

Economic Pasture-Based Cow-Calf Systems for Appalachia

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ABSTRACT

Pasture-based beef production is well-suited for the Appalachian region of the United States. This research investigated pasture, beef cattle, and economics components within the cow-calf sector of pasture beef production, and presents implications of their interplay for the vitality of the whole system. Samples of forage DM mass and CP, ADF, NDF, and ash contents in each paddock of a rotational stocking system were collected monthly for 4 grazing seasons. Effects of month, stockpiling, hay feeding, temperature, precipitation, and durations of paddock grazing and rest on forage mass and quality measurements were investigated. The system was complex and dynamic; precipitation and rest days in particular showed clear interactions with both month and stockpiling when predicting forage mass and quality. Available DM, TDN, and CP were compared to nutrient density requirements for beef cows to conclude that the system met or exceeded requirements. Six years of production data from a spring-calving cow-calf enterprise that utilized rotational stocking and fall stockpiling were analyzed. Comparisons among 2 cow frame size and 2 calf creep system treatments for production efficiency (total weaning weight per land area), and net returns to the enterprise, were made. Pastures with medium frame cows and designated creep systems had the greatest production efficiency, but also had the highest costs and netted the least returns. Greatest net returns were achieved in large frame, forward creep systems, which had the lowest production efficiency but also the lowest

costs. Provided the quality of calves produced is suitable for other phases of the production stream, we conclude that minimizing costs rather than maximizing productive outputs is a better focus for cow-calf enterprises faced with similar decisions among frame size and creep system treatments.

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CHAPTER 1: INTRODUCTION

GENERAL INTRODUCTION

This research is part of a larger systems project funded by the USDA-ARS entitled “Economic Pasture-Based Beef Systems for Appalachia.” The project was designed to investigate profitable means of using beef production to capitalize on the abundant grassland in the Appalachian region. It involves several institutions cooperating to study soil, plant, animal, and economic interactions in all phases of the beef production stream. Research conducted by Virginia Tech at the Shenandoah Valley Agricultural Research and Extension Center (SVAREC) emphasizes production systems for the cow-calf and backgrounding phases. An overarching agreement and specific objectives for Virginia Tech’s role in this project can be found at http://www.ars.usda.gov/research/projects/projects.htm?accn_no=414225. This dissertation research seeks primarily to aid in addressing subobjective 1.1: *Evaluate the use of variation in frame scores of sires and dams and different creeping systems to expand the harvest window of grass-fed beef.*

In this context, the dissertation will specifically address three components of the project title: pasture, beef, and economics. Following a review of the literature (Chapter 2), the experimental analyses for each of the three components will be organized into the following chapters:

- Chapter 3: Describing a rotational stocking system: Approaches for describing forage dynamics in a rotational beef cattle stocking system

- Chapter 4: Beef cow carcass ultrasound validation: Use of ultrasound scanning and body condition scores (BCS) to evaluate composition traits in mature beef cows
- Chapter 5: Cow-calf production and economics: Effects of mature size and creep grazing system on cattle performance and net returns for a pasture-based cow-calf system in Appalachia

The chapters will each serve as standalone papers for publication, but the ways in which their components interact to define the system as a whole is of paramount importance. Therefore, a synthesis of Chapters 3-5 will be presented in a final chapter. It is understood that this research explains only a fraction of the total system in terms of environmental, economic, and social sustainability of regional pasture beef production systems. The hypotheses that follow are intended to investigate specific factors and their interrelationships within the cow-calf sector of pasture-based beef production, and to make an important contribution to the full story.

INTRODUCTION OF HYPOTHESES

Hypotheses specific to pasture (Chapter 3)

Pasture ecology plays a vital role in the overall system. It supplies the nutrition necessary to fuel beef cattle performance and profitability, and pasture health is crucial to maintaining long-term sustainability. Understanding the dynamics of forage mass and quality and the factors that influence them is vital for proper pasture management. Rotational stocking systems present advantages for both cattle and forage; however, they are particularly complex and thus challenging to describe. This project will involve analyzing previously-collected records of

forage mass and quality, weather patterns, and cattle stocking in a rotational stocking systems. Its main objectives are to 1) describe patterns in forage mass and quality throughout 4 grazing seasons, 2) identify the factors influencing these forage dynamics, and 3) evaluate the ability of the forage system to meet the nutritional needs of grazing beef cattle.

In general, forage growth and composition are most likely influenced by factors including forage species, soil type, time of year, weather, etc. However, the transitional nature of rotational stocking systems necessitates that, even when all of these factors are constant, different paddocks within the system are at different points in a rotation. Hence, at any given time, their forage contents are expected to vary. One specific goal for this analysis is to develop methods to account for differences in rotation status, while seeking to identify the factors that influence forage mass and quality and the ways in which these factors interact.

Hypothesis 1: When other major sources of variation are accounted for, forage quantity and quality can be accurately predicted by variables denoting the days since a paddock was last grazed, the number of days it was grazed in the previous rotation, and/or the number of days it had been grazed immediately prior to sampling.

The use of winter “stockpiling”, where cattle graze forage mass in the late fall that has been rested for several months, offers the potential to extend the grazing season and reduce overwintering costs for tall fescue-based pastures in the Appalachian region. However, stockpiling has implications during other parts of the year(s), which likely affect forage characteristics in all paddocks in ways that are not fully understood.

Hypothesis 2: When predicting measurements of forage quantity and quality, a paddock’s stockpiling designation (i.e., whether to be stockpiled or not) has significant effects

and also interacts with others sources of variation including month, temperature, precipitation, and/or duration of paddock rest.

A final difference in the management of the SVAREC paddocks is the confinement of cows to specific paddocks during the winter months when hay is fed. In addition to the heavy stocking during winter, hay feeding paddocks are generally rested longer than others the subsequent spring. Hay feeding may affect the quantity and/or quality of forage on offer in that paddock in the following grazing season.

Hypothesis 3: When predicting measurements of forage quantity and quality, a paddock's hay feeding designation (i.e., whether hay was fed in the previous winter or not) has significant effects and also interacts with others sources of variation including month, temperature, precipitation, and/or duration of paddock rest.

Once the factors and interactions influencing forage mass and quality in the system are understood, the question of practical importance to cow-calf production is whether the resulting forage is adequate to meet the nutritional needs of grazing cow-calf pairs. If it is not, investigating the factors contributing to any deficiencies, and making appropriate adjustments to management is warranted.

Hypothesis 4: The forage mass and quality produced as the result of management and all other influencing factors meets or exceeds the nutritional requirements of the grazing cattle during all points of the grazing season.

Testing these hypotheses to better understand the forage characteristics and managerial components of the grazing system should not only strengthen its description, but should add value to the evaluation and comparison of cattle performance in Chapter 5.

Hypotheses specific to ultrasound scanning (Chapter 4)

Mature size and body composition can affect nutrient requirements, food intake, reproductive efficiency, cull value, and/or progeny growth potential of beef cows. Accordingly, they have key implications for profitable cow-calf systems. Historically, the SVAREC researchers assessed mature size with body weight and hip height, and composition with body condition score. While these measures are commonly used in the beef industry, they do not specifically, or objectively, assess fat and muscle tissue contents. Changes in these tissue measurements and their relative proportions are expected to occur during the beef cow production cycle; specific and objective measures of cow composition might allow better prediction of cow productivity as compared to traditional measurements.

Ultrasound has been shown to be useful for assessing fat and muscle in young animals, but it has not been widely used to evaluate composition in mature beef cows. This chapter investigates the use of ultrasound as a tool to better describe mature cow size and composition. Of interest are both the precision and accuracy of measurement, when the technology is used by experienced technicians. Statistics for evaluating precision and accuracy are used commonly by the Ultrasound Guidelines Council (UGC) for young beef animals. These statistics include correlation, bias, and standard error, for both repeated ultrasound measurements on the same animals and prediction of carcass measurements. Very few of these statistics have been previously reported for mature beef cows.

Hypothesis 5: Ultrasound measures of fat and muscle in live cows are repeatable across multiple measures on the same animal, as measured by correlation between repeated measures, repeatability bias, and standard error of repeatability.

Hypothesis 6: Ultrasound measures of fat and muscle in live cows are accurate measures of the analogous traits in a carcass, as measured by correlation between ultrasound and carcass measures, prediction bias, and standard error of prediction.

If the UGC statistics generated from a well-designed cow ultrasound validation study are within an acceptable range, they can be used to infer that the ultrasound methods are suitable for use in mature cows of similar type. However, cow populations are expected to differ significantly, and variation among animals is not explicitly considered in the construct of the UGC guidelines. Understanding of the impact of cow variation on UGC statistics is likely needed to draw conclusions about ultrasound reliability that can be generalized to other cows.

Hypothesis 7: Both repeatability bias and prediction bias are influenced by the variation in the animal population that is used to generate them, as indicated by a significant animal effect in models predicting the difference between measurements.

In addition to its implications for the larger beef industry, validation of ultrasound measurement of composition in mature cows would strengthen the use of ultrasound in the research described in Chapter 5.

Hypotheses specific to beef production (Chapter 5)

The overarching goal of the experimental program at SVAREC is to improve the efficiency of cow-calf production. Efficiency is merely a ratio of outputs to inputs, but it has historically been defined in many ways. At the animal level, an “efficient” cow might make better metabolic utilization of nutrients, wean a heavier calf relative to her own body weight, and/or be more likely to rebreed. However, holistic analysis of cow-calf systems expands beyond

evaluation of the individual cow to consider efficiency at the farm or enterprise level. This research evaluates beef cow-calf system efficiency in two contexts: production efficiency defined by the weight of calves produced per land area, and economic efficiency quantified by overall net returns to the cow-calf enterprise. The experiment was designed to investigate two major factors that could influence production and or economic efficiency: mature cow size and creep grazing system.

Mature cow size can influence efficiency in several ways. Cow-calf systems are rewarded for the total weight of weaned calves sold, and a positive correlation between mature size of cows and the growth rate of their calf progeny is widely acknowledged. However, total weight of calves sold from a production unit is also influenced by the number of calves produced from that unit. In this sense, larger cows could have several disadvantages. A greater number of smaller cows can be stocked on a similar area. Larger cows have increased nutritional requirements, which may not be met in systems based entirely on pasture, and smaller cows with less-limited nutrition may demonstrate greater reproductive performance. One or both of these factors could contribute to a greater number of calves sold per similar land area. The breeding program at SVAREC was designed to create 2 mature size classifications. Cows were considered either “large” or “medium” frame size based on parentage and hip height, and paddocks were stocked with either 8 medium or 7 large frame cows to have similar total cow weight per land area.

Hypothesis 8: When offered similar quantity and quality of forage, medium frame cows produce more total weight of saleable calf per land area due to greater stocking rate and/or greater reproductive efficiency, despite disadvantages in individual calf weight.

At SVAREC, calves were either given access to forward creep in the next fescue-clover paddock to be grazed by their dams, or to a designated creep area that remained fixed throughout

the season. The designated creep plots had been seeded with a nil-ergot, endophyte-infected fescue (MaxQ) and alfalfa. The improved forage in the designated creep area is expected to be conducive to greater calf growth.

Hypothesis 9: A designated creep area providing higher quality forage to calves results in heavier weaning weights than forward creeping calves ahead of their dams on the same fescue-clover forage base.

The principal objective of this research is to identify cattle types and creep strategies that will yield greater net returns for pasture-based cow-calf production systems. Revenues will be calculated by multiplying the productive outputs considered in hypotheses 8 and 9 by an appropriate sale price per weight. Costs including hay, medication, and breeding expenses for cows differing in mature size, and fence and reseeding for the creep treatments, will be subtracted from revenues to calculate net returns.

Hypothesis 10: Within the SVAREC system, when all relevant income and expenses are accounted for, the “medium” cows result in greater net returns than “large” cows.

Hypothesis 11: Despite greater establishment costs, a designated creep area providing higher quality forage to calves results in greater net returns than forward creeping calves on the same forage base as their dams.

CHAPTER 2: LITERATURE REVIEW

GRASSFED BEEF

The Appalachian region of the United States consists of an abundance of hilly, marginal land not well-suited for row crops or many other agricultural endeavors (Scaglia et al., 2008). Beef cattle are able to graze hilly terrain, consume forages that are lowly digestible by humans, and convert that fibrous material into beef products that humans can utilize (Burns, 2008). Compared with other areas of marginal land across the country, the Appalachian region is fortunate to have proximity to the relatively dense human population of the Eastern seaboard (Evans, 2003; Young, 2006), minimizing one hurdle in the product distribution stream. Additionally, consumers have demonstrated an interest in the health and societal benefits of pasture-raised beef and, more importantly, a willingness to pay for the product (Evans, 2007a).

In order to meet this demand, research that is focused on defining the production efficiency of grassfed beef, in both biological and economic terms, is needed. Beef production efficiency has been explored in the scientific literature for decades (Kress et al., 1969; Dickerson, 1970; Kirkpatrick et. al, 1985; Naazie et al., 1999; Johnson et. al, 2010), and has been comprehensively reviewed several times (Morris and Wilton, 1976; Harris and Newman, 1994; Jenkins and Ferrell, 2002). It may therefore seem that the topic would by now be well-understood, yet continued studies remain warranted (Johnson et al., 2010). The challenge of defining and measuring efficiency can be largely attributed to the variation in management and natural environments used for beef production (Echols, 2011), and therefore efficiency must be defined within the context of a specific system (Johnson et al., 2010). For determining optimal

production systems, Cartwright (1979) emphasizes that overall synthesis is as or more important than exactness of information within the subdisciplines. However, in evaluating beef production efficiency, careful attention given to describing the specific environment in which cattle are asked to perform efficiently is a necessary first step.

FORAGE GRAZING SYSTEMS

Describing grazing systems

Grazing systems are biologically dynamic (Burns, 2008), and can be challenging to describe. Despite their clear interrelationship, it is common for forage management and beef management to be considered separately in the academic literature (Young, 2006; Burns, 2008), and most studies describing animal performance on pasture did not describe the pasture dynamics in exhaustive detail. Studies that described plant and animal relationships in detail generally focused on a few specific cause-effect relationships (Van Keuren, 1970; Holloway and Butts, Jr., 1984), or used artificial harvest methods to imitate defoliation by grazing cattle (Burns et al., 2002).

Others used simulation to investigate these relationships and draw inferences about cattle performance (Long et al, 1975; Notter et al., 1979), plant response to defoliation (Noy-Meir, 1976), intake (Brereton et al., 2005), and/or economic and ecological risk (Kaine and Tozer, 2005). While simulation offers valuable tools for evaluating risk (Newman et al, 2012) and aiding in managerial decision-making in rapidly changing operations (Cros et al., 2004), and can often do so with less expense and effort than actual field experiments (Woodward et al., 1995),

the parameters used in such deterministic models still require knowledge of the field conditions. This knowledge more than likely requires field experiments.

Forage characteristics

The morphology, accumulation, and nutritive value of forage species have been studied at length in the plant sciences. However, these studies frequently do not use empirical data collected from actual grazing systems, and such work was not the focus of this review. However, despite little to no animal component, several works from the agronomy literature provided useful background information for the seasonal growth rates (Denison and Perry, 1990) and responses to defoliation intensity (Burns et al., 2002) of tall fescue, a cool season grass that is common in Appalachia. Fescue is so ubiquitous in the region that seldom is it not mentioned in the grazing literature. On one hand, fescue's hardiness and adaptability provide an easily-established, persistent and productive source of forage dry matter if properly managed. On the other hand, the endophyte content of unimproved fescue varieties pose health and reproductive challenges for cattle (Poore and Drewnoski, 2010). Together, these attributes of fescue are a central focus in discussions of the management of beef grazing systems in Appalachia.

Stockpiling

The morphology and seasonal growth of fescue allow it to be accumulated during the fall months and reserved for winter grazing in a practice called stockpiling (Poore and Drewnoski). Despite that winter hay feeding has been shown to have no negative effect on forage growth and

to offer potential benefits to forage production and land improvement (Flores and Tracy, 2012), hayfeeding is expensive and labor intensive. Stockpiling allows for a reduction in winter hay feeding costs (Poore and Drewnoski, 2012) and accordingly has won favor with many Appalachian graziers and is usually discussed in the associated scientific literature.

Rotational stocking

Another management practice that is commonly discussed is rotational stocking, or the practice of dividing a pasture into paddocks and controlling the movement of cattle through the paddocks, giving designed recovery periods in between grazing events. Compared to continuous grazing, rotational stocking systems offer opportunities for progressive producers to capture greater forage and animal production from similar land area (Blaser et al., 1986).

However, such systems present still greater challenges to portray (Noy-Meir, 1976). In rotational stocking, managerial decisions affecting order of paddock rotation, intensity of grazing and duration of rest are often made subjectively, in response to factors such as temperature, rainfall and forage growth with the goal of controlling animal output (Blaser et al., 1986). Simulation has shown that managerial decisions in rotational grazing have a profound impact on production and resulting profit (Cros et al., 2004); successful rotational stocking management is seldom based purely on a clock or calendar. Moreover, decisions may result in antagonistic outcomes with respect to economic and biological stability (Kaine and Tozer, 2005). Clearly, the value of accurate portrayal, if possible, is evident.

