1-1-2013

Effect of Chopping or Cubing Hay on Apparent Digestibility of Nutrients When Fed to Angus, Hereford, and Charolais Steers

Rebecca Ann Willcutt

Effect of chopping or cubing hay on apparent digestibility of nutrients when fed to Angus, Hereford, and Charolais steers

By

Rebecca Ann Willcutt

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Agriculture (Animal Nutrition)
in the Department of Animal and Dairy Sciences

Mississippi State, Mississippi

August 2013

Effect of chopping or cubing hay on apparent digestibility of nutrients when fed to

Angus, Hereford, and Charolais steers

By

Rebecca Ann Willcutt

Approved:

Brian J. Rude Professor and Graduate Coordinator of Animal and Dairy Sciences (Major Professor)	Stephanie H. Ward Assistant Professor of Animal and Dairy Sciences (Committee Member)
Jeremiah D. Davis Assistant Professor of Agricultural and Biological Engineering (Committee Member)	George Hopper Dean of the College of Agriculture and Life Sciences

Name: Rebecca Ann Willcutt

Date of Degree: August 17, 2013

Institution: Mississippi State University

Major Field: Agriculture (Animal Nutrition)

Major Professor: Dr. Brian J. Rude

Title of Study: Effect of chopping or cubing hay on apparent digestibility of nutrients when fed to Angus, Hereford, and Charolais steers

Pages in Study: 27

Candidate for Degree of Master of Science

The objective of this study was to evaluate digestibility of cubed hay as a feedstuff for ruminants. Angus (n=6), Hereford (n=3), and Charolais (n=3; total n=12; 226 ± 21.8kg) steers, stratified by breed, were randomly assigned to 3 treatment groups: 1) hay; 2) chopped; 3) cubed. There was no difference ($P > 0.05$) of DMI or digestibility of DM, OM, NDF, ADF, hemicellulose, and energy among treatments. Steers consuming hay digested more CP than those consuming chopped. Steers consuming cubed digested less CP than those consuming hay or chopped. More fat was digested by steers consuming hay or chopped than by those consuming cubed. Steers consuming cubed retained more nitrogen than those consuming chopped. Those consuming hay were intermediate. Nitrogen metabolized was greater for steers consuming hay than for steers consuming chopped. Those consuming cubed were intermediate. Steers consuming hay and cubed had greater metabolizable protein than those consuming chopped.

ACKNOWLEDGEMENTS

The author wishes to express acknowledgement and gratitude for all the help and support received while working toward this accomplishment. Special thanks to my parents for their continued support and encouragement and for reminding me to never give up. Acknowledgement and thanks are due to Dr. Brian J. Rude my major professor for being patient with me throughout this process and for his willingness to work with me. I would also like to express my gratitude to Mrs. Cathy Aultman and the student workers who spent their time working with me to complete the nutritional analysis of the samples. Thanks are due to Treena Ferguson, Chad Dunaway, and Jonathan Greene for assisting me during the trial. Finally, I would like to thank those at the Leveck Animal Research Center of Mississippi State University for the use of the facilities and for the assistance in handling the steers. Without the graduate students, faculty, and staff, this study would not have been possible.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

LITERATURE REVIEW

Introduction

Collecting enough hay to last through the winter and the dry months is necessary for efficient animal production (Van Soest, 1994). In many places, pastures do not provide enough nutrients to sustain livestock through unfavorable seasons (Perry and Cecava, 1995). Methods are constantly being developed to improve efficiency in management and handling of stored forage. One such method is the processing of hay to improve storage, handling and transport which can also decrease costs involved with handling hay (Meyer et al., 1959[a]). Improvement in handling also reduces the amount of labor needed to feed livestock (Anderson et al., 1974). The most common method of processing grass hays is pelleting while alfalfa is usually cubed. Cubing is essentially done the same as pelleting, but cubes are larger and forages do not have to be ground into fine particles (Gillespie and Flanders, 2010). The process of cubing grass and alfalfa are the same, however the nutritional value of each forage differs. Equipment made for drying and pelleting forages can be used in producing processed hay to reduce the cost (Balk et al., 1972). Alfalfa is more widely used because protein content is greater on a dry matter (DM) basis when compared to grass cubes. Legumes, in general, are more palatable and have greater yields per hectare than most grasses. Southern grasses when fed as long hay provide only 6 % to 18 % crude protein. Alfalfa fed as long hay provides

15 % to 25 % crude protein (Jurgens, 1997). Legumes also contain more calcium and carotene compared to grass hays (Gillespie and Flanders, 2010). Alternatively, hemicellulose of grasses provides greater digestion coefficients corresponding to cellulose than alfalfa (Sullivan, 1966). The greatest influence on nutritional value of forage is determined by its maturity at harvesting. In many cases, hay which is more mature when harvested has decreased nutritional quality which can lead to decreased intake and digestibility. It was noted in one study that the amount of crude fiber as a percentage of dry matter in hay harvested at an increased maturity was not more than hay harvested at younger maturity. However, the digestibility of crude fiber in mature hay decreased rapidly compared to hay harvested earlier (Miller et al., 1964).

