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EVALUATING THE EFFECT MATURITY ON THE INTAKE AND DIGESTIBILITY OF SWITCHGRASS HAY CONSUMED BY BEEF STEERS

David H. Davis
University of Kentucky, david.davis@uky.edu

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Dr. S. Ray Smith, Major Professor

Dr. Mark Coyne, Director of Graduate Studies

EVALUATING THE EFFECT OF MATURITY ON THE INTAKE AND DIGESTIBILITY OF SWITCHGRASS HAY CONSUMED BY BEEF STEERS

Thesis

A thesis submitted in partial fulfillment of the
requirements for the degree of Masters of Science in the
College of Agriculture, Food, and Environment
at the University of Kentucky

By

David Harold Davis

Lexington, Kentucky

Director: Dr. Samuel Ray Smith, Professor of Agronomy

Lexington, Kentucky

2014

ABSTRACT OF THESIS

EVALUATING THE EFFECT OF MATURITY ON INTAKE AND DIGESTIBLITY OF SWITCHGRASS HAY CONSUMED BY BEEF STEERS

There has been increased interest in utilizing switchgrass (*Panicum virgatum*) as biomass. There are several challenges to developing this industry, and these have led to the potential use of switchgrass as hay for feeding beef cattle in Kentucky. The effect of increasing maturity on crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and nutritive values of switchgrass hay has been well documented, but few *in vivo* intake and digestibility trials have been conducted to assess this effect on animal performance when feeding beef cattle. Two *in vivo* intake and digestibility trials were conducted in 2011 in which Angus x Hereford beef steers (200-265 kg) were fed Alamo and Cave-in-Rock switchgrass harvested as late vegetative, boot, and early flowering hay. The objectives of these trials was to evaluate the effect of increasing maturity on apparent dry matter intake (DMI), digestible dry matter intake (DDMI), and dry matter digestibility (DMD); and to discuss potential challenges that producers might face if incorporating switchgrass hay into their forage program for feeding beef cattle. Observed decreases in nutritive value, DMI, DDMI, and DMD indicate that producers should harvest Alamo and Cave-in-Rock switchgrass before it reaches the boot stage of maturity.

KEYWORDS: Switchgrass *Panicum virgatum*, harvest maturity, in vivo digestibility feeding trial, hay harvest and feeding, beef cattle

David Davis

July 30, 2014

EVALUATING THE EFFECT OF MATURITY ON INTAKE AND DIGESTIBILITY OF SWITCHGRASS HAY CONSUMED BY BEEF STEERS

By

David Harold Davis

Dr. S. Ray Smith
Director of Thesis

Dr. Mark Coyne
Director of Graduate Studies

July 30, 2014

I dedicate this to a family that has loved and supported me throughout my life and career. To my dad, Harold, that teaches me to persist and never settle; not even when the going is good. To my mom, Sandra, who always knows when to be firm; but also knows when to encourage. To my sister, Laura, who always reminds me I can always do better in her own sisterly way. Most of all I want to dedicate this to my wonderful, loving wife Leigh Davis for her love, support, and encouragement each and every day!

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Chapter One

Review of Literature

1.1 Characteristics of Switchgrass

Switchgrass (*Panicum virgatum)* is a perennial warm season grass (C_4) (Moser and Vogel, 1995) that is native to the Great Plains and most of the eastern United States (Ball et al., 2007). It is a loose bunchgrass, but has the capability to form a sod due to numerous short rhizomes (Berdahl and Redfearn, 2007). Switchgrass is adapted to a variety of environments including the open prairie, open ground, open woods, and brackish marshes (Hitchcock, 1951). It can grow on sites ranging from sand to clay soils and tolerates soil pH values from 4.9 to 7.5 (Berdahl and Redfearn, 2007).

Switchgrass is known for its extensive root system (Ball et. al., 2007), and root depths that reach up to 3 meters have been observed (Weaver, 1968). The inflorescence is a diffuse panicle with spikelets at the ends of long branches. Spikelets have two florets with the second floret being fertile and the first one staminate (Moser and Vogel, 1995). Most switchgrass tillers produce a fertile seed head (Berdahl and Redfearn, 2007), and the majority of cultivars are either tetraploids or hexaploids (Riley and Vogel, 1982).

Switchgrass has been separated into lowland and upland types. Lowland types are taller and coarser (Moser and Vogel, 1995) with more of a bunch type growth habit, and have a faster growing rate than upland types. Lowland types are primarily found on flood plains, whereas upland types are adapted to areas not subject to periodic flooding (Berdahl and Redfearn, 2007). Geographically, upland switchgrass populations tend to be better adapted from mid- to northern latitudes in the United States and lowland types are more common in lower latitudes (Sanderson et al., 2007).

1.2 Switchgrass for Biomass

In recent years, there has been an increased interest in renewable energy. This interest is driven by higher global energy demand and decreasing supplies of fossil fuels. Various governmental agencies and working groups have set aggressive targets and timelines for decreasing fossil fuel usage by substituting it with bio-based renewable energy sources (CAST, 2007). As a result, biomass production has been identified as a potential market opportunity for American Farmers (McLaughlin et al., 1999). Switchgrass has been identified as a model herbaceous biomass crop because of its high productivity across many environments, suitability for marginal and erosive land, relatively low water nutrient requirements, positive environmental benefits (Parish and Fike, 2005), and its capability to be produced using conventional farming practices (McLaughlin et al., 1999).

Switchgrass and other cellulosic crops are being considered for producing different forms of renewable energy. The two primary markets for production are the production of cellulosic ethanol for transportation fuel and the burning of biomass for the thermal power generation (McLaughlin et al., 1999). Producing ethanol from cellulosic biomass has been proposed in response to the supply challenge identified with the corn-based ethanol industry (Perlack et al., 2005). However, the cellulosic biomass industry faces several challenges in the United States. These challenges include 1) inaccurate biomass resource assessment, 2) lack of agronomic system development, 3) little previous biomass crop development, 4) feedstock supply logistics, and 5) current inefficient technologies for the conversion of cellulosic biomass to ethanol (CAST, 2007). Ethanol is produced from cellulosic biomass by either chemical and enzymatic processing or thermochemical processing (Moore et al., 2008). These processing methods will need to be further developed for the cellulosic ethanol industry to be viable in the United States (CAST, 2007).

A more direct way to produce renewable energy from switchgrass is through the production of electricity by co-firing with coal, which can be implemented in existing power plants. There are three commercial methods with which biomass can be co-fired with coal. Biomass can be blended in the fuel pile, separately injected into the broiler, or processed with gasification-based co-firing. The preferred method depends upon the existing technology and layout of the power plant (Tillman, 2000).

There is great interest for co-firing switchgrass with coal in Kentucky and in 2007 this led to a biomass project initiated by the University of Kentucky. With this project, 20 farms established, maintained, and harvested 2-ha fields of switchgrass. The harvested material was co-fired with coal at the East Kentucky Power Cooperative power plant located in Maysville, KY. The 20 farms were located within a 100 km-radius of the facility. Surveys of producers enrolled in the study showed strong support of the project (Keene and Smith, 2008).

The most relevant challenge with co-firing switchgrass with coal is economics. As long as biomass remains significantly more expensive than coal (Moore and Fales, 2008), and government incentives such as tax benefits are not initiated (CAST, 2007), economics will slow the development of biomass market development in Kentucky. Landowners require a net economic return that is at least equivalent to conventional crops or forages that could be produced on the same land. A stable source of income to supplement traditional crop returns will be required for landowner's to be willing to produce renewable biomass crops (McLaughlin et al., 1999). Without economic or environmental incentives, there is little potential for switchgrass to develop as a fuel product to be used in the production of electricity. It is currently difficult to encourage Kentucky producers to plant switchgrass solely for biomass production, but planting for biomass and forage may provide a valid dual use option.

Switchgrass has long been promoted as a valuable forage crop (Sanderson et al., 2007). Because it is a warm-season grass, switchgrass produces abundant herbage for hay or supplemental pasture during the hot summer months (Rountress et al., 1974). Regions dominated by cool-season grasses (such as the Upper Southeast) typically undergo a period where cool season forage growth rates slow due to hot, dry summers. This time period has been termed the “Summer Slump”. During the summer slump, it is often necessary to supplement with hay or other feeds, or graze warm-season grasses (Ball et al., 2007).

Switchgrass is usually considered to be low quality forage (Anderson and Matches 1983, Berdahl and Redfern 2007, Burns et al. 1997), and this perception has limited its implementation into forage programs. Previous research has measured switchgrass forage quality and the declining forage quality as the crop matures (Anderson and Matches 1983, Burns et al. 1997), but few studies have investigated effect of switchgrass maturity when fed to beef cattle.

1.3 Importance of Digestibility/ Intake Feeding Trials to Ruminant Livestock Production

The evaluation of feeds used for meeting the nutritional needs of domestic animals in the United States is a matter of great importance. The production of animal products such as meat, milk, or eggs requires high concentrations of energy and other chemical constituents over those required to meet maintenance requirements (Schneider and Flatt, 1975). Knowing that a feed contains the required nutritive value does not mean that it will be readily consumed by animals. A feeding trial determines if the animal will accept a feed, assesses animal performance, and allows a comparison of animal performance between different feeds (Jergens, 2002b). Digestibility feeding trials, in particular, measure dry matter intake and the portion of the feedstuff or dietary constituent that is absorbed in the digestive tract (Cochran and Galyean, 1994).

Chemical analysis is the starting point for determining the nutritive value of feeds (Jergens, 2002b). It is used to determine the energy, protein, fiber, vitamins and other nutrient components which are present in the feed. Energy is one of the most important components of interest. The sources of energy in feeds are carbohydrates, fats, and proteins (Schneider and Flatt, 1975). Carbohydrates make up approximately three-fourths of most plants on a dry weight basis and therefore form the largest part of an animal's food supply (Jergens, 2002a). Carbohydrates in plants form structural components and soluble cell components (2002a). Fats supply the animal with more calories than the same weight of either proteins or carbohydrates (Schneider and Flatt 1975). Proteins are the principal constituent of the organs and soft structures in the animal body. They provide diverse biological functions in the organs, other soft structures, and elsewhere throughout the body of the animal (Jergens 2002a).

Fiber and water content are also important components to consider with livestock nutrition. The fiber content of feeds is often poorly digested (Sneider and Flatt, 1975); therefore, it is important to understand this component of a feed and its relationship to animal performance (Jergens, 2002a). Understanding the water content of a feed is also useful to determine feed efficiency. Feeds containing more water will contain less energy when compared on an equal weight basis with feeds containing less water (Jergens, 2002a). Analysis of these components allows greater understanding of the ability of a feed to meet specific requirements of varying livestock systems (Jergens, 2002b).