To address the complexity of rotational stocking systems, several novel approaches to statistical modeling of pasture systems have been used, including the use of predator-prey graphs

to represent animal-plant dynamics (Noy-Meir, 1975). Deterministic models for forage growth or herbage utilization from rotational grazing studies are largely a reflection of the experimental design. Such practices as fixing the duration and order of paddock grazing (Brereton, et al., 2005; Woodward et al., 1995) may simplify the mathematics involved in statistical models, but they also may cause the results to be less applicable to other situations. Characterizing dynamic grazing systems may therefore necessitate a shift in the paradigm and vocabulary with which grazing management (Scarnecchia and Kothmann, 1982) and grazing systems research are commonly approached.

Pasture beef production in the Appalachian region

Only a few studies specifically addressed pasture beef systems in Appalachian region (Allen et al., 1992; Whetsell et al., 2006; Scaglia et al., 2008; Flores and Tracy, 2012; Newman et al., 2012; Tracy et al., 2012). Their conclusions focused on forage types and management protocols that yielded a desired combination of plant and animal performance.

Allen et al. (1992) concluded that using fescue-ladino clover stands for summer grazing, and fescue-red clover for creep grazing, hay, and winter stockpiling, was the most optimal combination of forage establishment and persistence, cattle (weaning weight) performance, and mechanical and labor requirements. The findings of Whetsell et al. (2006) were limited in their value for this review due to the use of concentrates and the focus on the calf backgrounding phase. None of the pasture treatments tested by Scaglia et al. (2008) significantly affected cow performance, although some pasture regimens were demonstrated to result in heavier calf weaning weights. Generally, those treatments that produced the most calf production per land

area did not produce adequate hay to meet animal needs, implying an intermediate optimum in the context of economic and ecological sustainability. Flores and Tracy (2012) focused on implication of winter hay feeding and concluded that well-managed hay feeding could benefit forage production and improve land productivity through the spread of nutrients and the introduction of legumes. Newman et al. (2012) used bootstrap distributions from Monte Carlo simulation to assess the risk of filling the summer slump of tall fescue with warm-season forages. They concluded that warm season grasses did produce adequate yields and nutrient values to fill the summer slump, and of those forages tested, Teff was the most consistent in meeting the requirements. In a study using GPS collars to track calf movement, Tracy et al. (2012) concluded that calves spent greater time in designated creep grazing with improved forages. Forage sampling revealed that fall stockpiling and winter grazing had positive effects on forage productivity in the subsequent season. If these observations translate into increased animal performance (not measured), such systems may be the best option for beef producers in the Appalachian/fescue region.

Summary

Generally, the conclusions from many forage-animal experiments are limited in application (i.e., to that experiment) and care must be used when extrapolating results from one experiment to another (Burns, 2008) or from theory to application (Noy-Meir, 1975). A commonly-drawn conclusion is that efficiency of production is more a matter of matching forage and animal characteristics to one another than of excellence in any one aspect of forage

dynamics or animal type (Holloway and Butts, Jr., 1984). A focus on optimization rather than more traditional focus on maximization (Van Keuren, 1970) also seems warranted.

In summary, a review of the beef grazing literature reveals that historic separation of plant and animal science in academia have resulted in a relative shortage of studies focusing in detail on both forage and animal components. In sustainable models it is vital that both components be considered and that they work in synergy. The concern over whether conclusions are robust across environmental conditions or animal types is clear. With that in mind, the single most important conclusion drawn from the grazing literature is that the interaction of environmental conditions and animal type is likely more important than any single main effect in defining overall efficiency.

BEEF PRODUCTION AND EFFICIENCY

Definitions of efficiency

The topic of efficiency has generated considerable literature and debate in the beef production area for at least 100 years. Increases and volatility in grain and energy costs have contributed to recently renewed focus on beef production efficiency. Dickerson (1970) defined efficiency as the ratio of total costs to animal product from females and their progeny over a specified period of time. By defining overall efficiency, Dickerson (1970) did not delineate between biological efficiency, defined as conversion of physical inputs into product, and economic efficiency, which relates expenditures to receipts. Efficiency in both senses is a necessary goal for all agribusiness, since its bottom line depends on biology. Dickerson and

Willham (1983) expanded on this earlier definition of efficiency focusing on innovative genetic strategies for improving efficiency. A decade later, Harris and Newman (1994) reviewed the same topic quite thoroughly, with more emphasis on economic aspects.

Optimizing the relationship between biological and economic efficiency is complex (Johnson et al., 2010) and requires understanding and managing the physical environment, the genetic potential of the cattle, and the market conditions and objectives for products. Comprehensive analysis clearly considers all three aspects. The content of this section will focus on the biological efficiency of production, and conclusions drawn about trait relationships and animal types. While literature focusing on biological beef types often foregoes detailed description of the forage component, an interaction between the two is generally implied. Evaluations of the economic impact of biological conclusions, when specifically investigated, will be revisited in a later section. Otherwise, these interactions likewise will stand as implied.

Characteristics of efficiency

Dickerson (1970) described an efficient cow herd as one that exhibits high reproductive rates, early sexual maturity, longevity, minimum maintenance requirements, and the ability to convert available energy from forage into calf weaning weight. These factors translate into reduced herd costs per animal marketed and greater product value per female per unit of metabolic body size (Dickerson, 1970).

Davis et al. (1983) investigated breed and heterosis effects on efficiency over a wide range of beef and dairy breeds as crosses. Efficiency was defined as weight outputs relative to feed inputs, and several strategies were explored including weighting these components by their

probabilities based on age and percent calf crop distribution. Tradeoffs between diet energy level, cow salvage value, and calf weaning weight—as they affected lifetime efficiencies—were presented. Jenkins and Ferrell (1994) reinforced this concept that interactions between available resources and genetic potential must be appropriately considered when evaluating breeds and crosses for productivity. Similarly, Nugent, III et al. (1993) emphasized the significant effect of energy availability x biological type interactions on evaluation of post-partum interval.

A resounding theme in articles both reviewing the history of efficiency study and making predictions for its future (Morris and Wilton, 1976) is that the relatively recent advent of interdisciplinary research has redefined how efficiency is evaluated. Still, attempts have been made to predict efficiency, when defined as a ratio of outputs to inputs, with models including only measures on cows (and not inputs) as independent variables (Kirkpatrick et al., 1985). Especially given that many of the data were 3 decades old at the time of analysis, these models explained a surprisingly high proportion of the variation in weaning efficiency (defined as weaning weight relative to cow and calf inputs) with dam weight and weight:height ratio. Using these variables singly as predictors, R^2 values of 0.56 and 0.59, respectively, were achieved. However, the ability of these predictions to generalize to other genotypes, production systems, and/or natural environments is questionable. Naazie et al. (1999) provided a more extensive discussion on the rate of maturity and its effects on reproductive fitness, age at culling, and overall life-cycle herd efficiency. This work (Naazie et al., 1999) made an important distinction in the evaluation of the entire herd versus only mature cows, and described the interrelationships between maturity and production traits in painstaking detail.

Ferrell and Jenkins (1985) balanced the efficiency literature that was focused on outputs with an emphasis on inputs, specifically, energy requirements. The well-known “Nutrient

Requirements for Beef Cattle” (NRC, 1996) describes how energy is first allocated to support maintenance, then to growth, followed by lactation, and finally to reproduction. It follows that a negative energy balance (a cow unable to consume adequate energy to meet needs) would first negatively affect her reproductive success, a topic to be discussed in greater detail later. As Ferrell and Jenkins (1985) reinforce, 70 to 75 percent of a cow’s total annual energy requirements are needed for maintenance and variation in maintenance requirements is generally greater than in other requirements. While level of milk production is another commonly-evaluated trait with respect to nutritional needs (Holloway and Butts, Jr., 1984; Montaño-Bermudez et al., 1990a, b, c; van Oijen et al., 1993), the majority of nutrition studies seeking to improve efficiency focus on the most important and variable energy need: maintenance.

Since calf weight is a primary driver of income, and calf growth and cow size are positively correlated ($r = 0.60$ to 0.72 ; Cartwright, 1979; Costa et al., 2011), the consequence of selection for increased receipts from heavier calves can result in increases in cow mature size (Cundiff et al., 1993). A basic premise in animal nutrition is that larger animals have greater maintenance energy requirements. Nutritional resources to meet that requirement may be limited in pasture systems, particularly during certain times of the year. If this is the case, less nutrition can be allocated to supporting productive and reproductive processes (e.g., lactation and rebreeding).

Compared to focus on output per animal, a more holistic approach to systems management is evaluation of output per land area. Efficiency defined based on land area brings greater focus to the carrying capacity of the pastureland. Simply put, if a group of cows have greater nutritional needs for maintenance, fewer of those cows can be stocked on the same land

area without supplemental feeding. Again, as has been a biological maxim for centuries if not longer, larger animals are expected to have larger maintenance requirements.

MATURE SIZE

Mature cow size, as it relates to maintenance requirements, is usually a focal trait in discussion of efficiency in beef cattle, despite an entertainingly frank early paper (Klosterman, 1972) claiming that this focus was off the mark. Echols (2011) concluded that understanding the relationship between frame score and immature body weight, and utilizing mature size EPD in selection programs, could help producers match their herd genetics to their specific environment and feed resources.

Mature size is generally defined by weight, height, or a ratio of the two. However, height is one-dimensional and weight is largely influenced by gut fill and pregnancy, and the two thus have limited ability to describe nutritional plane and requirements (Eversole et al., 2009). Containing additional dimensions, weight would be expected to explain more variation in metabolism, but has lower heritability than height (Dib et al., 2010).

In attempt to better represent energy needs, metabolic weight (MW) is commonly used as an alternative definition of size. MW defines a relationship between body weight and surface area, and relates energy metabolism to body weight (BW). Houghton et al. (1990a) calculated MW as $MW = BW^{0.75}$, although this power coefficient used differs slightly in other works and is the object of some consternation.

Employing simulation to model efficiency of beef production in the context of mature size, Notter et al. (1979) presented an eloquent conclusion worthy of quotation, “If feed quality is

not limiting, if all animals are fed at the same level in relation to their body size, and if degree of maturity at weaning and at slaughter are the same for each size class, there are no indications that mature size *per se* has meaningful effect on the rate of conversion of TDN to weaning weight or empty body weight. However, these qualifications are not usually all met under conventional management and pricing systems.” This conclusion once again reinforces the systems approach that mature size is best evaluated only in the context of its natural and economic environment.

Costa et al. (2011) asserted that mature size was well-described in the literature, but selection for mature size had not been widely implemented in breeding programs. The authors used a multiple-trait approach using weaning and yearling weights, as well as mature weights recorded in 2- to 5-yr-olds from the American Angus Association to discern genetic variance and covariance parameters for mature size. Implications for genetic evaluation of mature size were presented. Dib et al. (2010) conducted a similar genetic analysis, but used a repeatability model. Using two different subsets from a large Angus database, heritability estimates ranged from 0.45 to 0.48 for mature weight, and from 0.62 to 0.64 for mature height. Kaps et al. (1999) and Northcutt and Wilson (1993) produced similar heritability estimates for mature weight ($h^2 = 0.44$ and 0.43, respectively), although neither appeared to include permanent environmental effects in the model fitted. If skeletal development is at all hindered by nutrition, it may be possible that the exclusion of permanent environmental effects contributed to the substantially greater heritability for mature height ($h^2 = 0.83$) reported by Northcutt and Wilson (1993).

COMPOSITION

The relationship between the metabolizable energy needed for maintenance, and composition, which is manifested in the live animal as body condition, is also a common topic in the literature. Body condition is an estimate of energy stores, and has been shown to be closely associated with reproductive performance (percentage open cows, calving interval) in an exhaustive list of animal science studies. Metabolic weight was shown to interact with condition score to influence the fasting heat production in dairy cows (Birnie et al., 2000). Composition also has implication for cow salvage value as discussed by Gresham (1986). However, determining metabolic needs, energetic efficiency or any other correlated trait requires accurate estimates of body composition (Gresham et al., 1986; Wagner et al, 1988).

Body composition can be estimated by weight, component parts, carcass density and specific gravity, or chemical dilution (Gresham et al., 1986, Laurenz et al., 1992). However, none of these methods provide an accurate, repeatable, easily-obtained and/or inexpensive measure that is both applicable to live animals and robust across a diversity of ages and composition (Ferrell and Jenkins, 1984).

Body condition scoring (BCS) uses a combination of visual appraisal and palpation to assess energy reserves. For BCS a numeric scale of 1 (emaciated) to 9 (obese) is used to distinguish nutritional planes and/or needs of beefs cows (Eversole et al., 2009), although some older studies (Houghton et al, 1990b) have followed a 5-point scale. The BCS has been identified as superior to other measures such as weight:height ratio in predicting composition, and BCS plus body weight gives more predictive accuracy than weight or metabolic weight alone (Houghton et al., 1990a).

Adjusting feeding regimen to achieve target body condition scores at strategic points in the production cycle can substantially improve reproductive performance (Houghton et al.,

1990b). Therefore BCS can provide a useful, inexpensive tool for improving the bottom line of beef production (Eversole, 2009).

Typically, carcass components are described by weights and/or percentages of three tissue types: fat, muscle, and bone. Predictive models including live weight, condition score, and frame score explained 59% and 77% of the variation in percentage carcass fat and carcass fat weight, 49% and 91% of the variation in percentage carcass protein and carcass protein weight, and 76% and 69% of the variation in percentage carcass bone and bone weight fat weight, respectively, in mature cows (Gresham et al., 1986).

Evaluation of changes in composition has shown that breeds deposit and retrieve tissue energy at differing rates, and with different orders or priorities of tissue depots (Laurenz et al., 1992). Interestingly, it was suggested that these rates and prioritizations were primarily mediated by melatonin as photoperiod decreases seasonally, with different breeds having different mediated responses. An earlier paper (Wagner et al., 1988) emphasized that the relationship between cow body composition and energy requirements for maintenance during winter is variable and has important implications. Breed differences in these relationships were discussed, but differences in melatonin mediation between breeds were not mentioned as a possible cause. The two breeds evaluated by Laurenz et al. (1992) both originated in regions with considerable seasonal change in photoperiod, and the breed differences in mobilization of energy as a response to cold stress were not fully evaluated.

Because decreased BCS indicates mobilization of both adipose tissue and muscle (Yamakawa et al., 2012), BCS and subcutaneous fat thickness are not always significantly related (Rastani et al., 2001). Therefore, using BCS to measure fat cover specifically is more useful at a herd level than with individual animals (Yamakawa et al., 2012), and (objective)

measures that more specifically describe fat or muscle may have greater value in some situations requiring description of individuals.

ULTRASOUND

Real-time ultrasound offers an objective means of measuring fat and muscle traits in live cattle and, in a limited number of studies, has been shown to add value to BCS to predict composition (Bullock et al., 1991; Greiner et al., 2003a).

Ultrasound has been used to accurately predict body composition in young animals when body composition was measured directly by carcass dissection (Houghton and Turlington, 1992). Standard measurements on whole carcasses can also be predictive of dissected and/or chemical body composition in cattle (Ferrell and Jenkins, 1984; Houghton et al., 1990; Johnson and Rogers, 1997; O'Mara et al., 1998; Greiner et al., 2003a, 2003c) with some $R^2 > 0.90$ for equations using two or more simple linear carcass measures (Houghton et al., 1990). Greiner et al. (2003b) and Emenheiser et al. (2010) showed that ultrasound accurately predicts carcass measures, at least in young animals. If ultrasound can accurately predict whole carcass measures, and whole carcass measures can accurately predict dissected composition, it follows that body composition can therefore be evaluated indirectly using ultrasound.

However, that syllogistic argument has not been extensively validated in mature animals. Bullock et al. (1991) tested the value of adding ultrasound measures to other live measures indicative of body composition in mature cows. They concluded that ultrasound only marginally improved prediction above that using more easily-obtained inexpensive measures. Miller et al. (2004) and Odhiambo et al. (2009) used ultrasound to characterize temporal changes in mature

cow composition due to management. However these studies were not designed, or lacked the size, to thoroughly assess the reliability of the ultrasound tool itself.

A study exploring the novel use of ultrasound for evaluation of composition in U. S. lambs (Emenheiser et al., 2010) measured the standard error of prediction and standard error of repeatability across ultrasound technicians and image interpreters for several measurements. These validation statistics are commonly used in ultrasound technician certification for other species, and were reported by Emenheiser et al. (2010) to aid in developing certification standards for U.S. lamb ultrasound technicians.