Effect of particle size on rumen pH and rate of passage

The main variable that limits the production of livestock is the amount of forage consumed. Consumption of forage is affected by physical form and the ability of the animal to breakdown the forage by mastication to a size small enough to pass from the rumen with ease (Minson, 1990). The fiber content of the forage also plays a part in determining the amount of time material remains in the rumen (Shaver et al., 1986).The rumen is the major site of cellulose breakdown. The rate of digestion is controlled primarily by the amount of time the consumed forage remains in the rumen (O'Dell et al., 1962) and passage from the rumen (Bernard et al., 2000). The greater amount of time spent in the rumen leads to greater breakdown by microbes. If the hay is processed so that the initial length is greatly reduced compared to baled hay, rate of passage increases. O'Dell et al. (1962) determined that although the rate of passage was increased, digestion was not hindered. This was determined by feeding marked hay, either ground or long, to cattle and comparing the amount of time that passed before hay was excreted. They concluded that the smaller particles passing through the rumen provided more surface area for microbes to act on. Van Soest (1994) noted a decrease in the production of methane and an increase in the propionic acid to acetic acid ratio due to decreased particle size. Particle size also governs where the particles move within the rumen. Larger, less dense particles are located more dorsal in the fiber mat. Smaller, denser particles are located more ventrally. As the size decreases, the amount of rumen fill decreases. The fill is defined as the amount of fresh matter and water in the rumen (Bernard et al., 2000). Increasing rate of digestion by decreasing particle size can have an undesirable effect. Decreased particle length due to processing requires less chewing than long hay and results in less saliva production which can reduce rumen pH. One of the main functions of saliva is to act as a buffer to aid in the maintenance of normal ruminal pH range. The texture of forage and the amount of moisture it contains largely influences the amount of saliva produced (Church, 1993). Decreasing rumen pH reduces the ability of the rumen to digest what was consumed (Shaver et al., 1986), as with feeding processed forage. The reduced particle size of forages fed as cubes or pellets reduces the ability of microbes to breakdown cellulose (Shirley, 1986). Normally, rumen microbes begin digesting fat by first hydrolyzing unsaturated fats to free fatty acids and glycerol. When rumen pH is decreased, the amount of hydrogen available to microbes for lipid hydrolysis and biohydrogenation is decreased which leads to a build-up of unsaturated fats (Church, 1993). The increased rate of digestion from smaller particle size results in an increased production of organic acid and volatile fatty acid (VFA). With less saliva entering the rumen, the effects of acids are increased. Greater consumption of processed hay occurs because the increased rate of passage from the rumen results in more space which would remain filled with longer particles. In other words, more space becomes available sooner for more forage to be consumed (Moore, 1964).

Long Hay

Hay has been defined as forage that was dried to 15 % moisture (85 % DM) and stored (Van Soest, 1994). In the Southeast, round bales have been traditionally the preferred method of storage for long stem hay. Thus, equipment and barns have been designed and built around production and storage of round bales. It is necessary for efficient animal production for producers to store enough quality hay to last through winter or dry summers in drought prone areas. The goal in storing hay is to conserve the maximum amount of nutrients contained in grasses to sustain animals through periods where grazing is insufficient (Van Soest, 1994). In many areas of the country, adverse weather conditions such as drought or too much rain can decrease the quality and supply of hay (Beauchemin, 1997). The size of round bales can make them costly to transport long distances (Schurg et al., 1978) partly due to their bulkiness (Haenlein et al., 1966). Pelleting or cubing reduces the bulkiness of baled hay and can allow a greater quantity to be stored (Schurg et al., 1978). Some of these issues are offset by a reduced cost of production of round bales compared to producing other forms of hay such as pellets or cubes (Lindahl and Terrill, 1963). In addition to economical production, good quality, long stem hay provides the same nutritional benefits as good quality hay that has been processed into cubes or pellets (Moore, 1964). The total digestible nutrients (TDN) was similar in cubed or pelleted excellent quality hay compared to the same hay fed in round bales. If the long stem hay is of poor quality, its nutritional value was less than the same hay in a pelleted or cubed form (Reynolds and Lindahl, 1960). When cubed or pelleted, poor quality hay can offer more nutrition because the reduced particle size almost doubles the amount of surface area available for microbes to attach (Church, 1993). Poor quality hay does not provide enough nutrition to support growing or lactating animals (Foster et al., 2009). Part of the difference in nutrition between poor quality hay and excellent quality hay is due to the amount consumed. In a review of several studies, Cullison (1961) concluded that greater consumption of pellets compared to long hay in calves was due in part to increased palatability of the pellets. Even though pelleted hay leads to greater gain and consumption, the digestibility of DM, crude fiber and crude protein was decreased compared to long hay. Total digestible nutrients were also greater for long hay than for pelleted (O'Dell et al., 1962). Sorting of particles is a major factor in the amount of hay livestock consume (Reynolds and Lindahl, 1960). Feeding round bales can result in more waste of feed and decreased weight gains compared to feeding processed hay such as cubes or pellets (Lindahl and Terrill, 1963). The portions of long stem hay that are refused are often the coarser, more fibrous parts of the plant. In a study comparing the digestibility of long stem hay to pelleted and ground hay, dry matter (45.4 %) and crude fiber (56.5 %) were greater than the pelleted (50 % and 53.5 %, respectively) or ground hays (48.7 % and 55.2 %, respectively). Crude protein and ether extract were not increased in long stem hay compared to pelleted or ground hay. (Reynolds and Lindahl, 1960). Normally the portion of hay consumed is more digestible than what is refused (Van Soest, 1994). In other words, long stem hay fed free choice allows the animal to choose the more nutritious and more palatable portions of the plant (Minson, 1990). To determine the nutritional value of a feedstuff, there are two methods that can be used. The first method of calculation only considers the feed offered with the orts being left out. The second method of calculating TDN includes the feed offered as well as orts. These two different methods of calculation will yield two different results for the same forage. Reynolds and Lindahl (1960) conducted a study comparing long hay to pelleted and ground hays. Three trials were conducted using sheep. Alfalfa hay was used in the first two trials and second-cutting weathered grass in the third trial. They analyzed the TDN of the hays using both methods of calculation. Calculations using the first method indicate long stem grass hay having greater TDN than the pelleted or ground grass hays. The second method of calculation resulted in long grass hay TDN as either equal to or less than the pelleted or ground grass hays. Palatability also affects the amount of long stem hay animals consume. If the hay is dusty, it is more likely to be refused than hay that is not (Meyer et al., 1959[a]) due to mechanical irritation (Wallace et al., 1961). Increased consumption of cubed or pelleted hays can be attributed to the elimination of the dust in addition to preventing animals from sorting.