With forages and other feeds it is important to measure the crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) content. Crude protein is the measure or estimate of the total protein in a feed. It is determined by multiplying the total nitrogen (N) content by 6.25. This component of feeds encompasses all protein, and other nitrogenous products (Jergens, 2002a). Understanding CP content is important for a variety of reasons, but it is particularly important because it has been identified as the limiting constituent driving decreased dry matter intake (DMI) with advancing maturity in switchgrass

(Burns et al., 1997). Dry matter intake is important because it is an important factor affecting digestibility (Cochran and Galyean, 1994).

Neutral Detergent Fiber is the portion of the plant that contains variably digestible cell wall components (Jergens, 2002b). Observed intake responses by dairy cattle have been highly correlated with NDF of the feeds they were consuming (Van Soest, 1991). Acid detergent fiber is used as an indicator of forage digestibility. Acid detergent breaks down hemicelluloses and cell wall nitrogen, leaving behind lignicellulose which contains lignin. Lignin is important as it is considered to be non-digestible and acts as a barrier to microbial degradation of cellulose and hemicellulose (Jergens, 2002b). The ADF procedure is also a pretreatment step in determining many other components of the feed such as cellulose, acid detergent insoluble nitrogen (ADIN), and silica. Measuring ADIN is especially important as this measurement can be used to assess protein which has become indigestible due to heat damage (Van Soest, 1991).

1.4 Procedures Used in Determining the Digestibility of Livestock Feeds

Chemical analysis alone does not determine the quality of a feed. Consider that coal, wood sawdust, and starch all have similar energy values if determined by combustion. However, coal and wood sawdust are not readily digested and the energy contained in them is relatively useless to livestock (Schneider and Flatt, 1975). The actual value of ingested nutrients contained in a feedstuff depends upon use efficiency (Jergens, 2000a). Use efficiency of an animal is determined by measuring digestibility—how much is lost on passage through the digestive tract (Cochran and Galyean, 1994). There are several ways to measure digestibility. It can be measured with in vitro, in situ, or in vivo procedures (Cochran and Galean, 1994; Weiss, 1994).

In-vivo feeding trials were the earliest forms of assessing digestibility (Schneider and Flatt, 1975). These studies require the actual feeding of animals (Cochran and Galyean, 1994). In these studies the nutritive value of a feed is evaluated, the feed is fed to the animal, feces are collected and analyzed, and calculations are made to determine digestibility (Jergens, 2002b). Early in vivo procedures required animal confinement feeding facilities which would enable the collection and separation of all feces. These types of trials were labor intensive, time consuming, and did not allow assessment of digestibility in the grazing environment. These procedures have been modified to address some of these issues. Fecal collection bags were developed which could be attached to livestock. With these in place, digestibility coefficients could be calculated from animals in the grazing environment. However, these procedures were still relatively time consuming, and labor intensive. This led researchers to the concept of using fecal markers as part of estimating digestibility (Schneider and Flatt, 1975).

A fecal marker is used to estimate fecal output based on the measurement of an inert substance which internal or external to the feed. This approach eliminates the labor, time, and effort associated with total manure collection (Cochran and Galyean, 1994). An ideal fecal marker is an inert substance which is not absorbed; has no pharmacological action on the digestive tract; flows parallel with, is physically similar to, or is intimately associated with the material it is labeling; passes through the digestive tract at a uniform rate; and must have a specific and sensitive method of estimation (Owens and Hanson, 1992; Jergens, 2002b).

Reducing the need for total fecal collection lessened the amount of time and resources required to assess digestibility, but the actual feeding of animals still required large amounts of herbage, was time consuming, and costly to conduct (Tilley and Terry, 1963). The amount of time required to conduct digestibility feeding trials, and the cost were strong motivations to investigate other means of assessing digestibility (Weiss, 1994).

Plant breeders also needed alternative methods of assessing digestibility because of the large numbers of breeding lines they worked with. Digestibility feeding trials could be used to assess the digestibility of a sward, but were not useful for assessing its individual botanical components (Tilley and Terry 1963).

The in situ procedure involves incubating feeds in the rumen of an animal (Weiss, 1994). This method is useful to appraise the rate of digestion, but like in vitro procedures, it still does not accurately assess animal performance. In situ procedures ignore the impact of passage on the extent of digestion, and do not take into account sources of variation such as particle size. These procedures also are based upon mean retention time, and most often over estimate digestibility (Owens and Hanson, 1992). Many studies have been conducted to determine sources of variation of this method, but few studies have been conducted to determine how to make in-situ data more accurate (Weiss, 1994).

In-vitro literally means “in a test tube.” In vitro methods are conducted outside of the animal’s body, usually in the laboratory (Weiss, 1994). Tilley and Terry developed a two stage method of measuring in vitro dry matter digestibility (IVDMD). Their objective for developing this method was to provide plant breeders with a means to assess digestibility for the purpose of plant selection (Tilley and Terry, 1963). Many variations of this method are used to evaluate IVDMD (Weiss, 1994).

In addition to the evaluation of digestibility by IVDMD, there are enzymatic processes that have been used to estimate in vitro digestibility (e.g. one stage method using cellulase, and the two stage method using HCl-Pepsin as a pretreatment, then cellulase) These enzymatic methods of assessing digestibility show great promise when the objective is to produce a simple ranking of forage digestibility. However, they have not been shown to be very good at predicting animal performance since they lack accuracy and precision. Therefore, if in vitro procedures are to be used, IVDMD is currently the best means of measuring digestibility (Weiss, 1994).

Measuring digestibility by in vitro procedures saves time and resources, but this method is not good for predicting actual animal performance as observed in-vivo. This is due in part because in-vivo digestibility is not a constant characteristic of herbage (Tilley and Terry 1963). Furthermore, there are a series of variables in the IVDMD method (e.g., rumen fluid donor animal, donor animal diet, methods implemented, etc.) which affect the accuracy and precision of this procedure. In vitro methods are particularly useful when reported as analytical results. This is the case for plant breeders selecting genotypes for higher digestibility (Tilley and Terry, 1963; Anderson and Matches, 1983). Multiple cuttings or seasons and repeated IVDMD analysis provide useful information for breeding programs in terms of genotype selection (Anderson and Matches, 1983). However, a final in vivo evaluation with animals is essential as in vitro digestion trials can be a guide only to potential, rather than to the realizable value of a feed (Tilley and Terry, 1963).

Each procedure can be used to evaluate different aspects related to forage quality. In situ procedures are useful for determining the rate of digestion. In vitro procedures are useful when comparing forage with similar digestibility such as when comparing genotypes of a given forage species. As far as actual animal performance is concerned, in vivo feeding trials are the best indicators of digestibility and feed value in a ruminant livestock operation. However, it should be remembered that these trials indicate apparent digestibility. It is considered apparent, as opposed to true digestibility, because it is assumed that the feces are composed only of undigested feed (Jergens 2002b). This method does not attempt to account for digestive enzymes and bile that enter the gastrointestinal tract (Schneider and Flatt, 1975).

1.5 Methods of Measuring *In-vivo* Digestibility

Although the process of measuring apparent digestibility by in vivo methods in ruminants is very time-consuming, the concept is simple. Feeding trials are conducted to determine the digestion coefficients of chemical constituents (Schneider and Flatt, 1975). This process is more complex as the total amount of feed is not completely consumed leaving refused feed. This requires an adjustment calculation in which the amount of nutrient refused is subtracted from the amount of nutrient fed to determine the intake, or amount of nutrient consumed (Cochran and Galyean, 1994).

It is not possible to determine apparent in vivo digestibility without accurate determination of fecal output. Total fecal collection is still used, but it is primarily used to validate novel fecal markers. Partial manure collection is more frequently used if the research objective is to evaluate the digestibility and intake of a feed, or ration (Cochran and Galyean, 1994). Both internal markers and external markers are used to estimate fecal output. External markers do not naturally occur in the feed of interest and are added during diet formation (Jergens, 2002b). Internal markers are components of the feed of interest (Cochran and Galyean, 1994). Differentiation between internal and external markers is not always clear cut. When deciding which marker to employ in research, inadequacies of individual markers relative to an ideal marker should be considered (Owens and Hanson, 1992).

Examples of commonly employed external markers include rare earth markers (Owens and Hanson, 1992) and chromic oxide (Schneider and Flatt, 1975). Chromic oxide has been one of the most widely used digestibility markers (Fenton, 1979). It is simple to prepare in the feed, but often separates from specific feed fractions of interest and is not suitable to estimate *digesta* kinetics (Owens and Hanson, 1992). Diurnal variation is a concern with this marker and should be considered (Cochran and Galyean, 1994). This variation may result from inconsistency in sample dosing. Rare earth markers applied in excess of their binding capabilities will enhance migration. Loosely bound rare earth markers can migrate in the rumen. This is a concern because the label, not the originally marked component is being followed. The extent of migration can be checked using in situ procedures (Owens and Hanson, 1992). However, this is an added step which can be avoided by implementing a different marker if determining fecal output is the research goal.

Internal markers occur naturally within the feed (Jergens, 2002b). Naturally occurring waxes and other plant components such as n-Alkanes, Acid Detergent Insoluble Ash (ADIA), and Acid Insoluble Ash (AIA) have been used as internal markers to estimate fecal output (Cochran and Galyean, 1994, Owens and Hanson, 1992).

Naturally occurring odd-numbered carbon chain n-alkanes are found in most forage species in the plant cuticular wax. Therefore, these have been suggested as internal markers for predicting the digestibility of forage (Sanberg et. al., 2000). Mayes and colleagues suggested n-alkanes as internal markers for determining intake and digestibility of herbage in sheep (Mayes et. al., 1986). Ohajuruka and Palmquiest (1991) evaluated n-alkanes as a *digesta* marker in dairy cows. However, in each of these studies, a disappearance of N-alkanes was observed. The disappearance of n-alkanes was also observed in a recent study focused on hay, and hay plus concentrate diets in horses (Ordakowski et. al., 2001). According to Owens and Hanson (1992), the disappearance of N-alkanes was of particular concern as this could be a result of digestion of the marker. Sanberg and colleagues determined that the disappearance caused an underestimation of digestibility when n-alkanes were used as an internal marker in confinement feeding trials. They observed dry matter digestibility of range hay by beef steers (420 kg) to be 75.0% during in vivo DMD feeding trials, but estimated it to be 61.8% when using C31 N-alkane as an internal marker. However they also concluded that n-alkanes would be beneficial to estimate digestibility in grazing trials (Sanberg et. al. 2000).