In this review, no studies were found addressing the consistency of ultrasonic measurements across repeated scans of the same cows, except in cases where change was anticipated due to temporal and/or managerial differences (Rouse et al., 2000, 2001). Studies relating the relationship between ultrasound to carcass measurements in cows (Bullock et al., 1991, Miller et al., 2004) were based on correlations. With limited variability in condition among cows, and with statistical inferences based on correlation rather than prediction error, biases in estimation were not fully explored (Houghton and Turlington, 1992) and conclusions may not be robust for populations with animals more variable in body composition. Furthermore, in this review of the literature, no study was found that measured or validated ultrasonic estimates of intramuscular fat in cows. It follows that if ultrasound is to be used to estimate composition in cows, a study reporting both standard errors of (carcass) prediction and repeatability of ultrasound measures in cows, including intramuscular fat, is warranted.

ECONOMICS

There is some information on the costs and benefits that various definitions of production efficiency have to the bottom line in beef enterprises (Klosterman, 1972; McMorris et al., 1986; Davis et al., 1994). However, comprehensive economic analysis that directly relates traits to profit or loss in pasture beef systems is not commonly available. Most investigators used simulation (Stokes et al., 1986; Evans et al., 2007b) rather than empirical data to draw their conclusions. In these cases, enterprise budgets are often needed to perform the simulations, but are not the intended outcome of the analyses.

The results of most studies imply that profit in the cow-calf sector is driven by a few primary factors. Davis et al. (1994) outline these factors particularly clearly and over the lifetime of a cow. Income in pasture-based beef cow-calf enterprises is nearly exclusively from the sale of weaned calves and, to a much lesser extent, cull cows. Relating receipts to biological type therefore focuses mostly on traits that influence calf weaning weight, including growth and milk production. Expenses vary by operation, but generally include hay, labor, fertilizer, bull/breeding costs, and interest and depreciation on livestock, equipment and facilities. The majority of economic analysis relating cattle traits to profit focuses on indirect costs of reproductive failure, death, etc., as they relate to biological type. Most budgets include a line item for death loss, and many also include sensitivity analysis as a way of quantifying the costs alluded to. However, sensitivities are commonly derived from simulation and not from replicated field-level trials, due to the difficulty and expense involved with collecting empirical data.

Stokes et al. (1986) simulated feeder calf and cull cow sales for cow-calf herds that varied in mature size and milk production. Price equations were estimated from market reports based on month and year of sale, and calf/cow sex, age, weight, and condition as well as slaughter steer and grain prices. Revenues, costs and returns were calculated for a ten-year

period. Forage consumption as it affected stocking rate, and the amount of hay fed, were calculated based on a combination of mature size and peak lactation potential factors. Under these assumptions, net returns were most desirable for large, medium-milking cows. However, no specifics were discussed as to differences in reproductive efficiency, and actually all biological types modeled in this scenario produced losses.

McMorris et al. (1986) presented economic analysis of beef production systems in Canada, using actual records. Linear programming was used to evaluate optimal combinations of production systems, beef-to-feed costs ratio, cow weight, and milk yield. The results included a comprehensive summary of the marginal effects of these traits on gross margins, but the analysis assumed use of grain feeding in a feedlot, and compared profits as if the enterprise was integrated from conception to slaughter. Therefore, this study was of limited use in evaluating trait relationships for pasture-based beef cow-calf operations.

A final study by Davis et al. (1994) analyzed records from a 10-year study of cow-calf production using five cattle types under range conditions. The groups were different in breed composition, size, growth rate and milk production. The computer simulation developed by the authors compared differential inputs and outputs for the various group, and wisely included a cost of developing replacement females. Sensitivity analysis was conducted for breed group rankings for profit:price of feed and calf receipts:cows culled. The implications of the study focused mainly on breed substitution and heterosis as opposed to marginal effects of traits *per se*. However, in general, they found that antagonisms between growth and reproduction balanced in such a way that there was no clear profit advantage to a particular cow size. Most interestingly, the authors reached contradicting conclusions in the breed (trait) comparisons when comparing

energy conversion and net profit, implying that energetic efficiency does not necessarily increase economic performance.

The literature on the economics of beef enterprises can be summarized with the following conclusions about economic efficiency of pasture beef systems. Trade-offs between calf growth and cow reproductive efficiency are the crux of profit or loss in the cow-calf sector. Due to a limited number of studies focusing specifically on the economics of pasture beef, assessing the relationship between traits and profit will likely require drawing from the methods of studies that involved some degree of grain feeding. Economic analyses employing stochastic simulation generally provides more comprehensive results than those using only actual records, due to the expense and effort required in compiling and analyzing an adequate volume of real data. Studies that conducted profit sensitivity analysis for variables such as calf price, hay costs, and reproductive failure yielded results most likely to be intuitive and useful for cattle producers.

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CHAPTER 3: APPROACHES FOR DESCRIBING FORAGE DYNAMICS IN A ROTATIONAL BEEF CATTLE STOCKING SYSTEM

ABSTRACT

Characterization of forage dynamics is necessary for a comprehensive understanding of grazing systems. The objective of this study was to delineate the impacts of stockpiling, hay feeding, weather, and the durations of paddock grazing and rest on forage mass and quality in a beef cattle rotational stocking system in the Appalachian region. Twelve 6.47-ha fescue-clover pastures of 8 paddocks each were stocked with equivalent animal units between March and November over 4 yr. An alternating half of paddocks were stockpiled each year from August through November for winter grazing. The same paddock within a pasture was used for hay feeding each winter. Forage was sampled mid-monthly from April through November (8 mo). Sample measurements included forage DM mass (**MASS**, kg DM/ha) and CP, ADF, NDF, and ash contents (g/hg DM MASS). Average daily temperature (**TEMP**, °C) and precipitation (**PREC**, cm) were obtained by month. Days since last grazed (**REST**) and days grazed in the previous rotation (**PREV**) were calculated for paddocks on each sampling date. A linear mixed model was fitted with pasture, month, stockpiling, hay feeding, and their interactions as fixed effects. The covariates were REST, PREV, TEMP, and PREC; their interactions with month, stockpiling and hay feeding were also fitted. Year nested within pasture, and residual, were random effects. For MASS, a day of REST corresponded with an increase of 5.8 ± 5.1 kg DM/ha ($P < 0.001$), although there were clear interactions of REST with month ($P < 0.01$), and month-stockpiling interaction ($P = 0.01$). These interactions were also important for explaining quality

measures ($P < 0.02$). Hay feeding and its interactions only affected ash ($P < 0.03$). Influences of PREC and TEMP on both forage mass and quality varied by month ($P < 0.001$) and month by stockpiling interaction ($P < 0.03$), emphasizing the complex and dynamic nature of rotational stocking systems. Comparison of available DM, TDN, and CP relative to nutrient density requirements for beef cows indicated that the system met or exceeded nutrient requirements throughout the grazing season, and stockpiling should allow requirements to be met well into winter.

INTRODUCTION

Grazing systems are biologically dynamic (Burns, 2008) involving interactions among forages, animals, management and weather. Rotational systems are particularly challenging to describe (Noy-Meir, 1976). Paddock rotation, stocking and rest are managed in response to forage growth to control animal output (Blaser et al., 1986). In turn, forage growth responds to that management.

In the Appalachian region of the southeastern United States where tall fescue predominates (Allen et al., 1992), the grazing season can be extended by fall stockpiling (Poore and Drewnoski, 2010). This management technique alters stocking and rest periods further, accentuating the complexity of rotational systems. Grazing systems also depend on weather. The impacts of temperature and precipitation on forage growth vary by season and the physiological state of the plant. Variation in weather impacts management decisions, which depend on the forage mass and quality that is present or anticipated.

If the sources of variation – both controllable and otherwise – can be identified, changes in forage characteristics can be better predicted. Characterization of forage dynamics allows more comprehensive understanding of the grazing system, facilitating management decisions for more productive systems.

The objective of this study was to characterize changes in forage mass and quality in a rotational stocking system for beef cattle. The system was located in the Appalachian region, and utilized stockpiling to extend the grazing season. The management factors evaluated were durations of stocking and rest, and stockpiling and hay feeding. The impacts of temperature and precipitation on forage attributes were also investigated. A focus was on understanding the interactions amongst these variables across the grazing season. While the forage dynamics themselves were of primary interest, their implications on the nutrients available for the requirements of grazing beef cattle were also considered.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at Virginia Tech approved all procedures and protocols used in the experiment (IACUC Protocol Number 08-046-cvm).

Study site

The experimental data were collected at Virginia Tech's Shenandoah Valley Agricultural Research and Extension Center in Steeles Tavern, VA (37°55'55") from 2008 to 2011. The location was characterized by Frederick-Christian silt loams, fine, mixed, semiactive, mesic

Typic Paleudults soil. Regional climate center data describes the area as temperate, with a mean air temperature of 17°C ranging from 4.7°C in January to a high of 28.5°C in July. The majority of the precipitation falls as rain, peaking between May and September, with an annual mean of 987mm (Flores and Tracy, 2012).

Forages

Pastures were killed and reseeded with tall fescue (*Festuca arundinacea* ‘Kentucky 31’ and mixed clover (*Trifolium pretense* ‘Cinnamon Red’, *Trifolium repens* ‘Huia White’, and *Trifolium repens* ‘Will Ladino’) during development of the site in 2000, and were subsequently frost seeded with 4.5 kg/ha each of red clover (*Trifolium pretense* ‘Cinnamon +’) and mixed white clover (*Trifolium repens* ‘Pinnacle’, and *Trifolium repens* ‘Kopu II’) in February 2007. The only external seed input during the course of this study was a second frost seeding of red and white clover (same varieties and rates as in 2007) in February 2009.

Cattle

Angus-cross cow-calf pairs (n=90) were used. Cows were bred to calve in March, and calves were stocked alongside their dams until weaning in September. Cows were stocked at a rate of 1.39 AUE/ha. The experiment was designed as a 2x2 factorial with cow frame size and calf creep system as treatments. Cows were classified as either large or moderate-framed based primarily on their sires, which were selected for divergent yearling hip height EPD. Paddocks were stocked with either 7 large or 8 moderate-framed cows to provide approximately equal

AUE. The paddocks did not provide shade. Calves were either given access to forward creep in the next fescue-clover paddock to be grazed by cows, or to a designated creep that remained fixed throughout the season. Dedicated creep paddocks were seeded with a nil-ergot, endophyte-infected fescue (*Festuca arundinacea* ‘MaxQ’) and alfalfa (*Medicago sativa* ‘Ameristand 403T’). An analysis of these creep grazing systems was conducted by Tracy et al. (2012). The 2x2 design was replicated 3 times for a total of 12 pastures.

Paddock management

The twelve 6.47-ha fescue-clover pastures were used for the grazing season from March to November in each of 4 yr. Each pasture consisted of 8 paddocks. The paddocks were rotationally stocked with the order and durations of stocking determined by the farm superintendent. From April through July, rotation decisions were based on rest days, with the rest periods increasing as forage growth slowed.

In each pasture, 4 of the 8 paddocks were stockpiled for winter grazing. In July, the 4 paddocks to be stockpiled were grazed while the other 4 paddocks were rested. The stockpile paddocks were then fertilized with 67 kg/ha of N (urea) in mid-August and rested through the fall. Grazing of stockpiled forage began in mid to late-November and usually continued until January. If needed, hay was fed after stockpile was depleted and until grazing began the subsequent spring. With few exceptions, paddocks were given alternating stockpiling treatments in consecutive years.

Additionally, 1 of the 8 paddocks in each pasture was used for hay feeding from approximately January through mid-April prior to the start of the grazing season. The same

paddock was used for hay feeding in each pasture throughout each of the 4 yr evaluated. Flores and Tracy (2012) evaluated the impacts of winter hay feeding using these same 12 paddocks.

Sampling techniques

Forage quantity and quality were measured in each of 96 paddocks monthly from April through November (8 mo). These inventories were taken at approximately the middle of each month. Inventory dates varied no more than 10 d across the 4 yr of data. A randomly chosen 0.76 m by 3.66 m strip was mowed at a height of approximately 5 cm and as-fed herbage mass was weighed using a forage harvester (Swift Forage Harvester, Swift Current, SK, Canada).

Inventory samples were dried and reweighed to determine DM content, which was used to calculate DM mass (**MASS**). Dried samples were sent to the Virginia Tech Ruminant Nutrition Laboratory and analyzed for CP, ADF, NDF, and ash contents using standard methods (Undersander et al., 1993; AOAC, 2000).

Dates were recorded for each animal movement event. For each paddock on the day of sampling, the number of days since last grazed (**REST**) and the number of days grazed in the previous rotation (**PREV**) were calculated. If cattle were present in the paddock at the time of sampling, the number of days grazed currently (**CURR**) was determined. The time of day paddocks were rotated was not recorded. Therefore, the first (partial) day of a new rotation was counted as a full day, while the last (partial) day was not counted. If cattle were moved out of a paddock on the same day an inventory was taken, that paddock was assigned a REST value of 1 for that inventory event.

Extensive weather data were logged daily to an on-site weather station (Natural Resources Conservation Service site 2088), and temperature and precipitation measures were downloaded for analysis (<http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=2088&state=va>). For the time period prior to each inventory (approximately 30d), the daily mean temperature (**TEMP**) and precipitation (**PREC**) were calculated.

Statistical analyses

The variable month reflected the time period leading up to an inventory. For instance, May referred to the day after the April inventory through the day of the May inventory.

Hay feeding was confined to a single paddock within a pasture. In order to investigate hay feeding simultaneously with other factors and to avoid confounding, pasture instead of paddock was considered as a fixed factor. Since the forage attributes of a pasture may have varied across years, year was nested within pasture and considered random. Frame size and creep feeding treatments were balanced within pasture. Variation due to these treatments were accounted for in the random effect, and therefore not explicitly fitted. After hay feeding commenced in a paddock, data from that paddock were excluded.

For any paddock grazed twice prior to an inventory month, the days of REST and PREV were calculated based on the second grazing event. The time between the first event and the previous inventory was ignored. The REST and CURR were mutually exclusive; a value for one necessitated a zero value for the other. A missing value was assigned for PREV during the first inventory of each year. The CURR had no clear impact on forage mass or quality in preliminary analyses ($P > 0.05$), and was not considered subsequently.

Data were analyzed using the MIXED procedure of SAS. Least squares means comparisons were made using a Tukey-Kramer adjustment.

Stockpiling and hay feeding

A linear mixed model with pasture, month, stockpiling, hay feeding, and their interactions as fixed effects was initially fitted. The general form of the mixed linear model considered was:

$$Y_{ijklmn} = \mu + P_i + M_k + S_l + H_m + (MS)_{kl} + (MH)_{km} + (SH)_{lm} + (MSH)_{klm} + R_{j(i)} + e_{ijklmn} \quad [1]$$

where Y_{ijklmn} was the response variable for a paddock in pasture P ($i = 1, \dots, 12$) during year R ($j = 1, \dots, 4$) and month M ($k = 1, \dots, 8$), with a stockpiling S ($l = 1, 2$) and hay feeding H ($m = 1, 2$) treatment, where $(MS)_{kl}$, $(MH)_{km}$, and $(SH)_{lm}$ were the month by stockpiling, month by hay feeding, and stockpiling by hay feeding interactions, respectively. The term $(MSH)_{klm}$ was their three-way interaction. The random terms included year nested within pasture ($R_{j(i)}$) and the residual error (e_{ijklmn}).

From initial analyses, the main effect of pasture ($P = 0.98$) and the three-way interaction among month, stockpiling, and hay feeding ($P = 0.85$) did not explain variation in MASS. These effects were therefore excluded, and the final model fitted was:

$$Y_{ijklmn} = \mu + M_k + S_l + H_m + (MS)_{kl} + (MH)_{km} + (SH)_{lm} + R_{j(i)} + e_{ijklmn} \quad [2]$$

Fit of covariates

Covariates for weather (TEMP and PREC) and days (REST and PREV) were added to Eq. 2, along with their two-way interactions with month, stockpiling, and hay feeding, and their

three-way interactions with month by stockpiling, month by hay feeding and stockpiling by hay feeding. The MASS was used as the response variable for model selection.

Model selection was based on backward elimination, where terms that defined limited variation in MASS ($P > 0.10$) were dropped sequentially from the model. Three-way interactions that included both stockpiling and hay feeding did not explain variation in MASS ($P > 0.15$) and were removed. Interactions of PREV with month ($P = 0.39$) and with hay feeding ($P = 0.89$) were also unimportant and were therefore dropped from the model.

Hay feeding did not improve prediction of MASS when fitted as a main effect ($P = 0.94$) or as interaction effects ($P > 0.14$) after the addition of the covariates. As a further test, when CP, ADF, and NDF were considered as response variables, the main ($P = 0.17$ to 0.91) and interaction ($P > 0.10$) effects of hay feeding were likewise unimportant. Thus, hay feeding was excluded in the final model fitted (Eq. 3).

Nutrient availabilities

Forage nutrient availabilities were summarized by month, using only paddocks that were actively grazed in that month for calculations. Actively-grazed paddocks included both stockpiled and non-stockpiled in April through June, stockpiled in July, and non-stockpiled in August through November. The DM availabilities for a given month were calculated from average MASS (kg DM/ha) for the 4 or 8 paddocks actively grazed. A stocking rate of 1.39 AUE/ha was used, which reflected an average of 7.5, 545 kg cows grazing a 6.47 ha pasture. The daily DM available per cow reflected her access to a single paddock within the pasture at a given time, assuming a 30 d period between inventories.

