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I am submitting herewith a thesis written by Bobby Gene Nutt entitled "Rumen Volume of Mature Cows: Its Relationship to Forage Consumption, Body Measurements and Animal Performance." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Science.

J. W. Holloway

J. W. Holloway, Major Professor

We have read this thesis
and recommend its acceptance:

J. David Kirkpatrick

Will T. Butts Jr.

Accepted for the Council:

L. Evans Pond

Vice Chancellor
Graduate Studies and Research

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RUMEN VOLUME OF MATURE COWS: ITS RELATIONSHIP TO FORAGE CONSUMPTION, BODY MEASUREMENTS AND ANIMAL PERFORMANCE

A Thesis

Presented for the

Master of Science

Degree

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Bobby Gene Nutt

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ABSTRACT

Seventy-eight mature Angus cows were evaluated for rumen fluid volume using a 2.5% lithium sulfate ($Li_2SO_4 \cdot H_2O$) solution as a marker substance. At this time all cows were weighed and ultrasonic fatness over the twelfth rib was estimated. Cows were then photographed and height at the withers, length from point of shoulder to hooks, depth of heart and hook width were estimated from slides. Each cow was fed 4.75 grams of Cr_2O_3 in 249 grams of feed at each of two feedings (8:00 a.m. and 5:00 p.m.) per day for 158 days (April 20 - October 5). Fecal samples collected were analyzed for chromium and acid detergent lignin (ADL). Forage ADL was estimated by the cage and strip method simultaneously. Regression was used to predict dry matter intake per day (DMI), digestibility (DIG) and digestible dry matter intake per day (DMD) for each cow (mean values for period). Digestibility of the high quality pasture was 59% compared to 55% for the low quality pasture. DM intake, digestibility, and digestible DM intake as averages of grazing season for cows grazing high quality pasture was not significantly affected by rumen fluid volume ($P > .05$). Average DM intake and average digestibility intake were influenced ($P < .06$ and $P < .08$ respectively) by rumen fluid volume for cows grazing low quality pasture. Body weight (kg), height at the withers (cm), length from point of shoulder to hooks (cm), depth of heart (cm), and hook width (cm) all significantly affected rumen fluid volume

positively ($P < .05$). Fat thickness (mm) had no signigicant effect on rumen fluid volume ($P > .05$). However, fat thickness did have a significant negative effect on rumen fluid volume as a percent of body weight ($P < .05$). Body weight also had a significant negative effect on rumen fluid volume as a percent of body weight ($P < .05$). Mean milk production, milk solids non-fat and weaning weight of the calves were not significantly affected by rumen fluid volume or rumen fluid volume as a percent of body weight ($P > .05$ and $P > .05$ respectively). However, rumen fluid volume and rumen fluid volume as a percent of body weight did have a significant negative effect on milk butterfat percent ($P < .05$ and $P < .05$ respectively) which was possibly due to chance.

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CHAPTER I

INTRODUCTION

There are a number of feed stuffs that can be utilized by ruminants. Dairy cattle are fed high quality rations which are easily digested. These high quality rations must be fed if dairy cattle are to maintain a high level of milk production. However, the purpose of beef cattle is to convert low quality forages into economical products like meat, milk, and calves. Since the majority of beef cattle in Tennessee graze pastures of low quality forage, they must be able to consume large quanities in order to meet their requirements. These low quality forages have low digestibilities and are very bulky and fibrous. If the ability of beef cows to consume a large quantity of low quality forage is impeded in any way, it will cause the animal to draw upon body reserves to meet productive performance requirements or else productive performance will decline or cease. Consequently the greater the ability of beef cows to consume large quantities of low quality forage over their maintance requirements, the easier and more economical production is.

Many theories have been proposed as to what limits the intake of low quality forages by ruminants. The majority of researchers today feel that the intake of low quality forages is controlled by physical factors (Freer and Campling, 1963; Conrad *et al.*, 1964; Montgomery and Baumgardt, 1965; Blaxter *et al.*, 1966). These physical factors consist of (1) the physical capacity of the gut to hold large amounts of bulky, fibrous

material, (2) the pressure on the gut wall caused by a large amount of bulky material in the gut, and (3) the weight of the material in the gut. Most likely it is a combination of all three factors that control the intake of low quality forages. If the assumption is made that gut size is porportional to body weight (Conrad *et al.*, 1964), then the intake of low quality forages can be thought to be related to weight$^{1.0}$ but, no research has been performed with beef cows to substantiate this.

Presently all the research concerning the relationship of intake to capacity of the gut in cattle has been done using dairy cows in small numbers and in confinement situations. There has been no research reported relating intake to capacity of the gut in beef cows consuming pasture. Also, the relationship of gut size to measurable physical characteristics like height, length, width, weight, and body fat are still undefined in the literature. Due to the lack of research pertaining to these relationships, a widespread controversy has developed in the beef industry.

This controversy consists of what is the right size and shape of cattle and which is the most efficient. The many different sizes and shapes among cattle make it hard for the producers to pinpoint the right size and shape. Some producers feel that beef cattle need a large gut or capacity in order to have a good productive performance level. They also like to see animals that are wide standing in front and have a lot of spring of rib with a large barrel-shaped middle.

Other producers feel that this large gut or capacity is unimportant in determining the ability of an animal to have a good productive performance level. These producers desire their animals to be trim and uniform in shape with an angular shaped middle with little spring of rib. There is a possible advantage to this type of animal in that the dressing percentage would be higher than that of the large gutted animal. This would mainly be due to the less wastage from gut and its associated materials in the trim uniform animal. The possible disadvantage to the trim uniform animals is the fact that when given a low quality forage, they would not be able to consume enough of the forage to maintain productive performance. However, no research has been done to substantiate this.

The main decision that would affect the type of beef animal chosen would be the quality and type of forage the animals were to be fed and what level of production this animal would be used in. A final perplexing question that would have an effect on the type of animal chosen would be whether gut size really changes as a percentage of the body weight or is it merely an optical illusion.

Evidently there are many questions left unanswered by present research pertaining to the type of cattle that should be produced. The purpose of this experiment was to obtain estimates of rumen volume from a wide range of sizes and shapes of mature Angus cows that were consuming two distinctly different qualities of pasture forage and to establish the relationship of rumen volume to measurable characteristics, dry matter intake, digestibility, and animal performance.

CHAPTER II

REVIEW OF LITERATURE

I. TECHNIQUES FOR ESTIMATING RUMEN VOLUME

The capacity of the gastrointestinal tract has been known for quite some time to be of fundamental importance in physical mechanisms controlling the nutrition of ruminants. The capacity of the gastrointestinal tract can be estimated either directly or indirectly.

Under conditions where direct measurements of capacity are not feasible, possibly the most practical and widely used method of estimating capacity is a marker dilution technique.

The marker dilution technique has been used for estimating capacity for quite a long period of time. Many materials, both organic and inorganic, have been used as markers. The markers used will be discussed later, but the dilution technique will be explained below.

Dilution Technique

The dilution technique involves the addition of a given quantity of marker into the reticulo-rumen and then the estimation of its volume via calculations based on the change in the marker's concentration after uniform distribution with the reticulo-rumen contents. The dilution technique is simple in closed systems, but in open systems such as the reticulo-rumen a few assumptions have to be made and mathematical treatment becomes necessary.

Treatment of the Dilution Technique

The present mathematical treatment assumes instantaneous and complete mixing, even though in actuality, mixing is relatively slow and never complete due to the continual influx of water into the reticulo-rumen from the saliva (Warner and Stacy, 1968). Bailey (1961) working with permanently rumen fistulated cattle found that the rate of secretion of mixed saliva into the rumen to be 229 ml/min. during eating, which was two to four times greater than the rate of secretion of mixed saliva during rest. Ternouth (1967) found that there were periods when the outflow rate reached 50% or more of the rumen volume per hour. If this were true it would be most unlikely that any marker introduced during these periods would have the opportunity to mix adequately with the rumen contents so that precise volume estimations could be made. Lemenager *et al.* (1978) has reported inflated rumen volumes due to incomplete equilibration of markers with rumen contents.

Since the reticulo-rumen is an open system, steady-state conditions required for kinetic measurements are not usually attainable. Warner and Stacy (1968 a,b) stressed the importance of having conditions in the reticulo-rumen changing at a constant rate (if not steady-state) to avoid discontinuity in the dilution curve over the period of extrapolation. Also, Warner and Stacy (1968 a) found that a similar discontinuity could be caused by eating and/or drinking and for this reason they criticized other workers for giving the marker before feeding. Hyden (1961) assuming steady-state conditions and rapid mixing of the marker was able to show an exponential

relation between marker concentration and time. Warner and Stacy (1968 a) obtained a linear relation and suggested that this linearity be a criterion for the steady-state condition. However Ulyatt (1964 a) found the relationship to be curvilinear rather than rectilinear and that a quadratic fit increased the statistical precision of estimating initial marker concentration.