The AIA and ADIA procedures analyze similar fractions of a feed—the acid insoluble ash portion. They simply require different laboratory methods of evaluation. The procedure for analyzing AIA was developed by Van Kuelon and Young (1977). In this procedure, samples of interest are ashed at 450 °C and then treated with hydrochloric acid (HCl). The procedure for analyzing ADIA was originally developed by Van Soest, Robertson, and Lewis (1991). In the most recent variation of the procedure, samples are analyzed for ADF using the filter bag system (Van Soest et. al., 1991).

The remaining ADF is then ashed at 525 °C. The two procedures both evaluate AIA. However, the Van Soest procedure is preferable as it is shorter than that of Van Keulon and Young. Also, the Van Keulon and Young procedure can have incomplete recovery of silica due to incomplete acid dehydration (Van Soest et al., 1991).

1.6 Predictors of Nutritive Value and Performance of Cattle Consuming Switchgrass

The factors that influence forage quality include herbage maturity, soil fertility, temperature, and other environmental factors. Of these, the most important factor influencing forage quality for all forages is herbage (plant) maturity (Buxton, 1996). With perennial grasses, forage quality generally declines with advancing plant maturity (Harrison et al., 2003). However, the effect of maturity is more pronounced in some species than others.

Crude Protein

Low CP is a characteristic of switchgrass when compared with other forages that producers might harvest in Kentucky. It has been reported to be less than 13% even at the vegetative stage (Anderson and Matches, 1983; Burns et. al. 1997; Griffin and Jung, 1983; Vona et al., 1984); whereas CP of 17.2% was observed for tall fescue harvested at late-vegetative stage in Kentucky (Fieser and Vanzant, 2004). Crude protein of 15.5% was observed for ‘Tifton 85’ Bermudagrass harvested at the vegetative stage (Mandebvu et. al., 1998).

Crude protein decreases as harvest is delayed past the late vegetative stage with all forages, but with switchgrass this decrease is much more pronounced. Burns and colleagues (1997) observed that the most rapid decline in CP occurred during stem elongation in preparation for boot stage. They observed a decrease in CP from 11.3% to 6.9% when harvest of Kanlow hay was delayed from the early to late vegetative stage (Burns et. al., 1997). Crude protein of tall fescue harvested in Kentucky only decreased from 17.4%, when harvested at the vegetative stage, to 15.6% when it was harvested at the boot stage in the study conducted by Fieser and Vanzant (2004). After reaching mid-boot stage CP continued to decline in switchgrass from 5.6% at boot to 4.4% at the floret stage), but this difference was not as great (Burns et. al., 1997). Crude Protein of tall fescue declined from 15.6% to 8.2% when comparing between hay harvested at the boot stage, and at heading. (Fraizer and Vanzant, 2004) making it comparable to that reported by Burns and colleagues (1997) for Kanlow switchgrass harvested at 20% heading. Mandebvu and colleagues (1998) observed 9.0% CP for bermudagrass harvested with non-flowering stems.

Griffin and Jung determined that the rapid decline in CP in switchgrass resulted from the rapid increase of the stem components in relation to leaf components. They found that leaf CP decreases with maturation in switchgrass, but the decline in stem protein was twice that of leaves (Griffin and Jung 1983). The rapid decline of CP along with an observation of decreased animal digestible dry matter intake, and dry matter digestibility (DMD) led Burns and colleagues to determine that CP was the major factor reducing forage quality as switchgrass matures (1997).

Fiber and Cell Wall Contents

The effect of maturity on Neutral Detergent Fiber of switchgrass has been observed to be similar with other forages when harvested at later maturities, but NDF increases at an earlier maturity with switchgrass when compared with other forages. Neutral detergent fiber of Kanlow switchgrass, tall fescue, and Tifton 85 Bermudagrass were similar in three different studies when harvested at the vegetative stage. Burns and colleagues (1997) reported NDF of Kanlow produced in North Carolina to be 69.3% when harvested as hay at the early vegetative stage. This was similar to that reported for other forages. Fieser and Vanzant (2004) reported NDF of 68.7% when tall fescue was harvested as hay at the vegetative stage. Tifton 85 bermudagrass harvested in Georgia was observed at 68.6% NDF when harvested as hay at 3 weeks of re-growth (vegetative stage) (Mondebvu, 1999). However, by the time switchgrass reached the late vegetative stage, but prior to boot, NDF had increased to 74.5%.

Neutral detergent fiber of 72.3% was observed for Tifton 85 harvested after 6 weeks of regrowth (prior to flowering) (Mondebvu, 1999). Delaying harvest of Kanlow switchgrass from the late vegetative stage until mid-boot resulted in a slight increase 76.8% NDF (Burns et. al. 1997). This was similar to 73.9% NDF of tall fescue harvest at the boot stage as reported by Fieser and Vanzant (2004). Neutral Detergent fiber of switchgrass harvested at early flowering (20% heading) of 78.8% as observed by Burns and colleagues (1997) is similar to

76.8% observed for tall fescue harvested at a mature stage (Fieser and Vanzant, 2004).

Decreasing nutritive values of forages is considered linear with advancing maturity (Blaser et. al., 1986). However, the trend of increasing NDF of switchgrass has been shown to be cubic with the greatest increase in NDF occurring before the late vegetative stage (Burns et. al. 1997). Burns and colleagues (1997) suggested that this difference in considered and observed trends could be an artifact of the maturity intervals selected. The findings of NDF reported for tall fescue (Fieser and Vanzant, 2004) and Tifton 85 Bermudagrass (Mondebvu, 1999) do not dispute this given that they were only reported for two and three maturities, but producers growing switchgrass should consider the possibility that the fiber fraction of switchgrass may increase at an earlier maturity compared to other forages. This would show a need to harvest switchgrass prior to the boot stage since increases of NDF are associated with reduced dry matter intake (Van Soest, 1991).

Many studies have been conducted to changes in the nutritive value of with advancing maturity of switchgrass hay, but few research studies have been conducted to determine the effect of advancing switchgrass hay maturity on actual animal performance when it is fed to cattle. In a study involving several switchgrass cultivars harvested at different locations, a decline with dry matter intake (DMI) was observed during feeding mature beef cows. This decline was attributed to a delayed harvest date and to the increasing effect of maturity on the switchgrass stand (Vona et. al. 1984). This was also observed by Burns and colleagues in a study in which switchgrass was fed to yearling beef steers (1997). In both studies, dry matter digestibility declined as stage of maturity at harvest increased (Burns et al. 1997, Vona et al. 1984). Vona and colleagues did not observe differences of DMI and DMD among cultivars and did not observe a cultivar x location effect on DMD or DMI (Vona et al. 1984). In the study by Burns and colleagues (1997), for growing steers, only the DMI and DMD observed for the early vegetative harvest would support a 0.9 kg/d weight gain (NRC, 1984). The later vegetative harvest was only slightly better than maintenance diet for feeding dry mature beef cows. They also concluded that the mid boot and heading harvests would be of sufficient quality for maintenance of dry mature beef cows (Burns et al. 1997). Vona and colleagues also determined that warm season grasses harvested at an earlier maturity can provide a high intake of digestible energy for mature beef cattle (Vona et al. 1984).

Predictors of forage quality and feeding trial results confirm that there is an effect of maturity of switchgrass hay quality. This effect has not been well documented with in-vivo digestibility feeding trials, or with animal performance in relation to feeding hay. Furthermore, observations of nutritive value for switchgrass compared to other forages producers might harvest for hay in Kentucky suggest that producers may need to harvest switchgrass prior to boot stage if it will be fed to beef steers. Kentucky producers interested in switchgrass hay production need more information to better understand the effect of maturity on switchgrass hay quality, to be able to apply it in their farming operations. The objective of the current study was to determine the effect of maturity on switchgrass hay digestibility in cattle, and to investigate the potential challenges that producers might face if incorporating switchgrass into their forage program.

1.7 Justification

The evaluation of feed is very important to livestock nutrition and the ability of livestock production systems to meet production goals. This evaluation begins with chemical analysis of nutrients, but nutrient composition is only an indicator of nutritive value. To evaluate the utilization of a forage by an animal requires the conduct of feeding trials to measure both dry matter intake and digestibility. Switchgrass has potential use for grazing and hay production, but there has been a lack of research on nutrient intakes and digestibilities over a range of maturities. Therefore, a feeding trial was conducted to determine the effect of maturity on switchgrass hay digestibility and dry matter intake in cattle, and to discuss potential challenges that producers might face if incorporating switchgrass into their forage program.

Chapter Two

Effect of Maturity on the Apparent In-vivo Intake and Digestibility of Alamo and Cave-in-Rock Switchgrass

2.1 Materials and Methods

Hay Harvest

The switchgrass used in this study was harvested as hay and processed as round bales. ‘Alamo’, a lowland cultivar, was harvested from the University of Kentucky (UK) Spindletop Research Farm in Lexington, KY. ‘Cave-in-Rock’, an upland cultivar, was harvested from the UK Eden Shale Research Farm located near Owenton, Ky. Green-up occurred in late April for both fields in 2010, and in early May in 2011. Nitrogen was applied at a rate of 68 kg ha^{-1} at Eden Shale on April 27, 2010 and May 10, 2011. Nitrogen was applied at the same rate at Spindletop on April 20, 2010 and May 3, 2011. Soil samples were taken in March 2010, and again in March of 2011 to determine if lime, phosphorous (P), or potassium (K) should be applied according to University of Kentucky recommendations (AGR-1). There were adequate K and P concentrations in both 2010 and 2011 at both locations. Soil test for the Eden Shale site indicated 290 kg K ha^{-1} and 64 kg P ha^{-1} in 2010, and 279 kg K ha^{-1} and 60 kg P ha^{-1} in 2011. Soil test for the Spindletop location indicated 274 kg K ha^{-1} and 572 kg P ha^{-1} in 2010, and 229 kg K ha^{-1} and 508 kg P ha^{-1} in 2011. Lime was not applied at either location. Soil test indicated the soil pH at the Eden Shale location to be 5.81 in 2010 and 5.44 in 2011, and 6.07 and 6.04 for the Spindletop location in 2010 and 2011 respectfully. Herbicide (2-4 dichlorophenoxyacetic acid) was applied at a rate of 4.67 L ha^{-1} both years in early April to control broadleaf weeds.