Chopped Hay

Chopped hay is nutritionally much like long stem hay. Animals given chopped hay spent the same amount of time chewing and ruminating as those given long hay. The amount of saliva produced from chewing has a pronounced effect on ruminal pH. Hay chopped to a mean particle size of less than 0.78 cm has the potential to decrease ruminal pH which in turn can negatively affect the rate of digestion (Shaver et al., 1986). There are some differences between long stem hay and chopped hay. The main difference between long and chopped is the length. The plant stems of chopped hay are much shorter than the stems baled from the field. As with long stem hay, sorting is still an issue although it is not as big of a problem as it is with long stem hay. Refused portions of chopped hay generally contain more crude protein and less fiber than what was offered and consumed (Wallace et al., 1961). When comparing chopped hay to other forms such as pellets or cubes, there are some varying differences. Johnson et al. (1964) found that chopped hay had decreased apparent digestibility of DM, cellulose and crude fiber compared to long stem hay but these same parameters were greater compared to ground or pelleted hay. In a different study, it was determined that the TDN of chopped hay was not different from pelleted hay. The digestibility of lignin and cellulose was the same for both treatments. The results were attributed to increased consumption of the pelleted hay (Meyer et al., 1959[a]) which in one study was 26 % greater for pelleted hay compared to chopped hay (O'Dell et al., 1962). Weir et al. (1959[a]) found that feeding chopped hay to lambs and steers resulted in decreased body weight gain and consumption while pelleted hay produced more desirable weight gains with increased consumption. The TDN and digestibility of crude fiber for chopped hay were greater but had decreased energy content in contrast to the same hay in pelleted form. Meyer et al. (1959[b]) determined that weight gain and amount of consumption were greater for the ground hay treatment group than for chopped hay treatment group. In contrast to the amount of gain and consumption for animals on pelleted hay, those which were fed wafered or chopped hay did not differ for gain or consumption (Wallace et al., 1961).

Cubed Hay

Cubed hay is similar to pellets in that they are compressed forage, but unlike pellets, the forage does not have to be ground before compression. Cubed hay can be coarsely or finely chopped, is generally square and 1-4 inches in length (Moore, 1964).

Special cubing machines have been developed that allow producers to cube hay in the field after it has been cut and dried. In-field cubing eliminates storing bales at an off-site facility until they are ready to be processed into cubes. (Lowe, 2011). Cubing increases the amount of forage that can be stored and transported by reducing volume. This in turn decreases the cost of handling cubes (Van Soest, 1994). For producers shipping internationally or across the United States, more hay can be shipped as cubes because of decreased volume. This reduction in volume means more weight can be shipped which generally increases profit. By increasing the weight of hay being shipped, the cost of producing cubes can be offset (Perry and Cecava, 1995). Although the cost of producing cubes may still be somewhat greater than producing bales if the producer is not shipping hay, cost could potentially be outweighed by the advantages provided by the physical characteristics of cubes. Reduction in bulkiness of round bales can be as much as 75 % (Haenlein et al., 1966) and requires less labor to feed livestock. The small size of cubes allows them to be moved mechanically (Anderson et al., 1974). If dusty forage is an issue, cubing can increase palatability and consumption (Meyer et al., 1959[b]). The drawbacks to feeding cubed hay are increased cost and the time necessary for animals to become accustomed to cubes. As seen in numerous studies, reduced particle size increases consumption (Meyer et al., 1959[b]; Reynolds and Lindahl, 1960; Wallace et al., 1961; Johnson et al., 1964; Haenlein et al., 1966; Bernard et al., 2000). Switching to cubed hay would require more hay overall than would be needed when feeding only bales of hay but cubed hay can be fed less frequently than baled hay. Due to decreased particle size, cattle consume more cubes because the cubes pass through the rumen faster than long hay which prompts cattle to eat more to achieve satiation. In one study, cows were fed second-cutting alfalfa hay either as bales or cubes. Cows given cubed hay consumed 2.4 kg/d more than cows fed long hay. Some sorting was still observed by those consuming cubed hay. Cows appeared to prefer whole cubes while refusing broken cubes and cubes which had crumbled into fine particles (Anderson et al., 1974). Animals also spend less time chewing and ruminating when consuming cubes compared to long stem hay due to reduced particle size (Tabil et al., 2002). This was determined by using strain gauge transducers and recording continuously. Time spent eating and chewing was decreased for cows fed cubed hay compared to those fed long hay or silage. The decrease in time spent eating was attributed to decreased DM intake as a result of decreased particle size (Beauchemin et al., 1997). Decreased feed sorting for cubed hay compared to long hay leads to greater consumption. Haenlein et al. (1966) observed that consumption of cubed hay was 9 % greater than the long hay. These researchers also determined that although the rate of digestion was increased due to smaller particles, the animals' ability to retain nutrients increased. The nutrients retained by sheep fed cubes were not digested differently than those fed loose hay with the exception of ether extract which was decreased in cubed hay. When compared to chopped hay, gains of animals fed cubed hay were not different. Chopped and cubed hay both resulted in more refusals and decreased consumption compared to pelleted hay. The apparent digestibilities of the chopped, cubed and pelleted hay were not different with respect to crude protein, DM, cellulose, and energy. The portions of chopped and cubed hay categorized as orts had an increased crude protein and decreased cellulose matter than the hay which was consumed by animals (Wallace et al., 1961). Cubing hay results in a decreased metabolizable energy (ME) but no change in the net energy available (King et al., 1962). The decrease in ME may be due to decreased methane production while eating tends to increase heat production (Van Soest, 1994). Thus, NE remains unchanged since NE is calculated by subtracting ME from heat increment (Jurgens, 1997). The decrease in ME is counteracted by the general increase in consumption of processed hays and also accounts for the increase in heat (King et al., 1962). The actual process of drying and cubing forage results in decreased crude protein. Due to the smaller particle size, chewing and ruminating were decreased. The reason for the decrease is believed to be the reduced DM intake instead of increased ease of chewing cubes (Beauchemin et al., 1996).