Classification of Markers

The dilution technique requires the use of a marker substance to develop the indirect measurements of reticulo-rumen contents. The type of marker chosen can play an extremely important role in allowing accurate estimation of reticulo-rumen volume. To employ a marker for estimation of reticulo-rumen volume, it must meet these requirements (Hyden, 1960):

1. The substance should be freely soluble in the fluid.
2. It must be well defined from a chemical point of view and it ought to be easily and accurately determinable.
3. It should not be taken up or absorbed, produced or destroyed to any significant degree by microorganisms or by other parts of the contents in the gut.
4. It should not influence the normal digestive processes or be absorbed to any appreciable degree.

It is very hard to find a marker substance which strictly fulfills all these criteria.

Markers can also be classified in the following manner as prepared by Kotb and Luckey (1972):

I. Elements

A. Inert Metals (heavy and rare earth)

B. Natural Isotopes (^{40}K)

C. Artificial Isotopes (^{144}Ce)

II. Compounds

A. Inorganic

1. Metal Oxides (Cr_2O_3, FeO_2, TiO_2)
2. Mineral Salts ($BaSO_4$, CuSN)

B. Organic

1. Natural dyes (carmine, chromogen)
2. Synthetic dyes (Methylene blue, phenol red, basic fuchsin)
3. Other (cellulose, lignin, plant sterols)

III. Particulates

A. Polymers (polyethylene glycol (PEG), plastics, glass, rubber)

B. Cells (yeast and bacteria)

C. Charcoal

D. Metal particles (sized aluminum particles)

E. Other particulates, seeds, cotton string

This classification does not cover all of the substances that have been used as markers and not all of the markers that have been used are of value in determining rumen volume under certain experimental conditions. The markers that have been used effectively to estimate rumen volume are polyethylene glycol, lithium sulfate, ^{51}Cr-EDTA, Cr-EDTA, phenol red, radioisotopes, and rare earth metals.

A. Indirect Ways to Estimate Rumen Fluid Volume

Polyethylene Glycol

Since polyethylene glycol (PEG) was first introduced by the Swedish workers Sperber, Hyden, and Ekman (1953), it has apparently

become the most used and widely accepted indirect method of determining rumen fluid volume. The polyethylene glycols are highly polymerized long chain compounds of the general formula $HO \cdot CH_2 \cdot (CH_2 \cdot O \cdot CH_2)_n \cdot CH_2 \cdot OH$. Those with molecular weights above 1,000 are solids, but are water soluble. Corbett *et al.* (1959) using PEG with a molecular weight of 4,000 reported that PEG was associated with the water in the digesta of the reticulo-rumen contents.

Repeatability

A number of workers have found that PEG dilution method to be inaccurate. Corbett *et al.* (1959) observed that recovery of PEG was low if rumen fluid or feces samples were not adequately diluted before analysis. Smith (1959) suggested that sixty minutes were required to develop a stable turbidity rather than the five minutes suggested by Hyden (1955). Downes and McDonald (1964) reported variations in turbidity from day to day. Lemenager *et al.* (1978) proposed that when fed, PEG enters the liquid fraction near the cardia and may exit from the rumen before complete dispertion within the rumen. Although Alexander *et al.* (1969) found in an experiment done to test the accuracy and repeatability of PEG determinations that the concentration of PEG in rumen fluid and that refrigerated storage did not affect the accuracy of the method. Also, Alexander *et al.* (1969) found that analysis of PEG solutions exposed to light for

seventy-two hours indicated no measurable destruction of PEG. In a further experiment Alexander *et al.* (1969) concluded that only about 83% of the total water was available to PEG five minutes after mixing. Tulloh *et al.*(1965) has reported that PEG measurements showed no significant bias when compared with direct measurements of rumen fluid volume.

Ration Effects

Ulyatt (1964) has reported that several factors will determine the volume of distribution of any marker substance; (1) the physical characteristics of the feed, (2) the fraction of the digesta it is associated with, and (3) its rate of flow through the digestive tract. Thus, the nature of the diet can have a marked effect on the value of PEG as a rumen fluid marker. Alexander *et al.* (1969) found that cows had only a small amount of unavailable water in the rumen when consuming an alfalfa hay ration. He concluded that for cows consuming an alfalfa hay ration a five minute mixing time would be adequate. Clark *et al.* (1972) working with sheep fed either ground alfalfa hay or a ration containing 40% and 100% cotton seed hulls (CSH) found that 91% of the PEG added to the rumen contents of sheep fed alfalfa was recovered; however, when PEG was added to the rumen contents of sheep fed either 40% or 100% CSH, recovery was decreased as CSH increased. Clark *et al.* (1972) suggested that PEG was being physically retained in some manner by the CSH particles and was not following the more rapid movement of water from the rumen. In another study pertaining to ration effect on PEG, Czerkowski and Breckenridge

(1969) found that PEG was excluded from a large proportion of the water contained in the swollen sugar-beet pulp food particles and that this proportion was large enough to give erroneous estimates of rumen fluid volume of sheep. However, Sinha *et al.* (1970) working with cattle being fed a ration of 60% alfalfa and 40% grain and Bauman *et al.* (1971) working with cattle being fed either liberal amounts of roughage and grain (control) or high-grain, low fiber diets reported that PEG provides an accurate measure of rumen fluid volume as compared to direct measurements. Bauman *et al.* (1971) reported that the cows had average rumen fluid volumes of 41.5 $\pm$ 9.2 liters for the control diet and 41.4 $\pm$ 6.3 liters for high grain, low fiber diet.

Lithium Sulfate

Another marker substance that has been used for indirect measurements of rumen fluid volume is lithium sulfate ($Li_2SO_4 \cdot H_2O$ - molecular weight 127.96). Lithium is the lightest of all known alkali metals and is in the family with sodium, potassium, rubidium, and cesium (Baum and Scaife, 1975). Lithium is easily determined by flame spectrophotometry at 670 mμ wavelength. Schou (1957) has reviewed comprehensively the metabolism of the lithium ion by mammals but could provide little information on ruminants. Harrison *et al.* (1963) inferred that lithium was absorbed rapidly by the anterior part of the digestive tract and that a small amount was recirculated into the rumen via the saliva. Ulyatt (1964) working with sheep

found that lithium appeared in venous blood and saliva within three hours of dosing. He also found that urine was a major route of excretion and the reticulo-rumen was a major site of lithium absorption. These results are in agreement with those of Harrison *et al.* (1963). However, Walker and Hawley (1965) working with sheep receiving diets of lucerne hay or wheat grains both *ad libitum* and in controlled quanitiies found that there was a close agreement between rumen volume measurements with PEG and Li_2SO_4 on the first day, but thereafter lithium concentrations in the rumen were higher than expected and consequently the rumen volume was underestimated. These results suggested that lithium was being absorbed and probably returned to the rumen via the saliva (Walker and Hawley, 1965). Johnson (1965) has stated that "although some workers recommended sampling one hour after dosing sheep, workers in this laboratory have determined that a more representative sample is obtained 2½ to 3 hours after dosing in beef cattle" when using lithium salts to determine liquid volume in the rumen.

Cr-EDTA

The chromium-complex or ethylenediamine tetracetic acid (Cr-EDTA) has been used in both digestion trials and rumen fluid volume experiments. Binnerts *et al.* (1968) used Cr-EDTA in digestion experiments and outlined a procedure to measure soluble chromium by atomic absorption. El-Shazly *et al.* (1976) proposed a colorimetric technique for analyzing Cr-EDTA and found that when compared with PEG similar values were obtained for rumen fluid volume. The actual measurements

through evacuating the rumen contents gave values 20-68% higher than those estimated by the color method, but were similar when corrected for dry matter. Lemenager *et al.* (1978) used Cr-EDTA to predict rumen fluid volume and rumen turnover time.

Phenol Red

In attempts to overcome some of the faults of estimating rumen fluid volume new markers are being tried. Phenol red has been used to estimate rumen fluid volume (Hecker *et al.*, 1964). They found that phenol red like PEG is not broken down in the rumen fluid and has the advantage of simplicity of estimation and the correlation between the estimated and the actual volumes measured by emptying the rumen contents was .90. Hecker *et al.* (1964) also showed that the time taken for mixing was greatest when the rumen contents were most solid in consistency and that complete mixing was within one hour in fed sheep.

