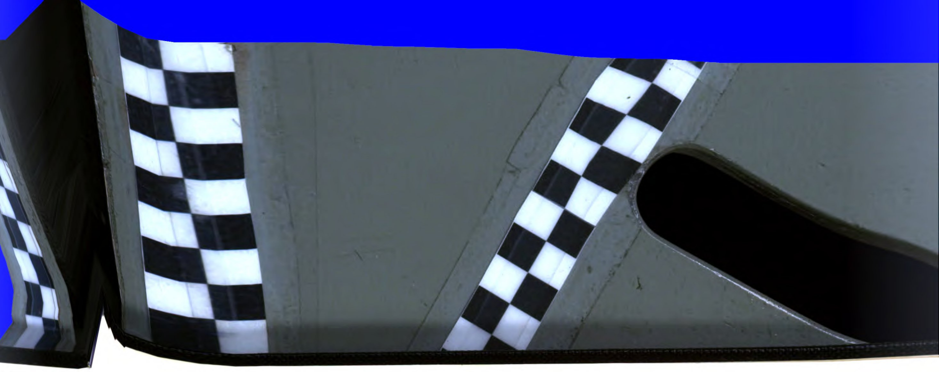

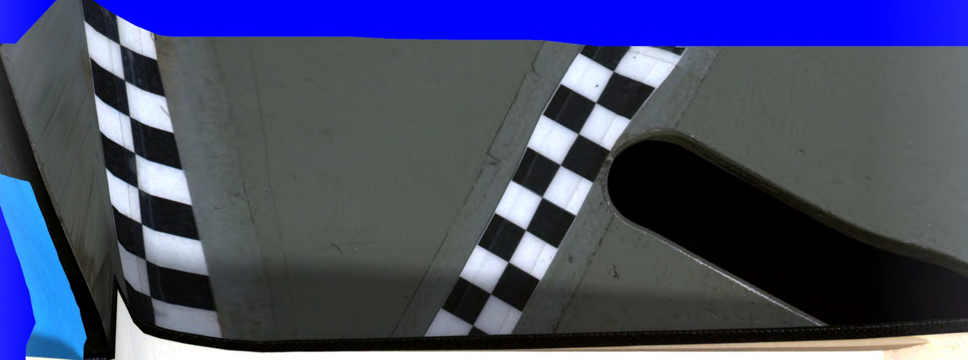

ABSTRACT

RATE OF PASSAGE OF INGESTED MATERIAL THROUGH THE DIGESTIVE TRACT OF STEERS

by Charles M. Derrickson

Eight yearling Angus steers of uniform weight, age and from the same sire were used in a series of four trials to study the effects of particle size and level of intake on the rate of passage of "all-concentrate" rations and a concentrate plus 20% roughage ration. The treatments were arranged with two steers on each in a reversal design so that during the four trials eight observations were made on each treatment. Inert plastic particles (specific gravity 1.425) with physical characteristics similar to the feed were used as indicators to measure the rate of passage. The effects of particle size were studied by separating the plastic (Delrin Acetal Resin) into groups having a mean diameter of 4.76, 2.38, 1.19 and .595 mm. Within this size range the rate of passage of inert particles through the digestive tract decreased as the size of particles increased in diameter. There were highly significant differences in the rate of passage of all size particles at the 72, 96, and 120 hour intervals after feeding.

Comparison of rations showed a highly significant difference in their rate of passage. The finely ground concentrate plus 20% roughage ration passed at a significantly ($P < 0.01$) faster rate than the finely ground corn, coarse cracked corn or the finely ground ration force fed.

The finely ground all concentrate ration passed through the digestive tract of the steer significantly ($P < 0.01$) faster than the coarse cracked ration. Inert particles in the coarse cracked corn ration passed through the digestive tract of the steer at a slower rate than the particles in the other rations. These results indicate the importance of particle size on the rate of passage of undigested residues through the digestive tract as measured by the movement of inert plastic particles. The data suggest that 20% corn cobs in a concentrate-roughage ration stimulated some portion of the digestive tract increasing the rate of passage of inert particles in comparison to all concentrate rations. Comparing these results with other experiments of mixed rations suggests that the cobs may act as a mechanical stimulus increasing ruminal contractions and speeding up the passage rate.

The results of this study showed that increasing the level of feed intake of a finely ground all concentrate ration decreased the rate of passage of inert particles in that ration during the 7 day collection period. Observations on animals voluntarily consuming their allotted ration plus 0.5% of their body weight more of the finely ground feed showed a decrease in rate of passage. All particle sizes decreased in rate of passage in contrast to the same ration consumed at a lower level. However, the force fed steers showed a more rapid rate of passage than steers consuming the same level of intake without force feeding. The faster rate of passage of the inert particles in the concentrate plus roughage ration in comparison to the all concentrate rations indicates some physical and/or chemical changes take place in the digestive tract of steers on different rations.

The ration remaining in the digestive tract for the shortest period of time showed a significant decrease in its digestibility as compared to the ration with the longest retention time. The rate of passage as measured by inert plastic particles was indirectly related to digestibility.

RATE OF PASSAGE OF INGESTED MATERIAL THROUGH

THE DIGESTIVE TRACT OF STEERS

By

Charles M. Derrickson

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RATE OF PASSAGE OF INGESTED MATERIAL THROUGH

THE DIGESTIVE TRACT OF STEERS

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Charles M. Derrickson

J. A. Hoefer

(Director of Dissertation)

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Date

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Chapter I

INTRODUCTION

The nutritive value of feeds depends upon what the animal's digestive tract can extract from the feed and what the body can assimilate from the extracted portion of the feed. In order to evaluate effectively the usefulness of any feedstuff for livestock, it has long been realized that the incomplete availability of nutrients to the animal should be considered. The length of time a given quantity of feed spends in the digestive tract may be of considerable importance in determining how much nutrient material can be absorbed by an animal. Consequently, knowledge of the rate of feed passage through the digestive tract is important, especially in digestibility studies. The information obtained in digestive studies would indicate how long a feed could exert an influence on digestibility and would be especially useful in interpretation of results when animals are changed from one ration to another. If feeds are moved through the digestive tract at a very rapid rate, enzymes may not have adequate time to exert their maximum effect. A fast rate of movement may reduce absorption with large amounts of the nutrient material being excreted. If passage is slow, the animal may not pass the undigested residue fast enough and voluntary feed consumption could be reduced considerably.

There are conflicting opinions in the literature on the effects of passage rate as well as a lack of definite information on the rate of passage of different feeds through the digestive tract of ruminants. The anatomy of the anterior part of the digestive tract of the ruminant complicates the rate of passage of feeds through the digestive tract. Indigestible substances have been utilized in investigating passage rate. They have included both natural and foreign components of the feed. Since physical characteristics exhibited by the reference substance influence its rate of passage through the digestive tract (Campling and Freer, 1962 and Johnson _et al_., 1964), the usefulness of inert reference materials is restricted to the study of nutrients with similar physical properties. When solid materials such as plastics are fed, consideration must be taken of the fact that the bovine regurgitates and remasticates a considerable portion of the food consumed; therefore the plastic material should be of a structure that will not be broken down during rumination. Campling and Freer (1962) have shown that the size and specific gravity of feed particles may be factors which influence the passage of various feedstuffs. Little consideration has been given to the use of indicators which have physical characteristics similar to those of the feed.

This study attempts to evaluate particle size, as a factor influencing passage by using an indicator which possesses many of the physical properties of feeds. The material should possess the following characteristics to be used as reference substance. The material must be inert, indigestible and recovery from the feces must be

possible. Therefore it is necessary to feed substances which the animal will not digest nor absorb and which do not affect the digestive system. The material should possess characteristics that would permit it to be ground into particle sizes similar to those of the feed.

Chapter II

REVIEW OF LITERATURE

It has been generally assumed that an increased rate of feed passage is accompanied by an increased voluntary feed intake and a lower digestibility. It was concluded by Blaxter *et al*. (1956) that the method of preparation modified the rate of feed passage through the gut and this rate was the determinant of its digestibility. Wright (1929) suggested that changes in the rate of feed passage influenced voluntary intake. Blaxter *et al*. (1956) and Crampton (1957) stressed the importance of the rate of disappearance of digesta from the reticulo-rumen in determining the voluntary intake of roughage. Ewing and Smith (1917) reported that, in general, more complete digestion of total dry matter was associated with more rapid passage of feed residue through the ruminant while crude fiber digestibility decreased. Blaxter *et al*. (1956) found that increasing the feeding level resulted in an increase in the passage of food and a fall in its digestibility.

Techniques for Estimating Rate of Passage

Various techniques have been employed in studying the rate of passage of feed through the digestive system of the ruminant. From these techniques have come several different terms used to indicate the rate of movement of digesta. Balch (1961) defines "rate of passage" as the time taken by undigested residues from a given meal to pass through the digestive tract or through some part of the digestive tract. This is distinctly different from the "flow of digesta" which is expressed as the rate at which the mixture of undigested residues from a previous meal passes a given point in the digestive tract. These terms are nearly synonymous when referring to the lower tract of the ruminant; but anterior to the reticulo-omasal orifice, mixing and sifting of rumen contents occurs to such an extent that digesta flowing past any one point at any one time contains residues from several meals.

The "mean retention time", defined as the mean length of time food stays in the digestive tract, was obtained by Blaxter et al. (1956) by dividing the sum of the times which individual stained dried grass particles spent in the tract by the total number of particles. Castle (1956) measured the "mean retention time" by adding together the times of excretion from 5 to 95% at intervals of 10% and then dividing by 10. This value termed "R" represented the mean retention time in hours of stained hay, was calculated from percentage excretion curves and was used as a measure of rate of passage.

The most widely accepted technique of measuring rate of passage is the one based on the method of Balch (1950). It involves counting the number of previously stained feed particles appearing in the feces in successive intervals of time. Blaxter et al. (1956) using mature sheep and Balch (1950) using mature cattle estimated the effect of grinding on the passage rate of stained hays. The investigations of rate of passage with goats by Castle (1956) have included use of stained oats, straw, hay

and fecal fibers.

The conventional method of measuring rate of passage by using non-feed markers ingested as a loose mixture with feed has not generally been accepted as satisfactory since the markers have a tendency to become separated from the food with which they were originally fed. Many such substances have been used in studying the rate of passage of feeds through the digestive system. Hoelzel (1930) used rubber, cotton threads, seeds, glass beads and several metals. Moore and Winter (1930) used ferric oxide and rubber. Campling and Freer (1962) investigated the passage of inert particles through the cow using rubber and several plastics.

The early work of Ewing and Smith (1917) estimated the rate of feed passage through steers using rubber markers and moisture content of feces. They assumed that a higher moisture content of feces was indicative of a rapid rate of passage; however, no actual determination of the time taken by food to pass through the gut was made. These workers also used digestion trials followed by slaughter and examination of the digestive tract contents. King and Moore (1957) used inert plastic materials of different size and density along with powdered chromic oxide to study passage rate and Johnson _et_ _al_.(1964) used chromic oxide incorporated as a component of paper and as a powder. Brandt and Thacker (1958) studied the passage of radio-active chromic oxide and Weller _et_ _al_. (1962) compared the passage of lignin and polyethylene glycol.