In both the Alamo and Cave-in-Rock fields, areas were allocated to be harvested at the vegetative, boot, and flowering stage of maturity (Anthesis)   Approximately one half of each area was allocated for the vegetative harvest. The remaining area was divided and allocated to be harvested at either the boot or the flowering stage. Subdividing in this manner compensated for the difference in yield between different maturity stages and provided a sufficient quantity of feed to be harvested for completing feeding trials. The Alamo stand was harvested at the vegetative stage June 6, at boot on June 16, and the early flowering (Floret) on June 25 in 2011. Approximate forage heights were0.9, 1.3, and 2.0 m for the late-vegetative, boot, and flowering (floret) maturity stages respectfully. The Cave-in-Rock stand was harvested at the late vegetative, boot, and early flowering (floret) stages of maturity on May 31, June 10, and July 25 respectfully in 2011. Approximate forage heights of 0.9, 1.0, and 1.3 m for the late-vegetative, boot, and early flowering stage of maturity.

Standard haying equipment was used for this study at both locations and included a mower-conditioner, standard bar rake, and round baler. The mower-conditioner was modified with cutting height extensions to harvest the hay at a cutting height of 15 cm. This was lower than the cutting height of 20 cm (SP-731D) recommended by the University of Tennessee Cooperative Extension

Service. However, this was the highest possible cutting height adjustment for the mower conditioner used. Hay was not rolled until it had dried in the field to at least 18% moisture. Hay moisture concentration was determined prior to rolling using a microwave oven (Steevens et. al, 1993). After rolling, bale moisture level was also assessed using a hay moisture probe (Delmhorst Inc., Towacco NJ). If the bales were determined to be less than 18% moisture, they were immediately stored inside. They remained in storage until feeding. Fifteen to twenty cores from each harvest were taken to analyze forage quality using a 'Penn State' forage sampler (Nasco, Fort Atkinson, WI.).

Prior to feeding, hays were transported to the feeding site at Eastern Kentucky University. Each hay treatment was tub ground to an approximate 15 cm stem length to allow for easier handling and weighing, and to minimize variation resulting from steer selection of leaf over stem. After grinding, each hay treatment was stored inside in an individual bunk space.

Intake and Digestibility Feeding Trials

Intake and Digestibility feeding trials were conducted in 2010 and 2011 in accordance to the standards determined by and the Institution for Animal Care and Use Committee (IACUC) at Eastern Kentucky University (2010-01). In 2010 a preliminary study was conducted in which 20 Hereford x Angus steers (200-255 kg) were fed to five different treatments of switchgrass hay. Treatments consisted of Alamo switchgrass hay harvested at the late-vegetative, boot, and early flowering stages of maturity, and Cave-in-Rock switchgrass hay harvested at the late-vegetative and early flowering stages of maturity (Table 1). Each treatment was fed to 4 different steers for the purpose of replication. Steers were grouped by weight and were randomly assigned to each replicate. Cave-in-Rock hay harvested at the boot stage was not included as a treatment in 2010 because it was lost during harvest due to multiple rain events prior to baling. In 2011, the study was repeated with two feeding trials that included all 6 treatments. This required feeding 24 Hereford x Angus steers (Table 2). The only data reported is from the 2011 hay harvest and feeding trials with the 2010 preliminary feeding trial being used for method development.

Table 2.1. Description of Alamo and Cave-in-Rock (CIR) switchgrass hay treatments and the number of steers allocated for each treatment in the preliminary feeding trial in 2010.

	Cultivar	Stage of Maturity	# Steers
1	CIR	Late-vegetative	4
2	CIR	Boot	Hay lost
3	CIR	Early Flowering	4
4	Alamo	Late-vegetative	4
5	Alamo	Boot	4
6	Alamo	Early Flowering	4

Table 2.2. Description of trials, Alamo and Cave-in-Rock (CIR) switchgrass hay treatments, and steers (n=4) allocated for each treatment in 2011.

	Trial 1		Trial 2	
	Cultivar	*Stage of Maturity	Cultivar	*Stage of Maturity
1	CIR	Late-vegetative	CIR	Late-vegetative
2	CIR	Boot	CIR	Boot
3	CIR	Early Flowering	CIR	Early Flowering
4	Alamo	Late-vegetative	Alamo	Vegetative
5	Alamo	Boot	Alamo	Late Boot
6	Alamo	Early Flowering	Alamo	Early Flowering

*V=Vegetative, LB=Late Boot, EF= Early Flowering

An open feeding barn was converted into a 24 stall feeding facility prior to the beginning of the study. Bunk dividers were constructed to only allow individual steer access. Corral pens were used to construct individual steer pens. The feeding and living areas were covered, but the barn was open to the outside environment on two sides and was subject to environmental conditions. Water tanks were equipped with full flow valves to allow steers continuous access to fresh water. Steers also had continuous access to a mineral block. Each pen was 1.8 x 3.7 m with the exception of pens 1 and 24. These two pens were 1.7 x 3.7 m. The difference in pen size originated from design constraints of the barn. The size difference was addressed by rotating steers each day by replication throughout the adjustment and collection period.

Long-stem bermudagrass hay was fed for preliminary feeding period of 3 weeks prior to each feeding trial to transition them to a warm-season grass hay. The preliminary feeding period also allowed the animals to adjust to the feeding facility. Throughout the preliminary feeding of bermudagrass hay, steers were not individually confined and had open access to the entire barn. All steers had open access to fresh water, and were fed mineral *ad lib*. During the preliminary feeding period steers were observed for temperament and health. Animals observed to display poor temperament or poor health were not selected for the feeding. At the end of the last day of the preliminary feeding period steers were weighed, and then individually confined to the corral pens. Shrinking or fasting was implemented prior to weighing.

Day 1 of the digestibility feeding trial began with individual steer confinement. Throughout the digestibility feeding trial, each steer was fed an allocated treatment of switchgrass hay for 12 days. During confinement, steers had continuous access to fresh water and mineral. Steers were given a 7 day adjustment period (days 1-7) to adjust to the respective feeding treatment. The collection period consisted of 5 days (days 8-12).

Throughout the adjustment and manure collection period steers were fed at approximately 1700 hrs. On Day 1, steers were fed at 2.5% of their body weight on a dry matter basis (DM). Dry matter of each treatment was determined prior to feeding. Refused Feed (orts) was collected and weighed each day prior to the next feeding. This allowed for calculation of dry matter intake (DMI) as described by Cochran and Galyean (1994) in which kilograms of dry matter in the collected orts (kg) were subtracted from the dry matter amount fed (kg). During the feed adjustment period, the amount designated to be fed was increased or decreased with the goal of 15% of DMI as Orts only when there was an over or under-abundance of orts collected. . Throughout the collection period, orts were thoroughly mixed and sub-sampled each day and stored for latter analysis. Sub-samples consisted of approximately 200 g of orts animal^{-1} day^{-1}.

Partial manure collection using an internal marker was utilized to estimate daily fecal output throughout the collection period as described by Cochran and Galyean (1994). Acid Detergent Insoluble Ash (ADIA) was used as the internal marker. Grab samples of manure were collected between 14 to 15 hours after feeding. These grab samples were taken from fresh manure. It was preferred that this sample be taken fresh from each steer. To do this, each steer was placed in a confinement chute. This was not always possible as steers would sometimes defecate prior to entering the confinement chute. When this was the case, samples were collected from the excreted manure. For this reason, each individual pen was cleaned each day. Areas in which steers traveled to reach the confinement chute were kept as clean as possible before and during collection.

Lab Analysis

Manure samples for each animal were individually packaged and frozen each day immediately after all samples were collected. Manure samples were later dried at 70°C, weighed for determining partial DM, and ground to pass a 1-mm screen in a Wiley Mill. After grinding, manure samples were stored in a freezer until lab analysis. Orts were composited for the collection period based on daily percentage steer intake. Orts were dried at 70°C, ground to pass a 1mm screen in a Wiley Mill, and stored for lab analysis.

Crude Protein (CP), Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), Acid Detergent Insoluble Ash (ADIA) were determined on a dry matter basis (DM). Lab DM for hay, orts, and feces was determined by heating for 24 h at 105°C in a forced air oven. Crude Protein was determined using combustion (AEOC 1995; method no. 990.03, Nitrogen Analyzer model FP-528, LECO Corporation, St. Joseph, MI, USA). Neutral Detergent Fiber concentrations of hay, orts, and feces were determined with a fiber analyzer (ANKOM model 200; ANKOM Technology Corp., Fairport, NY, USA) using a modification of methods as described by Komarek and Sirois (1993a). Sodium Sulfite was not used in the fiber analysis. Acid Detergent Fiber components of the hay, orts, and feces were also determined using the same fiber analyzer (Komarek and Sirois 1993b) using a modification of the methods described by Van Soest, Robertson, and Lewis (1991). Residual ash was not subtracted from the reported NDF and ADF values. Acid Detergent Fiber analysis was carried out as a preliminary step to the ADIA, and lignin procedure (Van Soest 1991). Acid Detergent Insoluble Ash was determined by ashing at 525°C for 12 hours. Samples were analyzed in duplicate for all lab procedures with a threshold of five percent difference between duplicate samples. When individual samples varied by more than five percent they were re-analyzed. The sample means from each duplicate were used for data analysis.

Calculations

The calculations presented by Cochran and Galyean (1994) were used to calculate percent apparent DM digestibility (DMD). Since intake was known, (1) the dose of ADIA for each day was determined my multiplying the amount of ADIA in the hay (g) by the daily steer intake (g). Once calculated, the daily ADIA dose was divided by the concentration of the ADIA in the feces (g/g of dm) to determine (2) fecal output. The (3) percentage of DMD was determined by subtracting the amount of DM in the feces from the amount of DM consumed. This was divided by the total amount of DM consumed and then converted to a percentage basis. Calculations used for estimating DMD for a given day are the following;

1) $\text{ADIA dose(g)} = \text{ADIA}_{\text{hay}} \bullet \text{DM Intake (g)}$

2) $\text{Fecal Output} = \dfrac{\text{ADIA dose(g)}}{\text{ADIA (g) per feces (g)}}$

3) % apparent Digestible DM=

$$\frac{[(\%\text{DM hay} * \text{fed (kg)}) - (\%\text{DM Orts} * \text{Orts (kg)})] - \%\text{DM feces}}{[\%\text{DM hay} * \text{fed (kg)}] - [\%\text{DM Orts} * \text{Orts (kg)}]}$$

Statistical Analysis

All Forage constituent data were analyzed using ANOVA. Since the Alamo and Cave-in-Rock hays were harvested at two different locations, each cultivar was analyzed separately using the GLM procedure of SAS (2002). Mean CP, NDF, and ADF responses were calculated using the LSMEANS option of SAS (2002), and LSD (0.05) was used for treatment comparisons. Intake and digestion data were analyzed as a Randomized Complete Block Design using the MIXED procedure in SAS (2002). Fixed effects were cultivar, maturity (stage of maturity at harvest), and cultivar x maturity interaction. Trial was treated as a random effect. Treatment means for apparent DMI, DMD, and DDMI were calculated using the LSMEANS procedure in SAS (2002). Least square means for apparent DMI, DMD, and DDMI were compared among treatments using the PDIFF option of SAS (2002).