Radioisotopes

Radioisotopes have been utilized as markers for estimation of rumen fluid volume in ruminants (Downes and McDonald, 1964; Warner and Stacy, 1968; Wright and Grainger, 1972). Radioisotopes have an advantage in the analytical procedures which are quite specific and highly accurate over a wide range of concentrations. Downes and McDonald (1964) were the first to use ^{51}Cr-EDTA as a soluble rumen fluid marker. They showed through fifteen comparisons of rates of disappearance from the rumen of PEG and ^{51}Cr-EDTA that the two markers gave the same results within experimental error and that

the concentrations of each decreased approximately exponentially. They also showed that a maximum of 4.7% of the ^{51}Cr-EDTA dose was excreted in the urine. Warner and Stacy (1968) found that ^{51}Cr-EDTA entered 95-98% of the water in the rumen and that mixing was not quite complete, even 1.5 hours after injection of the dose. They also concluded that less than .1% of the amount of ^{51}Cr-EDTA in the rumen is absorbed across the rumen wall per hour. Wright and Grainger (1972), working with sheep, injected 20 milliliters of ^{144}Ce into the rumen via stomach tube. They found that the average volumes of the whole rumen contents were proportional to time post feeding.

B. Techniques for Estimating Dry Matter Content

Since the total reticulo-rumen contents consist of both liquid matter and dry matter, it is important to be able to estimate both fractions accurately.

The attempts to develop an indirect method of estimation of the amount of solid ingesta have been widely unsuccessful. Any solid material used as an indicator should theoretically have approximately the same specific gravity and particle size as the solid ingesta. Since these two qualities are usually highly variable with most practical rations, the determination of the solid ingesta fraction is not easily made by indicator techniques presently available (Johnson, 1966).

Chromic Oxide

The one method that has been used most frequently in estimation of the quantity of solid ingesta in the reticulo-rumen is the use of chromic oxide (Cr_2O_3). Corbett *et al.* (1959) has shown that Cr_2O_3 is closely associated with the solid ingesta and that the distribution of Cr_2O_3 is similar to that of the dry matter. Pursior and Moir (1966) using Cr_2O_3 to predict rumen volume found that there was a wide variation in the Cr_2O_3 concentrations in the reticulo-rumen immediately after dosing but as time progressed the Cr_2O_3 concentrations in the reticulo-rumen became similar. Pursior and Moir (1966) and Lemenager *et al.* (1978) suggested that this method under certain conditions gave overestimation of the dry matter fraction. They proposed that this overestimation was possibly due to (1) dilution of the ingesta by saliva, (2) unequal distribution of the Cr_2O_3 in the rumen, (3) loss of Cr_2O_3 due to passage from the rumen, or (4) a combination of each of these factors.

Rare Earth Metals

The use of rare earth metals as multiple markers in nutrition studies have until recently been very seldom used. Hartnell and Satter (1979) did both *in vivo* and *in vitro* experiments to determine the extent of movement of samarium (Sm), cerium (Ce), and lanthanum (La) from the orginal feed stuff upon which they were absorbed to other feed particles. The rare earth elements were demonstrated to be tenaciously bound to the particulate phase, with essentially none of the elements occurring in the liquid phase. In a following experiment

Hartnell and Satter (1979) used these rare earth metals as multiple markers to estimate rumen fill in four fistulated lactating dairy cows.

Direct Estimates of Rumen Volume

The direct method of estimating rumen volume employs manual removal and measurement of all the solid ingesta and liquid in the reticulo-rumen. This manual removal can be accomplished by using fistulated animals (Campling and Balch, 1961; Freer and Campling, 1963; Pursior and Moir, 1966; Crabtree, 1967) or by slaughtering the animals, removing the reticulo-rumen and its contents, and then filling the reticulo-rumen with water until distention (Campling and Balch, 1961; Pursior and Moir, 1966; Forbes, 1969). In live fistulated or nonfistulated ruminants a suction technique may be used to evacuate the rumen contents (Sinha *et al.*, 1970; El-Shazly *et al.*, 1976).

All these methods have serious drawbacks under certain experimental conditions where large numbers of animals are used. The fistulation of steers is usually expensive and time consuming; also the fistula if not properly placed can leak or allow contamination of the rumen contents. The slaughter of animals is also expensive and will allow for only one estimate of that animal's rumen volume. The filling of the reticulo-rumen with water is not useful because there is no way of telling when the reticulo-rumen is overextended and the reticulo-rumen will perform differently outside the body than when inside the body. The suction technique is very time consuming due to the clogging effect of the dry matter portion of the reticulo-rumen contents and in

nonfistulated live animals there is no way of telling when all the reticulo-rumen contents have been evacuated. There is also the problem of continual influx of saliva into the reticulo-rumen which would be adding volume to the contents. A major problem is determining when the animal is physically "full" because not all animals consume feedstuffs to the same extent. In fistulated animals, the reticulo-rumen contents can be removed manually and then empty body weight can be found. Once empty body weight has been determined, rumen dry matter volume and fluid volume can be arrived at by weighing the animals and then subtracting the empty body weight from the full body weight (Tulloh *et al.*, 1965).

II. IMPORTANCE OF RUMEN VOLUME IN NUTRITIONAL STUDIES

The importance of feed intake for production in cattle is well documented (Conrad *et al.*, 1964; Montgomery and Baumgardt, 1965 a,b; Blaxter, 1967; Baumgardt, 1967; Baumgardt, 1969; Bines *et al.*, 1969). Rumen volume has been shown to have an effect on food intake and the ability of ruminants to digest feed (Blaxter *et al.*, 1961; Campling and Balch, 1961; Freer and Campling, 1963; Conrad *et al.*, 1964; Montgomery and Baumgardt, 1965). Campling and Balch (1961) removed swallowed hay as it entered the reticulo-rumen of cows and were able to show that the removal of swallowed hay had a direct and immediate affect of the point in time at which the cows ceased to eat hay. This removal of swallowed hay caused the cows to consume about 177% of their normal voluntary daily intake. They also showed that the addition of bulk or water into the reticulo-rumen decreased voluntary intake by .54 pounds for every

ten pounds of water in the bladders. They also showed that for every one pound change of dry matter in the reticulo-rumen and its associated water a decrease of .6 pounds in daily voluntary intake of hay could be expected. Pursior and Moir (1966) concluded that sheep with small rumen volumes, slow rates of intake, and low water consumption exhibited greater prolonged concentrations and below average rumen ammonia concentrations. They also concluded that sheep with large rumen volumes and rapid rates of intake exhibited an increase in dry matter digestibility and an increase in rumen retention time for the roughage part of the diet. Montgomery and Baumgardt (1965 a,b) suggested that for dairy cows to meet production requirements they must consume a highly digestible ration and consumption of this ration must not be limited by physical capacity. They suggested that for dairy cows to meet their production requirements on low digestibility ration, intake must be increased or capacity must not limit the cows intake. Pursior and Moir (1966) indicated that an increase in rumen volume tended to increase the digestibility due to slower rates of passage out of the reticulo-rumen.

A. Physical Control of Intake

Several researchers have explored the factors thought to control feed intake in ruminants (Ragsdale *et al.*, 1949, 1950, 1951; Kennedy, 1952; McCullough and Russell, 1959, 1962; Schinkel, 1960; Campling *et al.*, 1961; Pettyjohn, 1963; Conrad *et al.*, 1964; Montgomery and Baumgardt, 1965 a,b; Simkins *et al.*, 1965 a; Graham, 1969). Pursior and Moir (1966) using Cr_2O_3 to measure rumen volume suggested

that the *ad libitum* intake of dry matter of poor quality bulky roughages is proportional to the rumen volume. Campling *et al.* (1961) offered hay or oat straw *ad libitum* and at two controlled levels of intake to four cows and was able to show that the mean voluntary intake of hay was more than twice that of straw. They suggested that the intake of these two roughages was limited by their respective rates of disappearance from the alimentary tract. Intake was offset by passage from the tract so as to maintain a constant amount of food residues in the reticulo-rumen immediately before each feeding. Blaxter *et al.* (1961) working with sheep found that voluntary intake of long fodders and their resultant gain of body weight are closely related to the quality of forage where quality is donated by the apparent digestibility of its energy. The reason for this association appeared to be that sheep eat to a constant distention of their digestive tracts measured to be that "fill" which is in turn determined by the rate of passage and digestibility. Freer and Campling (1963) suggested that with roughages having a mean daily rate of disappearance from the reticulo-rumen greater than about 8.18 kilograms of dry matter, and consumption would cease when the reticulo-rumen contained 15.19 kilograms of dry matter, a limit possibly set by the capacity of the reticulo-rumen. Montgomery and Baumgardt (1965 a) offered support to the hypothesis that ruminants will adjust voluntary food intake in relation to physiological demand for energy if fill or rumen load does not limit their consumption by feeding four completely pelleted rations to eight Holstein heifers in a sixty-seven day continous

feed trial. They proposed that as concentrates make up a larger part of the ration, consumption is regulated by factors other than rumen load or fill and that with low nutritive feeds rumen load prevents the animal from consuming the amount of energy that its physiology demands. They also suggested that a feed with low digestibility will be of low nutritive value to the animal and consumption of this low digestibility feed is directly proportional to the nutritive value that the animal can obtain from the feed.