Indices of the rate of passage have been developed by several workers (Balch, 1950; Blaxter _et_ _al_., 1956; Castle, 1956; and Brandt and Thacker, 1958). In a rather extensive study of feed passage through the

cow, Balch (1950) used a 5% excretion time and an 80% minus 5% as descriptive of his accumulation curves. Balch has shown that the time taken to excrete 5% of the stained residues of a meal is approximately equivalent to the time required for the feed to pass through the omasum, abomasum and intestine. He further proposed that the 80% minus 5% excretion time was the interval between excretion of 5% and 80% of the stained particles and was indicative of the time the feed particles spent in the reticulo-rumen. Brandt and Thacker (1958) introduced the terms t_2 and t_1 to represent the time spent by the feed in the reticulo-rumen and the remainder of the tract, respectively.

Castle (1956) calculated a term "R" which was defined as the mean retention time in hours which stained hay particles spent in the digestive tract. This term was calculated by adding together the times of excretion from 5% to 95% at intervals of 10%, taken from graphs plotted on rates of excretion of undigested residues of stained hay, and dividing the sum by 10. This value was used as a measure of the mean retention time in hours, of the stained particles in the alimentary tract.

Another term used in describing rate of passage time is referred to as "mean time" (Blaxter et al., 1956). Mean time is a measure of the mean length of time food stays in the digestive tract and is determined by dividing the sum of time which individual stained particles spend in the digestive tract by the total number of stained particles excreted.

After using stained particle counts to calculate the rate of passage by each of the above mentioned methods Shellenberger and Kesler (1961) concluded that all methods discussed appeared satisfactory, but

these methods appeared to be slightly more reliable which measured mean time spent in the digestive tract by each stained particle.

Factors Influencing Rate of Passage

Effect of particle size

There is considerable evidence which suggests that, with diets containing normal levels of roughage, small particles are eliminated more rapidly than large ones. Ewing and Smith (1917), using rubber markers, concluded that finer particles of feeds and finer ground feeds passed through the ruminant animal more rapidly than coarser feeds and that coarse feeds and roughages retarded the rate of passage of feed residues. Blaxter *et al.* (1956) concluded, after feeding sheep dried grass in its natural form and in the form of cubes made from medium ground and finely ground material, that the method of preparation modified the rate of passage. The finely ground, cubed grass passed through the digestive tract more rapidly than the long, dried grass. Castle (1956b), using stained hay and stained fecal fragments as markers, reported that the small fecal fragments invariably traveled faster than the hay and suggested that the increased rate of passage was due mainly to the smaller particle size. Rodrigue and Allen (1960), comparing the rate of passage of unground hay with hay ground to different degrees of fineness observed a more rapid passage of finely ground hay throughout the entire tract. These workers concluded that the finer the grind the faster the rate of passage.

These observations are in agreement with Ewing and Smith (1917),

Blaxter *et al.* (1956) and Meyer *et al.* (1959). Ewing and Smith (1917) concluded that finer particles of feeds and finer ground feeds passed through the ruminant animal more rapidly than coarse feeds and that coarse feeds and roughages retarded the rate of passage of feed residues. Blaxter *et al.* (1956) concluded from feeding sheep dried grass in its long form and cubes made from medium ground and finely ground material, that the method of preparation modified the rate of passage. The finely ground, cubed grass passed through the digestive tract more rapidly than the long dried grass. Meyer *et al.* (1959) reported that ground pelleted hay passed through the digestive tract of sheep at a faster rate than unground hay. The fact that finely ground, cubed grass and hay passed through the digestive tract more quickly than long material is contrary to the results of Balch (1950) and Balch *et al.* (1954, 1955) who reported that ground hay in rations in which all the hay was ground was excreted over a longer period than hay in a similar ration in which the hay was not ground. Meyer *et al.* (1959) postulated that the increased feed intake of sheep which resulted when hay was ground and pelleted was the direct result of a faster rate of digestion in the reticulo-rumen. This accelerated digestion of the finer hay particles allowed a faster rate of passage of feed through the digestive tract. The pelleted ground roughage passed more rapidly through the digestive tract by virtue of a faster movement from the reticulo-rumen (Blaxter and Graham, 1956; Blaxter *et al.*, 1956; and Meyer *et al.*, 1959). Balch (1950) noted that ground hay given as a small addition to unground hay was excreted more rapidly than the unground hay. Stained hay particles were used to

measure the rate of passage of undigested residue.

King and Moore (1957), using inert plastic particles, reported that particles of 1.2 specific gravity passed at a faster rate than either lighter or heavier particles. The size particles of 1.2 specific gravity which passed most rapidly were between 20 and 30 cu. mm. Campling and Freer (1962) reported the mean retention time of inert particles of specific gravity 1.2 to be directly related to the size of the particle within the range of 17-58 cu. mm. The larger particles were retained 12% longer than the smaller.

Balch (1950) reported that the roughage in diets in which all the hay was ground required considerably longer periods of time to pass through the digestive tract than similar hay diets in which the hay was not ground. Hoelzel (1930), using several species of non-ruminants, found the rate of passage nearly proportional to the specific gravity of the materials used. King and Moore (1957), using Cr_2O_3, suggested that factors other than density and particle size apparently influenced the rate of passage. Cr_2O_3 (with a specific gravity of 5.1 and very finely dispersed) would be expected to move very slowly through the digestive tract; however, on the basis of comparison with plastic particles the Cr_2O_3 moved faster than predicted. Moore and Winger (1934) found considerable variation in the rate of passage of rubber rings and ferric oxide.

Nature of ration

Some of the early work on rate of passage in ruminants (Ewing and Smith, 1917) reported that the two most important factors determining the rate of passage were the nature of the ration and the level of feed intake.

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Balch et al. (1956) noted very slow passage of a ration containing much concentrate and little roughage. The roughage remained for an abnormally long time in the reticulo-rumen. Castle (1956) noted greater retention time for straw than for hay when both were fed together. Bell (1960) reported that roughages such as wheat straw and alfalfa hay which were least capable of swelling in water passed through the non-ruminant digestive tract at a slower rate than other "bulks" such as bran, cellulose or corn cobs. Blaxter et al. (1961) feeding poor, medium and good quality roughages to sheep found the poorest quality to pass through the gut more slowly than the medium quality roughage which, in turn, passed through the gut more slowly than the highest quality roughage.

Frequency of feeding

As previously cited, Ewing and Smith (1917) suggested that the rate of passage of feed residue was influenced by the quantity of ration consumed. They reasoned that an increase in consumption would cause an increase in the rate of passage of feed residues. Rakes et al. (1957) found no differences in the rate of passage of the same total daily intake of a medium quality chopped alfalfa-orchard grass hay when fed twice daily or ten times daily to dairy heifers. Campling et al. (1961) suggested that the voluntary intake of a roughage by a cow is closely related to the mean retention time in the digestive tract.

Level of intake

The level of feed intake appears to have a direct effect on the rate of passage of feed residue through the digestive tract. The work r

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of Campling et al. (1961) indicating a decreased retention time with increasing intake is in agreement with the results of Balch (1950) and Blaxter et al. (1956). Blaxter et al. (1956) found that increasing the level of feeding resulted in an increase in the rate of passage of feed and a decrease in its digestibility. These workers concluded that the method of preparation modified the rate of passage of feed through the digestive tract and this rate was the determinant of its digestibility. Castle (1956) reported the mean retention time to be directly related to the daily intake of feeds. As the feed intake increased the mean retention time ("R") decreased. Shellenberger and Kesler (1961) reported the rate of passage of feed residues to be faster in high producing cows consuming greater quantities of feed than low producing cows. These researchers found the level of dry matter intake was correlated with the rate of passage.

Rate of Flow

The flow of digesta along the digestive tract has been measured by using surgical preparations in which the flow of digesta was permanently exteriorized by means of re-entrant fistulas.

Harris and Phillipson (1962) and Hogan and Phillipson (1960) measured the flow of digesta into the duodenum by collecting digesta from the proximal cannula, measuring and sampling and returning the digesta through the distal cannula. Singleton (1961) measured the flow of digesta into the duodenum by an electromagnetic method on an unopened tube connecting the two cannulas through permanently exteriorized duos

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denal loops. Results of this work clearly showed the flow of digesta into the duodenum to be phasic with variations both in size and frequency of the gushes which were followed by varying amounts of backflow. Phillipson (1948) noted that digesta in the ruminant flowed in gushes every few minutes into the duodenum. The work of Phillipson (1952) showed that the flow of digesta passed to the duodenum in gushes at regular intervals for 17 out of 24 hours and that the flow was more regular during rumination. This work suggested that the flow of digesta from the abomosal cannula was accelerated during eating. Measurements taken by Hogan and Phillipson (1960) indicated the mean rate of flow to be 360 and 180 ml. per hour in the duodenum and ileum, respectively. Phillips and Dyck (1964) measured the flow of digesta into the duodenum of sheep by continuously infusing an indicator solution of polyethylene glycol 4000 at a constant rate into the abomasum via a cannula. The volume of digesta flowing was calculated from the dilution of the indicator in samples of digesta obtained from a duodenal cannula.

Balch (1950) introduced a suspension of ground stained hay into the abomasum of cows and found that the time at which 93 - 97% of the marker was excreted was the same as the time required for 5% excretion of the marker given by mouth. Castle (1956c) found stained fecal fragments that had been introduced directly into the duodenum of the goat appeared in the feces 9 to 12 hours later with a maximum concentration occurring in the feces 1 to 2 hours after their first appearance. Ninety-five percent of these particles fed by mouth appeared in the feces 1 to 4 hours after the appearance of the particles placed in the duodenum.

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Chapter III

EXPERIMENTAL METHODS

Animals and their treatments

Fourteen yearling Angus steers were used in a series of four trials. They were selected from one herd and had all previously been treated similarly. The steers were from the same sire and were of uniform weight and age.

The steers were placed in individual box stalls and fed a uniform ration for a 60 day adjustment period. The ingredients used in the ration fed during the adjustment period are given in table 1. The shelled corn was finely ground in a hammer mill and mixed with the other ingredients in a conventional feed mixer. The high concentrate ration consisting mainly of ground shelled corn was supplemented with protein, minerals and vitamins. All ingredients were mixed for at least 20 minutes. The steers were given only a small amount of the ration in the beginning of the adjustment period and gradually increased until they were receiving all they would consume each day. If a steer did not consume his daily ration it was cut back until the allotted amount was consumed. Steers were given free access to water while they were in the box stalls. The level of water intake of the steers for the experimental period was determined during the part of the preliminary periods in which the animals were kept in stanchions.