Cubed Hay as Biofuel

Cubing grasses is becoming more common than in previous years. There is a need to transform preservation of forages to increase ease of handling and to allow for other uses (Van Soest, 1994). Cubes stored for use as biofuel can be handled by conveyors with ease whereas most hay stored as alternative fuel is baled and much more difficult to handle (Sokhansanj and Turhollow, 2004). With a push for alternative sources of energy, second generation bioenergy crops have become the focus of research and the future of biofuels. One of the more popular second generation bioenergy crops are perennial grasses which have traditionally been used for hay and pasture grazing for livestock. The use of perennial forages for biofuel presents several advantages. The lignocellulose of these grasses provides a large and renewable source of energy. Forage crops grown for biofuel yield more energy and do not require as many energy demanding inputs as annual crops. For producers, it would not be necessary to grow and harvest forages strictly for biofuel. Much of the hay equipment used for livestock can also be used for biofuel production. The storage and transport is the same and producers would already have the necessary knowledge and equipment for growth and harvest. Addition of biofuel production would also improve the use of lands that are not used for grazing or other purposes. The nutritional value in this case is not important. The value of grasses grown on marginal lands lies in the cellulose content that can be converted to energy. Particularly in the southeast, the increased annual rainfall along with the long growing season makes it an ideal area for greater yielding energy forages. Adapting to the use of forages as a second generation biofuel will require some adjustment between the energy industry and agricultural industries because of its current role as a feedstuff for livestock and its uses as a renewable fuel source (Sanderson and Adler, 2008). Forage produced for biofuel has the potential to be used in several different applications as a source of alternative energy. It is not confined to a single use such as in furnaces as a replacement for coal (Samson et al., 2005). Producers choosing to switch to production of forage for biofuel or incorporating the production of forage as biofuel in addition to producing forage as a feedstuff for livestock will have flexibility in its uses and in the bioenergy markets.

Conclusion

As with most things, there are disadvantages and advantages to either switching to cubed forage or incorporating the production of cubed forage for bioenergy into forage harvesting for livestock. The cost of producing cubes is greater than the cost to produce bales of hay, but the benefits and flexibility of utilizing cubed forage may be worth the added cost. Cube production for bioenergy provides producers and farmers the opportunity to utilize land that is not capable of growing grain crops. Producers also have the choice of using cubes as a feedstuff for livestock. In this case, more hay can be stored in less space when cubes are produced instead of bales. The biggest advantage of cubing forage is increasing the nutritional value of aged grasses or poor quality hay. When cut at a mature stage, the DM and digestible energy decrease in addition to the neutral detergent fiber digestion coefficient (Miller et al., 1991). However, grass cut at more mature stages can still be used by producers by cubing the grass and feeding it either free choice or twice a day. This allows livestock to gain the most nutrition possible from aged grass (Balk et al., 1972).

CHAPTER II

MATERIALS AND METHODS

Digestion Trial

Care and use of animals used in this trial were conducted in accordance with and under the approval of the Institutional Animal Care and Use Committee of Mississippi State University (Protocol # 08-043).

The digestion trial was conducted at the Leveck Animal Research Center (LARC) Metabolism Unit at Mississippi State University. Twelve steers were used for this trial (226 ± 21.8 kg) consisting of Charolais, Hereford, and Angus. Breeds were obtained from the beef herd at the LARC Beef Unit, tamed, and halter broke before the initiation of the trial. While being halter broke, steers were kept in pens and were given *ad libitum* access to hay and water. Once halter broke, steers were randomly assigned to one of three dietary treatments: long (hay), chopped (hay), or cubed (hay). The composition of each diet is reported in Table 2.1. The long hay diet was prepared from round bales of mixed grass hay, predominately bermudagrass (*Cynadon dactylon*) and dalllisgrass (*Paspalum dialtum*). The chopped hay diet was prepared from the same round bales which were chopped to reduce particle size. The cubed hay diet was prepared from the same round bales instead of in-field due to time of year (late fall) which were fed into a John Deere 425 cuber. After being assigned to dietary treatments, steers were moved into pens to keep the treatment groups separate and given two weeks for their gastrointestinal tract to adapt to the new diets.