2.2 Results

Forage Nutritive Value

There was an effect of maturity (P<0.0001) on the percentages of crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) in the Alamo hays (Table 2.1). Estimated dry matter (DM), CP, NDF, and ADF of the Alamo Hays are presented in Table 2.2. Estimated DM of the vegetative, boot, and early flowering hays were 90.2%, 90.4%, and 91.0% respectfully. Alamo Crude Protein was 13.5% at the late-vegetative stage, 7.5% at the boot stage, and 5.1% for hay harvested at the early flowering stage of maturity. Neutral Detergent Fiber was 59.0 % at the late-vegetative stage, 62.2% at the boot stage, and 64.0% at the early flowering stage. Acid Detergent Fiber of the Alamo hay was 29.9% at the late-vegetative stage, 36.7% at the boot stage, and 39.9% at the early flowering stage.

Table 2.3. ANOVA for the overall effect of hay maturity on crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber of Alamo Hay harvested in 2011.

	Source	DF	Pr>F
CP	Maturity	2	<0.0001
NDF	Maturity	2	<0.0001
ADF	Maturity	2	<0.0001

Table 2.4. Percentage dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) for Alamo switchgrass hay harvested at three different stages of maturity in 2011.

	DM	Crude Protein	NDF	ADF
	------------------------------%	------------------------------		
Late-vegetative	90.2	13.5 a	59.0 c	29.9 c
Boot	90.4	7.5 b	62.2 b	36.7 b
Early Flowering	91.0	5.1 c	64.0 a	39.9 a

*Different letters indicate significant difference within columns at $P \leq 0.05$

There was a maturity effect ($P<0.0001$) CP, NDF, and ADF in the Cave-in-Rock (CIR) hay (Table 2.3). The estimated average DM, CP, NDF, and ADF concentrations of the Cave-in-Rock switchgrass hays are presented in Table 2.4. Dry Matter at the late-vegetative, boot, and early flowering stages of maturity were 90.1%, 90.5%, and 91.2% respectfully. Crude Protein of Cave-in-Rock hay was 11.3% at the late-vegetative stage, 5.7% at the boot stage, and 4.8% at early flowering stage of maturity. Neutral Detergent Fiber was 57.1% at the late-vegetative stage, 64.4% at the boot stage, and 65.1% at the early flowering stage of maturity. Acid Detergent Fiber was 29.2% at the late-vegetative stage, 38.6% at boot stage, and 40.5% at early flowering.

Table 2.5. ANOVA for the overall effect of hay maturity on the crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of Cave-in-Rock switchgrass hay harvested in 2011.

	Source	DF	Pr>F
CP	Maturity	2	<0.0001
NDF	Maturity	2	<0.0001
ADF	Maturity	2	<0.0001

Table 2.6. Percentage of dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) for Cave-in-Rock switchgrass hays harvested in 2011.

	DM	Crude Protein	NDF	ADF
	-----------------------------------	%	---------------------------------	
Late-vegetative	90.1	11.3 a	57.1 c	29.2 c
Boot	90.6	5.7 b	64.4 b	38.6 b
Early Flowering	91.2	4.8 c	65.1 a	40.5 a

*Different letters indicate significant difference within columns at P ≤ 0.05

Intake and Digestibility

There was a maturity effect ($p<0.0001$) on apparent DMI by beef steers consuming Alamo (Table 2.5). Apparent daily DMI of Alamo hay by beef steers was greatest ($P<0.05$) when harvested at the late-vegetative stage of maturity, followed by the boot, and early flowering stage (Figure 2.1). Average apparent DMI of Alamo was estimated at 2.2 % BW (4.4 -5.8 kg), 1.3 % BW (2.6 - 3.4 kg), and 1.2 % BW (2.4-3.1 kg) $steer^{-1}$ day^{-1} for those that consumed the late-vegetative, boot, and early flowering hays respectfully. On average, steers that consumed hay harvested at the late-vegetative stage consumed 0.9 % BW (1.8 – 2.4 kg BW) $steer^{-1}$ day^{-1} more ($P<0.0001$) than steers consuming hay harvested at the boot stage. Steer consuming Alamo harvested at the late-vegetative stage consumed 1.0 % BW (2.0 - 2.7 kg) steer-1 day^{-1} more ($P<0.0001$) than steers that were fed the early flowering hay. Estimated apparent DMI did not differ ($P>0.05$) when comparing between steers consuming Alamo hays harvested at the boot and early flowering stage.

Table 2.7. Type 3 sums of square tests for cultivar, maturity, and cultivar x maturity interaction fixed effects on average daily apparent dry matter intake (DMI) of Alamo and Cave-in-Rock switchgrass hay consumed by beef steers (200-265 kg) over two feeding trials in 2011.

Effect	Num DF	Den DF	F value	Pr>F
Cultivar	1	41	0.28	0.5967
Maturity	2	41	18.75	<0.0001
Cultivar x Maturity	2	41	2.12	0.1330

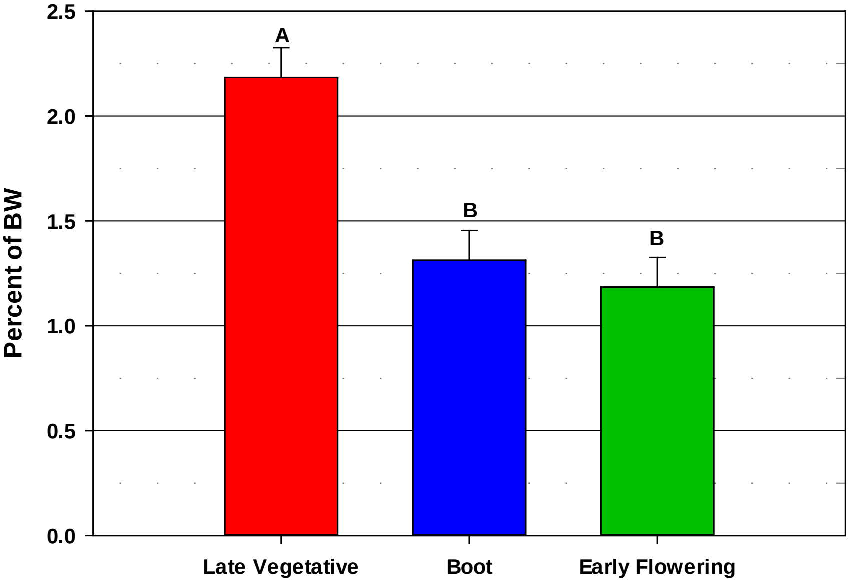

Figure 2.1. Average Apparent daily dry matter intake (DMI) per steer (200-265 kg) for three maturities of Alamo switchgrass hay over two feeding trials in 2011.
*Different Letters indicate significant difference among bars at P ≤ 0.05

Table 2.8. Comparing Least Square Means* for daily apparent dry matter intake per steer (200-265 kg) for three different maturities of Alamo switchgrass hay in 2011.

	DMI		DMI	Difference	Pr>t
	----% BW----		----------------% BW---------------		
Late-vegetative	2.2	Boot	1.3	0.9	<0.0001
Boot	1.3	Early Flowering	1.2	0.1	0.5108
Late-vegetative	2.2	Early Flowering	1.2	1.0	<0.0001

*LS Means were derived from two feeding trials

There was a maturity effect ($p<0.0001$) on apparent DMI by beef steers consuming Cave-in-Rock (Table 2.5). Average apparent daily DMI of Cave-in-Rock by steers at the late-vegetative stage did not differ ($P>0.05$). It also did not differ ($P>0.05$) between the boot and early flowering stage hays. However, daily apparent DMI of the late-vegetative Cave-in-Rock hay was greater ($P<0.05$) than that of steers which consumed hay harvested the early flowering hay (Figure 2.2). Apparent DMI of Cave-in-Rock hay consumed by beef steers was 1.9% BW (3.8 – 5.0 kg), 1.6% BW (3.2- 4.2 kg), and 1.3% BW (2.6 – 3.4 kg) steer^{-1} day^{-1} at the late-vegetative, boot, and early flowering maturities respectfully. On average, steers fed the late-vegetative hay consumed 0.6% BW (1.2 – 1.5 kg) steer^{-1} day^{-1} more than those that consumed hay harvested at early flowering stage (Table 2.7).

Table 2.9. Comparing the Least Squares Means* for daily apparent dry matter intake (DMI) per steer (200-265 kg) for three different maturities of Cave-in-Rock switchgrass hay in 2011.

	DMI		DMI	Difference	Pr>t
	--% BW--		----------------% BW-------------		
Late-vegetative	1.9	Boot	1.6	0.3	0.1036
Boot	1.6	Early Flowering	1.3	0.3	0.1366
Late-vegetative	1.9	Early Flowering	1.3	0.6	0.0028

*LS Means were derived from two feeding trials

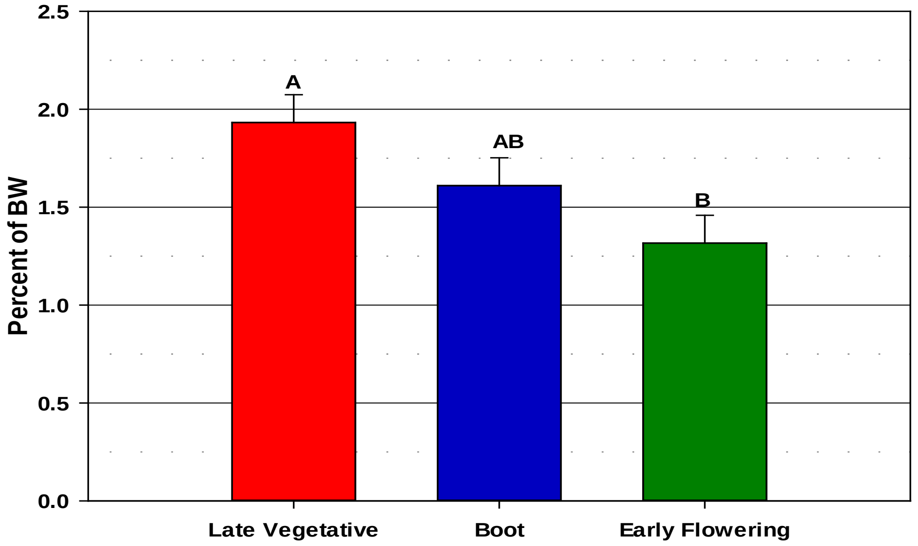

Figure 2.2 Average apparent daily dry matter intake (DMI) per steer (200-265 kg) for three maturities of Cave-in-Rock switchgrass hay over two feeding trials in 2011.
*Different letters indicate significant difference between bars at $P \leq 0.05$

Table 2.10. Type 3 sums of squares tests for cultivar, maturity, and cultivar x maturity interaction fixed effects on apparent dry matter digestibility (DMD) of Alamo and Cave-in-Rock switchgrass hay consumed by beef steers (200-265 kg) over two feeding trials in 2011.