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TABLE I. PRELIMINARY RATION

Ingredients	% of ration	Pounds per ton
Ground shelled corn	83.55	1,671
Soybean meal	15.00	300
Mineralized salt	0.50	10
Ground limestone	0.50	10
Steamed bone meal	0.40	8
Vitamin A & D premix*	0.05	1
Total	100.00	2,000

*Each gram of the vitamin A & D premix supplied 10,000 I.U. of vitamin A palmitate and 1,250 I.U. of vitamin D_2.

The stalls were bedded with tobacco stems to discourage the consumption of the bedding. During the last part of this preliminary period the steers were placed in stanchions for two 10 day periods. After remaining in the stanchions for 10 days the steers were returned to their box stalls for a rest period. They were allowed to remain in the stalls five days before returning to the stanchions. The conditioning period was conducted to accustom the steers to confinement. Final selection of the eight steers used in this study was based on the following conditions:

(a) Rapid adjustment to the confined conditions and maintenance of uniform feed consumption.

(b) No signs of swelling in their legs and joints while re

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remaining in the stanchions for extended periods. The eight steers were paired according to weight and placed in stanchion type collection crates for the 68 day feed passage and digestion experiment. The animals remained in the crates throughout the entire experiment except to be taken out at the end of each trial at which time they were weighed and returned to the crates. Each pair of steers was arranged in a reversal type arrangement so that during the four trials eight observations were made on each treatment.

Two steers were placed on each of the four rations with the daily allowance determined by the steer consuming the smallest amount of feed during the preliminary period. The feed offered and that left uneaten was weighed daily until the steers were on a constant level of intake. The steers were fed twice daily at 12 hour intervals. One-half of the daily ration was fed at 6 A.M. and the other one-half was fed at 6 P.M. The steers were watered twice daily, just prior to the morning and evening feeding. The level of water intake was held constant throughout the four feeding trials. The animals were offered two gallons of water before each feeding. The level of water intake determined during the preliminary period did not appear to affect the dry matter intake. The two steers on each of the four trials receiving the higher level of feed intake were given the same amount of water as the animals on the lower level of feed intake.

Rations and methods of preparation

The rations required for all four trials were ground and mixed at the same time with feed ingredients from the same source. The corn

in ration 1 and 3 and the corn and cobs in ration 4 were finely ground in a hammer mill. The corn in ration 2 was coarsely cracked with a burr mill. The remaining ration ingredients were not altered from their usual form.

One ton each of the four rations was mixed at the beginning of the experimental period. The rations were mixed in 1,000 pound lots in a 1,500 pound commercial feed mixer. The minerals and vitamins were premixed before adding to the corn and protein mixture. Each batch of the experimental ration was mixed for a period of thirty minutes.

During each trial two steers were fed (ration 1) finely ground shelled corn as the basal ration; two steers were fed (ration 2) the coarsely cracked corn; two steers were given (ration 3) the finely ground corn ration and force fed at the rate of 0.5% of the animals live weight above the basal ration; and two steers were fed (ration 4) finely ground corn plus 20% ground cobs. All four of the rations were supplemented with protein, minerals and vitamins A and D. The daily ration contained a total of 22,680 I.U. of vitamin A palmitate and 2,835 I.U. of supplemental vitamin D_2. The composition of each of the four rations is given in table 2. Rations 1, 2 and 3 were all concentrate rations of identical composition, they differed in particle size and method of administration.

TABLE 2. EXPERIMENTAL RATIONS

	Rations-pounds per ton	
Ingredients	1, 2 and 3	4
Ground shelled corn	1,686	1,286
Soybean meal (44% C.P.)	275	275
Ground corn cobs	---	400
Trace mineralized salt	20	20
Ground limestone	10	10
Steamed bone meal	8	8
Vitamin A & D premix*	1	1
Total	2,000	2,000

*Each gram of the vitamin A & D premix furnished 10,000 I.U. of vitamin A palmitate and 1,250 I.U. of vitamin D_2.

Proximate analyses of the experimental rations are given in table 3. In preparing the feed for analysis samples were taken each day during the experimental periods. The composite sample was mixed well at the end of each trial and an aliquot taken for analysis. The sample was ground in a Wiley mill, mixed and stored in an air tight container until analyzed. The rations were analyzed according to standard methods (A.O.A.C.,1960). Crude fiber determinations were not made; however, average cellulose percentages are listed for the four trials.

TABLE 3. PROXIMATE ANALYSIS OF RATIONS[1]

	Ration			
Component	1	2	3	4
Moisture (%)	12.37	11.95	12.37	11.79
Crude protein (%)	13.63	14.56	13.63	13.22
Cellulose (%)	6.26	6.84	6.26	11.33
Gross energy (kcal./g)	3.881	3.831	3.881	3.860

[1]Analysis made by the Kentucky Agricultural Experiment Station Animal Nutrition Laboratory.

Since attempts were made to study the rate of passage of corn, the fineness of grind of the corn was measured. Representative samples of ground corn were taken from the mixer after the corn was well mixed. The remainder of the ration ingredients were added to the corn and mixed for 30 minutes in a commercial feed mixer. The particle size or degree of fineness was established from the percentage of a 250 gram sample of the ground corn remaining on each of six screens (4, 8, 16, 30, 50, and 100 mesh) after the sample was shaken for five minutes on a mechanical shaker. The particle size was established from the average of five 250 gram samples taken from each mixture of cracked and fine ground corn. Therefore, the fineness of grind, as determined by the above method, is a measure of the particles remaining on each of the screens. The percent of ground corn remaining on each screen, taken as the average of five samples is

given in table 4. The majority of particles in the finely ground feed were 2.38 mm and smaller while the majority of the particles in the cracked corn were 2.38 mm and larger.

TABLE 4. THE SCREEN SIZE AND PERCENT OF CORN REMAINING ON EACH SCREEN

		% of material on each screen	
Screen mesh	Diameter of opening (mm)	Fine grind	Cracked
4	4.76	1.5	25.7
8	2.38	22.5	61.8
16	1.19	36.5	7.9
30	.595	21.5	2.7
50	.297	17.0	1.3
100	.149	1.0	.6

Material used as inert particles

The inert plastic material used in this study to measure the rate of passage of feeds through the digestive tract was based on the same percentage of fineness as the ground corn. A 250 gram sample of the ground plastic was placed in the number 4 mesh screen and shaken for five minutes on the mechanical shaker. Particle size was then separated according to the diameter of the opening of the screens as shown in table 4.

The material used as inert particles was Delrin Acetal Resin

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(E. I. du Pont, Wilmington 98, Del.). This material was selected for use because of its hardness, its grinding properties, which allowed it to be separated into sizes similar to ground corn, and its specific gravity (1.425) which is similar to that of ground corn. Since it has been shown that the physical characteristics of a feed determine to a large extent its passage rate, it appears logical that the inert material should possess as near as possible the physical characteristics of the feed.

The specific gravity of both the ground corn and plastic was determined with a Beckman Model 930 air compressed pycnometer. Since the specific gravity of the plastic was similar when measured with this instrument to the specific gravity given by the manufacturer it was assumed that measurements made were reasonably accurate. The pycnometer measures the volume of powder, granular, porous or solid materials. Therefore the specific gravity of a sample, which is the ratio of the sample density to water at 4°C, is readily computed since the pycnometer provides a method for volume measurement. To further check the reliability of the air compressed pycnometer the specific gravity of ground corn was calculated by first weighing the substance in the air and then weighing it under water. The values obtained by this method were similar to those given by the pycnometer.

The plastic which was obtained in 1/2" x 5' plastic rods was ground in the same hammer mill, through the same screen as was the corn. The ground plastic was separated into particle sizes, and ratio of sizes fed was based on the percentage of the respective size particles of corn as determined by separating through the different size screens.

The particle size and quantity of the inert material fed is given in table 5.

TABLE 5. THE NUMBER OF GRAMS AND APPROXIMATE NUMBER OF EACH SIZE INERT PARTICLES

	Amount fed (gms)		Approx. no. particles fed	
Screen opening	Fine grind	Cracked	Fine grind	Cracked
4.76	3.4	58.6	118	282
2.38	51.3	140.8	1,938	5,068
1.19	83.2	18.0	30,916	6,426
.595	49.0	6.2	105,052	16,625
.297	38.8	3.0	---	---
.149	2.3	1.4	---	---

Level of intake

The animals were fed at two levels of intake. During a preliminary period all steers were fed free choice, to determine the daily intake of full feeding as near as possible. The level of feed intake was determined by the steer consuming the smaller amount during this period. The daily allowance was set at 4560 grams with 2280 grams being fed at 6 A.M. and 6 P.M. daily. Two of the eight steers were force fed in each trial. The term "forced feeding" in this experiment is used to describe the method of feeding animals more than they would voluntarily consume. Two animals on each trial were fed 0.5% of their body weight more feed daily

than the intake level of the other steers. For example, steers weighing 600 pounds would receive an additional 3 pounds of feed daily or a total of 13 pounds of feed. The animals receiving the extra allowance were first offered their feed in metal feed boxes attached to the metabolism crates. The steers were not force fed unless they refused to consume their ration within a thirty minute period. The amount of feed remaining at the end of one half hour was mixed into a slurry and again offered to the animal. The portion of the feed not consumed by the animal was then force fed by using a plunger type gun which would hold approximately 6 pounds of the finely ground feed made into a slurry. To force feed an animal its head was elevated with the nipple like extension of the gun placed over the back part of the tongue. The slurry was then slowly forced into the animal's mouth. Most of the animals swallowed the feed with very little resistance after the first few feedings. The feed was made into a slurry by mixing with the 2 gallon portion of water allotted to the animal at each feeding. Although the steers were offered their feed in the dry and wet form, it was necessary to force feed a portion of their ration with the gun after two or three days of feeding. It was necessary to force the ration down six of the eight steers on the force fed ration. Once the animal failed to consume his total ration, it was usually necessary to force feed the entire ration throughout the remainder of the trial.

The force feeding mechanism was a simple plunger type gun made of 16 gauge stainless steel. The feeder was 4 inches in diameter and 15 inches long. It was designed so the feed and water mixture could be than the intake level of the other steers. For example, steers weighing 600 pounds would receive an additional 3 pounds of feed daily or a total of 13 pounds of feed. The animals receiving the extra allowance were first offered their feed in metal feed boxes attached to the metabolism crates. The steers were not force fed unless they refused to consume their ration within a thirty minute period. The amount of feed remaining at the end of the half hour was mixed into a slurry and again offered to the animal. The portion of the feed not consumed by the animal was then force fed by using a plunger type gun which would hold approximately 6 pounds of the finely ground feed made into a slurry. To force feed an animal its head was elevated with the nipple like extension of the gun placed over the back part of the tongue. The slurry was then slowly forced into the animal's mouth. Most of the animals swallowed the feed with very little resistance after the first few feedings. The feed was made into a slurry by mixing with the 2 gallon portion of water allotted to the animal at each feeding. Although the steers were offered their feed in the dry and wet form, it was necessary to force feed a portion of their ration with the gun after two or three days of feeding. It was necessary to force the ration down six of the eight steers on the force fed ration. Once the animal failed to consume his total ration, it was usually necessary to force feed the entire ration throughout the remainder of the trial.