B. Factors Influencing Rumen Volume

There are many factors that will influence rumen volume in cattle. However, only retention time, digestibility, intake, lactation, body fatness and pregnancy will be discussed.

Retention Time, Digestibility, and Intake

Retention time, digestibility, and intake are all confounded within each other. As retention time increases, digestibility usually increases while intake is decreased (Campling and Balch, 1961). Other experiments by Conrad *et al.* (1964) and Montgomery and Baumgardt (1965 a,b) reveal further interactions between intake, digestibility and retention time.

Lactation

Hartnell and Satter (1979) working with four fistulated dairy cows during the dry period and throughout lactation found that there was 40% less dry matter in the reticulo-rumen during the dry period as compared to the lactating period. The liquid portion of the rumen's

contents varied from 62.1 kilograms during the dry period to 89.3 kilograms during weeks 13 to 24 of lactation. They suggested that differences between cows in reticulo-rumen volume may have been due to differences in saliva production, turnover rate, and/or ruminal capacity.

Body Fatness

Taylor (1959) and Crabtree (1967) noted as cattle fatten, the organs which are chiefly concerned with nutrition decrease as a percent of the body weight. The fatter an animal becomes, the less feed it can consume as a percent of its body weight, so reticulo-rumen volume will be depressed proportionally.

Pregnancy

In advanced preganacies of both cattle and sheep, the reticulo-rumen volume will be depressed mainly due to competition for space between the reticulo-rumen and the gravid uterus with its associated products of reproduction (Taylor, 1959; Forbes, 1969). Graham and Williams (1962) and Forbes (1969) found that the level of hay intake was shown to be related to the volume of the reticulo-rumen contents and therefore to be depressed in late pregnancy.

CHAPTER III

RELATIONSHIP BETWEEN RUMEN FLUID VOLUME, DRY MATTER INTAKE, MEASUREABLE BODY CHARACTERISTICS AND ANIMAL PERFORMANCE FOR ANGUS COWS GRAZING HIGH AND LOW QUALITY PASTURES

I. SUMMARY

The rumen fluid volumes were evaluated for a total of thirty-nine Angus cows in the fall (two weeks after weaning) for two years using lithium sulfate as a marker substance. Cow linear body measurements of weight, ultrasonic fat thickness, height at the top of the withers, length from shoulder to hook, depth and hook width were taken prior to rumen fluid volume determinations. The daily dry matter (DM) intake and digestibility of DM intake was estimated over the spring and summer for these Angus cows utilized the chromic oxide-acid detergent lignin ratio technique. Cows grazed either high or low quality pastures with cow size confounded with pasture within pasture quality. Animal performance characteristics of mean milk production, milk butterfat percent, and solids non-fat were measured in the fourth, fifth, and sixth months of lactation. Weaning weight of the calves was also measured.

The mean rumen fluid volume for the cows was 60.32 ± 13.39 liters. Rumen fluid volume had no effect on average DM intake, average percent digestibility of the forage or average digestible DM intake for cows grazing high quality pastures ($P > .05$). However, rumen fluid volume did influence average DM intake ($P < .06$) and average digestible DM intake ($P < .08$) for cows grazing low quality

pastures. High quality pastures had a digestibility of 59% compared to 55% digestibility for low quality pastures. Forage DM intake was found to be more influenced by seasonal changes in the forage than rumen fluid volume. Cows with small rumen fluid volumes were more suceptible to digestibility changes than were cows with large rumen fluid volumes. Rumen fluid volume was affected by weight, height, length, depth and hook width ($P < .05$). However, only weight and fat had an effect on rumen fluid volumes as a percent of body weight ($P < .05$). Rumen fluid volume was found to be negatively related to milk butterfat percent, but this was probably due to chance. Rumen fluid volume was not significantly related to mean milk production, solids non-fat in the milk and weaning weight of the calves ($P > .05$).

II. INTRODUCTION

Through the introduction of suitable markers as dietary dilutes, it has now become possible to research the relationship between *in vivo* rumen volume or "capacity" and intake of forages by cattle. The majority of forage intake experiments that have been performed do not apply to cattle under grazing conditions. Although work relating physical capacity and intake has been done by Conrad *et al.* (1964), Baumgardt (1969) and Campling (1969), in which they used small numbers of dairy animals for short intensive periods. Montgomery and Baumgardt (1965 a) have postulated that the intake of low quality forages (less than 67% digestible) by dairy cattle is limited by gut capacity.

The purpose of this research project was to (1) evaluate the rumen volumes of Angus cows using a dietary dilutant, (2) relate cow body measurements of weight, height, fat, depth, length and hook width to rumen volume and rumen volume as a percent of body weight, and (3) to determine the relationship between forage intake, digestibility of intake and rumen volume or capacity of Angus cows grazing high and low quality pastures.

III. MATERIALS AND METHODS

Estimation of Rumen Volume Feeding Description

A total of thirty-nine Angus cows were evaluated for rumen volume in October of 1977 and 1978 (about two weeks after weaning each year). They were placed in a dry lot and fed a 99.5% cotton seed hull (CSH) and .5% NaCl ration for eight days. The cows were fed CSH *ad libitum* every morning at 7:00 a.m. and allowed to consume the CSH until 10:00 a.m. Only during the feeding time were the cows allowed access to water. On the eighth day of feeding, the cows were fed at the regular time, but after consuming all the CSH they would eat, they were allowed to consume hay until they were apparently satisfied. After this, they were moved into a holding area and prepared for sampling and dosing.

Lithium Dosing and Determinations

The cows were placed in a head chute and a 50 ml sample of rumen fluid was withdrawn via stomach tube passed through the mouth and into the rumen. Immediately after the sample of rumen fluid

was drawn, each cow was drenched with 175 ml of a 2.5% lithium sulfate solution. In 1977 this procedure was followed on two days separated by a day, while in 1978 the cows were dosed on two continuous days. In 1977, after dosing, two rumen samples were taken; one at one hour after initial dosing time and one at two hours after initial dosing time. In 1978, the sampling times were increased by sampling also at three hours and at four hours after the initial dosing time.

All lithium determinations were done by flame photometry and with a modified method of that used by Ulyatt (1964). The only modification consisted of measuring lithium ion emission at 740 mμ to overcome interference from the sodium in the samples and also to obtain increased repeatability.

Cow Body Measurements

Cow body measurements and photographs were taken at the time of rumen volume estimation. Measurements taken were weight, hook width (measured with a precision caliper), and fat thickness over the twelfth rib measured ultrasonically (Swaim *et al.*,1966). Slides were projected to life size then the following linear measurements were made: height (HT) at the top of the withers, length from point of shoulder to hooks (LPSH) and depth of heart.

Forage Intake and Digestibility Estimation

Total fecal dry matter excretion was estimated for each cow for a period of 180 days (April 20 - October 17) by the Cr_2O_3 dilution

method for both 1977 and 1978. Holloway *et al.* (1979) has previously described the methods and equations used to obtain the estimates of dry matter intake, digestible dry matter intake, and digestibility values used in this paper.

Animal Management

The seventy-eight Angus cows had one of the following pretrial treatments. Thrity-nine of the cows had been removed from low quality pastures which were homogenous swards of Kentucky-31 tall fescue (*Festuca arundinacea*) that were allowed to mature. The other thirty-nine cows came from high quality pastures which consisted mainly of fescue (approximately 60-70% of total forage available) and legume (approximately 30-40% of total forage available). The cows were chosen because they approached the range in variation for mature fall weight, body size, and milk production for Angus cows.

Animal Performance Estimation

The milk production of these cows was estimated by the calf-suckle technique (Holloway *et al.*, 1979) for each month of lactation for a total of seven estimates. Total milk collections were taken for analysis during the fourth, fifth, and sixth months of lactation and analyzed by the method described by Holloway *et al.* (1979).

Statistical Analysis

The data were analyzed statistically with programs prepared by Barr *et al.* (1976). Regression procedures were employed to describe the percent Cr_2O_3 in fecal dry matter:

Equation 1. $g\ Cr_2O_3/g\ \text{fecal DM} = b_0 + b_1(\text{Julian day}) + b_2(\text{Julian day})^2$.

The percentage of ADL in fecal DM was arrived at by using:

Equation 2. g ADL/g fecal DM = $b_0 + b_1$ (Julian day) + b_2 (Julian day)^2.

The percentage of ADL in consumed forage was arrived at by using:

Equation 3. g ADL/g forage DM = $b_0 + b_1$ (Julian day) + b_2 (Julian day)^2.