Effect	Num DF	Den DF	F value	Pr>F
Cultivar	1	41	0.18	0.6745
Maturity	2	41	54.22	<0.0001
Cultivar x Maturity	2	41	6.37	0.0039

There was a cultivar x maturity interaction effect (P<0.05) on apparent DMD of Alamo and Cave-in-Rock when consumed by beef steers. Maturity had an effect (p<0.0001) on apparent DMD for Alamo (Table 2.8). The greatest apparent DMD (P<0.05) of Alamo was observed for the late-vegetative hay, followed by the boot and early flowering hays (Figure 2.3). Estimated apparent DMD of Alamo was 72.6%, 61.6%, and 56.7% for the late vegetative, boot, and early flowering hays respectfully. Apparent DMD of Alamo harvested at the late-vegetative stage was estimated to be 11.0% higher (p<0.05) than hay harvested at boot stage. Apparent DMD by Steers fed late-vegetative hay was estimated to be 15.9% units higher (P<0.05) than that by steers fed the early flowering hay. When comparing between groups of steers that received hay harvested at boot, and early flowering, apparent DMD was estimated to be 4.9 % higher for hay harvested at boot stage (Table 2.9).

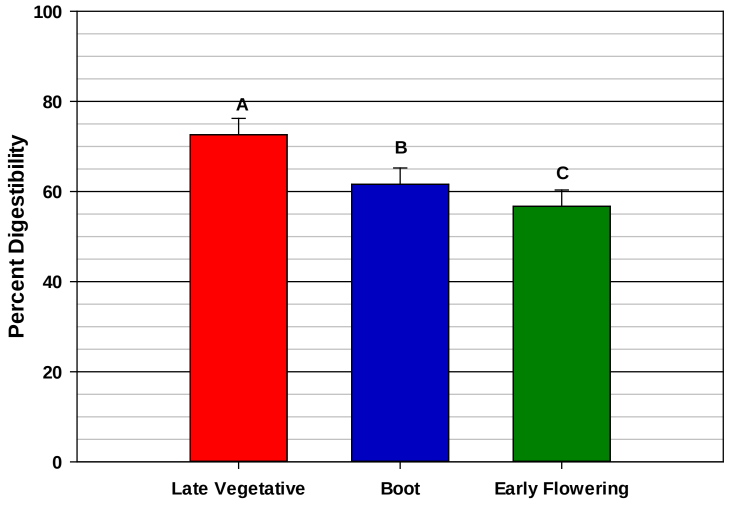

Figure 2.3. Comparing the percentage apparent dry matter digestibility for three maturities of Alamo switchgrass hay when consumed by beef steers (200-265 kg) in two feeding trials in 2011.
*Different Letters indicate significant difference between bars at P ≤ 0.05

Table 2.11. Comparing Least Squares Means* of dry matter digestibility (DMD) between three different maturities of Alamo switchgrass hay fed to beef steers (200-265 kg) in two feeding trials 2011.

	DMD		DMD	Difference	Pr>t
	-------%------		-----------------%------------------		
Late-vegetative	72.6	Boot	61.6	11.0	<0.0001
Boot	61.6	Early Flowering	56.7	4.9	<0.0001
Late-Vegetative	72.6	Early Flowering	56.7	15.9	0.0222

*LS Means were derived from two feeding trials

Maturity had an effect ($p<0.0001$) on apparent DMD for Cave-in-Rock (Table 2.8). Apparent DMD of the Cave-in-Rock early flowering hay was less ($p<0.05$) than the other two maturities, but it did not differ ($P>0.05$) between the late-vegetative and boot stage (Figure 2.4). Estimated apparent DMD of Cave-in-Rock hay consumed by beef steers was 70.0% for the late-vegetative stage, 67.7% for the boot stage, and 51.5% for the early flowering stage of maturity. The difference in apparent DMD at the early flowering stage was estimated to be 18.5% less than the late-vegetative stage of maturity, and 16.22% lower than that for hay harvested at the boot stage of maturity (Table 2.10). Apparent DMD was not different ($p>0.05$) when comparing between the other two maturities.

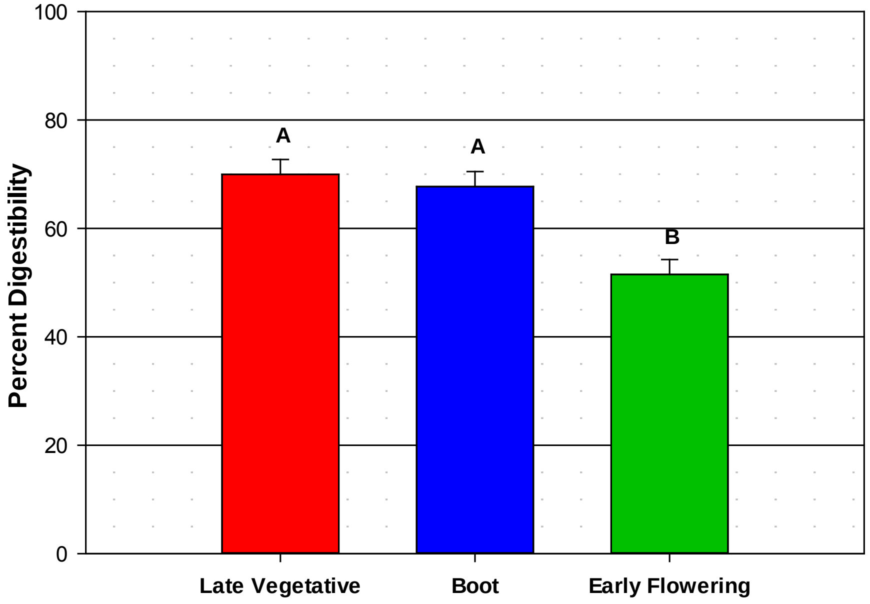

Figure 2.4 Comparing the percentage apparent dry matter digestibility (DMD) for three maturities of Cave-in-Rock switchgrass hay fed to beef steers (200-265 kg) in two feeding trials in 2011.
*Different Letters indicate significant difference between bars at P ≤ 0.05

Table 2.12. Comparing the Least Squares Means* of dry matter digestibility (DMD) between three different maturities of Cave-in-Rock switchgrass hay fed to beef steers (200-265 kg) in two feeding trials in 2011.

	DMD		DMD	Difference	Pr>t
	-------%------		-----------------%------------------		
Late-vegetative	70.0	Boot	67.7	2.3	0.4136
Boot	67.7	Early Flowering	51.5	16.2	<0.0001
Late-vegetative	70.0	Early Flowering	51.5	18.5	<0.0001

*LS means were derived from two feeding trials

There was a cultivar x maturity interaction effect ($p<0.05$) on apparent daily intake of digestible dry matter (DDMI) for steers consuming Alamo and Cave-in-Rock switchgrass hay. Maturity had an effect ($p<0.0001$) on apparent daily DDMI of Alamo (Table 2.11). The estimated apparent daily DDMI of Alamo was significantly higher ($P<0.0001$) for steers that consumed the late than for steer that consumed hay harvested at the other two stages of maturity. Steers that consumed hay harvested at the boot stage did not differ ($P>0.05$) from steers consuming hay harvested at early flowering in terms of apparent daily DDMI (Figure 2.5). Apparent DDMI of Alamo hay by beef steers was 1.7% BW (3.4 – 4.5 kg), 0.8% BW (1.6 – 2.1 kg), and 0.7% BW ((1.4-1.9 kg) steer^{-1} day^{-1} for the late-vegetative, boot, and early stages respectfully. On average, steers fed Alamo hay harvested at the late-vegetative stage consumed an estimated 0.9% BW (1.6-2.1 kg) steer^{-1} day^{-1} more digestible dry matter than those that consumed hay harvested at the boot stage. Those steers also consumed 1.0% BW (2.0-2.7 kg) steer^{-1} day^{-1} more than steers fed hay harvested at early flowering (Table 2.12).

Table 2.13. Type 3 sums of squares for cultivar, maturity, and cultivar x maturity interaction fixed effects on apparent digestible dry matter intake (DDMI) of Alamo and Cave-in-Rock switchgrass hay fed to beef steers (200-265 kg) over two feeding trials in 2011.

Effect	Num DF	Den DF	F value	Pr>F
Cultivar	1	42	0.02	0.8787
Maturity	2	42	47.68	<0.0001
Cultivar x Maturity	2	42	4.40	0.0184

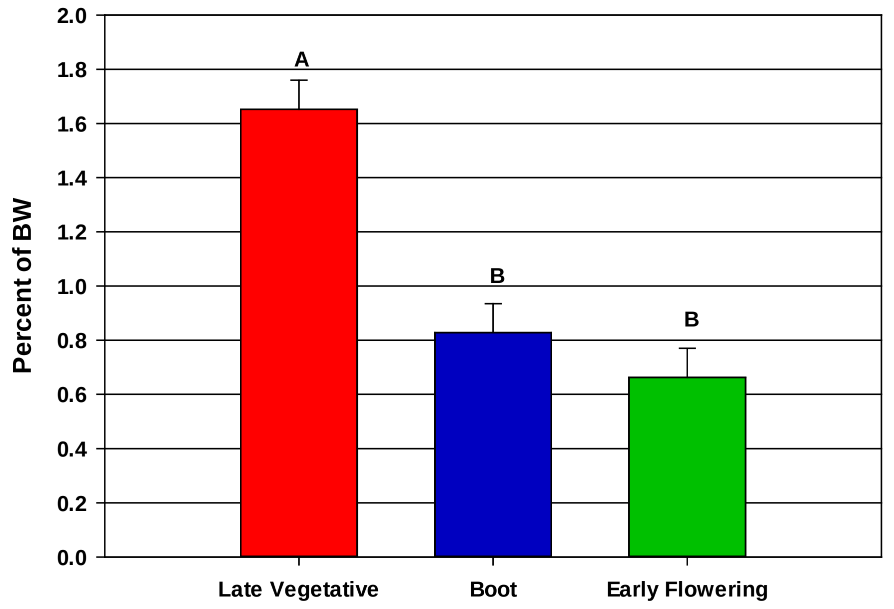

Figure 2.5. Apparent digestible dry matter intake (DDMI) for three maturities of Alamo switchgrass hay consumed by beef steers over two feeding trials in 2011. *Different Letters indicate significant difference between bars at $P \leq 0.05$

Table 2.14. Comparing Least Squares Means* of digestible dry matter intake (DDMI) between three different maturities of Alamo switchgrass hay fed to beef steers (200-265 kg) in two feeding trials in 2011.