The force feeding mechanism was a simple plunger type gun made of 16 gauge stainless steel. The feeder was 4 inches in diameter and 15 inches long. It was designed so the feed and water mixture could be poured in from the plunger end. The opposite end had a 4 inch bevel which reduced it to 1 inch in diameter. The inch diameter was extended to a length of 6 inches for placing on the back of the animal's tongue.

Measurement of rate of feed passage

The measurement of the rate of feed passage through the digestive tract was a modification of the method of Balch (1950). At a single feeding the steers were given a small amount of stained corn and colored plastic particles so undigested particles could be identified visually in the feces. Brilliant green stain (Fisher certified) was used in concentrations of one gram per liter of water. The grain was colored by steeping for six hours in a hot solution of the stain then thoroughly washed with cold water and dried.

On the morning of the 11th day of the experimental period 5.0% of the daily intake of dry matter was fed as stained corn and 5.0% substituted with the plastic particles. The plastic particles and the stained grain were mixed with a portion of the normal diet before being offered to the animals. In order to get the steers to consume the mixture it was moistened with a portion of the water allotted to the steer. The feed and marker mixtures were very rapidly consumed when made into a slurry. The animals were allowed one-half hour to eat the allotted feed with the midpoint in this half hour taken as the time of feeding. All steers consumed their feed in the allotted time.

The collection of feces began 12 hours after feeding the indicators and continued at 6 hour intervals for the first 72 hours of

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the collection period and at 12 hour intervals for the following 96 hours. At each time of sampling the accumulated feces were weighed, thoroughly mixed and sampled. A 200-gram sample was taken for plastic and stained particle counts. Additional portions of 10% of the total collection for each period were taken for dry matter determinations, the dried material being retained for the analyses connected with digestibility trials. The fecal samples were stored at -17°C. in polyethylene freezer bags until they were prepared for analysis.

For the plastic and stained particle count two 50-gram aliquots of feces were taken and washed through sieves that had previously been used to separate the plastic particles into different sizes. The fecal material was placed on the 4 mesh screen and each particle size washed over to its respective screen by placing under a stream of water. After thoroughly washing the sample over each screen, the plastic particles and the stained corn particles were counted and recorded. Particles were retained on the 4, 8, 16 and 30 mesh screens with none being found on the 50 screen. Total plastic particles on each screen were counted when the total did not exceed 100. When the count exceeded 100, the feed residue and particles retained on a screen were washed from the screen onto a 12.5 cm filter paper in a suction funnel. The materials were evenly distributed on the filter paper by shaking and rotating the funnel and then pulling the water into the suction flask. A hardware cloth with 1/2 inch square openings was placed over the filter paper and particles from 10 of the 76 squares were counted. The number of those particles of different sizes for each individual sampling period the collection period and at 12 hour intervals for the following 96 hours. At each time of sampling the accumulated feces were weighed, thoroughly mixed and sampled. A [illegible]-gram sample was taken for plastic and stained particle counts. Additional portions of 10% of the total collection for each period were taken for dry matter determinations, the dried material being retained for the analyses necessary with digestibility trials. The fecal samples were stored at [illegible] in polyethylene freezer bags until they were prepared for analysis.

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Digestibility trials

Determination of digestibility of dry matter, crude protein and gross energy was made from the composited fecal samples for each of the 7 day collection periods and results are given in appendix tables II, III and IV. During the collection periods the feces were collected on plastic sheets in metal pans placed behind the steer. The 20 samples collected from each steer during each trial were composited and an aliquot was taken and stored for chemical analysis. During the experimental periods the feeds were sampled daily. The feces were dried in a forced-draft oven at 65°C. to a constant weight and then allowed to equilibrate with the atmospheric moisture. The samples of feed and feces were then ground in a Wiley mill through a medium-fine screen. After the samples were ground, each was mixed and stored in an air tight sample bottle. Rations and feces were analyzed according to standard methods (A.O.A.C., 1960). The digestion data were analyzed by the analysis of variance technique (Snedecor, 1956) and significance of individual differences determined by Duncan's Multiple Range Test (Duncan, 1955).

Chapter IV

RESULTS AND DISCUSSION

The term "rate of passage" has been used in this study to denote the time taken by inert particles after feeding to pass through the digestive tract of the steer. Since corn made up 64.3% of ration 4 and 84.3% of ration 1, 2 and 3 it was used as the basis in determining the material selected for studying the rate of passage in this study.

The cumulative percent excretion of the inert particles is shown on figures 2-6. Each curve represents the mean values of observations on eight steers. The cumulative percent excretion was used in order to calculate the rate of feed passage by various methods as R, 5% and 80% minus 5% values. These methods are explained on pages 6 and 7 of the review of literature. R refers to the mean retention time as determined by Castle (1956a). The 5% value as the rate of passage through the omasum, abomasum and intestines and the 80% minus 5% as the rate of passage through the rumen and reticulum as determined by Balch (1950). Since a 95% recovery is required for calculation of R and the recovery rate in this study was below 95% in most cases, calculations could not be made on the percent recovery of the total number of particles fed. However, the excretion curves calculated on the percent of inert particles fed appear to follow the same general pattern as those calculated on the percent of the total particles excreted in the feces. This can be observed in figure 1. These two curves represent data obtained with the

Chapter IV

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The recovery of undigested particles of stained corn when washing samples over the screens was insufficient to calculate passage rate. The stained corn was digested or broken into particles less than .595 mm which would not have been retained on the screens or it may be possible that the dye was extracted from the grain during digestion. However, the stained feed particles recovered had retained a sufficient amount of their artificial coloration to differentiate them from regular feed particles. No attempts were made to calculate curves from the few particles that were recovered.

These data show that the rate of passage of inert particles through the digestive tract of the steer is significantly affected by the nature of the ration and the size of particles fed. Statistical analyses show ration composition and particle size have a highly significant ($P < .01$) effect, whereas the rate of passage between animals approached significance only at the 10% level. Figure 2 illustrates the cumulative percent excretion of inert particles for the finely ground concentrate ration 1. These excretion curves show that the finer particles represented in the top curve with a mean diameter of .595 mm in size, were excreted more rapidly ($P < .01$) than the larger particles shown in the lower curves. Others have made similar observations and attempted to explain the faster movement of smaller particles. Shalk and Amadon (1928) suggested that small particles of ground hay moved rapidly out of the rumen because they would absorb water faster than the large particles. These workers further theorized that the digesta

Figure 1. Comparison of total receovery of fed particles to cumulative fecal recovery.

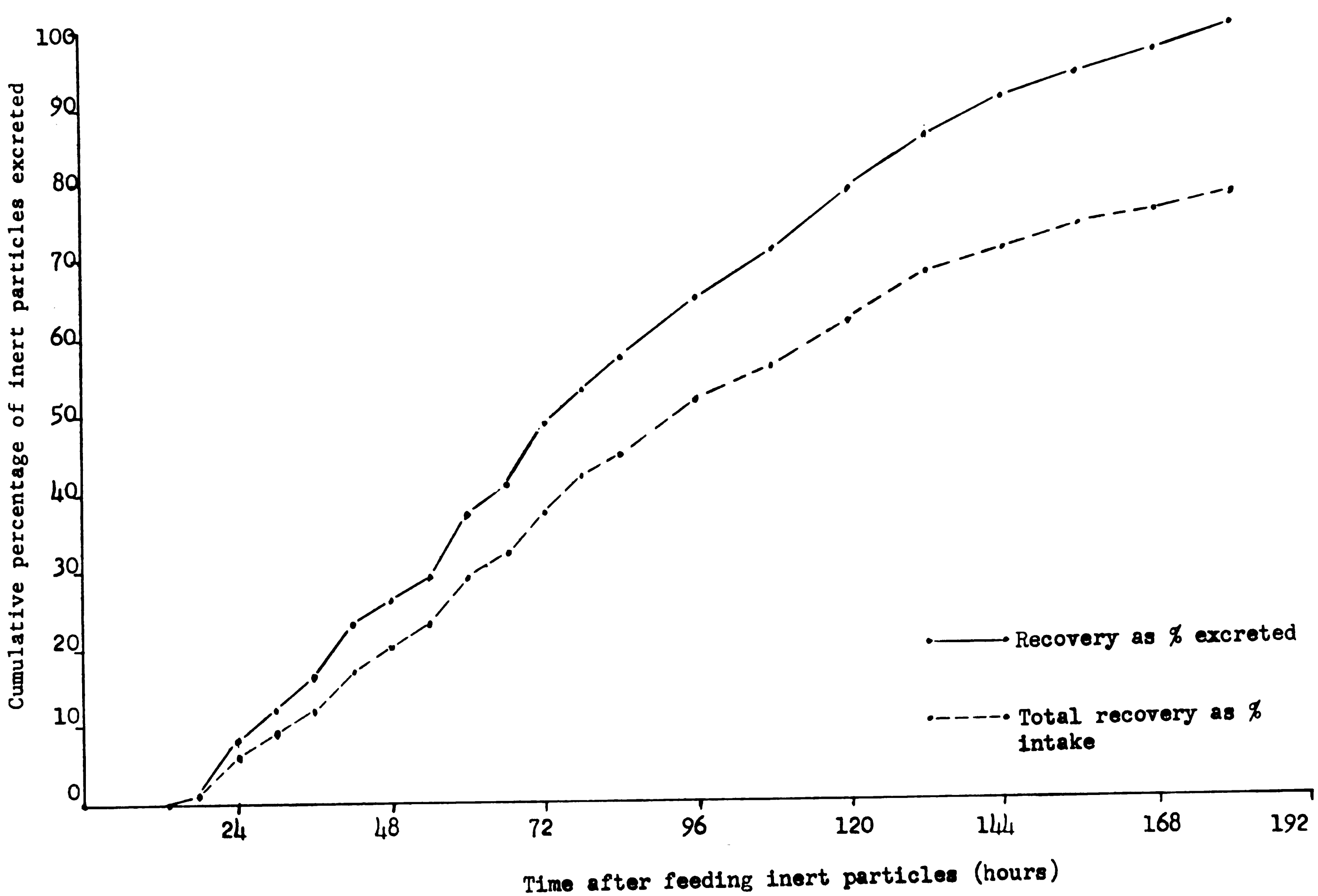
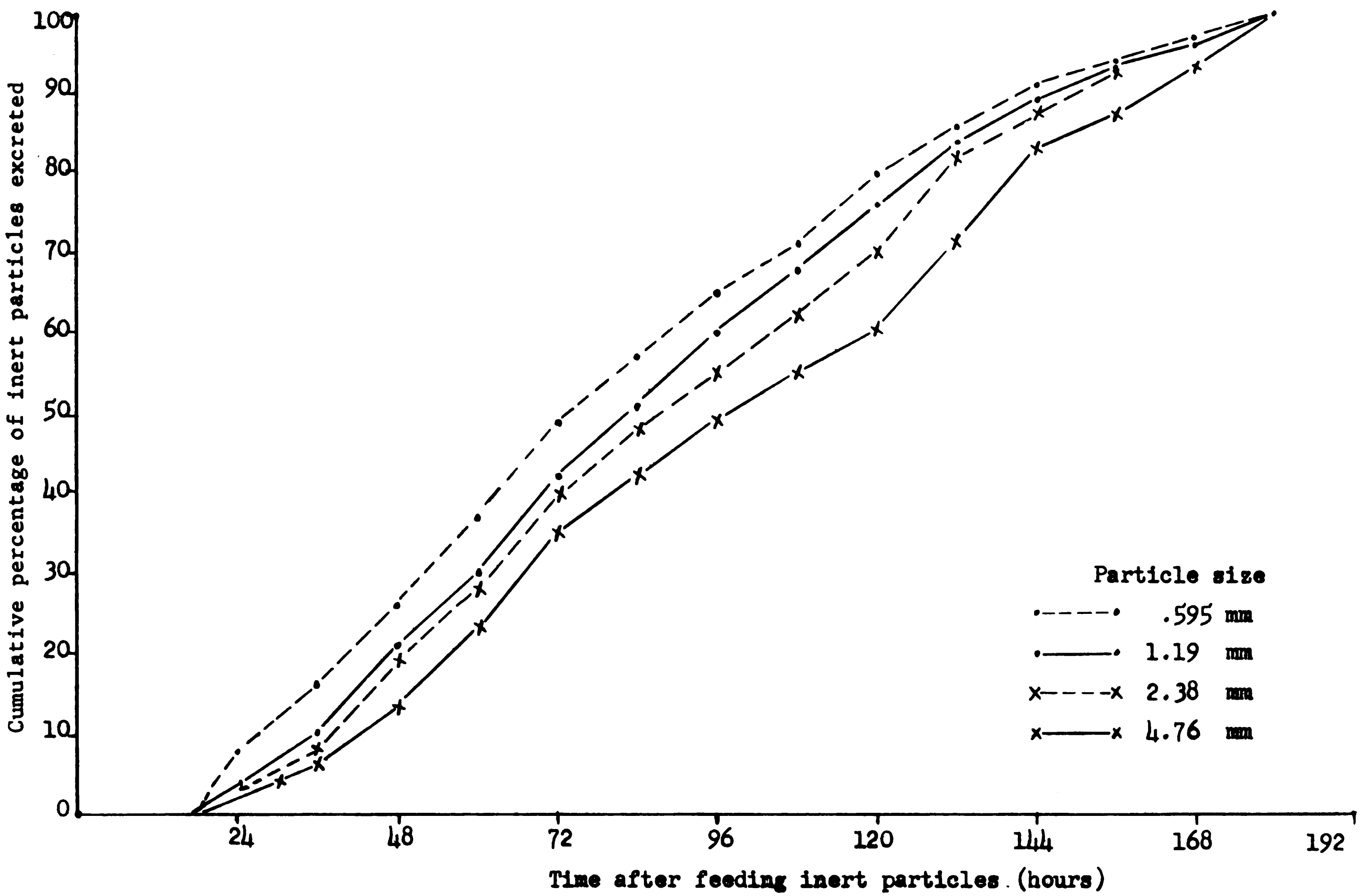