These regression equations were evaluated for each day of the experimental period. Predicted values were then used in calculations to estimate fecal production, DM digestibility, forage DM intake and forage digestible dry matter intake (DDMI) for each cow each day of the experiment. Regression equations were then employed to describe seasonal changes of these variables.

Equation 4. DM digestibility, DM intake and DDMI = $b_0 + b_1$ (Julian day) + b_2 (Julian day)^2.

Linear regression analysis was used to describe the effect of weight, height, fat, length, depth, hook width on the dependent variables rumen volume and rumen volume as a percent of body weight.

Model: $y = b_0 + b_1x$

Linear regression analysis was used to see if any of the variation in mean milk production, milk butterfat, solids non-fat and weaning weight of the calves could be explained by rumen volume and rumen volume as a percent of body weight.

IV. RESULTS AND DISCUSSION

Forage Dry Matter Intake

Dry matter intake, digestibility, and digestible dry matter intake as averages of the grazing season for cows grazing high

quality pastures were not significantly affected by rumen fluid volume ($P > .05$, Table 1). This was probably due to the fact that these cows were able to meet their requirements due to the higher digestibility of the high quality pastures (Holloway *et al.*, 1979). However, rumen fluid volume did affect average DM intake and average digestible DM intake of cows grazing low quality pastures (Table 1). Montgomery and Baumgardt (1965 a,b) have shown that lactating dairy cattle consumed low quality forages (less than 67% digestible) until rumen distention. This is possibly the case here. Cows on low quality pasture were consuming a 55% digestible forage as an average of the grazing season, which was possibly too low to meet their requirements so they consumed forage until rumen distention, while cows on high quality pastures were grazing a 59% digestible forage which was possibly adequate to meet their requirements. Since Conrad (1964) and Montgomery and Baumgardt (1965 a) were using high producing dairy cattle, they found that less than a 67% digestible forage caused the cattle to consume to rumen distention. However, the beef cattle in this experiment did not have such high requirements for production. Therefore, the 59% digestible forage was possibly able to meet their requirements without eating until rumen distention.

The general patterns of change in DM intake, DM digestibility and digestible DM intake for 1978 are shown in Figures 1, 2, and 3

TABLE 1. PARTIAL REGRESSION COEFFICIENTS FOR DESCRIBING THE INFLUENCE OF RUMEN FLUID VOLUME ON AVERAGE FORAGE DRY MATTER INTAKE, AVERAGE FORAGE PERCENT DIGESTIBILITY AND AVERAGE FORAGE DIGESTIBLE DRY MATTER INTAKE [a]

	Pasture Quality			
	High		Low	
	b_1 rumen fluid volume	significance[b]	b_1 rumen fluid volume	significance[b]
ADMCD[c]	+.008	.44	+.018	.06
R^2	.01		.38	
ADIG[d]	+.00008	.63	+.001	.65
R^2	.76		.88	
ADDMI[e]	+.005	.41	+.011	.08
R^2	.11		.63	

[a] MODEL: ADMCD, ADIG, ADDMI = year, treatment, year x treatment, and rumen fluid volume.

[b] Level of significance as determined by the F test for partial sum of squares (Probability > F).

[c] Average dry matter consumed per day.

[d] Average digestibility.

[e] Average digestible dry matter intake.

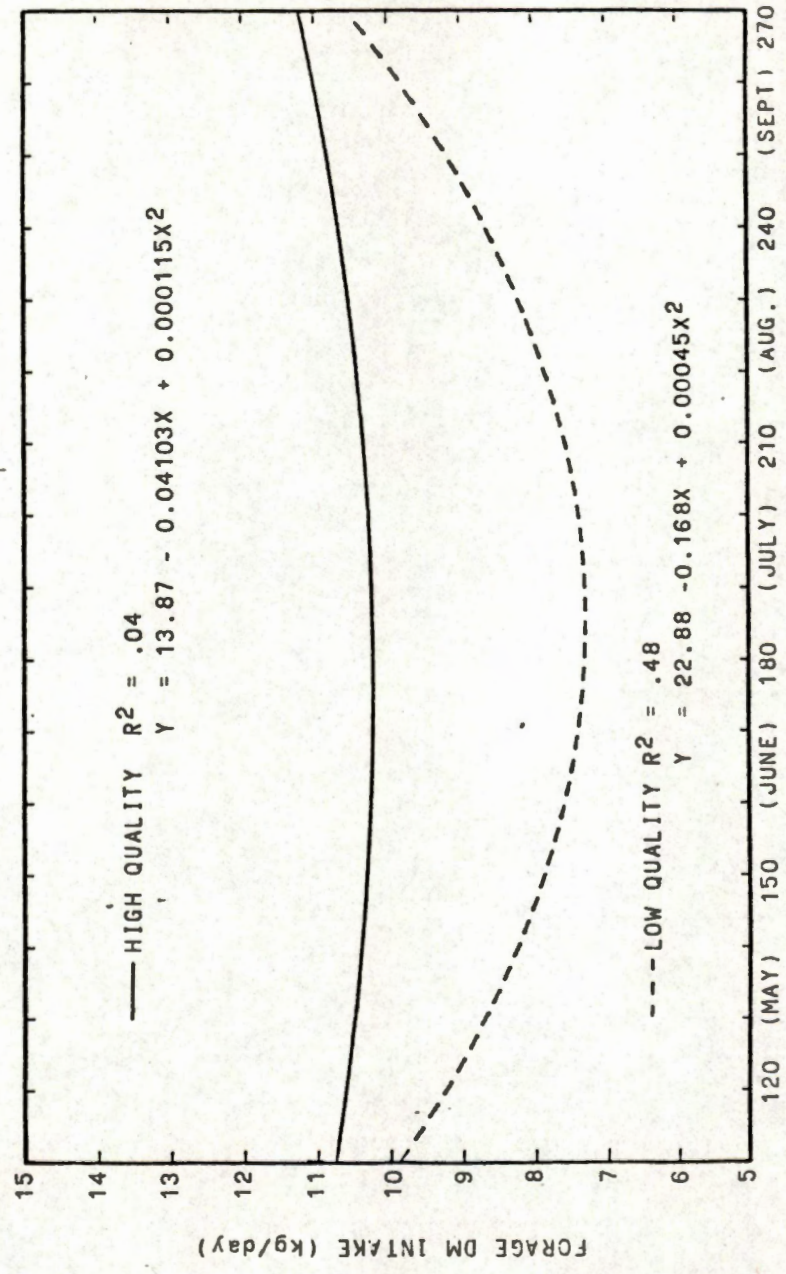


Figure 1. Dry Matter Intake of Lactating Angus Cows Grazing High and Low Quality Pastures

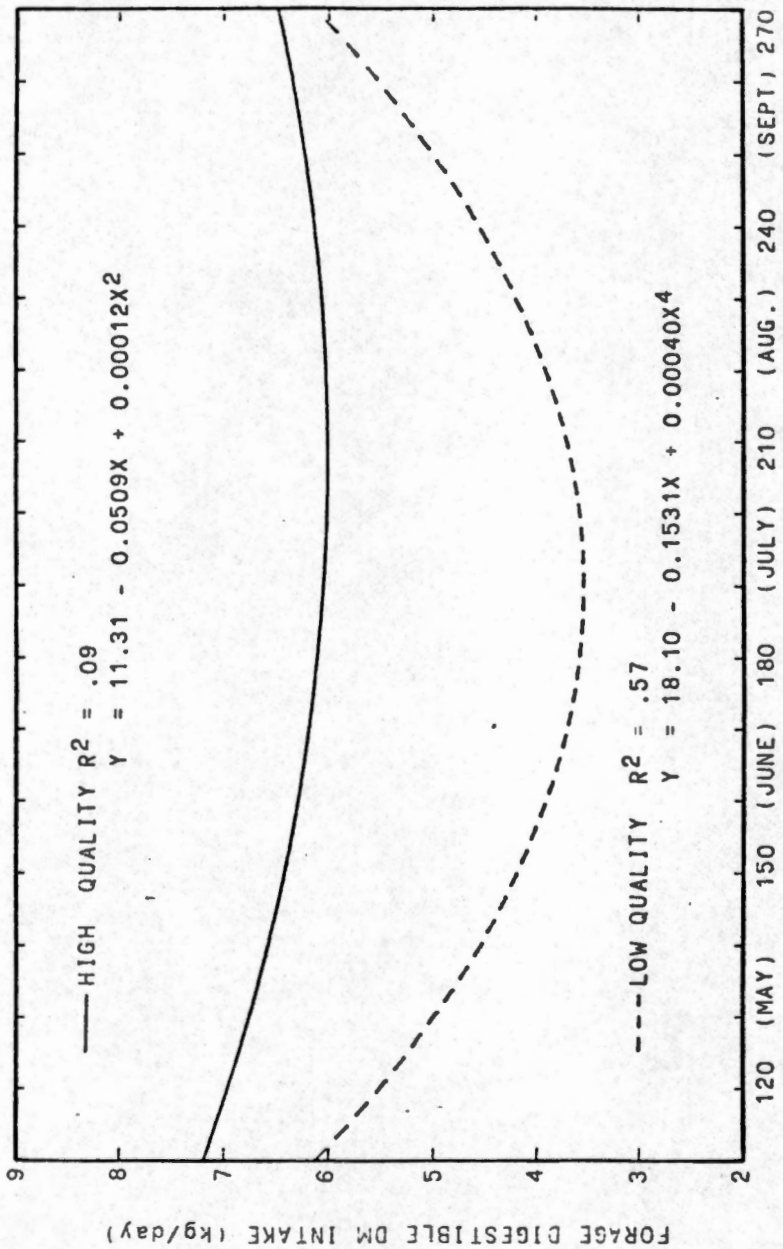


Figure 2. Digestible Dry Matter Intake of Lactating Angus Cows Grazing High and Low Quality Pastures