The TDN contents were calculated from mean ADF values, using the methods described in Undersander et al. (1993) for mixed forages. The equation used to calculate TDN was:

$$TDN = 4.898 + (89.796 \times (1.0876 - (0.0127 \times ADF))). \quad [4]$$

RESULTS

Summary statistics for all response variables are presented in Table 3.1. All measures of forage quantity and quality are reported on a DM basis. Of these measures, MASS was considerably more variable (CV = 64.6) than quality (CV = 13.2 to 32.9) across combinations of paddock, month and year.

Stockpiling and hay feeding

The month of the year was anticipated to be a main factor contributing to variation in MASS. Overall means for MASS for each of the 8 mo, across years, are presented in Table 3.2. Average MASS increased prior to the June inventory, only slightly decreased through the September, and then increased thereafter. The highest mean MASS was in November [3199 (SD 2229) kg DM/ha]. This pattern would be unexpected with cool season forages in the absence of a stockpiling management regime.

Least squares means for MASS are shown by month in Fig. 3.1 for stockpiled and non-stockpiled paddocks. Prior to August, no differences between stockpiling treatments were observed ($P > 0.58$). In July, which was reflected in the August inventory, only the 4 stockpiled paddocks were actively grazed. The reduction in MASS in these paddocks during July was

surprisingly modest. This may reflect reduced intake as a result of warm summer temperatures in combination with endophyte-infected fescue and the absence of shade. After August, MASS accumulated in stockpiled paddocks and decreased in non-stockpiled paddocks. This was due to the stockpiled paddocks being rested and the non-stockpiled paddocks being stocked, and it resulted in substantial differences in MASS between treatments ($P < 0.001$) from August until November.

Least squares means for hay feeding by month interaction are shown in Fig. 3.2. No differences were observed ($P > 0.89$) between hay feeding treatments except perhaps at the May inventory ($P = 0.06$).

Temperature and precipitation

The overall mean TEMP was $16.3 \pm 4.8^{\circ}\text{C}$ and PREC was 0.28 ± 0.14 cm across the 4 yr. Seasonal patterns in TEMP and PREC are shown in Fig. 3.3 and 3.4, respectively. The TEMP was parabolic across the 7 mo and ranged from $9.2 (\pm 1.2)^{\circ}\text{C}$ in November to $22.2 (\pm 1.5)^{\circ}\text{C}$ in August, and was similar within month across years (CV = 3.6 to 13.4). The PREC ranged from $0.19 (\pm 0.04)$ cm in August to $0.36 (\pm 0.13)$ cm in May, but was variable within month across years (CV = 17.2 to 70.2). Within year across months, TEMP (CV = 24.8 to 33.0) was less variable than PREC (CV = 27.4 to 56.8). Summary statistics for TEMP and PREC at all months are shown in Table 3.3. Months with the highest mean temperatures (July and August) coincided with decreasing average MASS (Table 3.2).

Days of rest and previous grazing

The REST showed substantial non-normality [mean 23.3 (SD 26.4) d; median 14 d; minimum 0 d; maximum 122 d; skewness 1.38; kurtosis 1.11]. The clear right skewness was due to the intentional resting of stockpiled paddocks in the second part of the year. Typically a paddock within a pasture was being grazed on the inventory date, with the value of REST necessarily zero; this also contributed to the non-normality of this variable. Summary statistics for REST by month and stockpiling treatment are shown in Table 3.4. The resting of stockpiled paddocks after August and of non-stockpiled paddocks in July resulted in greater mean REST in the subsequent months for these paddocks.

The PREV was more normally distributed [mean 4.6 (SD 1.9) d; median 4 d; minimum 0 d; maximum 23 d; skewness 0.77; kurtosis 6.44]. Despite having less skewness, the distribution of PREV was highly kurtotic and characterized by a comparatively narrower range in days, in which 29 percent of observations had $PREV = 4$ d.

Fit of covariates

MASS

Using Eq. 3, the month by stockpiling interaction was highly predictive of MASS, particularly after accounting for weather and REST ($P < 0.001$). The interplay of both PREC and TEMP with month and stockpiling defined substantial variation in MASS ($P < 0.001$).

The REST had a key effect on MASS ($P < 0.001$). Based on the fit of Eq. 3, each day of REST corresponded with a 5.8 ± 5.1 kg DM/ha increase in MASS over all paddocks and months.

However, the impact of REST also depended on its interaction with month and stockpiling ($P = 0.01$). The main effect of PREV was unimportant for predicting MASS ($P = 0.29$).

In order to understand the interaction of REST with month and stockpiling, least squares means for MASS for each month-stockpiling combination were obtained. Means were calculated at the maximum and minimum values for REST (Table 3.4), and the average TEMP and PREC for each month (Table 3.3). These results are shown for stockpiled and non-stockpiled paddocks for select months (June, August, and October) in Fig. 3.5.

Early in the season (e.g., June), REST periods were shorter and forage accumulation similar in both stockpiled and non-stockpiled paddocks. In mid-season (e.g., August), REST periods are shorter in the stockpiled paddocks and longer in the non-stockpiled paddocks (Fig. 3.5), with negative forage accumulation in those paddocks being grazed (stockpiled). The stockpiled paddocks were increasingly rested in the later months (e.g., October), resulting in considerable accumulation of forage. As a consequence, those paddocks being actively grazed in later months (non-stockpiled) showed negative forage accumulation.

Quality variables

The means for CP, ADF and NDF by month and stockpiling treatment are shown in Table 3.5. When predicting CP content of the forage with Eq. 3, REST was important as a main effect and in all interactions involving month and stockpiling ($P < 0.001$). However, when considered over all paddocks and months, a day of REST corresponded with a negligible increase in CP (0.0 ± 0.01 g CP/hg DM).

Although no overall effect was observed, forage CP accumulated in those paddocks that were stockpiled paddocks later in the season. Differences in CP contents between stockpiling

treatments were substantial ($P < 0.001$) in September and approaching significance ($P = 0.14$) in October. Earlier in the year, there were no differences ($P > 0.22$) in CP between the stockpiling treatments.

Means for ADF and NDF at month-stockpiling combinations (Table 3.5) indicate that differences in forage fiber contents were more distinct across months than between stockpiling treatments within month. The ADF content was lowest at the beginning (May) and end (October and November) of the grazing season. A clear peak in ADF contents during July and August in both stockpiled and non-stockpiled paddocks was observed.

Compared with other variables, the factors influencing ash were decidedly unique. Beyond the effects included in Eq. 3, prediction of ash required the addition of the main effects of pasture ($P = 0.03$) and hay feeding ($P < 0.001$), as well as all possible higher order interactions involving hay feeding ($P < 0.03$), and the PREV by month interaction ($P < 0.001$). The important pasture effect was not attributable to any specific pasture within the system. Within months across hay feeding treatments, substantial differences in ash content were only found in the May inventory ($P = 0.001$, with $P > 0.28$ in other months). Mean ash contents for month-stockpiling combinations are shown in Table 3.5.

Nutritional implications for grazing cattle

The diet nutrient density requirements (NRC, 2000) for DM, CP, and TDN for a 545 kg cow with moderate milk production (9 kg) are presented in Table 3.6. The requirements are presented for months since the calving date, which in this system was in March. Additionally, means for available DM mass, CP, and TDN contents are presented for the corresponding

months. Nutrient requirements for DM, TDN, and CP generally decreased from time of calving; availability of these nutrients fluctuated slightly over the grazing season.

Within a month, depending on application of stockpiling treatment, the rotational stocking was restricted to 4 or 8 paddocks within a pasture. Accounting for the number of paddocks available for stocking and the 30-d period between inventories, the DM available to a cow was expressed on a daily basis (Table 3.6). The daily DM available to cows exceeded requirements by at least 2.7 times in every month, and available TDN and CP contents were also greater than was required in all months.

DISCUSSION

Stockpiling and hay feeding

A reduction in mass during the hot summer months is expected for cool season forages such as tall fescue, especially if there is a moisture deficit (Blaser et al., 1986; Denison and Perry, 1990). Considering that inventories were taken in the middle of each month, MASS decreased after mid-June. The decreasing MASS through the July and August inventories did indeed coincide with the highest mean TEMP values. However, the MASS showed a less exaggerated “summer slump”, and the fall forage accumulation was both later and slower than reported by Denison and Perry (1990) for tall fescue on the Appalachian plateau.

Importantly, the MASS data summarized in Table 3.2 reflected all paddocks simultaneously. Designation of paddocks for stockpiling is intended to alter the accumulation of forage mass at strategic times over the grazing season. When MASS reflects an average over

very different management practices including fertilizer, stocking, and rest treatments, the expected temporal changes in forage mass are likely masked. This observation supports the inclusion of stockpiling as a dynamic factor that affects a grazing system.

For the month prior to the August inventory, greater grazing pressure was applied to paddocks to be used for stockpiling. After the removal of cattle and the application of nitrogen fertilizer in August, the expected forage accumulation in stockpiled paddocks ensued. In contrast, the decrease in MASS in non-stockpiled paddocks in fall likely reflected the combination of increased stocking rate and seasonal plant senescence. Tracy et al. (2012) found that stockpiled paddocks produced more forage mass in the following year relative to paddocks that were not stockpiled. Because the stockpiling treatment for a paddock was alternated each year, their result explains the generally higher forage mass in non-stockpiled paddocks prior to September observed in our experiment.

Investigating the effects of hay feeding on forage growth in the subsequent grazing season, Flores and Tracy (2012) concluded that hay feeding had a neutral to positive effect. With an additional year of forage data included, our findings were similar. The MASS available was less in hay feeding paddocks than in others at the MAY inventory, but was similar among the hay feeding treatments after June. This result likely reflects the fact that paddocks used for hay feeding in the previous winter were frequently not grazed until late May.

While stockpiling defined variation in MASS, hay feeding did not. In general, it appears that stockpiling was a more important managerial component than hay feeding for explaining changes in MASS in this system.

Fit of covariates

MASS

The negative forage accumulation in both stockpiled and non-stockpiled paddocks in various months, suggests potential exists for grazing pressure to exceed available MASS; additional REST adds little to the available MASS in such circumstances.

The REST was more predictive of changes in MASS than was PREV. This may be due to the reduced variation, and the greater temporal distance from the inventory event, for PREV as compared to REST. The differences in MASS per day of REST among month and stockpiling combinations (Fig. 3.5) demonstrate the complex nature of forage accumulation. Describing a rotational stocking system solely by rest days relative to stocking rate appears to be overly simplistic. Clear differences can be expected in that relationship throughout the year and under differing stockpiling treatments.

Predicting the consequences of REST on MASS is challenging. That relationship not only varies with month and stockpiling treatment, but it is also affected by precipitation and temperature. In our study, MASS was predicted at average monthly levels of PREC and TEMP. However, as shown in Fig. 3.4, PREC is extremely variable across years even for a given month. Therefore, developing robust management programs for forage systems that account for precipitation levels is difficult.

Our analyses focused on the relationship of month and stockpiling treatments with MASS. When considering the covariates, only their interactions with these fixed factors were fitted. Although interactions among the covariates themselves might have been considered, their interpretation within the structure of these data would be difficult. If the focus was instead on

managerial implications of a rotational grazing system, assessing risk due to weather variation on decisions regarding grazing and rest days could be valuable.

Quality variables

While CP, ADF, NDF, and ash contents of the forage would be expected to vary with days since the last grazing event, samples measured on an inventory date partly reflect the forage not grazed. When given the opportunity, cattle are expected to consume forages that better meet their metabolic needs. Early in lactation, cows require forages that are higher in protein and lower in fiber contents (NRC, 2000). In a rotational stocking system, it is therefore important to make managerial decisions with the cows' nutrient requirements in mind.

In evaluating the CP contents of the residual forage at a sampling event, we observed an important relationship between month, stockpiling and REST. Biologically, those findings reflect changes in plant maturity in tandem with stocking density. From September onward, the greater accumulation of CP in rested (stockpiled) as compared to stocked (non-stockpiled) paddocks suggested diet selectivity by cows. Otherwise, changes in CP are predominately temporal. The months of lowest quality forage (June through August) correspond with the “summer slump,” during which growth of cool season forages slows (Blaser et al., 1986; Denison and Perry, 1990). Stockpiling appears to allow the accumulation of quality forage for winter grazing, while not compromising the CP available to cattle when grazing is restricted to the non-stockpiled paddocks during the fall stockpiled period.

The ADF and NDF contents of the forages followed expected seasonal patterns. Fiber contents tended to be lowest during May, which was characterized by lush new season growth, and highest during July, during the heat of summer. Grazing pressure (stocking rate relative to

forage accumulation) was greatest during July. The higher fiber contents in the forage sample likely reflect the limited amount of quality new growth at that time being consumed. Conversely, the ADF contents were lower for stockpiled paddocks when being rested. This further substantiates selectivity for less fibrous material in the paddocks not rested (non-stockpiled), as well as continued new growth of cool season forages late into the fall.

The influence of hay feeding on forage ash content was considerable. Flores and Tracy (2012) reported higher concentrations of soil P and K in paddocks used for hay feeding. We found complex interactions of hay feeding treatment with most other factors, making interpretation of its impact on ash difficult. However, hay feeding only affected ash contents in May, suggesting its importance within this system is relatively temporary.

Nutritional implications for grazing cattle

The comparison of available nutrients relevant to beef cattle requirements shown in Table 3.6 indicates that nutritional needs of the grazing cattle were adequately met by this system in all months that forage samples were evaluated. The availability of daily DM was at least 2.7-fold that required (NRC, 2000). Those predictions were conservative, since our calculations assumed no forage regrowth within a month. However, we also did not consider factors such as selectivity and grazing height, which would limit harvest efficiency.

Even during June and July, when providing quality nutrition with cool-season forages is known to be challenging, the CP and TDN contents available from this system exceeded the published requirements. The greatest availability of forage mass and quality was during the late spring, which coincided with early lactation when cows' nutrient requirements were highest.

Additionally, the resting of paddocks for stockpiling allowed accumulation of DM, CP, and TDN that was well in excess of requirements for bred cows entering their final trimester of pregnancy. With stockpiling in a rotational grazing system, we were able to provide ample quantity and quality of forage throughout the grazing season.

The seasonal changes observed in forage quantity and quality are well-tailored to the nutrient requirements of spring calving cows. However, the greatest potential for both nutritional and heat stress occurs during the summer months, which aligns with the breeding season for spring calving herds. Particularly on ergot-infected fescue pastures, that concurrence may result in reduced conception rates for cows bred in June (Porter and Thompson, 1992). Analysis of the productivity of the overall system, therefore, involves evaluation of the nutritional advantages relative to the reproductive risks inherent to such a production calendar.

Conclusions

Changes in forage mass and quality in a rotational beef cattle stocking system can be well-described only by considering the interacting effects of month, stockpiling, paddock grazing and rest, and precipitation and temperature on forage growth. Clearly the dynamics of this forage system are complex. Even so, the system was effective. It provided nutrients in excess of beef cow requirements throughout the grazing season, with forage accumulation from stockpiling sustaining the nutritional needs of the herd into the winter. At least in the Appalachian region with predominately tall fescue swards, rotational stocking with stockpiling appears to provide a viable forage system for cow-calf producers.

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Table 3.1. Summary statistics for measures of forage quantity and quality

Variable	No. ³	Mean	Min	Max	SD	CV, %
MASS ¹	2925	2557.0	51.8	11624.8	1651.2	64.6
CP ²	2924	14.0	3.5	30.1	4.5	32.4
ADF ²	2924	33.1	15.4	53.0	6.0	18.1
NDF ²	2924	61.5	28.8	83.2	8.1	13.2
Ash ²	2924	7.9	2.9	53.1	2.6	33.1

¹MASS = DM mass (kg DM/ha).

²Quality measures are expressed as g/hg MASS.

³Number of paddocks sampled.

Table 3.2. Summary statistics for forage mass (MASS; kg DM/ha) by inventory month

Period ¹	No. ²	Mean	Min	Max	SD	CV, %
April	337	1154	52	6230	882	76.4
May	385	2272	289	7442	1182	52.0
June	384	2954	230	8434	1530	51.8
July	387	2808	123	10482	1667	59.4
August	385	2726	81	8804	1541	56.5
September	387	2557	142	8319	1538	60.2
October	383	2792	104	9226	1684	60.3
November	277	3199	161	11625	2229	69.7

¹Inventory taken mid-monthly; month refers to preceding interval.

²Number of paddocks sampled.