Figure 2. Rate of excretion of different size inert particles by steers fed finely ground concentrate ration.

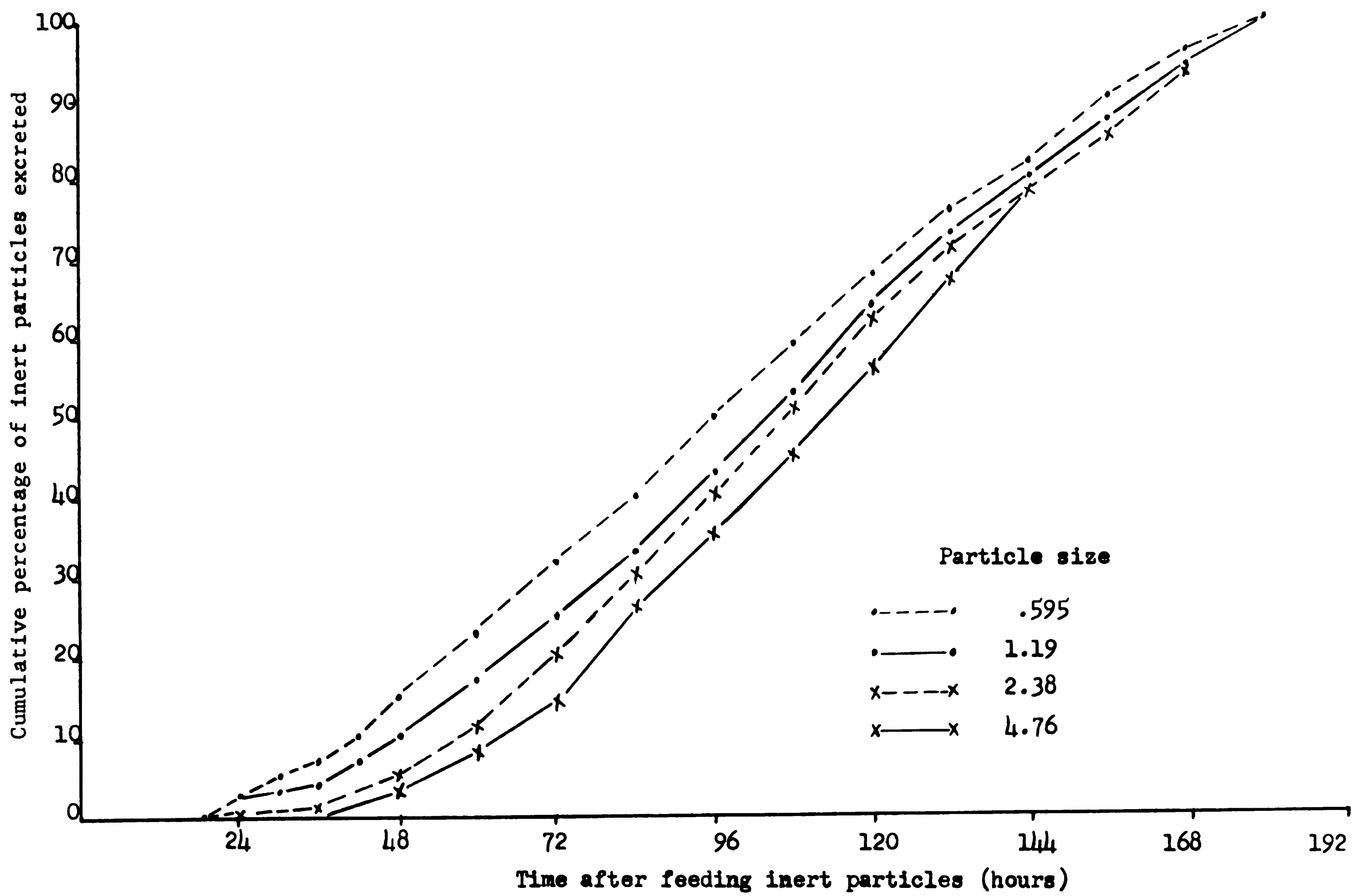


in the reticulo-rumen separated into two layers and as the particles of digesta became saturated and partly decomposed the specific gravity of the particles increased and the particles tended to sink into the ventral region of the reticulo-rumen, thus increasing their chance of passage to the omasum and abomasum. Balch (1950) suggested that the difference in passage rate of feeds with different particle size was due to a more rapid removal of fine particles from the reticulo-rumen. After studying the size of particles in the digesta at the reticulo-omasal orifice and in the feces, Balch suggested that either sifting of large food particles occurred at the orifice or the particle size was reduced at a later site in the digestive tract. The explanation presented would fit the present data, which suggest that the larger particles remain for a longer period in the reticulo-rumen until reduced to smaller sizes. The percent recovery of the large particles (4.76 mm) to small particles (.595 mm) during the 120 hour period for ration 1 was 60, 70, 76 and 80% respectively. Only 22 hours were required for excretion of 5% of the smallest (.595 mm) particles, whereas 34 hours were required for excretion of 5% of the large (4.76 mm) particles.

The results obtained with inert particles in a ration consisting of coarsely cracked corn (ration 2) are shown by the cumulative percent excretion of inert particles in figure 3. The excretion for the first 24-48 hours was slow; however, after 48 hours it increased with a constant and continuous curve.

The percent recovery of inert particles at the end of 120 hours was much lower than was found in ration 1, the recovery being 56, 62,

Figure 3. Rate of excretion of different size inert particles by steers fed coarsely cracked concentrate ration.

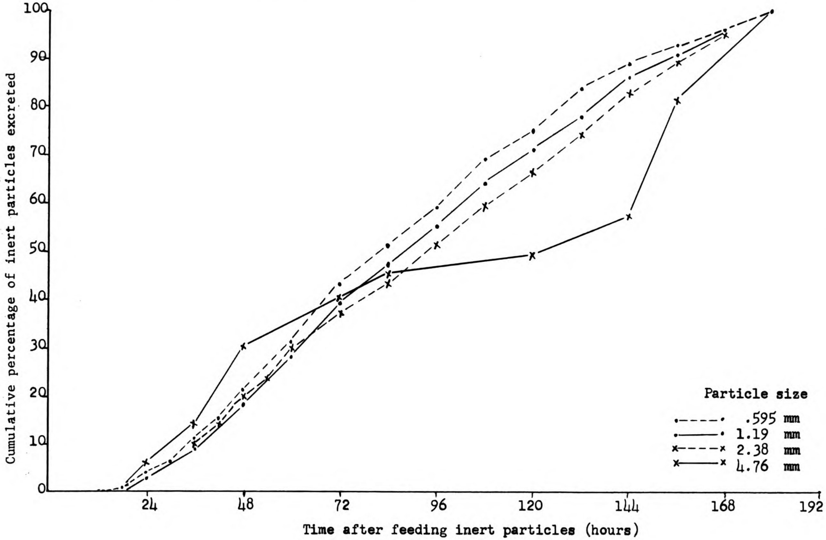


64 and 68 percent for the large to smaller particles. These results further suggest that larger particles remain in the digestive tract for a longer period of time than the finer particles. Whether this was due to some screening of large particles at the reticulo-rumen orifice as suggested by Balch (1950) was not determined. The slower rate of passage of the inert particles in this ration was apparently due to the higher percent of large particles fed in relation to those of smaller size. The smallest particles (.595 mm) fed in this ration passed through the digestive tract at a more rapid rate than the larger particles. This is in agreement with the results of others (Balch, 1950; Balch _et al_., 1954; Blaxter _et al_. 1956; and Castle, 1956) who reported small amounts of ground hay in mixed diets passed at a faster rate than the long hay in the ration. Although the smaller particles were excreted at a more rapid rate than the large particles in this ration, they were not excreted as rapidly as comparable sized particles in rations containing higher percentages of the finely ground material.