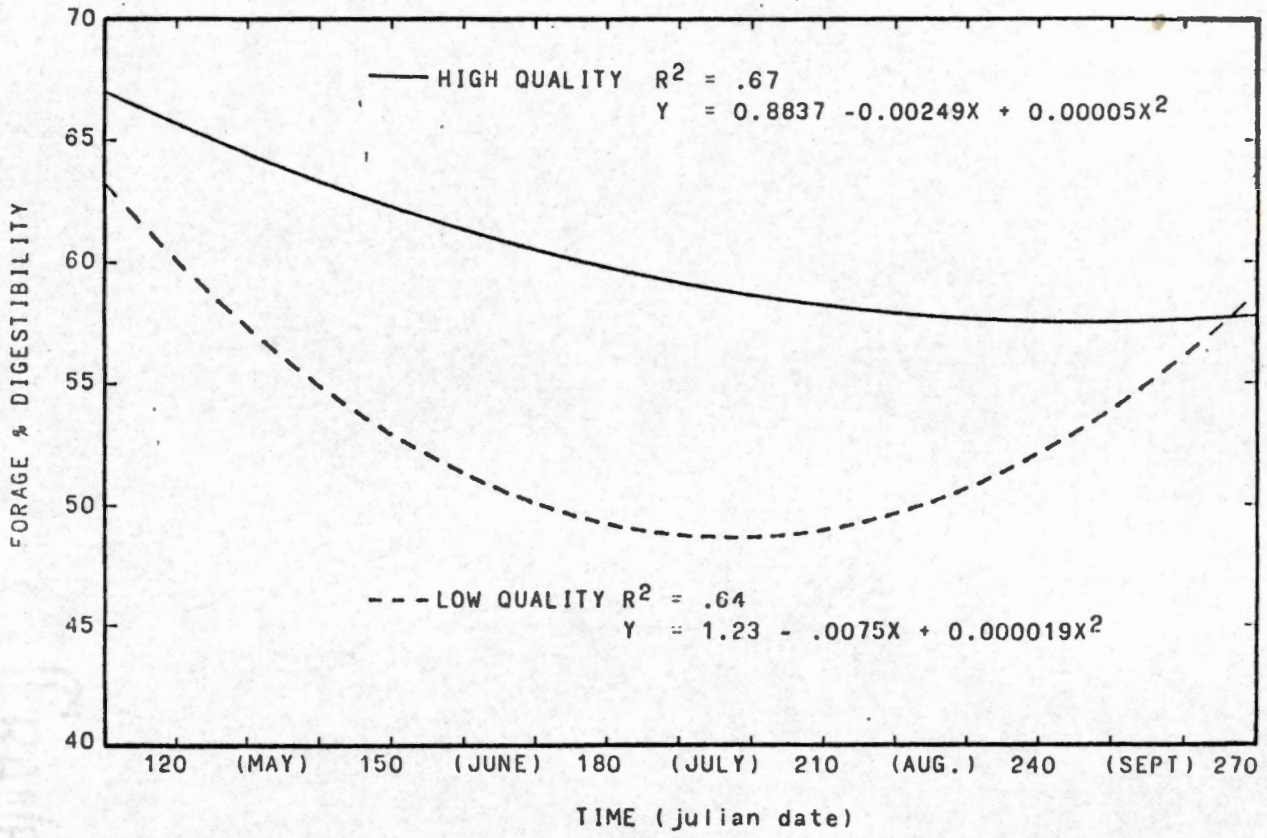


Figure 3. Forage Percent Digestibility of High and Low Quality Pastures

respectively. In general large advantages were apparent for cows grazing high quality pastures during the summer over those grazing low quality pastures. The patterns for 1977 were reported by Holloway *et al.* (1979). The influence of rumen fluid volume on seasonal patterns of DM intake is shown in Figures 4 and 5 for cows grazing high quality and low quality pastures respectively.

Rumen fluid volume had a large negative effect on DM intake of the cows grazing both high quality and low quality pastures in the early spring and late fall. The reason for this negative relationship was not apparent. However, at low DM digestibilities that occurred during the summer, there appeared to be a positive relationship between DM intake and rumen fluid volume. This agrees with Conrad *et al.* (1964) and Montgomery and Baumgardt (1965 a,b).

DM intake of cows with small rumen fluid volumes were influenced more by seasonal changes in the forage than cows with large rumen fluid volumes for cows grazing high quality pasture. As digestibility decreased during the summer, DM intake increased for cows with large rumen fluid volumes, but decreased for cows with small rumen fluid volumes for cows grazing low quality pasture. All cows tended to reduce DM intake during summer but cows with large rumen fluid volumes appeared to experience a smaller reduction. For cows grazing high quality pasture, only 33% of the variation in DM intake was explained by rumen fluid volume and time, while cows grazing low quality pasture, 41% of the variation in DM intake was explained by rumen fluid volume and time (Table 2).

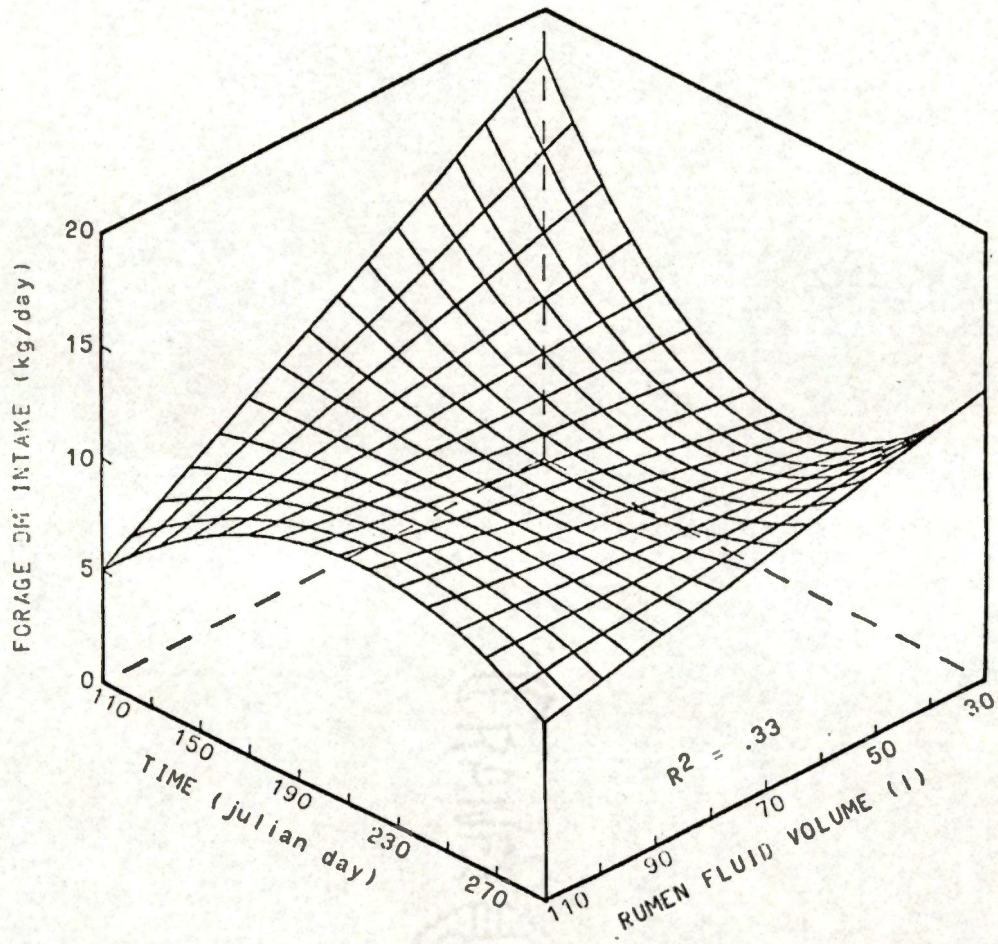


Figure 4. Relationship Between Forage Dry Matter Intake, Time and Rumen Fluid Volume of Angus Cows Grazing High Quality Pastures