Table 3.3. Summary statistics for weather variables by inventory month

Period ¹	No. ²	TEMP ³			PREC ⁴		
		Mean	SD	CV, %	Mean	SD	CV, %
April	385	9.3	1.9	20.4	0.24	0.04	16.7
May	385	14.3	0.7	4.9	0.36	0.13	36.1
June	384	18.9	1.0	5.3	0.26	0.12	46.2
July	387	21.2	1.1	5.2	0.28	0.07	25.0
August	386	22.2	1.5	6.8	0.19	0.04	21.1
September	387	19.6	0.7	3.6	0.30	0.19	63.3
October	383	14.1	1.9	13.5	0.25	0.07	28.0
November	278	9.2	1.2	13.0	0.36	0.25	69.4

¹Inventory taken mid-monthly; month refers to preceding interval.

²Number of paddocks sampled.

³TEMP = Mean daily air temperature (°C).

⁴PREC = Mean daily precipitation (cm).

Table 3.4. Summary statistics for days since last grazed (REST; d) by inventory month and stockpiling treatment

Month ¹	Stockpiled ²	No. ³	Mean	SE	Min	Max
May	no	193	13	0.7	0	36
	yes	192	15	0.7	0	36
June	no	193	18	1.1	0	64
	yes	191	17	1.2	0	64
July	no	193	21	0.8	1	59
	yes	194	11	0.8	0	43
August	no	193	49	0.9	27	87
	yes	193	8	0.5	0	40
September	no	195	11	1.3	0	122
	yes	192	40	0.5	25	66
October	no	191	11	0.7	0	47
	yes	192	70	0.6	54	95
November	no	134	9	0.6	0	25
	yes	144	92	1.7	84	113

¹Inventory taken mid-monthly; month refers to preceding interval.

²Stockpiled paddocks will be used for winter grazing beginning after the November inventory.

³Number of paddocks sampled.

Table 3.5. Summary statistics for forage quality measures (g/hg DM) by inventory month and stockpiling treatment

Month	No. ²	CP		ADF		NDF		Ash	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Stockpiled									
April	167	18.9	3.7	27.0	4.3	52.2	6.3	8.1	1.1
May	190	15.1	2.9	30.9	3.1	57.9	4.4	10.0	7.4
June	191	11.1	2.8	36.2	5.5	63.6	6.4	7.9	1.4
July	194	10.3	2.6	37.1	4.0	67.6	5.7	7.1	1.4
August	193	11.1	2.8	38.2	4.4	68.8	5.3	7.2	1.7
September	192	19.4	3.5	29.2	3.8	56.6	5.6	8.9	1.3
October	192	17.0	3.0	28.3	2.9	56.0	4.3	8.5	1.1
November	144	15.2	2.6	27.9	3.0	55.1	4.6	7.9	1.3
Non-stockpiled									
April	170	20.6	3.3	24.8	3.9	49.7	6.4	8.5	1.2
May	193	15.7	3.1	30.3	2.7	57.7	4.6	8.5	3.8
June	193	10.7	2.7	37.4	5.8	64.5	6.8	7.5	1.5
July	193	10.2	2.5	38.1	3.7	68.5	5.2	6.6	1.2
August	193	11.2	2.9	37.7	4.1	67.9	5.6	6.9	1.3
September	195	12.2	2.9	36.4	3.9	66.9	4.4	7.6	1.3
October	191	13.5	3.8	34.5	4.6	64.3	5.5	7.5	1.5
November	133	12.6	2.9	32.8	4.0	62.3	6.1	7.3	1.1

¹Inventory taken mid-monthly; month refers to preceding interval.

²Number of paddocks sampled.

Table 3.6. Mean forage nutrients available relative to diet nutrient density requirements for beef cows in different months given March calving

Month	Nutrient Requirements ¹			Nutrient Availability ²		
	DM (kg/cow/d)	TDN (%)	CP (%)	DM (kg/cow/d)	TDN (%)	CP (%)
April	12.2	58.7	10.1	33.2	73.1	19.8
May	12.6	59.9	10.7	65.4	67.6	15.4
June	12.9	57.6	9.9	85.0	60.6	10.9
July	12.4	56.2	9.3	36.6	60.2	10.3
August	12.0	54.7	8.5	48.1	59.6	11.2
September	11.7	53.4	7.9	39.7	61.1	12.2
October	11.0	44.9	6.0	31.4	63.2	13.5
November	10.9	45.8	6.2	29.6	65.2	12.6

¹Nutrient requirements are derived from NRC (2000) and assume a 545 kg cow with moderate (9 kg) milk production.

²Nutrient availabilities consider only those paddocks being actively grazed in a month.

Figure 3.1. Least squares means for forage mass (MASS; kg DM/ha) by inventory month and fall stockpiling treatment

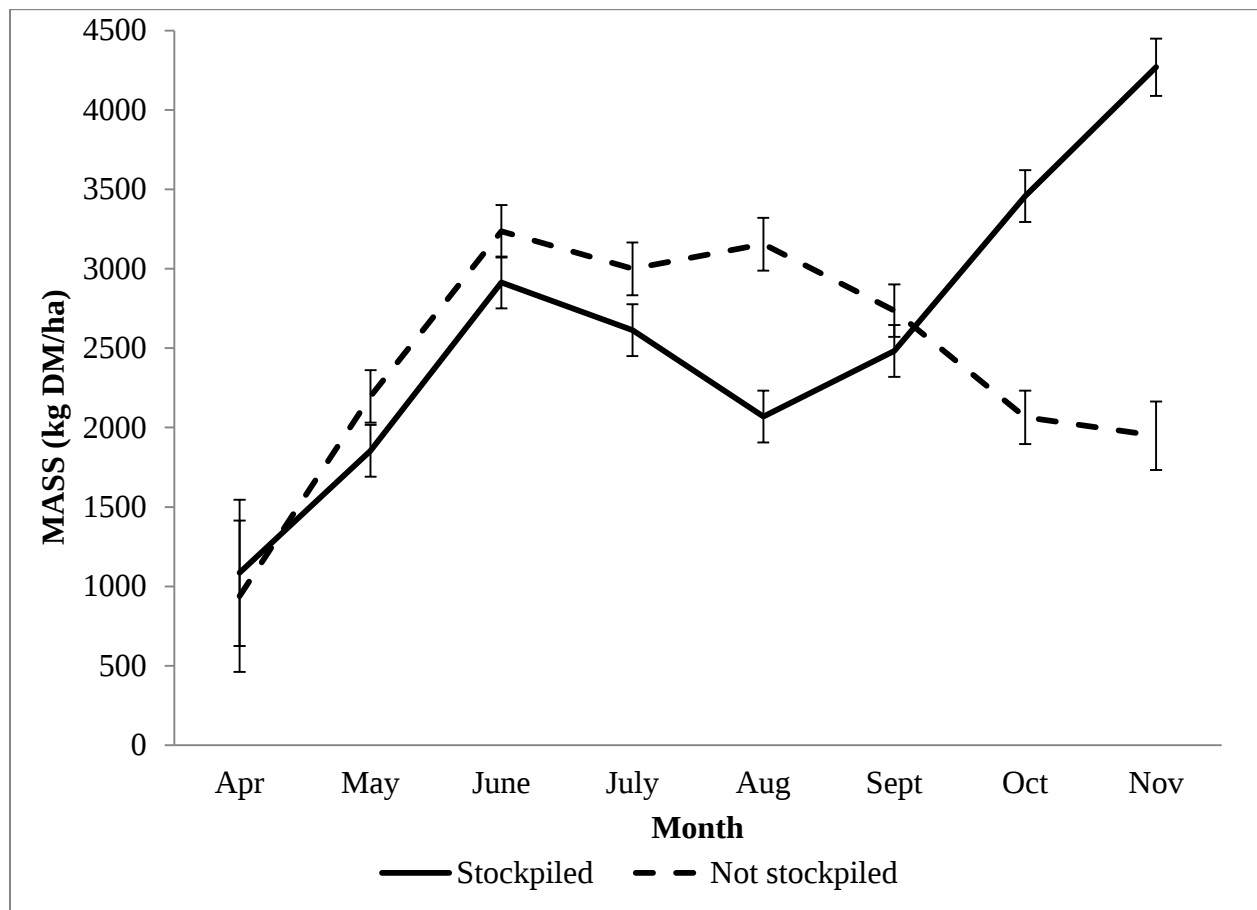


Figure 3.2. Least squares means for forage mass (MASS; kg DM/ha) by inventory month and winter hay feeding treatment