The effects of particle size on passage rate of a higher level of feed intake administered by a method of force feeding animals are shown in figure 4. The graph shows the larger particles to be excreted faster at the beginning of the collection period than other sizes but at a much slower rate after 84 hours. All particle sizes decreased in rate of passage in contrast to the same ration consumed at lower levels.

However, observations on steers that voluntarily consumed the same level as steers being forced showed a slower passage rate than the force fed steers. The fact that increasing the level of intake

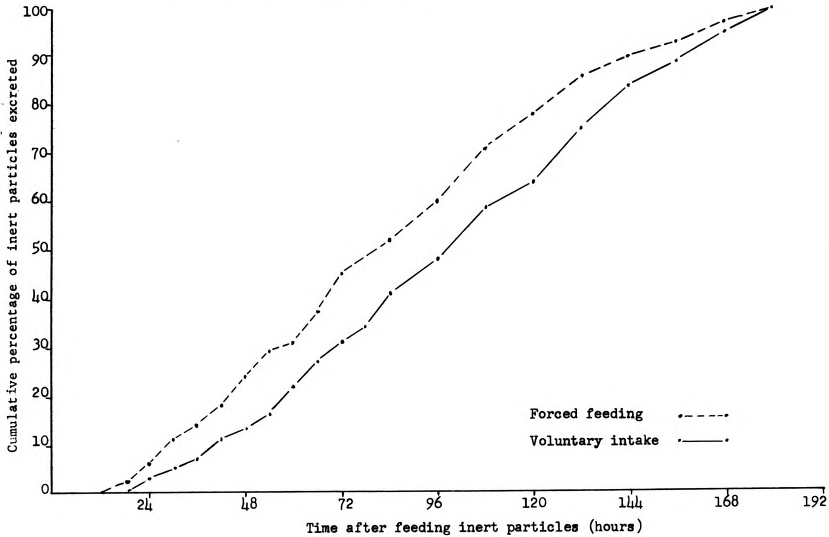
Figure 4. Rate of excretion of different size inert particles by steers force fed finely ground concentrate ration.



decreased the rate of passage of inert particles in contrast to the effect of feeding the same ration at lower levels is contrary to the results obtained by other researchers (Balch, 1950; Blaxter et al., 1956 and Campling and Freer, 1961). These workers reported that increasing the feeding level resulted in an increase in the rate of passage of residues through the digestive tract. The exact causes of the reduced rate of passage in this study are unknown; however, two theories may be postulated. First, the method of force feeding may cause some digestive disturbances which in turn may alter the rate of feed passage. Second, the higher level of intake may cause distention of the rumen with the feed leading to atony of the rumen musculature. If the latter occurs, then it is likely that a 10 day preliminary period is insufficient for such a study. From observations shown in figure 5, it seems unlikely that the method of feeding is the cause of a slower passage rate of inert particles. Two steers consuming the same amount of feed made into a slurry and two steers which refused to consume this amount of feed were force fed as previously described. These observations show a more rapid rate of passage for force fed steers than for those consuming the feed voluntarily. From this and daily observations of the force fed animals it is likely that force feeding increases the fill of the rumen. Some preliminary observations with force feeding were made prior to the start of this experiment.

Two animals were force fed at the rate of $1\frac{1}{2}\%$ of their body weight for 10 days without observing any abnormal disorders. The level of one steer was increased to $2\frac{1}{2}\%$ of its body weight. The animal showed

Figure 5. Rate of excretion of inert particles through steers fed at same level by voluntary intake and forced feeding.



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discomfort from the increased feed with rectal temperatures ranging as high as 107°F. The animal died on the ninth day on this level of intake and was examined shortly after death. The reticulo-rumen contents weighed 117 pounds. The intestine was almost empty and the abomasal contents appeared to have a higher dry matter content than normal and showed some indication of blocked passage at the pyloric valve.

It can be observed in figure 4 that the initial excretion for the large inert plastic particles (4.76 mm) in ration 3 was faster than the small particles. This may have resulted from the low recovery of this size particle. Less than 25% of these particles were recovered, with some steers showing no excretion during the experimental period. These particles were probably retained in the reticulo-rumen and may remain in this compartment for several weeks.

Figure 6 gives the cumulative percentage of inert particles excreted when fed with ration 4, a concentrate ration containing 20% corn cobs. Statistical analyses showed that the rate of passage of inert particles fed with this ration was significantly ($P < 0.01$) faster than the same size particles in the other three rations. The faster rate of passage of the inert particles in the corn and cob ration in comparison to the all concentrate rations may have been due to the cobs acting as a physical stimulus increasing the ruminal contractions. If the roughage portion of this ration caused an increase in ruminal contraction, it may have agitated some particles which had been retained in the reticulo-rumen from the previous feeding trials. These additional particles could explain the large percentage recovery of

Figure 6. Rate of excretion of different size inert particles by steers fed concentrate roughage ration.

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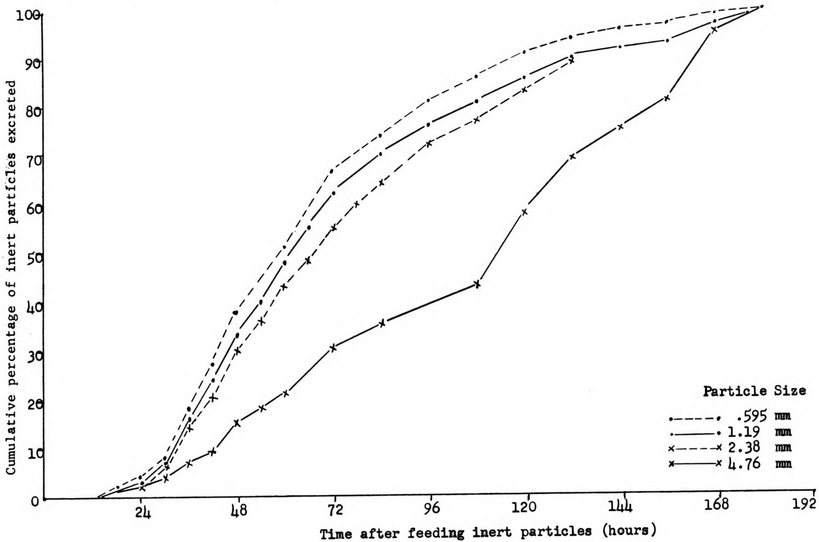

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inert particles which exceeded 100%, when fed with this concentrate-roughage ration. Eng et al. (1965) reported the rate of passage of an all roughage ration to be as fast as the rate of passage of an all concentrate ration. It appears that the roughage portion of the ration may act as a stimulus to increase ruminal contractions. Lack of rumination was observed throughout the entire experiment, with animals showing little or no rumination on all rations. This is in agreement with (Cole and Meade, 1948; Balch, 1952 and Agrawala et al., 1953). Agrawala et al. (1953) observed a distinct lack of rumination by cattle and sheep fed purified diets. Cole and Meade (1948) and Balch (1952) observed that ruminants rarely or never ruminated when fed rations of finely ground alfalfa hay; while Gordon (1958) found that when hay was cut into two inch lengths the total rumination time actually increased over that of long hay, which was apparently due to increased physical stimulus.

It was reported earlier (Agrawala et al., 1953; Cole and Mead, 1948 and Balch, 1952) that rumination was rarely observed when ruminants were fed finely ground feeds or purified rations. The slower rate of passage of all concentrate ration in comparison to a concentrate-roughage ration indicates that concentrates may have some inhibiting effect on the digestive tract. Ash (1959) reported buffered solutions of acetic, propionic and butyric acids (100-200 mM) at pH 3.65 inhibited reticulo-rumen contractions. Balch and Rowland (1957) found, when hay alone was fed to a fistulated cow, there was little variation in the concentration of total VFA at hourly intervals after feeding. On high concentrate rations the VFA concentration increased to peak values between two and

six hours after feeding. Diets containing only small amounts of hay or hay in the finely ground state produced the greatest ranges in concentrations. It was noted that intraruminal pH varied inversely with the concentration of total VFA with the lowest pH and the greatest range in pH occurring on the high concentrate ration.

These results suggest that the rate of passage of feeds through the digestive tract of steers, as measured by plastic particles, follows a fairly constant pattern. All curves show somewhat the same general shape, although some animals excreted the marker more rapidly than others. The excretion curves in figures 2 through 6 show that the time of the initial appearance of the marker in the feces was between 12 and 18 hours after feeding. These results agree with the findings of Balch (1950) who found that stained hay particles appeared in cow feces between 12 and 24 hours after feeding.

The various calculations of the time the different rations and particle sizes remained in the digestive tract are shown in table 6. It is evident from these calculations that the rate of passage of inert particles was faster when ration 4 was fed than when the other rations were fed. The R, 5% and mean time values for ration 4 are smaller than for rations 1, 2 and 3. It is evident that rations 2 and 3 were retained in the digestive tract for longer periods than rations 1 and 4. The faster rate of passage for ration 4 has already been discussed, however it may be of interest to point out that the percent recovery of the inert particles for this ration was slightly greater than 100%. The high level of recovery for the concentrate-roughage ration, which may have

TABLE 6. RATE OF PASSAGE OF FOUR SIZES OF INERT PARTICLES THROUGH THE DIGESTIVE TRACT OF STEERS WHEN FED IN FOUR RATIONS

Ration	Particle size (mm)	Time index (hrs.)			
		R[a]	5%[b]	80%-5%[c]	Mean time[d]
1 Fine Grind	0.595	81.1	22.0	99.0	85.1
	1.19	88.1	28.0	99.0	91.9
	2.38	91.1	28.0	102.0	94.4
	4.76	98.9	34.0	106.0	100.5
2 Coarse Grind	0.595	97.0	30.0	108.0	102.1
	1.19	104.4	37.0	107.0	108.6
	2.38	107.9	48.0	106.0	111.6
	4.76	123.1	54.0	94.0	116.2
3 Fine Grind Force Fed	0.595	86.2	26.0	101.0	91.1
	1.19	92.2	30.0	103.0	95.5
	2.38	94.4	30.0	110.0	98.6
	4.76	102.6	23.0	131.0	106.8
4 Fine Grind Plus 20% Roughage	0.595	66.1	26.0	69.0	73.9
	1.19	71.1	27.0	75.0	74.4
	2.38	75.1	28.0	92.0	78.9
	4.76	105.1	34.0	123.0	110.6

(a) Mean retention time (Castle, 1956a).
(b) Rate of passage through the omasum, abomasum and intestines (Balch, 1950).
(c) Rate of passage through the rumen and reticulum (Balch, 1950).
(d) Mean retention time (Blaxter *et al.*, 1956).

been due to inert particles remaining in the digestive tract from the previous feeding may aid in explaining the increased rate of passage.

There were greater differences between steers in the rate of passage on all concentrate rations than on a concentrate-roughage ration. The addition of the roughage to the ration lowering the specific gravity may account for some of the differences by speeding up the passage rate. However, the passage of the larger particles (4.76 mm) was somewhat slower than for the same particle size in the basal ration 1. King and Moore (1957) reported maximum rate of passage of particles with a specific gravity of 1.20 in a ration of hay and grain. Campling and Freer (1962), feeding concentrates, reported that the fastest rate of passage was for particles with a specific gravity of 1.21 as compared with particles of specific gravity of .96 to 1.02. However these workers state that for cows receiving all concentrate rations the average mean retention time in the reticulo-rumen was no longer for particles of specific gravity 1.40 than of particles of 1.21 specific gravity.