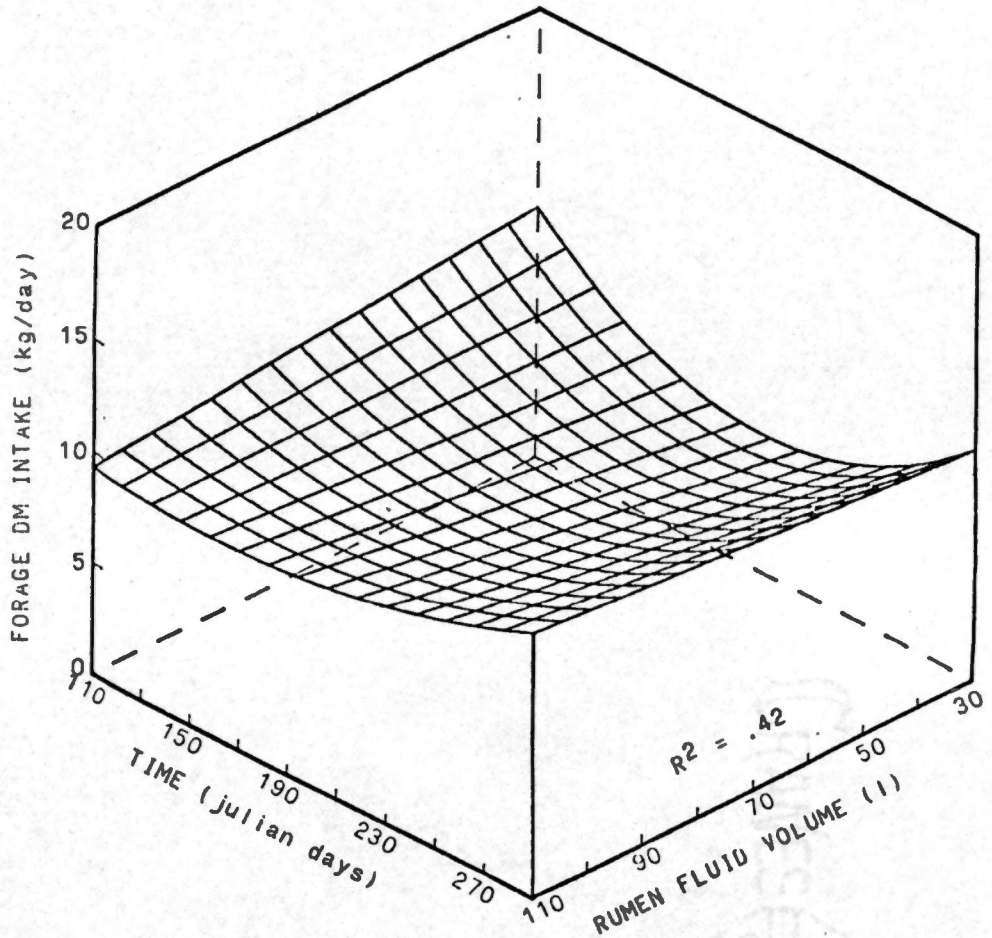


Figure 5. Relationship Between Forage Dry Matter Intake, Time and Rumen Fluid Volume of Angus Cows Grazing Low Quality Pastures

TABLE 2. PARTIAL REGRESSION COEFFICIENTS FOR DESCRIBING THE INFLUENCE OF TIME AND RUMEN FLUID VOLUME ON FORAGE DRY MATTER INTAKE[a]

	Pasture Quality	
	High	Low
	b_1 dry matter intake	b_1 dry matter intake
Time	-0.674[b]	-0.291[b]
Time^2	+0.001[b]	+0.00004[b]
Rumen fluid volume	-0.835[b]	-0.198[b]
Time * Rumen fluid volume	+0.008[b]	+0.002[b]
Time^2 * rumen fluid volume	-0.00002[b]	-0.0000003[b]
R^2	.33	.41

[a]Model: DMI = time, time^2, rumen fluid volume, time x rumen fluid volume, and time^2 x rumen fluid volume.
[b]Level of significance as determined by F test for partial sum of squares ($P < .01$).

When rumen fluid volume as a percent of body weight was substituted into the model, the same relationships were found to exist between seasonal changes in DM intake and rumen fluid volume (Figures 6 and 7). For cows grazing high quality pasture only 38% of the variation in DM intake was explained by rumen fluid volume as a percent of body weight and time, while for cows grazing low quality pasture, 44% of the variation in DM intake was explained by rumen fluid volume as a percent of body weight (Table 2).

Body Measurements

The regression coefficients describing the influence of body weight, body fat, height at the withers, length from point of shoulder to hooks, depth of heart, and hook width on rumen fluid volume and rumen fluid volume as a percent of body weight are shown in Table 3.

Rumen fluid volume increased .6 liters per 10.0 kilogram increase in body weight ($P < .05$, $\hat{y} = 31.15 + 0.06$ (weight in kg)). Rumen fluid volume was shown to increase at the rate of 1.0 liter per centimeter increase in wither height ($P < .02$, $\hat{y} = -56.64 + 1.022$ (height in cm)). No relationship between rumen fluid volume and ultrasonic fatness could be detected ($P > .05$). Rumen fluid volume increased 0.76 liters per centimeter increase in length ($P < .05$, $\hat{y} = -17.331 + 0.762$ (length in cm)). Rumen fluid volume increased 1.3 liters per centimeter increase in depth ($P < .05$, $\hat{y} = -25.39 + 1.25$ (depth in cm.)). All the measurements made except

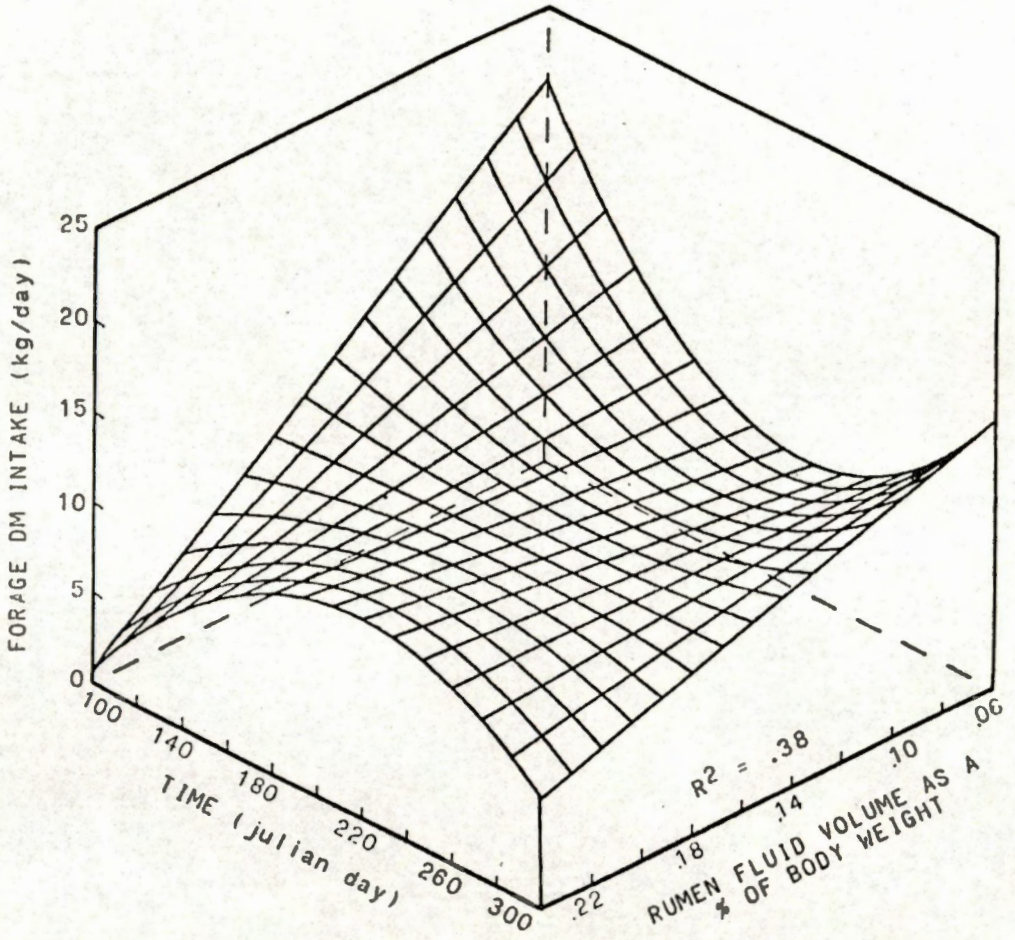


Figure 6. Relationship Between Forage Dry Matter Intake, Time and Rumen Fluid Volume as a Percent of Body Weight for Angus Cows Grazing High Quality Pastures