Following the two-week adaptation period, all steers were moved to the indoor facility at the LARC Metabolism Unit. They were placed into individual metabolism crates which provided steers with *ad libitum* access to treatment diet and water and allowed for total urinary and fecal output collection and monitoring of feed intake. Steers remained in metabolism crates for a 10-day period. The first three days gave steers time to become accustomed to their new environment including crates during which no samples were collected. The following seven days were for gathering data and for sample collection. Each day during the seven day collection period, orts from the previous day were weighed and recorded. Before fresh hay was offered to steers, it was weighed and recorded. Total feces weight and total urinary volume were obtained and recorded daily. A 5 % sample of feces and orts was collected daily as well as a grab sample from the feed offered each day. Urine samples were collected as 5 % of the total volume and acidified to 2 % with 2N H_2SO_4 to prevent volatilization of ammonia. Feed, orts, and fecal samples were dried at 60 °C in a forced air oven for approximately 48 hours. These samples were combined by animal and stored in sealed plastic bags until analysis. Urine samples were also combined by animal, placed in sealed containers, and stored at -20 °C until analysis. At the end of the seven day collection period, steers were taken out of the metabolism crates and returned to the herd at the LARC Beef Unit.

Laboratory Analysis

Feed, orts, and dried feces were ground through a 2-mm screen using a Thomas Wiley Mill® (Arthor H. Thomas, Philadelphia, PA) and analyzed for DM, ash, NDF, ADF, crude protein, fat, and gross energy (AOAC, 2003). Urine was thawed and analyzed for crude protein and energy density. For feed, orts, and feces dry matter analysis, 2 g of the sample was placed in an aluminum pan and dried in a 100 °C oven for at least 24 hours and weighed again. Ash content was determined by placing the sample from the dry matter analysis in a muffle furnace set at 550 °C for five hours, after which ashed samples were allowed to cool to 100 °C and then weighed. Fiber analysis was performed by placing 0.5 grams of sample in an Ankom® nylon bag and heat sealing the bag. To determine neutral detergent fiber content, batches of 24 bags were digested at 100 °C for one hour in 2000mL of neutral detergent fiber solution (Goering and Van Soest, 1970), including 20 g of sodium sulfite and 4 mL of α – amylase (4.2 mg / mL). After one hour, the samples were rinsed with two washes of 2000 mL of warm distilled water and 4 mL of α – amylase (4.2 mg / mL), followed by one rinse with 2000 mL of warm distilled water and one rinse with acetone. Samples were then placed in a 100 °C oven for at least 24 hours and then weighed. To determine ADF content, the same bags containing samples from the NDF analysis were placed in 2000 mL of acid detergent fiber solution (Goering and Van Soest, 1970) and digested at 100 °C for one hour. The bags were then rinsed three times with warm distilled water and once with acetone. Samples were then dried at 100 °C in an oven for at least 24 hours and weighed. Crude protein was determined using the Kjeldahl nitrogen method (AOAC, 2003); 0.9 grams of sample, 15 mL of H2SO4 (96% w/w), and one FisherTab ™ (Thermo Fisher Scientific Inc., Waltham, MA) were placed in glass tubes and digested at 213 °C for 3 hours. The digested samples were then distilled and titrated to calculate crude protein content using a Foss Kjeltec 1035 Analyzer ™ (Foss, Eden Prairie, MN) distillation unit. Fat content was determined by ether extraction; 2 grams of sample were placed in alundum crucibles and placed in a goldfisch ether extraction apparatus with 40 mL of ether. Samples were boiled in ether for four hours, dried at 100 °C for at least 24 hours, and weighed. Gross energy was determined using an isoperibol oxygen bomb calorimeter (Parr Instrument Co., Moline, IL). For urine samples, 1 mL of urine and one FisherTab™ (Thermo Fisher Scientific Inc., Waltham, MA) were placed in glass tubes and digested in H_2SO_4 at 213 °C for 3 hours. Digested urine samples were then distilled and titrated to calculate crude protein content using a Foss-Tecator Kjeltec 1035™ (Foss, Eden Prairie, MN). To determine the energy density of the urine, first, a blank (no urine added) cellulose powder pellet was placed in an isoperibol oxygen bomb calorimeter (Parr Instrument Co., Moline, IL) and analyzed. Then, 1 mL of urine was pipetted onto 1 g pellet of pelleted cellulose powder which was then placed in an isoperibol oxygen bomb calorimeter (Parr Instrument Co., Moline, IL) and analyzed. Energy density of the urine was calculated by subtracting the energy density of the cellulose pellet from the energy density of the cellulose pellet saturated with urine.

Statistical Analysis

Data for body weight, dry matter intake, nutrient digestibility, digestible energy content of feed, and crude protein retention was analyzed as a completely randomized design using the general linear model procedure of SAS (Version 9.2). Individual animal was the experimental unit, and there were four animals per treatment. Data is reported as least square means. Differences in least square means were determined to be significant when the P-value was less than 0.05. Significantly different least square means were separated using Fisher's Least Protected Significant Difference.

Table 2.1 Composition of feedstuffs, % DM basis

	Treatment		
Item	Hay	Chopped	Cubed
DM[1]	85.1	85.0	88.0
OM[1]	94.8	93.9	90.1
NDF[1]	74.7	73.3	70.8
ADF[1]	35.7	33.6	38.9
CP[1]	6.5	5.2	9.7

[1]DM = Dry matter, OM = Organic matter, NDF = Neutral detergent fiber, ADF = Acid detergent fiber, CP = Crude protein.