The results of this experiment show the importance of particle size in determining the rate of passage of inert particles through the digestive tract of the steer. With all concentrate rations and concentrate plus roughage ration, the rate of passage of inert particles decreased from the small (.595 mm) to the large size (4.76 mm). The effects of particle size on the rate of passage probably result from the rate at which the particles separate from the main mass of digesta and sink to the floor of the rumen and reticulum. The larger feed particles are probably retained in the reticulo-rumen until broken into

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smaller sizes before passing to the omasum with the liquid digesta from the rumen.

In the four digestion trials, the digestibility of dry matter, crude protein and gross energy was determined. The mean coefficients of apparent digestibility are given in table 7. The all concentrate rations show much higher mean digestion coefficients than the concentrate-roughage ration.

TABLE 7. MEAN DIGESTION COEFFICIENTS

Ration	1	2	3	4
D. M.	88.09	89.13	88.58	78.80
Crude protein	82.42	85.79	83.53	75.21
Gross energy	85.02	86.21	85.44	75.12
Cellulose	72.46	75.70	66.33	56.05

The ration spending shorter periods of time in the digestive tract of steers showed a lower mean digestion coefficient than rations with a slower passage rate. The corn and cob ration (4) which showed the fastest passage rate through the digestive tract shows a considerable drop in the digestion coefficients of dry matter, crude protein and gross energy. The digestion coefficients for all concentrate rations are significantly ($P < 0.01$) greater than for the concentrate-roughage ration.

The results of this study indicate that factors which cause an increase in the rate of passage result in a decrease in digestibility and the rate of passage as measured by inert particles is affected by the nature of the ration as well as the size of particles fed. Increasing the feeding level did not result in a decrease in digestibility, but the addition of cobs to the ration resulted in a significant ($P < 0.01$) increase in the rate of passage and a decrease in the digestibility of the ration. Blaxter et al. (1956) reported an increase in the feeding level resulted in a very slight fall in digestibility of long hay and a fall in digestibility of the finely ground cubed hay.

The digestibility of all rations in this experiment was very high, especially the all concentrate rations which were retained in the digestive tract for long periods of time.

Chapter V

SUMMARY AND CONCLUSION

Eight yearling Angus steers of uniform weight and age and by the same sire were used in a series of four trials to study the effects of particle size and level of intake on the rate of passage of all concentrate rations and concentrate plus 20% roughage ration. The treatments were arranged with two steers on each in a reversal type design so that during the four trials eight observations were made on each treatment. Inert plastic particles (specific gravity 1.425) with physical characteristics similar to the feed were used as indicators to measure the rate of passage. The effects of particle size were studied by separating the plastic (Delrin Acetal Resin) into groups having a mean diameter of 4.76, 2.38, 1.19 and .595 mm. Within this size range the rate of passage of inert particles through the digestive tract decreased as the size of particles increased. There were highly significant differences in the rate of passage of all size particles at the 72, 96, and 120 hour intervals after feeding.

Comparison of rations showed a highly significant difference in their rate of passage. The finely ground concentrate plus 20% roughage ration passed at a significantly ($P < 0.01$) faster rate than the finely ground, coarse cracked corn or the finely ground ration force fed. The finely ground all concentrate ration passed through the digestive tract

of the steer significantly ($P < 0.01$) faster than the coarse cracked ration. Inert particles in the coarse cracked corn ration passed through the digestive tract of the steer at a slower rate than the particles in the other rations. These results indicate the importance of particle size on the rate of passage of undigested residues through the digestive tract as measured by the movement of inert plastic particles. The data suggest that 20% corn cobs in a concentrate-roughage ration stimulated some portion of the digestive tract, increasing the rate of passage of inert particles in comparison to all concentrate rations. A comparison of these results with other experiments with mixed rations suggests that the cobs may act as a mechanical stimulus increasing ruminal contractions speeding the passage rate.

The results of this study showed that increasing the level of feed intake of a finely ground all concentrate ration decreased the rate of passage of inert particles in that ration during the seven day collection period. Observations on animals voluntarily consuming their allotted ration plus 0.5% of their body weight more of the finely ground feed without forcing with the plunger type gun showed a decrease in rate of passage. All particle sizes decreased in rate of passage in contrast to the same ration consumed at a lower level. However, the force fed steers showed a more rapid rate of passage than steers with the same level of intake without force feeding. The faster rate of passage of the inert particles in the concentrate plus roughage ration indicate that some physical and/or chemical changes take place in the digestive tract of steers on rations of different composition.

The ration remaining in the digestive tract for the shortest period of time showed a significant decrease in its digestibility as compared to the ration with the longest retention time. The rate of passage as measured by inert plastic particles was indirectly related to digestibility.

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VITA

The author of this thesis was born in Breathitt County, Kentucky, April 26, 1927. He attended the Breathitt County School system and graduated from Breathitt County High School at Jackson, Kentucky in January 1948. He entered the United States Navy in 1945, and was honorably discharged in 1946. In 1948 he enrolled at Lees Junior College in Jackson, Kentucky for three semesters. In 1949 he enrolled in the College of Agriculture at the University of Kentucky and received a Bachelor of Science Degree in Agriculture in August, 1951. The author was employed by the Kentucky Agricultural Extension Service until February, 1955. He entered Graduate School at the University of Kentucky in February, 1955, where he held a research assistantship in the Animal Husbandry Department and was engaged in studies leading to a Master of Science Degree in Agriculture which was awarded in May, 1956. He then returned to his position with the Agricultural Extension Service until January 1, 1957 at which time he was transferred to the Robinson Agricultural Experiment Substation, Quicksand, Kentucky as its Superintendent. In June 1961 he entered Graduate School at Michigan State University for two terms. In January 1963 he took sabbatical leave and re-entered Michigan State to study toward the Degree of Doctor of Philosophy in Animal Husbandry.

He was married to Lena Myrtle Noble in March 1949. They have three children, Ralph, Ada Ruth and Charlene, ages 13, 8 and 7, respectively.

A P P E N D I X

APPENDIX TABLE I

IDENTIFICATION OF ANIMALS BY RATIONS DURING THE 4 TRIALS

Animal number	Trial 1	2	3	4
136	4	2	3	1[a]
137	2	4	1	3
139	4	2	3	1
140	1	3	4	2
142	3	1	2	4
143	1	3	4	2
146	2	4	1	3
147	3	1	2	4

[a]Ration 1 Consisted of finely ground corn plus protein, minerals, and vitamins.

Ration 2 Consisted of cracked corn plus protein, minerals and vitamins.

Ration 3 Same as ration 1 fed at a higher level.

Ration 4 Consisted of finely ground corn plus 20% cobs, proteins, minerals and vitamins.

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APPENDIX TABLE II

DIGESTIBILITY OF DRY MATTER BY INDIVIDUAL STEERS

	Steer number			
	136	137	139	140
Trial 1				
D.M. intake (gms)	28,310.0	28,070.0	28,310.0	--------
D.M. excreted in feces (gms)	6,063.0	3,091.0	5,490.0	--------
Percent digested	78.6	89.0	80.6	
Trial 2				
D.M. intake (gms)	28,074.0	28,070.0	28,074.0	36,351.0
D.M. excreted in feces (gms)	2,445.0	5,803.0	3,109.0	4,088.0
Percent digested	91.3	79.3	88.9	88.8
Trial 3				
D.M. intake (gms)	37,808.0	27,987.0	37,808.0	28,074.0
D.M. excreted in feces (gms)	4,030.0	3,302.0	4,305.0	6,446.0
Percent digested	89.3	88.2	88.6	77.0
Trial 4				
D.M. intake (gms)	27,943.0	37,747.0	27,943.0	28,153.0
D.M. excreted in feces (gms)	2,637.0	3,362.0	2,548.0	3,539.0
Percent digested	90.6	91.1	90.9	87.4

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APPENDIX TABLE II CONTINUED

DIGESTIBILITY OF DRY MATTER BY INDIVIDUAL STEERS

	Steer number			
	142	143	146	147
Trial 1				
D.M. intake (gms)	37,270.0	27,952.0	28,070.0	36,270.0
D.M. excreted in feces (gms)	5,356.0	2,433.0	3,088.0	4,261.0
Percent digested	85.6	91.3	89.0	88.6
Trial 2				
D.M. intake (gms)	28,000.0	37,088.0	28,109.0	28,000.0
D.M. excreted in feces (gms)	4,827.0	3,742.0	6,181.0	3,725.0
Percent digested	82.8	90.7	78.0	86.7
Trial 3				
D.M. intake (gms)	28,125.0	28,074.0	27,987.0	28,125.0
D.M. excreted in feces (gms)	3,518.0	5,260.0	4,043.0	3,049.0
Percent digested	88.5	81.3	85.6	89.2
Trial 4				
D.M. intake (gms)	25,355.0	28,153.0	37,747.0	28,125.0
D.M. excreted in feces (gms)	5,451.0	2,595.0	5,319.0	5,859.0
Percent digested	78.5	90.8	85.9	79.2

APPENDIX TABLE III

DIGESTIBILITY OF PROTEIN BY INDIVIDUAL STEERS

	Steer number			
	136	137	139	140
Trial 1				
Intake (gms)	4,325.8	4,028.1	4,325.8	-------
Output (gms)	917.3	602.2	839.9	-------
Percent digested	78.8	85.1	80.6	-------
Trial 2				
Intake (gms)	4,166.1	1,058.1	4,166.1	4,769.3
Output (gms)	565.2	240.8	484.4	816.8
Percent digested	86.4	74.2	86.0	82.9
Trial 3				
Intake (gms)	5,126.7	3,795.1	5,126.7	3,683.3
Output (gms)	836.6	683.9	759.1	1,035.3
Percent digested	83.7	82.0	85.2	71.9
Trial 4				
Intake (gms)	3,926.0	5,303.5	3,926.0	4,591.8
Output (gms)	558.1	696.2	525.1	565.8
Percent digested	85.8	86.9	86.6	87.7

APPENDIX TABLE III CONTINUED

DIGESTIBILITY OF PROTEIN BY INDIVIDUAL STEERS

	Steer number			
	142	143	146	147
Trial 1				
Intake (gms)	5,147.0	3,860.2	4,028.1	5,147.0
Output (gms)	881.0	536.0	595.0	832.5
Percent digested	82.9	86.1	85.2	83.8
Trial 2				
Intake (gms)	3,673.6	4,866.0	3,701.9	3,673.6
Output (gms)	770.4	802.1	1,011.3	762.2
Percent digested	79.0	83.5	72.7	79.3
Trial 3				
Intake (gms)	4,145.6	3,683.3	3,795.1	4,145.6
Output (gms)	616.8	749.6	827.2	701.6
Percent digested	85.1	79.7	78.2	83.1
Trial 4				
Intake (gms)	3,085.7	4,591.8	5,331.6	3,422.8
Output (gms)	891.3	561.5	1,096.3	934.5
Percent digested	71.1	87.8	79.4	72.7