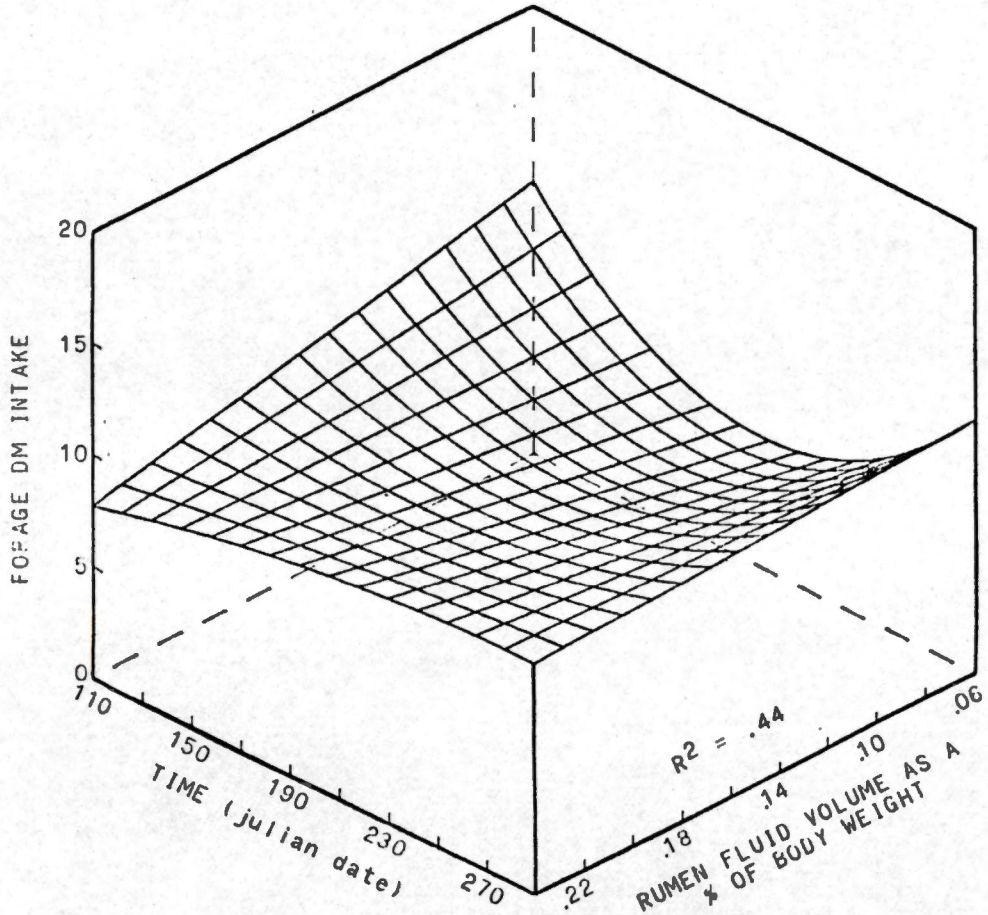


Figure 7. Relationship Between Forage Dry Matter Intake, Time and Rumen Fluid Volume as a Percent of Body Weight for Angus Cows Grazing Low Quality Pastures

TABLE 3. THE EFFECT OF COW BODY MEASUREMENTS ON RUMEN FLUID VOLUME[a]

Body Measurement	Parameters: Rumen Fluid Volume (liters)	R^2	Rumen Fluid Volume as a % of body weight	R^2
Weight (kg)	0.06[c]	.21	-0.0001[c]	.30
Fat[d] (mm)	-0.1623[c]	.17	-0.0026[c]	.34
Height[e] (cm)	1.0[c]	.23	-0.00051	.25
Length[f] (cm)	0.76[c]	.25	+0.00036	.25
Depth[g] (cm)	1.25[c]	.21	-0.0018	.27
Hook Width[h] (cm)	0.92[b]	.19	-0.0015	.27

[a]Model: $\hat{Y} = b_0 + b_1$ (body measurement).

[b]Level of significance as determined by F test for partial sum of squares ($P < .1$).

[c]Level of significance as determined by F test for partial sum of squares ($P < .05$).

[d]Ultrasonic measurement over twelfth rib.

[e]Photographic measurement at withers.

[f]Photographic measurement from point of shoulders to hooks.

[g]Photographic measurement at heart girth.

[h]Actual measurement.

fat thickness had a positive relationship to rumen fluid volume, so this would tend to indicate that cows that are larger in structural size possess larger rumen fluid volumes.

Rumen fluid volume as a percent of body weight decreased by 0.01 liters per 100 kilogram increase in body weight ($P < .05$, $\hat{y} = 0.190 - 0.00013$ (weight in kg)). Rumen fluid volume as a percent of body weight decreased by 0.0026 liters per millimeter increase in ultrasonic fatness ($P < .05$, $\hat{y} = 0.1472 - 0.0026$ (fat in mm)). This is in agreement with Taylor (1959) and Crabtree (1967) who found that as cattle fatten, the organs which are chiefly concerned with nutrition decrease as a percent of the body weight. Rumen fluid volume as a percent of body weight was not affected ($P > .05$) by height at the withers, length from point of shoulder to hooks, depth of heart and hook width. Several researchers (Conrad *et al.*, 1964; Montgomery and Baumgardt, 1965 a,b) have postulated that the limiting factor to consumption of low quality forages is rumen volume. This assumption is consistent with the results of this experiment. They have also postulated that consumption of low quality forages is proportional to weight$^{1.0}$ assuming weight to be proportional to rumen volume. This assumption is not consistent with the results of this experiment.

The low R^2 values of .20 and .30 could be explained by the fact that some animals were not completely full while others were

very full (Table 3). The variations in sampling techniques could have given biased estimates of the rumen fluid volume. A small, short cow could have been estimated to have a greater rumen fluid volume than a large cow.

Animal Performance

Animal performance included mean milk production, butterfat percent of the milk, solids non-fat of the milk and weaning weight of the calves (Table 4).

Mean milk production was not significantly affected by rumen fluid volume ($P > .05$) and rumen fluid volume as a percent of body weight ($P > .05$). Holloway *et al.* (1979) has suggested that under these pasture conditions the amount of milk produced by beef cattle was possibly determined by non-nutritional factors such as the capacity of calves to consume milk and the willingness of older calves to consume milk. Wyatt *et al.* (1971) has shown that calf capacity is important in determining milk production of beef cows.

Milk butterfat percent was negatively related to rumen fluid volume ($P < .05$) and rumen fluid volume as a percent of body weight ($P < .05$). Some research has shown that increased milk production caused a decrease in butterfat percent, but this was not the case here. No explanation can be given at this time for the negative relationship unless it was possibly due to chance.

Rumen fluid volume and rumen fluid volume as a percent of body weight had no effect on solids non-fat in the milk ($P > .05$ and $P > .05$ respectively).

TABLE 4. THE REGRESSION COEFFICIENTS DESCRIBING THE INFLUENCE OF RUMEN FLUID VOLUME AND RUMEN FLUID VOLUME AS A PERCENT OF BODY WEIGHT ON ANIMAL PERFORMANCE[a]

Performance Measurements	Parameters: Rumen Fluid Volume (liters)	R^2	Rumen Fluid Volume as a % of body weight	R^2
Mean Milk Prod. (lbs.)	-0.6759	.18	-0.00044	.26
Butterfat %	721.02[b]	.23	-1.24[b]	.31
Solids non-fat (g)	9.4129	.18	-0.7671	.30
Weaning weight of calves (kg)	-0.05238	.18	-0.00007	.27

[a]Model: $\hat{y}$ = year, treatment, year x treatment, and animal performance.

[b]Level of significance as determined by F test for partial sum of squares ($P < .05$).

Rumen fluid volume and rumen fluid volume as a percent of body weight did not significantly affect the weaning weight of calves for both the large and small cows ($P > .05$ and $P > .05$ respectively).

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VITA

Bobby Gene Nutt, son of Katherine G. Nutt, was born in Lawerenceburg, Tennessee on August 5, 1955. He grew up and attended elementary and secondary schools in Williamson County, Tennessee. He entered The University of Tennessee, Knoxville in September of 1973 and received the Bachelor of Science Degree in Animal Science in March of 1978. He entered graduate school at The University of Tennessee, Knoxville in March of 1978 to study ruminant nutrition and beef production and was granted the Master of Science Degree in Animal Science in August of 1979.