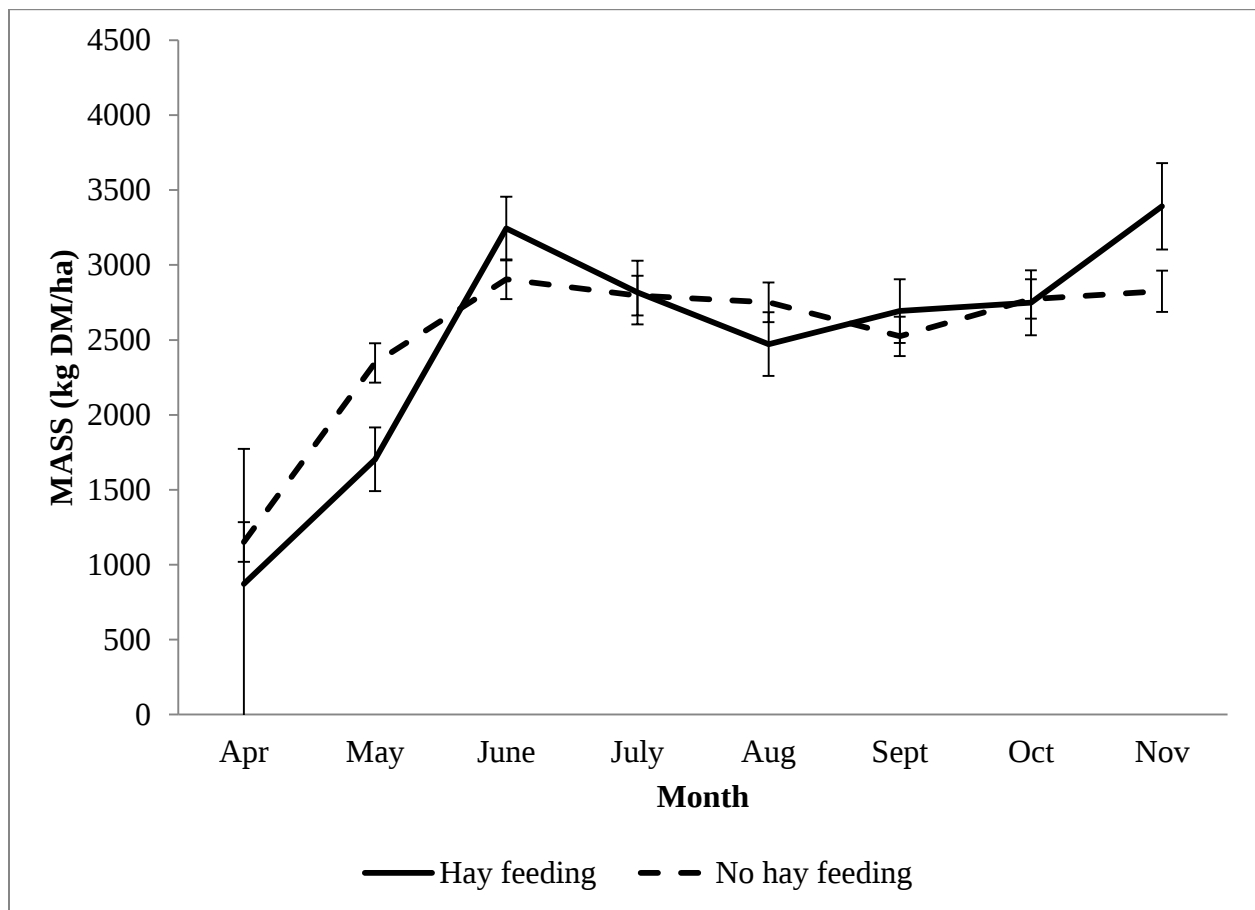


Figure 3.3. Average daily air temperature (TEMP; °C) by inventory month

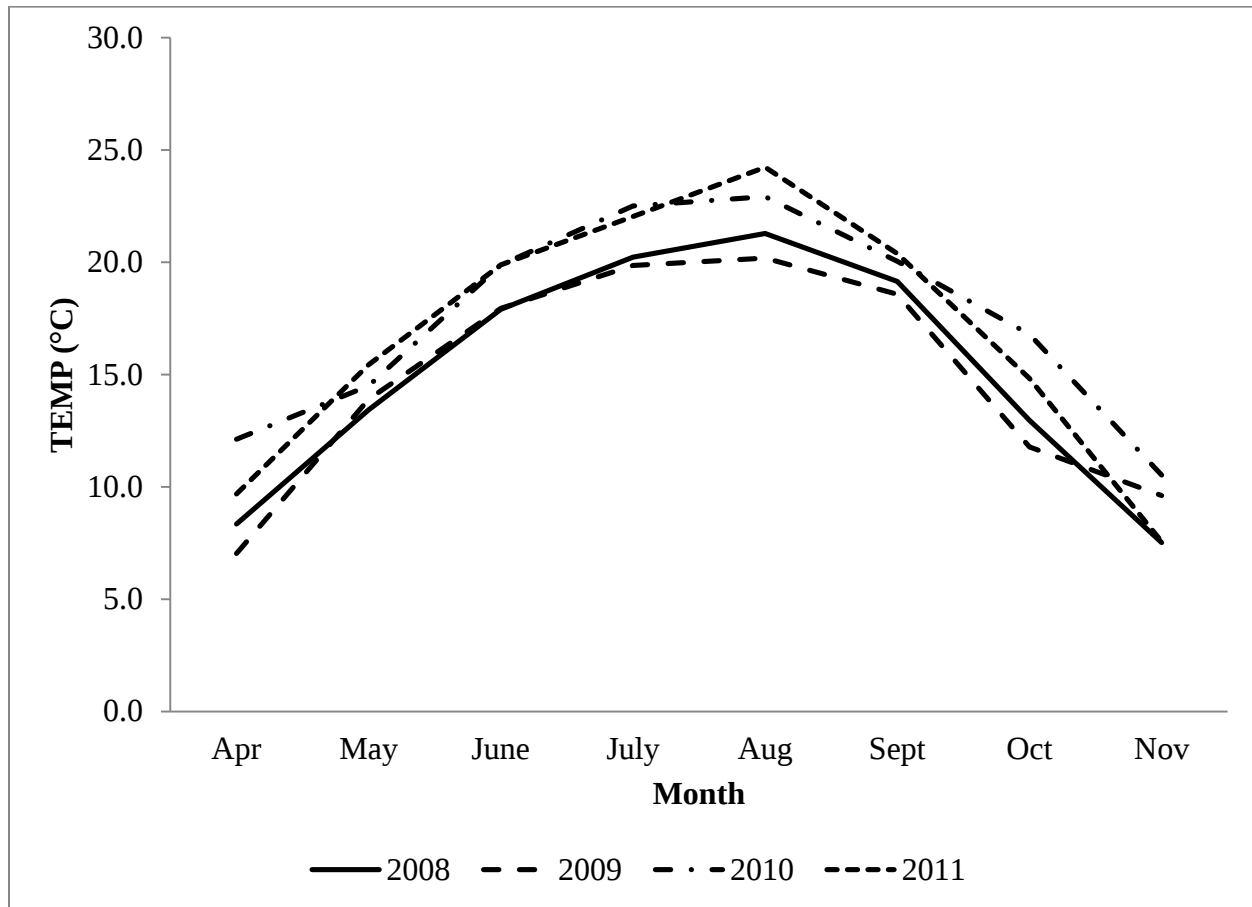


Figure 3.4. Average daily precipitation (PREC; cm) by inventory month

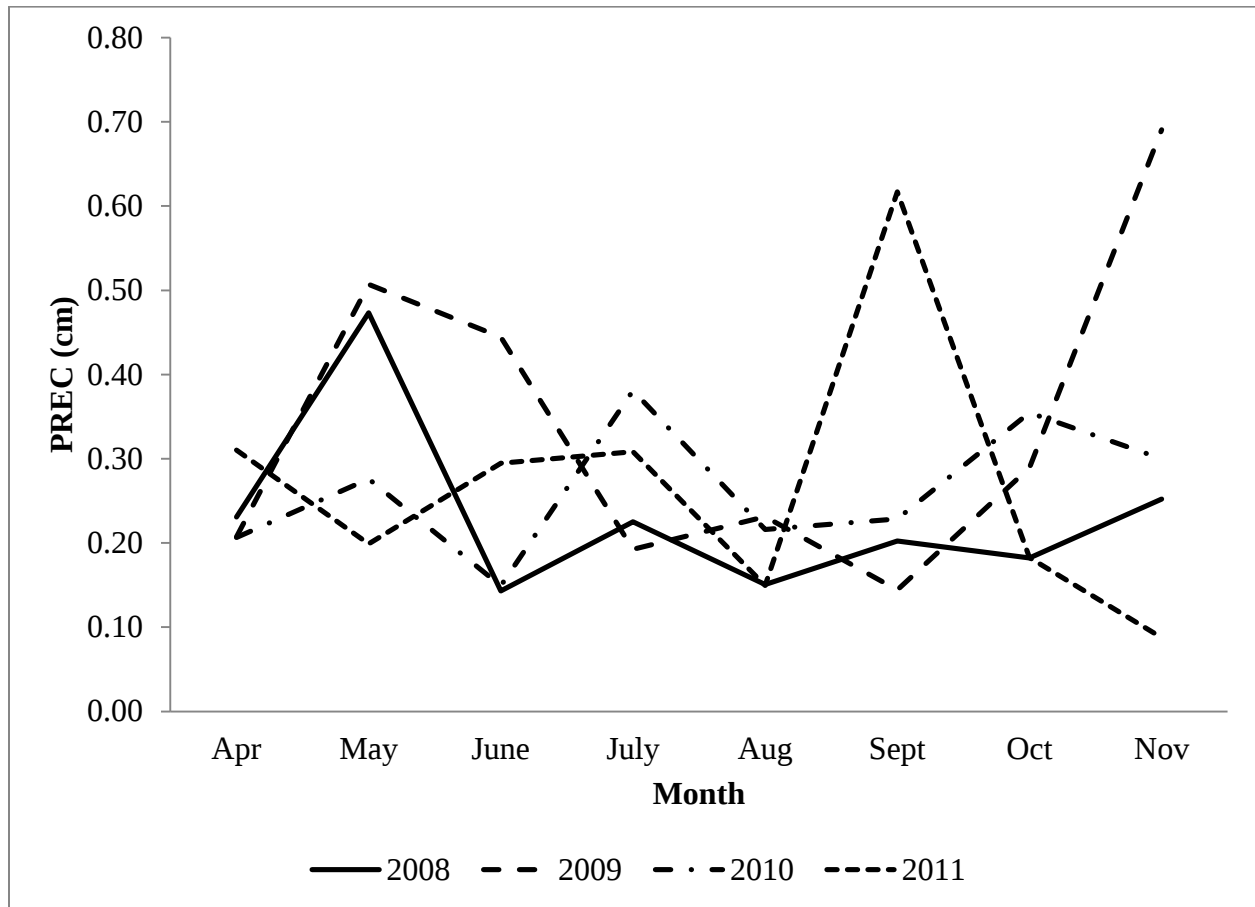
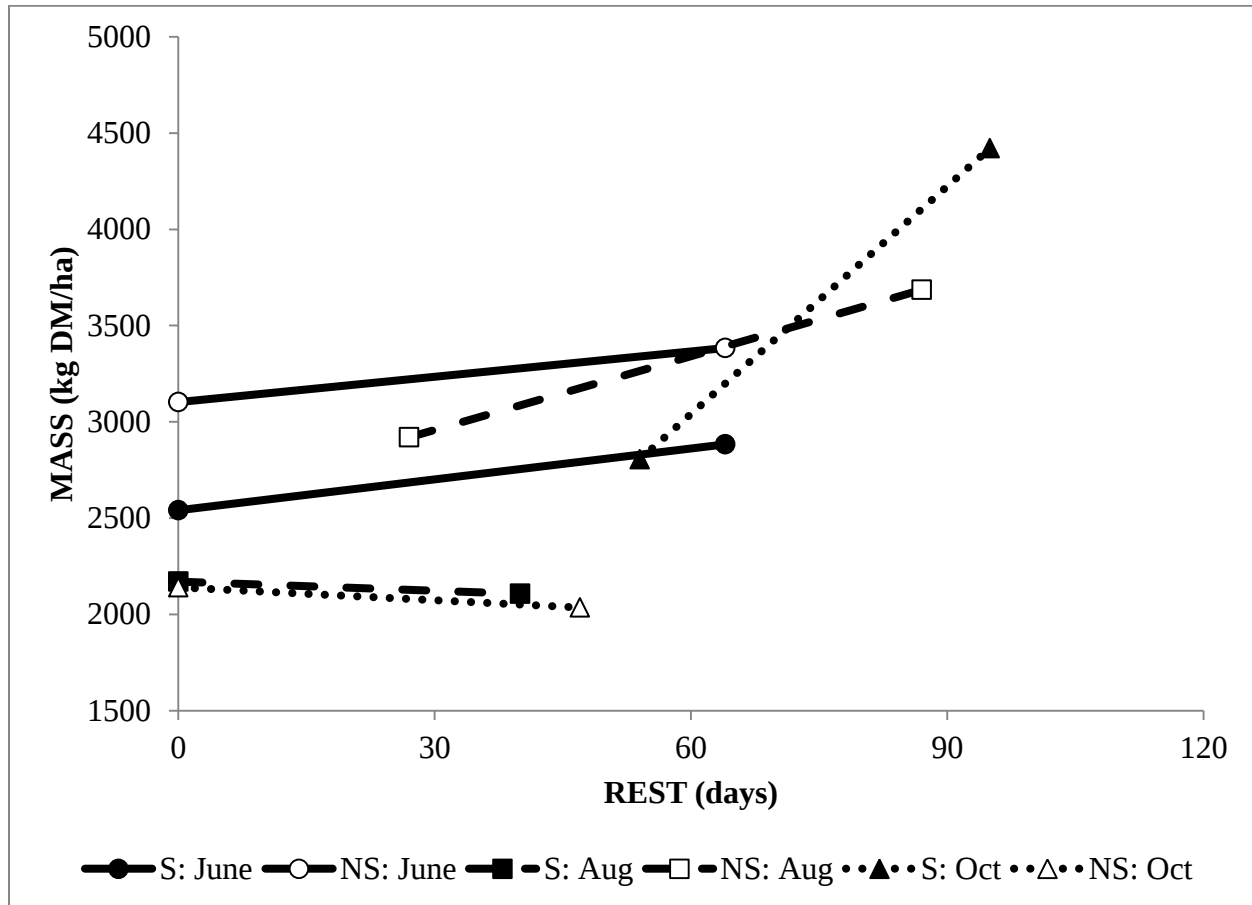


Figure 3.5. Least squares means for forage mass (MASS; kg DM/ha) in stockpiled (S) and non-stockpiled (NS) paddocks, over the range of values for days since last grazed (REST; d) for select inventory months



CHAPTER 4: USE OF ULTRASOUND SCANNING AND BCS TO EVALUATE COMPOSITION TRAITS IN MATURE BEEF COWS

ABSTRACT

The experiment was designed to validate the use of ultrasound to evaluate body composition in mature beef cows. Both precision and accuracy of measurement were assessed. Cull cows ($n = 87$) selected for highly variable fatness were used. Two experienced ultrasound technicians scanned and assigned BCS to each cow on 2 consecutive days. Ultrasound traits were backfat thickness (UBFT), LM area (ULMA), body wall thickness (UBWT), rump fat depth (URFD), rump muscle depth (URMD), and percentage intramuscular fat (UIMF). Cows were then harvested. Carcass traits were HCW, backfat thickness (CBFT), LM area (CLMA), body wall thickness (CBWT), and marbling score (CMS). Correlations between consecutive live measurements were greatest for subcutaneous fat ($r > 0.94$) for the 2 technicians, and lower for BCS ($r > 0.74$) and URMD ($r > 0.66$). Repeatability bias differed from zero for only 1 technician for URMD and UIMF ($P < 0.01$). The 2 technicians differed in repeatability SE for only ULMA ($P < 0.05$). Correlations between live and carcass measurements were high for UBFT and UBWT ($r > 0.90$), and slightly less for UIMF and ULMA ($r = 0.74$ to 0.79). Both technicians underestimated all carcass traits with ultrasound, but only CBFT and CBWT prediction bias differed from zero ($P < 0.05$). Technicians had similar prediction SE for all traits ($P > 0.05$). Technician effects generally explained $<1\%$ of the total variation in precision. After accounting for technician, animal effects explained 50.4% of remaining variation for BCS differences ($P < 0.0001$) but were minimal for scan differences. When cows with mean BCS <4 or >7 (9-pt scale)

were removed, the portion of remaining variation defined by animal effects increased (to 15.7 to 23.6% from 1.8 to 11.2%) for UBFT, ULMA, URFD and URMD and was significant for UBFT and URFD ($P = 0.03$). Technician defined trivial variation in accuracy ($P > 0.24$). However, animal effects explained 87.2, 75.2, and 81.7% ($P < 0.0001$) of the variation remaining for CBFT, CLMA, and CBWT prediction error, respectively, and remained large and highly important ($P < 0.0001$) when only considering cows with BCS from 4 to 7. We conclude that experienced ultrasound technicians can precisely and accurately measure traits indicative of composition in mature beef cows. However, animal differences define substantial variation in scan differences and prediction errors. Implications for technician certification, carcass pricing, and genetic evaluation are discussed.

INTRODUCTION

Body condition influences mature size (Klosterman et al., 1968), nutrient requirements (NRC, 2000), food intake (Holloway and Butts, Jr., 1984), reproductive efficiency (Richards et al., 1986), and cull value (Apple, 1999) of beef cows. Accordingly, it has key implications for profitable cow-calf systems. Subjective BCS is commonly used to assess body reserves (Miller et al., 2004; Odhiambo et al., 2009). Real-time ultrasound allows such energy depots to be measured objectively.

Standard carcass measurements reflect composition (Greiner et al., 2003c). Since ultrasound can reliably predict carcass measurements (Greiner et al., 2003b; Emenheiser et al., 2010), it follows that ultrasound can be used to estimate composition indirectly. That syllogism

has been validated in young animals with carcass dissection (Greiner et al., 2003a; Tait et al., 2005), but has not been widely explored in mature cows.

Bullock et al. (1991) confirmed that ultrasound adds value to BCS for predicting cow composition. Ultrasound consistency across repeated scans of the same cows has not been considered. The accuracy of prediction of cow carcass traits has been evaluated only by correlation, which does not reflect measurement bias (Houghton and Turlington, 1992). Statistics used by the Ultrasound Guidelines Council (**UGC**) to certify scanners of young beef animals for submission of ultrasound body composition data to U.S. breed associations (Tess, 2012), namely bias, and standard error of repeatability (**SER**) and standard error of prediction (**SEP**), have not been reported for cows.

This experiment was designed to evaluate: i) relationships among live animal body composition and carcass traits in cows varying appreciably in BW, BCS, and therefore fatness; ii) precision and accuracy of ultrasound scanning and BCS in cows using UGC statistics; and, iii) consequences of variation in BCS among cows on these statistics.

MATERIALS AND METHODS

This study was conducted at the Roman L. Hruska U. S. Meat Animal Research Center (USMARC), Clay Center, NE in November, 2012. Animals were raised in conformation with the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010) and their care was approved by the USMARC Animal Care and Use Committee.

Animals

Beef cows ($n = 87$) targeted for cull (for age or reproductive failure) were used. Cows originated from multiple research herds at USMARC with variable breed composition and production history, and ranged in age from 2 to 13 yr. The experimental population therefore provided considerable variation in BW, fatness and muscling, which was focal to the hypotheses tested.

Experimental design

Each cow was ultrasonically scanned in random order on 2 consecutive days by 2 experienced technicians. A cow remained in the chute until evaluated by both technicians, who operated independently and in alternating order. Cows were then harvested at a commercial plant and related measurements were taken on carcasses.

Live animal measurements

A weigh scale was not available on the scanning days, but recent BW were available on the cows. With the exception of 1 record from 94 d prior, all BW had been collected within 3 wk of scanning.

Ultrasonic images were captured on the left side of the animals. Each technician collected 1 rib, 1 rump, 1 body wall, and 5 intramuscular fat images per cow per day. Rib and body wall images were captured between the 12th and 13th ribs. Those images were used to estimate subcutaneous backfat thickness (**UBFT**), area of the LM (**ULMA**), and thickness of the body

wall (**UBWT**). The UBFT was measured $\frac{3}{4}$ of the length ventrally on the LM, and the UBWT was measured perpendicular to the external body surface 4 cm from the ventral tip of the LM. Rump images were collected midway between the hook and pin bones (ischium and ilium) and approximately 7.5 cm from and parallel to the dorsal midline. Rump images were used to measure rump fat thickness (**URFD**) at the interface of the *biceps femoris* and *gluteus medius* muscles. The rump muscle depth (**URMD**) was measured as the lean tissue depth from the ventral endpoint of URFD to the hip bone. Intramuscular fat images were collected over the LM, approximately perpendicular to and including the last 3 ribs, and were used to measure percentage intramuscular fat (**UIMF**). The acronyms assigned to live animal measurements are provided in Table 4.1.

Ultrasonic images were collected with an Aloka SSD-500 machine (Corometrics Medical Systems, Wallingford, CT), fitted with a 17 cm, 3.5 MHz linear transducer using vegetable oil as a couplant. To avoid tissue distortion in rib images affecting ULMA, the transducer was fitted with a Superflab wave guide standoff pad (Mick Radio-Nuclear Instruments, Inc., Mt. Vernon, NY) when possible. Rib images were occasionally collected without use of a standoff pad for thin or light-muscled cows. Images were captured and stored to a laptop computer using Scanning Partner software (UltraInsights, Inc., Maryville, MO), and sent to an UGC-certified lab technician for interpretation. Measurements were based on 1 interpretation of a single image for UBFT, ULMA, UBWT, URFD, and URMD, and the average interpretations of the best 4 of 5 images for UIMF.

Each technician independently assigned a subjective BCS to each animal before ultrasound scanning on each day. The BCS were assigned using a standard 9-point scale based on the technicians' visual estimations of fatness and muscling. Detailed descriptions of the

characteristics for each score are provided by Eversole et al. (2009). In this study, scores were assigned when cows were confined to the chute, and only the cows' left sides were used for evaluation.

In order to coordinate with the operations of the commercial plant, cows were sent in 3 harvest groups of 29, at 4, 6, and 11 d after the second scanning. Harvest groups were stratified by the average of the 2 BCS and a chute-side measurement of ultrasound backfat thickness collected on d 1.

Carcass measurements

On each harvest day, HCW were collected. The following day, carcasses were ribbed between the 12th and 13th ribs by a single personnel. After a “bloom” period of approximately 15 min, rib images were captured on both halves of the split carcass using the USMARC beef carcass image analysis system (Shackelford et al., 2003). Carcass measurements predicted by the system included backfat thickness (**CBFT**), LM area (**CLMA**), and marbling score (**CMS**). Due to inability to consistently capture 4 cm of the lower rib region on all images, carcass body wall thickness (**CBWT**) was measured manually with a probe on both carcass sides. If the probe measurement was noticeably affected by fat tear or other workmanship artifacts, that side was not used. When measurements were recorded on both sides, the 2 were averaged. The acronyms assigned to carcass measurements are provided in Table 4.1.

Statistical analyses

Data were analyzed using the MEANS, CORR, GLM and MIXED procedures of SAS (SAS Inst. Inc., Cary, NC). For repeatability and accuracy statistics, animals lacking complete data for each analysis were excluded to avoid imbalance.

Relationships among traits

Pooled residual correlations among all traits were calculated for combined data using a model that included the effects of technician, day, and technician by day interaction, with and without linear adjustment for the effects of HCW.

Precision of live animal measurements

Precision of measurement was evaluated for ultrasound traits and BCS by comparing repeated measurements taken by the same technician on the same animal on consecutive days. This was assessed using 3 statistics suggested by the UGC (Tess, 2012) for each trait. The first statistic was the simple within-trait correlation among a technician's repeated measurements. The second statistic was the mean difference between these repeated measurements, which is referred to as repeatability bias. Repeatability bias was calculated as $\mu_{RB_j} = \sum_i^n (y_{2ij} - y_{1ij})/n$, where y_{2ij} and y_{1ij} were the second and first measurements of a trait, respectively, on the i^{th} of n cows by the j^{th} technician. The third statistic was the standard error of the differences between repeated ultrasound or BCS measurements, which is referred to as SER. The SER was calculated as

$SER_j = \left[\sum_i^n (y_{2ij} - y_{1ij})^2 / n \right]^{1/2}$. To facilitate comparison of measurement precision among traits, SER for each trait were also presented as CV, scaled to the mean of the first and second live measurements for each technician.

Repeatability of ultrasound measurements may vary among technicians. In order to test that possibility, the differences between repeated live animal measurements (i.e., scan differences) were analyzed by fitting a linear model with technician as the fixed effect, and residual as the random effect. Comparisons of precision between technicians were made using Levene's test for homogeneity of variance.

Accuracy of carcass trait prediction

Accuracy was assessed by comparing measurements in live animals to their analogous measurements on the same animal's carcass. Again, 3 statistics suggested by the UGC were assessed. These were calculated within each technician for each trait on each scanning day. The first statistic was the simple correlation between live and carcass measurements of corresponding traits on the same animals. The second statistic was the mean difference between these measurements, which is referred to as prediction bias. Prediction bias was calculated as

$\mu_{PB_j} = \sum_i^n (y_{U_{ij}} - y_{C_i}) / n$, where $y_{U_{ij}}$ was the ultrasound measurement for a trait on the i^{th} of n cows by the j^{th} technician on a given day, and y_{C_i} was the carcass measurement for that trait on the i^{th} cow. The third statistic was the standard error of the difference between corresponding ultrasound and carcass measurements, and is referred to as SEP. The SEP was calculated as

$SEP_j = \left[\sum_i^n (y_{U_{ij}} - \mu_{PB_j} - y_{C_i})^2 / (n - 1) \right]^{1/2}$. To facilitate comparison of measurement accuracy among traits, SEP for each trait were also presented as CV, scaled to the mean carcass measurement for the trait.