APPENDIX TABLE IV

DIGESTIBILITY OF ENERGY BY INDIVIDUAL STEERS

	Steer number			
	136	137	139	140
Trial 1				
Intake (kcal.)	111,229.0	107,482.0	111,229.0	---------
Fecal loss (kcal.)	28,319.0	15,120.0	24,903.0	---------
Percent digested	74.5	85.9	77.6	---------
Trial 2				
Intake (kcal.)	102,918.0	30,986.0	102,918.0	141,697.0
Fecal loss (kcal.)	11,611.0	6,499.0	14,759.0	19,123.0
Percent digested	88.7	79.0	85.7	86.5
Trial 3				
Intake (kcal.)	147,374.0	109,095.0	147,374.0	107,550.0
Fecal loss (kcal.)	19,767.0	15,741.0	21,235.0	29,421.0
Percent digested	85.6	85.6	85.6	72.6
Trial 4				
Intake (kcal.)	108,809.0	146,988.0	108,809.0	107,602.0
Fecal loss (kcal.)	12,491.0	16,146.0	12,082.0	16,001.0
Percent digested	88.5	89.0	88.9	85.1

APPENDIX TABLE IV CONTINUED

DIGESTIBILITY OF ENERGY BY INDIVIDUAL STEERS

	Steer number			
	142	143	146	147
Trial 1				
Intake (kcal.)	138,681.0	92,830.0	107,482.0	138,681.0
Fecal loss (kcal.)	25,525.0	12,142.0	15,038.0	21,756.0
Percent digested	81.6	86.9	86.0	84.3
Trial 2				
Intake (kcal.)	109,145.0	144,569.0	108,415.0	109,145.0
Fecal loss (kcal.)	21,803.0	17,789.0	28,929.0	18,355.0
Percent digested	80.0	87.7	73.3	83.2
Trial 3				
Intake (kcal.)	106,930.0	107,550.0	109,095.0	106,930.0
Fecal loss (kcal.)	16,754.0	23,546.0	19,588.0	15,513.0
Percent digested	84.3	78.1	82.0	85.5
Trial 4				
Intake (kcal.)	96,931.0	107,602.0	146,988.0	107,521.0
Fecal loss (kcal.)	25,442.0	12,477.0	26,197.0	26,938.0
Percent digested	73.8	88.0	82.2	75.0

APPENDIX TABLE V

CHANGES IN BODY WEIGHT OF STEERS FED IN

METABOLISM CRATES BY 17 DAY PERIODS

	Steer number							
	136	137	139	140	142	143	146	147
Trial 1								
Ration fed	4	2	4	1	3	1	2	3
Initial weight	648	654	652	616	674	600	676	680
Final weight	670	677	657	---	746	648	675	733
Gain or loss (lbs.)	22	23	5	---	72	48	-1	58
Trial 2								
Ration fed	2	4	2	3	1	3	4	1
Initial weight	670	677	657	605	746	648	675	733
Final weight	722	704	700	640	706	700	692	706
Gain or loss (lbs.)	52	31	43	35	-40	52	15	-27
Trial 3								
Ration fed	3	1	3	4	2	4	1	2
Initial weight	722	704	700	640	706	700	692	706
Final weight	758	698	730	644	692	688	684	734
Gain or loss (lbs.)	36	-6	30	4	-14	-12	-8	28
Trial 4								
Ration fed	1	3	1	2	4	2	3	4
Initial weight	758	698	730	644	692	688	684	734
Final weight	750	735	736	675	696	688	755	750
Gain or loss (lbs.)	-8	37	6	31	4	0	71	16

APPENDIX TABLE VI

TRIAL 1

FECAL COLLECTIONS BY PERIODS (gms.)

	Steer number						
Collections	136	137	139	142	143	146	147
1	220	350	420	840	380	460	540
2	1,200	290	720	600	620	280	420
3	800	400	980	860	---	560	940
4	1,000	---	1,190	900	480	430	180
5	600	580	1,340	660	360	290	880
6	740	---	970	790	530	630	620
7	870	700	470	1,000	480	130	320
8	620	400	1,080	680	290	510	860
9	1,080	---	1,420	1,120	---	---	600
10	990	580	980	620	1,060	1,060	700
11	840	490	1,600	520	---	490	460
12	1,270	280	960	760	410	---	240
13	1,820	940	2,640	1,660	1,350	1,040	1,280
14	1,060	980	2,040	1,230	520	980	1,190
15	1,560	1,050	2,000	1,520	930	1,030	780
16	1,540	580	2,440	1,340	1,060	1,130	580
17	1,390	760	920	1,520	510	980	1,150
18	2,280	1,140	2,580	1,400	920	740	880
19	1,560	570	990	1,500	250	1,000	1,980
20	1,520	790	1,520	1,500	740	1,110	1,610

APPENDIX TABLE VI

TRIAL II

FECAL COLLECTIONS BY PERIODS (gms.)

	Steer number						
Collections	136	139	140	142	143	146	147
1	520	160	780	780	940	1,860	390
2	500	800	780	520	650	1,020	710
3	300	450	260	840	270	670	500
4	220	680	1,380	390	930	560	350
5	180	530	25	970	310	410	860
6	540	900	1,250	490	1,460	1,660	---
7	460	430	1,070	780	490	750	470
8	330	430	480	230	420	1,040	590
9	---	460	660	420	380	860	230
10	530	---	580	1,010	590	1,590	900
11	170	540	720	720	500	1,020	460
12	300	580	490	570	790	820	420
13	820	1,000	740	1,390	750	2,040	940
14	720	410	760	1,540	1,320	2,100	900
15	660	960	1,060	1,430	600	2,870	1,130
16	340	860	950	820	1,020	1,080	1,670
17	860	500	1,760	1,130	1,300	2,670	1,620
18	650	710	1,000	940	770	1,710	830
19	545	690	1,530	1,280	1,130	1,970	790
20	750	720	Steer died	1,080	750	1,150	880

APPENDIX TABLE VI

TRIAL III

FECAL COLLECTIONS BY PERIODS (gms.)

	Steer number							
Collections	135	136	137	139	142	143	146	147
1	1,540	540	650	920	420	670	730	260
2	500	360	510	530	280	750	700	520
3	460	220	580	600	280	540	660	360
4	930	480	220	330	230	1,740	460	900
5	810	720	620	600	490	420	830	310
6	1,350	360	240	460	360	940	320	440
7	290	670	420	550	620	530	---	490
8	1,290	480	640	330	250	950	1,260	550
9	530	480	400	510	550	710	500	---
10	1,180	610	190	990	1,020	1,020	410	880
11	280	310	480	240	660	400	780	180
12	980	760	280	610	470	1,170	500	670
13	1,780	960	1,180	1,210	1,260	1,420	1,340	540
14	2,250	1,220	580	1,060	1,030	1,700	1,070	770
15	1,690	760	860	1,110	1,040	1,720	610	790
16	2,230	1,880	830	1,380	1,210	1,980	1,310	940
17	1,870	860	700	1,580	1,100	1,650	770	960
18	1,980	840	650	500	1,060	1,370	740	790
19	1,880	1,390	1,190	920	1,240	1,330	1,790	920
20	1,640	840	880	1,470	850	1,810	990	810

APPENDIX TABLE VI

TRIAL IV

FECAL COLLECTIONS BY PERIODS (gms.)

	Steer number							
Collections	135	136	137	139	142	143	146	147
1	---	390	220	420	1,040	1,000	880	800
2	450	320	650	520	480	340	840	500
3	430	---	600	200	1,000	---	600	790
4	260	880	550	230	760	460	430	760
5	800	360	680	300	910	---	760	680
6	620	290	360	310	1,430	580	1,260	1,400
7	460	280	160	---	1,380	620	880	520
8	870	460	760	480	680	170	300	740
9	350	260	900	500	390	570	1,140	1,860
10	940	470	290	780	870	270	1,530	1,360
11	180	280	260	---	220	630	590	1,040
12	900	660	700	390	---	250	770	990
13	920	740	920	180	1,200	900	2,190	2,480
14	1,090	740	980	980	1,710	740	1,810	2,130
15	1,270	620	450	1,270	2,140	800	1,140	1,920
16	1,050	610	590	620	1,670	750	2,200	2,000
17	910	910	860	880	2,080	540	1,040	1,150
18	1,300	840	600	920	2,010	720	1,840	2,210
19	1,190	540	610	680	2,370	690	2,560	1,560
20	990	950	550	410	1,160	640	960	1,680

APPENDIX TABLE VII

ANALYSIS OF VARIANCE OF MEAN PASSAGE

RATE AT 72, 96 AND 120 HOURS

Source of variation	DF	SS	Mean Square	F-ratio
Total	127	67,373.28		
Replications	1	488.26		
Treatments	63	46,416.25	736.77	2.268[a]
Rations	3	7,972.96	2,657.65	8.180[b]
Particle size	3	19,841.20	6,613.73	20.356[b]
Steers	3	2,057.43	685.81	2.111
R x P S	9	2,152.68	239.19	.736
R x S	9	5,584.81	620.53	1.910
P S x S	9	3,951.39	439.04	1.351
R x P S x S	27	4,855.78	179.84	.554
Error	63	20,468.77	324.90	

[a] Significant ($P < 0.05$)

[b] Highly significant ($P < 0.01$)

APPENDIX TABLE VIII

ANALYSIS OF VARIANCE OF DRY MATTER DIGESTION

Source of variation	DF	SS	Mean Square	F-ratio
Total	31	698.11		
Ration	3	580.33	160.11	73.44[a]
Steers	7	71.97	10.28	4.71[a]
Error	21	45.81	2.18	

[a]Highly significant ($P < 0.01$)

DUNCANS MULTIPLE RANGE TEST

	78.80	88.09	88.58
89.13	10.33	1.04	.55
88.58	9.78	.49	
88.09	9.29		

	$S\bar{r}$	Table value	Difference for significance
4	.74	4.31	3.18
3	.74	4.20	3.11
2	.74	4.02	2.97

APPENDIX TABLE IX

ANALYSIS OF VARIANCE OF CRUDE PROTEIN DIGESTION

Source of variation	DF	SS	Mean Square	F-ratio
Total	31	735.48		
Ration	3	501.95	167.32	32.55[a]
Steers	7	125.49	17.93	3.49
Error	21	108.04	5.14	

[a]Highly significant ($P < 0.01$)

DUNCANS MULTIPLE RANGE TEST

	75.21	82.42	83.53
85.79	10.58	3.37	2.26
83.53	8.32	1.11	
82.42	7.21		

	$S_{\bar{r}}$	Table value	Difference for significance
4	1.134	4.31	4.89
3	1.134	4.20	4.76
2	1.134	4.02	4.59