	DDMI		DDMI	Difference	Pr>t
	----% BW----		--------------% BW-----------------		
Late-vegetative	1.7	Boot	0.8	0.9	<0.0001
Boot	0.8	Early Flowering	0.7	0.1	0.28502
Late-vegetative	1.7	Early Flowering	0.7	1.0	<0.0001

*LS means were derived from two feeding trials

Maturity had an effect ($p<0.0001$) on apparent daily DDMI of Cave-in-Rock when consumed by beef steers (Table 2.11). Estimated apparent DDMI by beef steers was significantly less ($p<0.05$) when steers consumed Cave-in-Rock hay harvested at the early flowering stage of maturity. No significant difference ($P>0.05$) was observed when steers which consumed the late-vegetative hay were compared with steers that were fed hay harvested at boot stage (Figure 2.6). Apparent daily DDMI by beef steers that consumed Cave-in-Rock hay harvested at the late-vegetative, boot, and early flowering stages was 1.3% BW (2.6 – 3.4 kg), 1.2% BW (2.4-3.2 kg), and 0.7% BW (1.4 – 1.9 kg) steer^{-1} for each respective hay harvest. On average, apparent DDMI was estimated to be 18.5% BW (37.0 – 49.0 kg) steer^{-1} day^{-1}less for steers that consumed the early flowering hay than for steers that consumed hay harvested at the late-vegetative stage of maturity. These steers also consumed 16.2% BW (32.4 – 43.0 kg) steer^{-1} day^{-1} less than steers that consumed Cave-in-Rock hay harvested at boot stage.

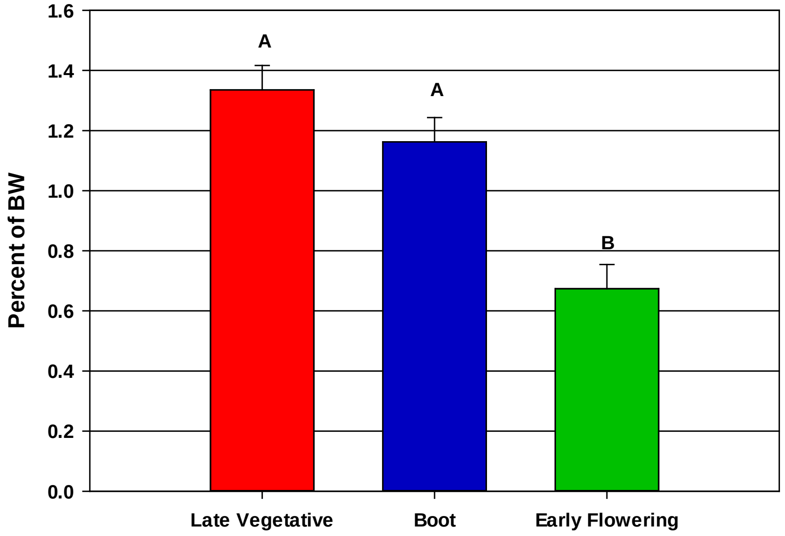

Figure 2.6. Apparent digestible dry matter intake for three maturities of Cave-in-Rock switchgrass hay when consumed by beef steers (200-265 kg) over two feeding trials.
*Different letters indicate significant difference between bars at P ≤ 0.05

Table 2.15. Comparing Least Squares Means* of digestible dry matter intake (DDMI) between three different maturities of Cave-in-Rock switchgrass hay fed to beef steers (200-265 kg) in two feeding trials in 2011.

	DDMI		DDMI	Difference	Pr>t
	----% BW----		--------------% BW----------------		
Late-vegetative	1.3	Boot	1.2	0.1	0.1461
Boot	1.2	Early Flowering	0.7	0.5	<0.0001
Late-vegetative	1.3	Early Flowering	0.7	0.6	0.0003

*LS means were derived from two feeding trials

2.3 Discussion

Forage Nutritive Value

These results along with the findings of others (Anderson and Matches 1987, Burns et. al. 1997), suggests that managing switchgrass stage of maturity at harvest is essential for forage quality. These results also indicate that the effect of maturity on forage quality is an extremely important consideration for producers harvesting both Cave-in-Rock and Alamo switchgrass hays.

Delaying switchgrass hay harvest until the stand reaches the reproductive stage resulted in the greatest decrease in forage quality. Increasing the stage of maturity at harvest had an effect ($P<0.0001$) on CP, NDF, and ADF in both the Alamo (Table 2.1) and Cave-in-Rock hays (Table 2.3). For both the Alamo and Cave-in-Rock hays, the greatest decrease in CP was observed when harvest was delayed past the late-vegetative to the boot stage. In fact, CP of Alamo hay harvested at the late-vegetative stage (13.5%) was almost double that of Alamo hay harvested at the boot stage (7.5%) (Table 2.2). Crude Protein in the Cave-in-Rock hay harvested at the late-vegetative stage (11.32%) was also double that at the boot stage (5.65 %) (Table 2.4). There was an additional decrease in CP ($P<0.05$) when harvest was delayed from the boot stage to the early flowering stage of maturity in both the Alamo and Cave-in-Rock hays, but the decrease was not as great when compared to that between the late-vegetative and boot stage (Table 2.4 and Table 2.5). It is also unlikely that a CP concentration of 7.5% or less in a forage would be satisfactory for many beef steer producers given observed DMI of the early flowering hay, and that the crude protein requirement for steers (250 kg) has been estimated at 450 g day^{-1} to support 1.0 kg steer^{-1} day^{-1} weight gain (NRC, 2000).

The results clearly show that NDF and ADF ($p<0.0001$) will increase for both Alamo (Table 2.1) and Cave-in-Rock hay (Table 2.3) as harvest is delayed. Increases in NDF have been associated with limited intake (Van Soest, 1987, Mertens, 1994). Increases in ADF have been associated with decreased digestibility (Van Soest, 1987). For both Alamo and Cave-in-Rock hay, the greatest increase ($P<0.05$) in NDF and ADF occurred as harvest was delayed past the late-vegetative stage of maturity to the boot stage of maturity. There was a further increase ($P<0.05$) in NDF and ADF as harvest was delayed from the boot stage to the early flowering stage of maturity, but the difference between the two maturities was not as great (Table 2.2 and Table 2.4).

Intake and Digestibility

There is strong evidence ($p<0.0001$) to suggest that stage of maturity at harvest has an effect on apparent dry matter intake by beef steers consuming Alamo and Cave-in-Rock switchgrass hay (Table 2.5). Delaying the harvest of Alamo after the late-vegetative stage of maturity reduced apparent DMI. For steers that consumed Alamo harvested at the late-vegetative stage, apparent DMI was higher ($P<0.05$) than steers which consumed the hay harvested at the boot, and early flowering stages. In fact, in terms of body weight, there was no difference

(P>0.05) in apparent DMI between steers that consumed Alamo harvested at the boot stage and steers which consumed Alamo harvested at the early flowering stage (Figure 2.1). Apparent DMI of Alamo hay harvested at the late-vegetative stage of maturity exceeded 2.0% BW, but apparent DMI by steers that consumed Alamo harvested at the boot and early flowering stages of maturity consumed less than 1.3% BW (Table 2.6).

Delaying harvest of Cave-in-Rock from the late-vegetative to the early flowering stage of maturity reduced apparent DMI (P<0.05). In fact, a decrease in apparent DMI (BW) of 0.6 percentage units was observed when comparing between groups of steers that consumed Cave-in-Rock hay harvested at these two different stages of maturity (Table 2.7). Apparent DMI by steers that consumed Cave-in-Rock hay harvested at the boot stage of maturity was not different (P>0.05) when compared to steers which consumed the late-vegetative or early flowering hay (Figure 2.2). The results do not show an effect of increasing maturity on apparent DMI as harvest was delayed past the late-vegetative stage to the boot stage, but apparent DMI of Cave-in-Rock was reduced as harvest was delayed to the early flowering.

Intake is an important quality parameter for all forage species, and has often been overlooked in favor of digestibility. However, digestibility and forage quality are meaningless unless an animal is able to consume a significant quantity of material. There are two very important factors that have been shown to affect intake that should be considered by farmers producing switchgrass hay for beef steers. The physical factors of forage or those factors that directly impact initial rumen fill and the rate of ingestion of the forage affect intake, and the size of the animal (Romney and Gill 2000).

Intake is especially important for beef steers since their rumen is not as developed as mature beef cows due to their size, age, and higher nutrient requirements. For switchgrass or any other forage to be suitable for animals, they must consume sufficient quantities for gain. The results of this research for both Alamo and Cave-in-Rock indicate that apparent DMI of the late-vegetative hay should not be a limitation for gain (Burns et al. 1997), but delaying harvest to the later stages of maturity reduces apparent DMI substantially. Based on these results for apparent DMI, producers harvesting switchgrass for hay should harvest at or close to the late-vegetative stage if feeding to beef steers.

There was a cultivar x maturity interaction ($P<0.05$) effect on apparent DMD of Alamo and Cave-in-Rock switchgrass (Table 2.8). This suggests a genetic and/or environmental influence since cultivars were grown at two separate locations. The effect of maturity was significant ($P<0.05$) on apparent DMD for both Alamo and Cave-in-Rock. However, the apparent DMD decreased differently for the two cultivars.

Apparent DMD by steers consuming Cave-in-Rock did not decrease (P>0.05) as the harvest was delayed from the late-vegetative to the boot stage (Figure 2.4). However, apparent DMD decreased by 16.2 percentage units when Cave-in-Rock harvest was delayed from boot to early flowering (Table 2.10).
For Alamo, apparent DMD of the late-vegetative hay was greatest (P<0.05) (Figure 2.3). On average, apparent DMD by beef steers that consumed Alamo late-vegetative hay was 11.0 percentage units higher (P<0.05) than steers consuming hay harvested at the boot stage, and it was15.9 percentage units higher than for steer consuming the early flowering hay (Table 2.9). On average, apparent DMD of Alamo hay by beef steers decrease by 4.89% when steers fed the hay harvested at the boot stage where compared to those which consumed hay harvested at early flowering (Table 2.9).