Differences in accuracy among technicians were tested by analyzing the differences between live animal and corresponding carcass measurements (i.e., prediction errors). A linear

model with technician, day, and their interaction as the fixed effects, and residual as the random effect, was initially fitted. In preliminary analyses, neither day ($P > 0.76$) nor the technician by day interaction ($P > 0.70$) defined substantial variation in prediction errors for UBFT, ULMA or UBWT. Least squares means for ultrasound-carcass bias also did not differ ($P > 0.72$) within technician across days. In light of this, and to better represent the application of ultrasound in practical settings, the accuracy statistics reported in this study consider only scans collected on the first day. The effects of day and technician by day interaction were then necessarily removed from the model. Comparisons of accuracy between technicians were made using Levene's test for homogeneity of variance.

Technician and animal variation

In the construct of the UGC guidelines, variation in live and carcass composition among animals is not explicitly stated. However, animal effects may impact both the precision and accuracy of ultrasound evaluations. The animal component of scan differences (i.e., the difference between second and first ultrasound or BCS measurement) and prediction errors (i.e., the difference between first ultrasound and the analogous carcass measurement) was assessed in 2 ways. First, the relative contributions of technician and animal effects to overall phenotypic variation in these differences were considered for each live animal measurement by fitting both technician and animal as random effects, in addition to the residual. Second, a random animal effect was added to the statistical models fitted for calculation of SER and SEP; doing so allowed the variation remaining once accounting for a fixed technician effect to be partitioned into animal and residual components. By fitting animal in these models, the probability of detecting differences in precision and accuracy between technicians would be expected to increase.

The cows for this study were chosen to be widely variable in BCS. To investigate the animal effects on technician performance in a population that was more likely to represent a typical breeding herd, the same analyses were repeated on a reduced data set of 67 cows that excluded cows with an average BCS <4 or >7.

RESULTS AND DISCUSSION

Summary statistics

Summary statistics for live variables and for analogous carcass measurements are presented in Table 4.2. With the exception of BW, each live trait was measured 4 times per cow (2 technicians and 2 days). In rare cases, ultrasound data were missing based on interpretation technician image quality assessment, which is reflected by fewer than 348 observations for the trait. No ultrasound measurements were missing for UBFT, ULMA, or UIMF. Carcass variables reflect a single measurement for each trait per carcass ($n = 87$).

Measurements of subcutaneous fat (URFD, UBFT, and CBFT) were most variable, with CV of 94.3, 81.9, and 64.2%, respectively. Weight traits (BW and HCW; CV = 15.9 and 20.4%, respectively) and muscle traits (URMD, CLMA, and ULMA; CV = 11.9, 16.3, and 16.8%, respectively) were least variable.

Compared to the few other studies evaluating ultrasound in mature beef cows, this study was larger in size and included a wider range in BW and fatness. The minimum BW in the current study (382.8 kg) was comparable to the average of the lightest group reported by Bullock et al. (1991); additionally, the average of the heaviest group in that study (528.7 kg) was lighter

than both the overall mean (608.4 kg) and maximum BW (868.6 kg) in the current study. Means for BW reported by Miller et al. (2004) were similar to ours, but did not approach either our maximum or minimum BW; their BW were also affected by pregnancy. In addition, neither Bullock et al. (1991) nor Miller et al. (2004) evaluated cows with the extremes in carcass fatness found in our study. Furthermore, with increases in cow mature weights generally over the past decades (Cundiff et al., 2007), periodic evaluation of current cow types is warranted.

Larger CV for measurements of subcutaneous fat as compared to BCS, weight, and muscle traits suggests that variation in fatness may offer the greatest potential to describe overall variation in composition. The evaluation of subcutaneous fat may therefore be the most valuable application of ultrasound technology in cows, provided it remains sufficiently precise when absolute measurements are small. The considerably lower CV for BCS than fat measurements suggests that BCS is also influenced by muscling traits, which are less variable.

Residual correlation

Pooled residual correlations between ultrasonic measurements and corresponding carcass measurements (shown above the diagonal in Table 4.3) were high ($r = 0.73$ to 0.94). Correlations with HCW were significant for all traits, and slightly greater for ultrasonic vs. carcass measurements of backfat thickness and LM area. After adjustment for HCW (shown below the diagonal in Table 4.3), most of the residual correlations between measurements of fat and muscle were not different from zero ($P > 0.05$) or were even significantly negative. The latter case implies that fat and muscle become antagonistic in cows of a given weight; that is, fatter animals tend to be relatively lighter muscled. After adjusting for HCW, residual correlations between

corresponding ultrasound and carcass traits were consistently lower although they remained positive and significant ($P < 0.0001$). The most appreciable reduction in size of the correlation was between ULMA and CLMA ($r = 0.78$ and 0.44 before and after adjusting for HCW, respectively). Since the correlation between HCW and CLMA is 0.75 , these results imply CLMA reflects carcass weight nearly as much as muscle size.

Precision of live animal measurements

Correlation

Within-technician correlations between live measurements taken on consecutive days are shown in Table 4.4. Correlations differed more among measurements than between technicians, and were greatest ($r = 0.94$ to 0.99) for measurements of subcutaneous fat or body wall thickness. Noticeably lower correlations between repeated measurements were observed for BCS ($r = 0.74$ and 0.75) and URMD ($r = 0.73$ and 0.66). The former is not surprising as BCS is subjective rather than objective, and was collected while cows were confined to the chute. Variation in shape of cows' hip bones likely causes the distance between the reference point (hook bone) and spine to differ among cows. This may have resulted in difficulty in assessing URMD at the same anatomical location across days. Although correlations among repeated ultrasound measurements were not found in the literature for beef cows, our correlations exceeded those required by the UGC (Tess, 2012) for UBFT, ULMA, UIMF, and URFD ($r \geq 0.90, 0.85, 0.85$, and 0.90 , respectively). Repeatability correlations in our study were also greater than those reported for ULMA, UBFT, and UBWT in lambs ($r = 0.66, 0.79$, and 0.67 ,

respectively) by Emenheiser et al. (2010). This is likely attributable to the greater variation in these traits in cows as compared to lambs.

Repeatability bias

Mean values for the differences between repeated measurements on live animals are reported for the 2 technicians in Table 4.4. Measurements were generally consistent across days ($P > 0.05$). The only exceptions were for Technician A for URMD and UIMF ($P < 0.01$). In both cases, the repeatability bias was negative, meaning the measurement was less on the second day. No comparative results were available in the literature for cows.

SER

Standard errors of repeatability between measurements taken on consecutive days for both technicians are shown in Table 4.4. The 2 technicians were similar in their SER for most traits, only differing for ULMA ($P < 0.05$). Both technicians met or exceeded UGC certification standards for SER for UBFT, ULMA, UIMF, and URFD. The other two traits, UBWT and URMD, are not routinely evaluated by UGC and hence there are not standards to compare to. When expressed relative to the mean for the trait across both days and within technician, the SER were greatest for BCS (CV = 16.2 to 18.1%), least for ULMA and URMD (CV = 5.8 to 9.6%), and varied little among remaining measurements of fatness (CV = 11.8 to 16.4%). Compared to a similar ultrasound validation study in lambs (Emenheiser et al., 2010), our repeatability CV were slightly less than those reported for ULMA, UBFT, and UBWT (CV = 9.8, 15.3, and 16.9% in that study, respectively).

Accuracy of carcass trait prediction

Correlation

Within-technician correlations between live (first day) and carcass measurements are shown in Table 4.5. Again, correlations differed more among measurements than between technicians. Correlations for fat measurements were high, with $r \geq 0.90$ for UBFT and UBWT. Correlations were slightly less for UIMF and ULMA ($r = 0.74$ to 0.79). This result was to be expected for UIMF, as CMS was a related but not analogous measure. The modest relationship between ULMA and CLMA is possibly explained by area measurements being 2- as compared to 1-dimensional. Bilateral asymmetry could also be a source of error since carcass measurements reflect the average of both sides. This is more likely, since the correlation between repeated measurements of ULMA was high ($r = 0.86$ to 0.94 ; Table 4.4). The correlations of 0.60 and 0.62 between BCS and CBFT are not surprising since the traits differ, including the fact that BCS considers both muscling and fatness.

Our accuracy correlations for cows were greater than those reported by Bullock et al. (1991) for UBFT ($r = 0.79$) but less for ULMA ($r = 0.90$). Our results were similar to those of Miller et al. (2004) for UBFT and UIMF ($r = 0.85$ and 0.69 , respectively) and considerably greater than that reported for ULMA ($r = 0.49$). A difference in methods between these studies is our use of predicted rather than actual carcass measurements.

Both technicians in our study met UGC guidelines for prediction correlations of UBFT ($r \geq 0.90$), but were slightly below certification standards for ULMA and UIMF ($r \geq 0.85$ and 0.85 , respectively; Tess, 2012). These comparisons are for reference only; the UGC guidelines are not intended to certify cow scan technicians. Also, in a UGC certification event, UIMF

measurements would instead be compared to the UIMF measurement of a reference technician rather than to CMS.

Prediction bias

Mean values for the differences between ultrasound and carcass measurements (prediction bias) are reported for the 2 technicians in Table 4.5. Both technicians underestimated carcass measurements with ultrasound for all traits, as indicated by consistently negative values for prediction bias. Of the 3 traits for which both ultrasound and carcass measurements existed, prediction bias for both backfat and body wall thickness differed from zero ($P < 0.05$). The composition of mature animals differs from young animals, with mean values for traits often larger. This may increase prediction bias. In addition, the carcass measurements were based on prediction equations developed for steer carcasses rather than cows. Still, our prediction bias nearly met the UGC's guidelines for UBFT (0.17 and $0.15 \geq 0.13$ cm), and was within the acceptable range for ULMA (0.96 and $0.11 \leq 6.45$ cm²).

SEP

Standard errors of prediction between analogous ultrasound and carcass measurements are shown for both technicians in Table 4.5. The 2 technicians were similar in prediction accuracy for all 3 traits ($P > 0.05$). Neither technician met the requirements for UBFT or ULMA SEP in young animals published by the UGC (Tess, 2012). However, it is important to note that UGC guidelines (Tess, 2012) generally calculate accuracy statistics relative to reference technician-collected ultrasound measurements, rather than carcass-collected data as we used in this study. When scaled to the mean carcass measurement for the trait within technician, the SEP

were greatest for UBFT (CV = 28.6%), and least for ULMA (CV = 10.6 to 11.0%). Our CV for UBFT and ULMA were slightly greater than those reported in lambs by Emenheiser et al. (2010) and slightly less than the CV for UBWT in that study (CV = 22.4, 9.9%, and 16.4% for UBFT, ULMA, and UBWT, respectively).

Technician and animal variation

Precision of live animal measurements

When considering variation in scan differences in the full data that was defined by technician and animal, errors due to technician were negligible ($P > 0.29$). For all traits except UIMF (3.1%), random technician effects accounted for <1% of the total phenotypic variation in scan differences. When the data were reduced to lessen variation in BCS, still very little (<3.9%) of the variation in scan differences for any trait was explained by technician ($P > 0.29$).

The remaining variation in scan differences, once accounting for technician effects, was partitioned into animal and residual components. For ultrasound traits, the animal effect accounted for between 1.4 and 12.2% of that remaining variation (Table 4.6; $P > 0.13$). Only for BCS was a substantial percentage of the variation unexplained by technician accounted for by animal (50.4%; $P < 0.0001$). Animal effects defined the lowest proportion of the remaining variation in scan differences in UBFT and ULMA (1.4 and 3.5%, respectively). Thus, the pattern of change in estimates of composition between the 2 d was consistent among animals for the 2 technicians only for BCS.

When animal (after accounting for technician) effects were evaluated in the reduced data where cows with average BCS <4 or >7 had been removed, the results were similar for BCS,

UBWT and UIMF as in the full data (Table 4.6). However, the animal component increased substantially for UBFT, ULMA, URFD and URMD (23.6 vs. 1.4%, 15.7 vs. 3.5%, 23.6 vs. 11.4%, and 20.7 vs. 7.3%, respectively). Furthermore, animal defined significant variation in scan differences for UBFT ($P = 0.03$) and URFD ($P = 0.03$). These results suggest that for fat traits particularly, when cows are comparatively more uniform in BCS, measurement precision is even more sensitive to animal differences.

Accuracy of carcass trait prediction

Technician also defined trivial variation in prediction errors in both the full and reduced data for most traits ($P > 0.24$). Although still not significant, technician explained 6.7% and 12.7% of the variation in body wall thickness prediction errors in the full and reduced data, respectively.

Animal effects were considerably more important for explaining prediction errors than scan differences (Table 4.6). For backfat, LM, and body wall prediction errors, animal effects accounted for 87.2, 75.2, and 81.7% of the variation remaining, respectively, after accounting for technician effects ($P < 0.0001$). This result indicates that large individual animal effects on prediction accuracy were present and were consistent among technicians. These animal effects likely reflect unique differences in amounts, shapes, or distributions of tissues among animals.

When investigating prediction errors using the reduced data set (Table 4.6), the animal component remained highly significant ($P < 0.0001$). Of the variation remaining in backfat, LM and body wall bias prediction errors, animal accounted for 93.2, 73.1, and 75.5%, respectively, in the reduced data. These results further substantiate that animal differences are highly influential

on typical UGC validation statistics for ultrasound of cows, even when variation in BCS is restricted to levels commonly encountered in practice.

Conclusions

Our results indicate that experienced ultrasound technicians can precisely and accurately measure traits indicative of composition in mature beef cows. Objective ultrasound measurements were more repeatable than subjective BCS, and were more predictive of carcass measurements. Ultrasound therefore provides more reliable, and more trait-specific, assessment of cow composition than BCS. Accuracy of carcass trait prediction was similar between the 2 technicians in this study, and those technicians were highly repeatable for all commonly-measured ultrasound traits. Repeatability estimates for the carcass imaging software were previously shown to be very high (> 0.97) for traits used in our analysis (Shackelford et al., 2003).

Innate discrepancy between ultrasound and carcass measurements therefore appears to exist that is not attributable to error in repeatability of either measure. Furthermore, prediction accuracy is more sensitive to differences among animals than between experienced technicians; in excess of 73% of the total variation in prediction errors for all traits was associated with animal effects. Such was the case with both a broader and narrower range of cow BCS.

Implications

There are 3 main contexts in which the precision and accuracy of composition estimation are important: i) certification of ultrasound technicians, ii) pricing of live animals based on carcass merit, and iii) genetic evaluation of composition traits. The technicians in our study mostly met the UGC criteria for technician certification, but evaluating sources of repeatability error and prediction error overwhelmingly reflected differences among animals rather than between technicians. This implies that UGC guidelines may not be sufficiently stringent when variation in fatness among animals scanned for a certification event is not standardized.

In practice, mature cows are not commonly scanned and variation in fatness among young animals is anticipated to be less. Still, investigation of between-animal effects on UGC statistics is likely warranted in younger animals to ensure that certification requirements for technicians are sufficiently, and consistently, rigorous.

Given the extent of prediction bias, the pricing of cow carcasses on direct carcass measurements is not likely improved by live animal ultrasound. Such is particularly the case given the relatively narrow range of cow carcass grades and prices, and the costs associated with implementing ultrasound technologies. However, if the spread of cow carcass value was greater and(or) ascribed in the live animal, the high repeatability of ultrasound indicates it could contribute to delineating differences in carcass composition and value and assisting management decision prior to marketing.

In genetic evaluation of composition traits, the current beef industry structure again focuses on younger animals. With the fit of contemporary group effects in BLUP evaluations, the batch effect of individual technicians is absorbed. Therefore, in the context of genetic evaluation, the ability of a technician to consistently rank animals is more important than lack of measurement bias. Despite discrepancy between ultrasound and carcass measurements in our

study, the high repeatability of ultrasound indicates it would be suitable for incorporation into genetic evaluation of composition in cows, if such was deemed valuable. Among the most promising applications of ultrasound in cows is its potential for more precise adjustment of mature cow weights to a constant endpoint for mature size EPD calculations.