CHAPTER III

RESULTS AND DISCUSSION

Body weight and DM intake measured as either kg/d or a % BW/d were not different (P= 0.3628; P= 0.7300; P= 0.7394, respectively) among treatment groups (Table 3.1). These results are in agreement with O'Dell et al. (1962) but contradict results obtained by Anderson et al. (1974) and Haenlein et al. (1966). O'Dell et al (1962) conducted 2 feeding trials over a period of 2 years using heifers. Fourth-cutting coastal bermudgrass was used for the treatment diets consisting of baled, ground, and ground and pelleted. Their data showed that for DM and BW, heifers consuming pellets (7.0 kg/d) and baled hay (6.8 kg/d) were not different (O'Dell et al., 1962). Anderson et al. (1974) conducted a study using dairy cows fed second-cutting alfalfa either cubed or baled. They reported that cows fed alfalfa cubes (13.1 kg/cow/d) consumed more than cows fed baled alfalfa (10.1 kg/cow/d). Differences in results may be attributed to the use of alfalfa in their study versus the use of bermudagrass for the present study. Alfalfa as a member of the legume family has a greater protein content that grass hays such as bermudagrass (Reynolds and Lindahl, 1960). Another factor that may contribute to the differences is the breed of cattle used. Their study focused on dairy cows, whereas the present study used beef steers (Anderson et al., 1974). Haenlein et al. (1966) found that sheep consumed 9 % more cubes than loose hay and 73 % more pellets than either cubed or loose hay. The contradiction could be due to differences between species of animals studied and to the physical form of the hay since pellets (smaller size) were also included in their research but not in this study. Their treatments diets consisted of second-cutting alfalfa that was partially dried using a wagon drying system as opposed to field drying.

Apparent digestion coefficients for treatment diets are reported in Table 3.2. Dry matter (P= 0.1587) and organic matter (OM; P= 0.1572) were not different among the treatments. Apparent fiber digestibility as indicated by NDF (P= 0.1778), ADF (P= 0.2472), and hemicellulose (P= 0.1561) also did not differ among treatments. Meyer et al. (1959[a]) and Shaver et al. (1986) obtained similar results in studies comparing alfalfa in long, chopped, and pelleted forms. Reynolds and Lindahl (1960) also obtained similar results when calculations were done on an as fed basis. However, CP was different (P= 0.0302) among the treatment diets. Steers consuming hay digested the most CP (64.92 %) while steers consuming chopped digested the least (39.10 %). Steers consuming cubed did not digest CP different from hay or chopped with an intermediate value (50.94 %). These results contradict those obtained by Wallace et al. (1961). Using native meadow hay, Wallace et al (1961) compared the nutritive value of three different forms of meadow hay: chopped, cubed, and pelleted. They reported increased cellulose (30.8 %) and energy (55.6 %) digestion with decreased digestion of crude protein (8.0 %) of cubes fed to calves. Chopped hay had decreased cellulose (27.5 %) digestion with energy (55.9 %) not different than cubed hay. Crude protein of chopped hay (11.3 %) was increased compared to cubed hay. Their results may be explained by the loss of leafier particles and addition of foreign material due increased winds during the processing of their cubes (Wallace et al., (1961). The percentage of fat digested from the treatment diets was not different (P= 0.0071) for hay or chopped (68.48 % and 62.94 %, respectively), but steers consuming cubed digested less fat (46.72 %). Apparent energy digestibility did not differ (P= 0.2597) among treatments. The digestion coefficients for fat reported in the present study contradict Reynolds and Lindahl (1960). These researchers conducted a digestion trial with sheep using second-cutting grass and alfalfa. Both forages were fed to sheep as long hay, ground hay, or pelleted hay. Their results showed that fat digestion of long grass hay (8.1 %) was decreased compared to pelleted grass hay (36.8 %) with ground grass hay being intermediate (28.9 %). However, the digestion coefficients for apparent energy digestibility for the present study are in agreement with Reynolds and Lindahl (1960). They found no difference among treatment diets in apparent energy digestibility but did report that sheep fed ground grass hay and pelleted grass hay digested more fat than those fed long grass hay. The differences in Reynolds and Lindahl's (1960) results can be accounted for by their use of pellets instead of cubes and possibly to their study using sheep rather than cattle.

Values for the retention of nitrogen and protein metabolism are reported in Table 3.3. Following the same trend for CP digestion, the nitrogen retention among treatments was different (P= 0.0582). Steers consuming cubed retained the most nitrogen (1.34 g/d) and steers consuming chopped the least (0.55 g/d). Steers consuming hay (0.89 g/d) did not retain nitrogen different from those consuming chopped or cubed. The amount of nitrogen metabolized was greater (P= 0.0317) by steers consuming hay (60.58 %) than for steers consuming chopped (33.60 %). Steers consuming cubed (45.35 %) did not metabolize protein different than steers consuming hay or chopped. These results are in opposition to those obtained by Meyer et al. (1959[a]) who found that sheep fed pelleted alfalfa digested and retained more nitrogen (74.6 %) than those fed chopped alfalfa (71.6

%). The differences between the present trial and that reported by Meyer et al. (1959[a]) may be accounted for by the use of alfalfa as pellets instead of cubes. There may also be some variation due to species since they used sheep and the present study used beef steers. Protein available for metabolism was different (P= 0.0034). Steers consuming hay or cubed diets did not differ (4.06 % and 4.31 %, respectively), whereas steers consuming chopped (1.72 %) retained the least amount of metabolizable protein.