The different trends of apparent DMD for steers that consumed Alamo (Figure 2.3) and Cave-in-Rock (Figure 2.4) switchgrass in this study seem to suggest that the maturity effect was not as pronounced in early hay harvests for Cave-in-Rock. This was perhaps due to the physiological growing characteristics of this upland cultivar. In central KY, Cave-in-Rock switchgrass has a more leafy appearance, and possibly reduced stem material in delayed harvests early in the growing season. Alamo, the lowland type, matures more rapidly; and has more stems. Alamo was most digestible at the late-vegetative stage as evidenced by its apparent DMD. However, apparent DMD decreased to below 65% when harvest was delayed to the boot stage of maturity, and decreased further as harvest was delayed to early flowering (Figure 2.3). For steers consuming Cave-in-Rock switchgrass, the apparent DMD decreased below 55% as harvest was delayed from boot to the early flowering stage (Figure 2.4). This is why Cave-in-Rock is more widely recommended as a switchgrass hay crop for feeding beef cattle in Kentucky. Cave-in-Rock has a wider window of harvest which gives more flexibility in harvest management, and still maintains an adequate level of DMD.

Apparent DDMI of Alamo decreased ($P<0.05$) half as harvest was delayed past the late-vegetative stage (Figure 2.5). Apparent DDMI of Alamo decreased from 1.7% of BW to 0.8% of BW when steers which consumed the late-vegetative hay were compared to those that consumed hay harvested at the boot stage of maturity (Table 2.12). Apparent DDMI of Cave-in-Rock showed a decreasing trend ($P>0.05$) as harvest was delayed from the late-vegetative to the boot stage, but it decreased ($P<0.05$) by almost half when harvest was delayed from the boot stage to the early flowering stage of maturity (Figure 2.7). Apparent DDMI for Cave-in-Rock harvested at the boot stage was 1.16% of BW, but decreased to 0.67% BW for Cave-in-Rock harvested at the early flowering stage of maturity (Table 2.13).

Apparent DDMI is important as it estimates the digestible dry matter portion of the hay that is fed that will actually be consumed. Another way to think about this is to consider that it is measuring the usable energy portion of the hay that is harvested. Energy is very important for all facets of beef production, but its importance is magnified in the production of beef steers because of the increased energy requirements for gain in growing steers. If the end use of Alamo hay is to feed beef steers, it is highly important to harvest it before boot stage when DDMI is the highest. Planting Cave-in-Rock for hay may be a better in Central Kentucky. In this study, Cave-in-Rock offered more harvest flexibility in terms of apparent DDMI. Harvesting hay at the late-vegetative stage can be difficult in most years due challenging hay harvesting, and weather conditions. Even planning to harvest at the boot stage can be difficult. However, if producers intend to harvest at the late-vegetative stage, but are delayed due to inclement weather, these results indicate Cave-in-Rock would be the better cultivar under those conditions in terms of apparent DDMI.

Producers should make it their goal to harvest Alamo and Cave-in-Rock hay at the late-vegetative stage for feeding beef steers. This was indicated in terms of forage nutritive value (CP, NDF, and ADF concentrations) of both cultivars. Producers should keep in mind that switchgrass is a lower quality forage when compared to cool season grasses at similar stages of maturity. This is evidenced by lower CP concentrations, and higher fiber concentrations than other cool season forages harvested at similar stage of maturity (Duble, Lancaster, and Holt 1971). As Alamo and Cave-in-Rock switchgrass matures past the late-vegetative stage of maturity, the fiber concentrations increases rapidly, and the CP concentration decreases rapidly. Given the low CP concentration of Cave-in-Rock of less than 6%, if hay is harvested after the late-vegetative stage, it should be not be feed to beef steers. This study indicated that apparent DMD of Alamo by beef steers decreases has harvest is delayed, and the greatest decrease was observed as harvest was delayed from the late-vegetative to the boot stage of maturity. The greatest decrease in apparent DMD of Cave-in-Rock consumed by beef steers was not indicated in this study until after the boot stage. The results of this study also suggest a similar trend for apparent DDMI. However, given the difficulty of harvesting hay in Kentucky, and a rapid decrease in CP concentration, harvesting hay at the late-vegetative stage of maturity should be the goal of producers harvesting Cave-in-Rock or Alamo switchgrass for hay in Central Kentucky.

2.4 Conclusions

For farmers producing switchgrass for feeding livestock, it is very important to manage switchgrass maturity at harvest. With few exceptions, waiting past the late-vegetative stage of maturity greatly reduces forage quality, and this in turn reduces its effectiveness for feeding beef cattle. Even when switchgrass is harvested at an earlier maturity, it is doubtful that it would be very useful as hay in a stocker back-grounding operation given its lower forage value, lower apparent DMI, and lower digestibility. It is highly probable that a feeder calf diet based upon switchgrass hay would not result in optimal beef performance. At best switchgrass hay should probably only be considered for a maintenance diet for dry beef cows when nutrient requirements are at their lowest. However, future studies should be conducted to evaluate switchgrass hay for feeding beef cows.

Another option for feeding beef steers with switchgrass is through grazing. Due its high growing point switchgrass would not be good in a continuous grazing operation, but would require rotational grazing for long term stand management. Rotationally grazing switchgrass might allow steers to selectively graze the leaves, and allow them to avoid the portions of the forage that are higher in fiber, and of lower forage quality. It would also allow steers to consume switchgrass at the late-vegetative stage of maturity, when forage quality is best, and might also allow for better gains. In a recent study conducted at the University of Tennessee over 2 years, steers allowed to graze switchgrass for 30 days in the early summer months exhibited averaged gains of 1.0 kg steer-1 day^{-1}. Later in the season, the switchgrass stands were allowed to grow, and harvested for late season biomass in a dual use production system (Keyser et al., 2012). In that same study steers that were rotationally grazed on switchgrass for 60-95 days for the entire season exhibited gains of 0.75 kg steer^{-1} day^{-1} (2012).

The best potential use of switchgrass in Kentucky initially came from its potential use as a duel use crop. Using switchgrass as a dual use crop not only incorporates it as a feed source for cattle, but in this system it would also be marketed for the production of bioenergy. However, recent interest in using switchgrass for producing energy has decreased in Kentucky. Much of the needed infrastructure has not been created to sustain the potential use of switchgrass as a bioenergy crop. For producers that already have switchgrass established, at this point there best utilization of the crop is as forage. Its use for forage has already had some benefit for Kentucky farmers.

Danny Blevins, Tom Malone, and Robert List are all farmers in Eastern, Kentucky who originally planted switchgrass as a biomass crop, but now maintain the stands as forage. For these producers and others like them, switchgrass was particularly useful for feeding beef cattle under dry conditions when traditional forages where not as readily available. Even under less than favorable weather conditions in 2012, beef cows fed switchgrass on these farms maintained favorable body condition when cattle that did not have access to switchgrass were not as well conditioned.

For producers that do not already have switchgrass established on their farms, there are many challenges that might hinder them planting it. It might be very difficult for producers to harvest Alamo switchgrass at the vegetative stage of maturity, or by the boot stage for Cave-in-Rock given usual weather conditions in Kentucky. It also takes at least three years to get the crop established.

There are many more summer forages that may be better for some producers. For instance, alfalfa has already been widely used by many producers as a very productive hay crop throughout the spring, summer, and fall months. Recent plant breeding innovations such as the release of “round-up ready” cultivars have made this an even easier crop for Kentucky producers to manage. Still, not all soils are adequate for the production of alfalfa. There are also annual warm season forages such as sorghum x sudangrass, and millets. These crops can be harvested in the same season that they are planted instead of waiting for the 3 year establishment period needed for switchgrass. However, these have to be planted every year. Coastal bermudagrass and gamma grass are two perennial warm season forage crops that could be implemented as a summer grazing crop.

Despite many of these challenges, switchgrass may still be an option for some Kentucky growers that are producing forage on more marginal ground that is not suited for annual cropping, tillage, or for alfalfa production. Some producers may also desire the potential benefit of wildlife habitat that comes from switchgrass. There is also the potential for cost share in which some or all of the cost of establishment is paid by governmental incentives programs through the Natural Resource Conservation Service and other agencies. These incentives highlight the need to continue researching switchgrass as a forage crop.

Producer desiring to feed switchgrass hay to beef steers in Kentucky need additional findings to help them make their management decisions. Apparent digestibility and intake may provide some insight on management considerations for switchgrass, but do little to help producers understand the “bottom line”.

Future research regarding harvest stage of maturity should be long enough to allow an estimation of gain, cost of gain, and consider other factors such as production efficiency. Switchgrass hay supplementation, cost of supplementing beef steers, and recommended supplements should be considered to give Kentucky producers that currently are utilizing switchgrass additional knowledge for improving their operations. Grazing studies and better understanding how to manage grazing cattle on switchgrass would be very beneficial for Kentucky producers. Studies on the effect of maturity on dry mature beef cows would also benefit many Kentucky producers.

Newer technologies, and forage markers can be utilized in future feeding trials to help in this endeavor. Also, future research regarding the stage of maturity at harvest should implement plant morphological means of measuring maturity. For instance, a scale based upon plant morphology that was developed by M.A. Sanderson (1992) could be used as a way to more precisely estimate and communicate the stage of maturity at each harvest. In the current study, the hays were also ground using a tub grinder for ease of feeding. Few Kentucky Beef producers have access to this technology, and most feed their switchgrass as long stem hay. This probably has an effect on DMI, and DMD. A future study might be conducted to gain a better understanding of the effect of grinding.

Further research is also needed for the differences between Alamo, Cave-in-Rock, and other cultivars of switchgrass for feeding beef cattle. These studies should be focused to better understand differences deriving from the different growing characteristics of the cultivars. Producing these cultivars at the same location would also help to rule out environmental causes of differences in relation to forage quality. In the current study, this could not be accomplished due to the lack of available hay supply.

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VITA

David Harold Davis attended high school in Burnsville, North Carolina and graduated with honors in May 2005. He began attending Berea College located in Berea, Kentucky in August 2005. During his college career he was a student assistant manager for the beef cattle enterprise at Berea College Farm from August 2006 to May 2008, and was student manager for the beef cattle enterprise at the Berea College Farm where he served from May 2008 until May 2009. He also completed a summer internship with the North Carolina Cooperative Extension Service as a research support technician at Mountain Horticulture Research Experiment Station located in Fletcher, North Carolina under the direction of Dr. Kelly Ivors, Plant Pathologist with North Carolina State University, from July to August 2008. David earned a Bachelor's of Science in Agriculture and Natural Resources from Berea College in May 2009. From May 2009 to April of 2010 he was Farm Assistant Manager at Davis Farms, his family's farm located in Burnsville, North Carolina. He was a Graduate Research Assistant for Dr. S. Ray Smith at the University of Kentucky from 2010 until August 2012. He currently works as the Cooperative Extension Service Agent for Agriculture and Natural Resources in Clark County, Kentucky, and will complete a Master's of Science in Integrated Plant and Soil Science in August 2014.