetic/Propionic	1.14	0.97	1.04	0.88	0.11	NS
Rumen condition						
Color[b]	2.4	2.0	3.3	2.2		
Erosion[c]	2.2	2.3	2.4	2.4		
Matted papillae[c]	3.3	2.4	3.3	3.3		
Entrapped hair[c]	3.0	2.2	3.0	2.5		

[a]NS = non-significant (P>.05)

[b]1 = normal, 2 = slightly dark, 3 = dark, 4 = very dark

[c]1 = normal, 2 = slight, 3 = moderate, 4 = severe

efficiency is limited. More efficient utilization of propionic acid in relation to acetic acid may be a partial explanation for the improved efficiency noted with polyethylene additions.

SUMMARY

Four long-term feeding trials (Trials 1, 2, 5, and 6) were conducted to investigate some of the effects of ration density, bulk, caloric source and energy concentration on feed intake and feedlot performance of steers. In addition to standard performance and carcass data, concentrations of volatile fatty acids in rumen fluid were determined in two of these trials. Data concerning condition of the liver and the rumen epithelium were also collected.

Two short-term trials (Trials 3 and 4) were conducted to determine the effects of ration composition on feed intake and ruminal volatile fatty acid patterns.

In comparing the effects of conventional and high concentrate rations, steers fed conventional rations consumed more total ration than steers fed high concentrate rations. This was significant in Trials 4 and 5. Higher values for daily volume intake and daily estimated net energy intake were also obtained with conventional rations. Feed efficiency expressed as total pounds of ration per pound of gain tended to favor the high concentrate rations; however, in Trial 5 the amount of concentrate required per pound of gain was significantly lower for the conventional ration. Conventional rations resulted in significantly higher ruminal acetic: propionic ratios than high concentrate rations in Trials 3,

4, and 5. Rumen pH was significantly higher for conventional rations in Trials 4 and 5. Conventional rations also resulted in more favorable rumen condition scores than high concentrate rations in Trial 5.

The caloric source in the experimental rations was varied by replacing 5 per cent milo with a like quantity of stabilized animal tallow. The addition of fat to either conventional or high concentrate rations tended to decrease total feed consumption in Trials 4 and 5, while fat additions to a high concentrate ration resulted in increased feed consumption in Trial 6. Fat additions did not significantly affect average daily gains. The presence of fat in the ration tended to reduce the pounds of ration required per pound of gain in Trials 1 and 5; however, the addition of fat to a high concentrate ration resulted in a nonsignificant increase in pounds of ration per pound of gain in Trial 6. The addition of fat to a conventional ration significantly reduced the concentration of acetic acid in rumen fluid; however, the acetic:propionic ratio was not significantly affected.

Ration density (weight/unit volume) was increased by adding 20 per cent sand to conventional rations in Trials 1 and 2. The addition of sand resulted in an increase in total ration intake; however, complete compensation for the nutrient dilution was not obtained in either trial. Daily volume intake was similar to that obtained with the conventional ration without sand. Gains were increased by sand additions in Trial 1 and reduced in Trial 2; however, these differences were not significant. Sand additions did not have any significant effects on carcass traits.

The effects of bulk *per se* were studied by adding 13 per cent polyethylene resin (Alathon), an inert plastic material, to conventional rations and high concentrate rations with added fat. In all cases daily intake of total ration and daily volume intake increased with polyethylene additions. Complete compensation for the nutrient dilution was obtained in Trials 1, 4, and 5, but polyethylene significantly reduced nutrient material intake when added to a conventional ration in Trial 2 and when added to high concentrate rations in Trial 6. In the four long-term feeding trials, the addition of polyethylene to the rations reduced the amount of nutrient material required per pound of gain in all cases; however, this was significant only in Trial 5. Also in Trial 5, the presence of bulk in the ration in natural form (cottonseed hulls) or inert form (polyethylene) significantly increased average daily gains. The addition of polyethylene to high concentrate rations with or without added fat resulted in a nonsignificant reduction in the ruminal acetic:propionic ratio in Trials 4, 5, and 6. The presence of polyethylene in the ration also tended to reduce the incidence of hair trapped among papillae in the rumen.

Total ration intakes and intakes of estimated net energy were reduced when high concentrate rations were compared with conventional rations. Whenever 20 per cent sand or 13 per cent polyethylene was added to finishing rations, daily intake of total ration increased; however, complete compensation for the energy dilution was not obtained in all cases. It appeared that the steers were trying to equalize energy intake regardless of the bulk and density factors. Pounds of feed required per pound of gain favored the high concentrate rations; however, the inclusion of limited bulk in the form of cottonseed hulls or polyethylene resin resulted in the most efficient utilization of the concentrate portion of rations used in this study. Variable results with respect to feed intake and performance were obtained when 5 per cent animal tallow was included in finishing rations for steers.

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