Table 3.1 Body weight and dry matter intake of steers fed three diets

	Treatment				
Item	Hay	Chopped	Cubed	SEM	P =
BW[1], kg	217.50	223.0	237.25	9.558	0.3628
DMI[1]					
kg/d	4.02	4.35	4.32	0.320	0.7300
% BW[2]/d	1.85	1.95	1.82	0.120	0.7394

[1]DMI = Dry matter intake, BW = Body weight

Table 3.2 Apparent digestion coefficients (%, DM basis) for three diets fed to steers

	Treatment				
Item, % DM	Hay	Chopped	Cubed	SEM	P =
DM[1]	71.11	66.94	61.29	3.266	0.1587
OM[1]	72.62	68.67	63.47	3.031	0.1572
CP[1]	64.92[b]	39.10[a]	50.94[ab]	5.620	0.0302
NDF[1]	72.26	68.29	62.73	3.299	0.1778
ADF[1]	69.69	64.11	59.85	3.854	0.2472
Hemi[1]	74.58	71.59	66.09	2.839	0.1561
Fat	68.48[b]	62.94[b]	46.72[a]	3.772	0.0071
GE[1]	70.75	65.50	62.86	3.201	0.2597

[a, b, ab]Within a row, means without a common superscript differ (P<0.05).
[1]DM = Dry matter, OM = Organic matter, CP = Crude protein, NDF = Neutral detergent fiber, ADF = Acid detergent fiber, Hemi = Hemicellulose, GE = Apparent digestible energy.

Table 3.3 Nitrogen retention and protein metabolism by steers fed three diets

	Treatment				
Item	Hay	Chopped	Cubed	SEM	P =
N Ret[1], g/d	0.89[ab]	0.55[a]	1.34[b]	0.200	0.0582
N Met[1], % of CP[1]	60.58[b]	33.60[a]	45.35[ab]	5.938	0.0317
MP[1], %	4.06[b]	1.72[a]	4.31[b]	0.423	0.0034

[a, b, ab]Within a row, means without a common superscript differ (P<0.05).

[1]N Ret = Nitrogen retention, N Met = Nitrogen metabolized, MP = Metabolizable protein, CP = Crude protein

CHAPTER IV

SUMMARY AND CONCLUSION

The results from the present study indicate that chopped or cubed hay can be used as alternative feedstuffs for ruminants. For steers fed chopped hay, digestibility of CP, retention of nitrogen, nitrogen metabolized, and MP were less than those for steers fed long stem hay. Digestibility of fat was the same for steers fed chopped and long stem hay diets. Although digestion coefficients for chopped hay was not negative, the ability of steers to digest CP or retain nitrogen as a percentage of CP is decreased when compared to steers fed the cubed hay diet. Crude protein, nitrogen retention and metabolism, and MP were not different for cubed hay compared to long stem hay. However, for the steers fed cubed hay, the digestibility of fat was less than for steers consuming long stem hay.

In addition to being as digestible as long stem hay, cubed hay is also easier and safer to handle and store. Cubes may be moved more easily with belt conveyors compared to bales which have to be moved with heavy equipment such as tractors and unrolled before being processed. Cubes are safer because they can be loaded and unloaded as bulk compared to bales which have to be moved one at a time and restacked with each move (Sokhansanj and Turhollow, 2004). The ability to store more hay in the form of cubes compared to round bales or large square bales could potentially be great use in areas where forage may be in short supply (Beauchemin et al., 1997). Many areas of the US are prone to severe droughts. Producers in these areas are often forced to have bales of hay shipped in from out of state. During seasons with ample rainfall, producers would be able to store more cubed hay from their field cuttings than baled hay to prepare for the next drought. While cubed hay could be more costly to produce, it may still be less than the cost of feeding concentrates or having bales of hay shipped to the producer (Lindahl and Terrill, 1963). Costs may also be offset by increased production, less sorting, fewer feedings, and decreased labor as a result of its handling characteristics (Anderson et al., 1974).

The increased focus on renewable energy sources has led the US to set a goal of switching 50 % of the power usage to renewable resources by 2030 (Sanderson and Adler, 2008). These researchers note that increasing the use harvested forage as biofuel will result in some competition with the livestock feed industry. Producers choosing to invest some of their forage land in biofuel may have the flexibility to respond to fluctuations either in the energy industry or livestock industry because cubed hay can be used as both a biofuel and a feedstuff for ruminants (Sanderson and Adler, 2008).

REFERENCES

Anderson, M. J., G. E. Stoddard, C. H. Mickelsen, and R. C. Lamb. 1974. Cubed versus baled alfalfa for dairy cows. Ag. Research Service, USDA, Logan, UT.

Balk, W. A., R. F. Wheeler, R. L. Edward, J. J. Starnes, and S. G. Woods. 1972. Effect of maturity on the nutritive value of coastal bermudagrass pellets. J. Anim. Sci. 34:1061-1066.

Beauchemin, K. A., L. M. Rode, and M. V. Eliason. 1997. Chewing activities and milk production of dairy cows fed alfalfa as hay, silage, or dried cubes of hay or silage. J. Dairy Sci. 80:324-333.

Bernard, L., J. P. Chaise, R. Baumont, and C. Poncet. 2000. The effect of physical form of orchardgrass hay on the passage of particulate matter through the rumen of sheep. J. Anim. Sci. 78:1338-1354.

Church, D. C. 1993. The Ruminant animal: Digestive physiology and nutrition. Waveland Press, Long Grove, IL.

Cullison, A. E. 1961. Effect of physical form of the ration on steer performance and certain rumen phenomena. J. Anim. Sci. 20:478-483.

Foster, J. L., A. T. Adesogan, J. N. Carter, A. R. Blount, R. O. Myer, and S. C. Phatak. 2009. Intake, digestibility, and nitrogen retention by sheep supplemented with warm season legume hays or soybean meal. J. Anim. Sci. 87:2891-2898.

Gillespie, J. R., and F. B. Flanders. 2010. Modern livestock and poultry production. 8^{th} ed. DELMAR Cengage Learning, Clifton Park, NY.

Haenlein, G. F., R. D. Holdren, and Y. M. Yoon. 1966. Comparative response of horses and sheep to different physical forms of alfalfa hay. J. Anim. Sci. 25:740-743.

Johnson, R. R., G. E. Ricketts, E. W. Klosterman, and A. L. Moxon. 1964. Studies on the utilization and digestion of long, ground, and pelleted alfalfa and mixed hay. J. Anim. Sci. 23: 94-99.

Jurgens, M. H. 1997. Animal feeding and nutrition. 8^{th} ed. Kendall/Hunt Publishing Co., Dubuque, IA.

King, W. A., G. D. O'Dell, C. C. Brannon, and H. J. Webb. 1962. Effect of grinding and pelleting in the utilization of coastal bermuda grass hay by dairy heifers. Tech. Bull. No. 404. South Carolina Ag. Experiment Station, Clemson, SC.

Lindahl, I. L., and C. E. Terrill. 1963. Use of pelleted roughage in the feeding regime for breeding sheep. J. Anim. Sci. 22:953-955.

Lowe, J. W. 2011. Investigation of in-field cubing as a method of densification of grass-based biomass. Master's Thesis Mississippi State Univ., Starkville

Meyer, J. H., R. L. Gaskill, G. S. Stoewsand, and W. C. Weir. 1959[a]. Influence of pelleting on utilization of alfalfa. J. Anim. Sci. 18:336-346.

Meyer, J. H., W. C. Weir, J. B. Dobie, and J. L. Hull. 1959[b]. Influence of the method of preparation on the feeding value of alfalfa hay. J. Anim. Sci. 18:976-982.

Miller, P. S., W. N. Garrett, and N. Hinman. 1991. Effects of alfalfa maturity on energy utilization by cattle and nutrient digestibility by cattle and sheep. J. Anim. Sci. 69:2591-2600.

Miller, W. J., C. M. Clifton, O. L. Brooks, and E. R. Beaty. 1964. Influence of harvesting age and season on digestibility and chemical composition of pelleted coastal bermudagrass. J. Paper No. 376. College and Branch Experiment Stations, Athens, GA.

Minson, D. J. 1990. Forage in ruminant nutrition. Academic Press., San Diego, CA.

Moore, L. A. 1964. Symposium on forage utilization: Nutritive value of forage as affected by physical form: Part I: General principles involved with ruminants and effect of feeding pelleted or wafered forage to dairy cattle. J. Anim. Sci. 23:230-238.

O'Dell, G. D., W. A. King, W. C. Cook, and S. L. Moore. 1962. Effect of physical state of coastal bermuda grass hay on passage through digestive tract of dairy heifers. Tech. Bull. No. 405. South Carolina Ag. Experiment Station, Clemson, SC.

Perry, T. W., and M. J. Cecava. 1995. Beef cattle feeding and nutrition. 2nd ed. Academic Press, Inc., San Diego, CA.

Reynolds, P. J., and I. L. Lindahl. 1960. Effect of pelleting on the digestibility of hay by sheep. J. Anim. Sci. 19:873-880.

Samson, R., S. Mani, R. Boddey, S. Sokhansanj, D. Quesada, S. Urquiaga, V. Reis, and C. H. Lem. 2005. The potential C_4 perennial grasses for developing a global bioheat industry. Critical Reviews in Plant Sciences. 24(5,6):461-495.

Sanderson, M. A., and P. A. Adler. 2008. Perennial forages and second generation bioenergy crops. Int. J. Mol. Sci. 9:768-788.

Schurg, W. A., R. E. Pulse, D. W. Holtan, and J. E. Oldfield. 1978. Use of various quantities and forms of ryegrass straw in horse diets. J. Anim. Sci. 47:1287-1291.

Shaver, R. D., A. J. Nytes, L. D. Satter, and N. A. Jorgensen. 1986. Influence of amount of feed intake and forage physical form on digestion and passage of prebloom alfalfa hay in dairy cows. J. Dairy Sci. 69:1545-1559.

Shirley, R. L., 1986. Nitrogen and energy nutrition of ruminants. Academic Press, Orlando, FL.

Sokhansanj, S., and A. F. Turhollow. 2004. Biomass densification – Cubing operations and costs for corn stover. Applied Engineering in Ag. 20(4):495-499.

Sullivan, J. T. 1966. Studies of the hemicelluloses of forage plants. J. Anim. Sci. 25:83-86.

Tabil, L. G., S. Sokhansanj, W. J. Crerar, R. T. Patil, M. H. Khoshtaghaza, and A. Opoku. 2002. Physical characterization of alfalfa cubes: Hardness. Canadian Biosystems Engineering. 44:3.55-3.63.

Van Soest, P. J. 1994. Nutritional ecology of the ruminant. 2nd ed. Cornell University Press, Ithaca, NY.

Wallace, J. D., R. J. Raleigh, and W. A. Sawyer. 1961. Utilization of chopped, wafered, and pelleted native meadow hay by weaned Hereford calves. J. Anim. Sci. 20:778-781.

Weir, W.C., J. H. Meyer, W. N. Garrett, G. P. Lofgreen, and N. R. Ittner. 1959. Pelleted rations compared to similar rations fed chopped or ground for steers and lambs. J. Anim. Sci. 18:805-814.