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Table 4.1. Description of acronyms

Acronym	Definition
BW	Live body weight, kg
HCW	Hot carcass weight, kg
BCS	Body condition score (1 to 9)
UBFT	Ultrasound backfat thickness, cm
CBFT	Carcass backfat thickness, cm
ULMA	Ultrasound longissimus muscle area, cm ²
CLMA	Carcass longissimus muscle area, cm ²
UBWT	Ultrasound body wall thickness, cm
CBWT	Carcass body wall thickness, cm
URFD	Ultrasound rump fat depth, cm
URMD	Ultrasound rump muscle depth, cm
UIMF	Ultrasound intramuscular fat, %
CMS	Carcass marbling score

Table 4.2. Summary statistics for traits measured in live animals and carcasses¹

Item	No.	Mean	Min	Max	SD	CV, %
Live variable ²						
BW, kg	87	608.4	382.8	868.6	96.9	15.9
BCS	348	5.9	2.0	9.0	1.4	23.5
UBFT, cm	348	0.61	0.10	2.64	0.50	81.9
ULMA, cm ²	348	73.97	34.52	108.84	12.41	16.8
UBWT, cm	347	3.19	1.52	7.90	1.15	36.1
URFD, cm	346	0.92	0.10	5.84	0.87	94.3
URMD, cm	346	8.41	5.21	11.86	1.00	11.9
UIMF, %	348	4.04	2.00	8.56	1.28	31.6
Carcass variable ³						
HCW, kg	87	322.7	176.9	521.6	65.9	20.4
CBFT, cm	87	0.77	0.10	2.51	0.50	64.2
CLMA, cm ²	87	74.59	23.16	101.81	12.15	16.3
CBWT, cm	87	3.72	1.50	9.05	1.51	40.7
CMS	87	386.1	237.0	710.0	96.7	25.0

¹See Table 4.1 for a description of acronyms.

²Live measurements, with the exception of BW, were measured by 2 technicians on 2 consecutive days.

³Carcass measurements of CBFT, CLMA, and CMS were recorded from rib images of both sides of split carcasses using the USMARC beef carcass image analysis system (Shackelford et al., 2003). The CBWT was measured manually with a probe, on both carcass sides when possible.

Table 4.3. Residual correlations among and between ultrasonic and carcass measurements with and without prior adjustment for hot carcass weight^{1,2}

Variable	Live animal measurement								Carcass measurement				
	BW	BCS	UBFT	ULMA	UBWT	URFD	URMD	UIMF	HCW	CBFT	CLMA	CBWT	CMS
BW	-	0.65***	0.60***	0.74***	0.65***	0.58***	0.60***	0.36***	0.96***	0.59***	0.72***	0.70***	0.40***
BCS	-0.28***	-	0.68***	0.66***	0.72***	0.68***	0.51***	0.34***	0.73***	0.66***	0.55***	0.75***	0.41***
UBFT	-0.43***	0.32***	-	0.55***	0.92***	0.93***	0.38***	0.59***	0.72***	0.91***	0.29***	0.93***	0.48***
ULMA	-0.26***	0.16**	-0.09	-	0.65***	0.53***	0.59***	0.22***	0.82***	0.56***	0.78***	0.68***	0.38***
UBWT	-0.49***	0.35***	0.83***	0.04	-	0.90***	0.44***	0.55***	0.78***	0.88***	0.39***	0.94***	0.48***
URFD	-0.40***	0.35***	0.86***	-0.08	0.80***	-	0.36***	0.62***	0.69***	0.84***	0.29***	0.90***	0.55***
URMD	-0.11*	0.06	-0.16**	0.15**	-0.14**	-0.16**	-	0.10	0.65***	0.41***	0.57***	0.47***	0.22***
UIMF	-0.08	0.08	0.48***	-0.19**	0.42***	0.52***	-0.22***	-	0.39***	0.54***	0.00	0.57***	0.73***
HCW	3	3	3	3	3	3	3	3	-	0.70***	0.75***	0.81***	0.45***
CBFT	-0.43***	0.31***	0.82***	-0.04	0.75***	0.69***	-0.08	0.41***	3	-	0.27***	0.91***	0.47***
CLMA	0.01	0.00	-0.52***	0.44***	-0.45***	-0.47***	0.17**	-0.47***	3	-0.55***	-	0.43***	0.31***
CBWT	-0.50***	0.40***	0.85***	0.06	0.84***	0.81***	-0.14**	0.46***	3	0.81***	-0.44***	-	0.51***
CMS	-0.13*	0.14*	0.25***	0.02	0.22***	0.36***	-0.12*	0.68***	3	0.24***	-0.06	0.27***	-

¹See Table 4.1 for a description of acronyms.

²Correlations above the diagonal are from a model that included only the effects of technician, day, technician by day interaction, and animal. Those below the diagonal are further adjusted for linear effects of HCW. Bold typeface indicates a correlation between the same measurements in live animal and carcass.

³Not available when HCW is included in the model.

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.0001$.

Table 4.4. Within-technician (A or B) correlation, repeatability bias, standard error of repeatability (SER), and CV associated with live animal measurements repeated on consecutive days¹

Live variable	Correlation ²		Repeatability bias ³		SER ⁴		CV, % ⁵	
	A	B	A	B	A	B	A	B
BCS, 1 to 9	0.74***	0.75***	-0.01	0.10	0.96 ^a	1.06 ^a	16.2	18.1
UBFT, cm	0.98***	0.99***	-0.00	-0.01	0.09 ^b	0.09 ^b	14.9	14.6
ULMA, cm ²	0.86***	0.94***	-0.13	-0.04	6.35 ^c	4.32 ^d	8.6	5.8
UBWT, cm	0.94***	0.95***	-0.03	0.02	0.38 ^e	0.39 ^e	12.4	11.8
URFD, cm	0.98***	0.99***	0.02	0.00	0.15 ^f	0.13 ^f	16.4	14.0
URMD, cm	0.73***	0.66***	-0.28*	-0.12	0.75 ^g	0.81 ^g	9.0	9.6
UIMF, %	0.93***	0.90***	-0.14*	0.01	0.50 ^h	0.55 ^h	12.1	13.9

¹See Table 4.1 for a description of acronyms.

²Simple correlation between repeated measurements taken on consecutive days.

³Calculated by averaging the subtraction of first day measurement from the second.

⁴Standard error of repeatability. $SER_j = \left[\sum_i^n (y_{2ij} - y_{1ij})^2 / n \right]^{1/2}$ where y_{2ij} and y_{1ij} are the second and first measurement of a trait, respectively, on the i^{th} of n cows by the j^{th} technician.

⁵SER relative to the mean for the trait in both days, within technician.

***Correlation differs from zero ($P < 0.0001$).

*Bias differs from zero ($P < 0.01$).

^{a-h}Means in the same row with the same superscript do not differ ($P < 0.05$).

Table 4.5. Within-technician (A or B) correlation, prediction bias, standard error of prediction (SEP), and CV associated with traits measured both in live animals and carcasses^{1,2}

Live variable	Correlation ³		Prediction bias ⁴		SEP ⁵		CV, % ⁶	
	A	B	A	B	A	B	A	B
BCS, 1 to 9	0.60***	0.62***						
UBFT, cm	0.90***	0.91***	-0.17*	-0.15*	0.22 ^a	0.22 ^a	28.6	28.6
ULMA, cm ²	0.79***	0.78***	-0.96	-0.11	7.93 ^b	8.19 ^b	10.6	11.0
UBWT, cm	0.94***	0.94***	-0.65*	-0.42*	0.59 ^c	0.57 ^c	15.8	15.3
UIMF, %	0.77***	0.74***						

¹See Table 4.1 for a description of acronyms.

²Calculated using only live animal measurements collected on the first day.

³Simple correlation between ultrasound and carcass measurements. Correlations for BCS, UBFT, ULMA, UBWT, and UIMF are with CBFT, CBFT, CLMA, CBWT, and CMS, respectively.

⁴Calculated by subtracting the carcass measurement from the ultrasound measurement.

⁵Standard error of prediction. $SEP_j = \left[\sum_i^n (y_{U_{ij}} - \mu_{PB_j} - y_{C_i})^2 / (n - 1) \right]^{1/2}$ where $y_{U_{ij}}$ is the ultrasound measurement for a trait on the i^{th} of n cows by the j^{th} technician, and y_{C_i} was the carcass measurement for that trait on the i^{th} cow.

⁶SEP relative to the mean carcass measurement for the trait.

***Correlation differs from zero ($P < 0.0001$).

*Bias differs from zero ($P < 0.05$).

^{a-c}Means in the same row with the same superscript do not differ ($P < 0.05$).

Table 4.6. Random animal and residual variation, and respective SE, for scan differences and prediction errors, after accounting for fixed effect of technician¹

	Full data ⁴				Reduced data ⁵			
	Animal		Residual		Animal		Residual	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Scan differences ²								
BCS ₂ -BCS ₁	0.513***	0.123	0.505***	0.077	0.504***	0.140	0.514***	0.089
UBFT ₂ -UBFT ₁	0.000	0.001	0.008***	0.001	0.001*	0.001	0.004***	0.001
ULMA ₂ -ULMA ₁	1.043	3.184	28.468***	4.340	3.690	2.930	19.823***	3.451
UBWT ₂ -UBWT ₁	0.018	0.016	0.131***	0.020	0.015	0.015	0.109***	0.019
URFD ₂ -URFD ₁	0.002	0.002	0.018***	0.003	0.003*	0.002	0.009***	0.002
URMD ₂ -URMD ₁	0.044	0.068	0.568***	0.088	0.112	0.070	0.429***	0.076
UIMF ₂ -UIMF ₁	0.025	0.030	0.252***	0.038	0.013	0.032	0.248***	0.043
Prediction errors ³								
UBFT ₁ -CBFT	0.041***	0.007	0.006***	0.001	0.033***	0.006	0.002***	0.000
ULMA ₁ -CLMA	48.897***	8.823	16.112***	2.472	40.309***	8.473	14.846***	2.604
UBWT ₁ -CBWT	0.276***	0.047	0.062***	0.009	0.151***	0.031	0.049***	0.009

¹See Table 4.1 for a description of acronyms.

²Calculated by subtracting the first day measurement from the second.

³Calculated by subtracting the carcass measurement from the first ultrasound measurement.

⁴Includes scans on all animals ($n = 86$) by both technicians.

⁵Excludes animals with average BCS <4 or >7 (20 cows were removed).

* $P < 0.05$; *** $P < 0.0001$.

CHAPTER 5: EFFECTS OF MATURE SIZE AND CREEP GRAZING SYSTEM ON CATTLE PERFORMANCE AND NET RETURNS FOR A PASTURE-BASED COW-CALF SYSTEM IN APPALACHIA

ABSTRACT

Production data from 2007 to 2013 for a spring-calving cow-calf enterprise in the Appalachian region of the U.S. were analyzed. The operation was based primarily on tall fescue and utilized rotational stocking and fall stockpiling. The primary research objective was to determine which combinations of cow frame size (**FS**) and calf creep system (**CS**) treatments resulted in the greatest calf weaning weight (**WW**) per land area and (or) maximized net returns to the enterprise. Cows were assigned to either large (**LF**) or medium (**MF**) FS categories primarily based on the yearling hip height (**HH**) EPD of their sires. Calves had access to either forward creep (**FC**) in the next fescue paddock to be grazed by their dams or to a designated creep (**DC**) seeded with higher quality forage. Ninety Angus-cross cow-calf pairs were stocked in the rotational system, and subdivided into 3 replicates of 7 LF and 8 MF pairs grazed on each CS treatment. The difference in cow numbers was to achieve similar stocking rates. The LF cows had 42.0 kg (7.6%) heavier BW and were 2.0 cm (3.9%) taller than MF cows at weaning ($P < 0.0002$). Cow BCS was not affected by FS, CS, or their interaction ($P > 0.24$). Pastures with MF cows contained 217.9 kg (5.2%) more total cow BW at weaning than LF pastures ($P = 0.002$). Calf WW from LF cows was 12.0 kg (5.6%) heavier than from MF cows ($P = 0.03$). However, the advantage in mean WW of LF calves did not compensate for the 1 fewer calf weaned from LF vs. MF cows. The combination of MF cows and DC creep systems resulted in the greatest

WW production efficiency (261 kg WW/ha). The FS and CS treatments and their interaction had no influence on calving rates ($P > 0.20$). The significant yr effect on AI calving rate ($P < 0.0001$) was attributable to minimum daily temperature and the temperature-humidity index for the first 9 d post-breeding ($R^2 = 0.95$; $P = 0.02$). In an average yr, 12.7 ($SD = 1.5$) kg of hay was fed to each cow daily for 99 ($SD = 28$) d. After adjustment for cow BW, the MF+DC combination required the most total kg of hay over an average production yr. The MF+DC systems had the greatest total costs, and netted the least returns. The greatest net returns were achieved in the LF+FC systems, which had the lowest production efficiency but also the lowest costs. We conclude that minimizing costs rather than maximizing productive outputs is a better strategy for cow-calf enterprises faced with similar choices between FS and CS treatments.

INTRODUCTION

Production efficiency is a driver of profitability in beef production (Klosterman, 1972; McMorris et al., 1986; Davis et al., 1994), and therefore its improvement is a goal for most cattle enterprises. Within the cow-calf sector, the primary receipts are for the weight of weaned calves marketed (Stokes et al., 1986; Davis et al., 1994). However, efficiency considers not only outputs but inputs as well. Because increasing outputs often requires increasing inputs, maximization of individual calf WW may not necessarily be the most efficient or profitable strategy for cow-calf production.

Although considerable emphasis has been placed on identifying cow types that are “efficient” from a metabolic or reproductive standpoint, holistic analysis of cow-calf systems extends beyond evaluation of the individual cow to consider efficiency at the farm or enterprise

level. This research evaluates whole system efficiency in two contexts: production efficiency defined by the weight of calves produced per land area, and economic efficiency quantified by net returns to the cow-calf enterprise. The experiment was designed to investigate two major factors that could influence production and or economic efficiency: mature cow size and creep grazing system.

The principal objectives of this research are to determine i) whether large or medium frame cows produce more total weight of saleable weaned calves per land area, ii) whether a designated calf creep area that offers higher quality forage to calves results in heavier WW than forward creeping calves ahead of their dams on the same fescue-clover forage base, and iii) which combination of these two factors (mature cow size and creep system) results in the greatest net returns to the enterprise.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at Virginia Tech approved all procedures and protocols used in the experiment (IACUC Protocol Number 08-046-cvm).

Overview

The production system was a spring-calving, cow-calf enterprise that utilized rotational stocking and fall stockpiling of tall fescue in the Appalachian region of the United States. The experiment was designed as 3 replicates of a 2x2 factorial, with frame size (large or medium) and creep system (designated or forward) as factors. Production data from 2007 to 2013 were

analyzed. These included 5 full production yr defined as the period between sequential weaning events.

Study site

The experiment was conducted at Virginia Tech's Shenandoah Valley Agricultural Research and Extension Center (SVAREC) in Steeles Tavern, VA (37°55'55"). The location was characterized by Frederick-Christian silt loams, fine, mixed, semiactive, mesic Typic Paleudults soil. Regional climate center data describe the area as temperate, with a mean air temperature of 17°C ranging from 4.7°C in January to a high of 28.5°C in July. The majority of the precipitation falls as rain, peaking between May and September, with an annual mean of 987mm (Flores and Tracy, 2012). Extensive weather data were logged daily to an on-site weather station (Natural Resources Conservation Service site 2088) for the duration of the experiment, and temperature and precipitation measures were downloaded for analysis (<http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=2088&state=va>).

Pasture

The grazing land consisted of twelve 6.47-ha pastures. Pastures were equally assigned to the 2 creep system (CS) treatments. The 6 pastures where forward creeping (FC) was utilized were evenly divided into eight 0.81-ha paddocks. Cow-calf pairs were rotationally stocked among the paddocks, and calves were given access to the next paddock to be grazed by their dams. In the other 6 pastures allotted for designated creeping (DC), 0.65 ha of each was

designated as a calf creep paddock that remained fixed throughout the yr. Cows-calf pairs were rotationally stocked on the remaining 5.83 ha, which was evenly divided into eight 0.73-ha paddocks.

Cow paddocks were killed and reseeded with tall fescue (*Festuca arundinacea* ‘Kentucky 31’) and mixed clover (*Trifolium pretense* ‘Cinnamon Red’, *Trifolium repens* ‘Huia White’, and *Trifolium repens* ‘Will Ladino’) during development of the site in 2000. Paddocks were subsequently frost seeded with 4.5 kg/ha each of red clover (*Trifolium pretense* ‘Cinnamon +’) and mixed white clover (*Trifolium repens* ‘Pinnacle’, and *Trifolium repens* ‘Kopu II’) in February 2007. Designated creep paddocks were seeded with 16.8 kg/ha of a nil-ergot, endophyte-infected fescue (*Festuca arundinacea* ‘MaxQ’) and 5.6 kg/ha of alfalfa (*Medicago sativa* ‘Ameristand 403T’) in fall 2006, followed by 11.2 kg/ha of each forage again in spring 2007. In fall 2006, between 1120.9 and 3362.6 kg/ha of lime was applied to paddocks according to soil sample recommendations. At that time, paddocks were also fertilized with 123.2, 134.5, and 3.4 kg/ha of P, K, and B, respectively. The only subsequent fertilizer application to designated creep paddocks was 44.8 kg/ha of N and 2.2 kg/ha of B applied in spring 2007. The only external seed input during the course of this study was a second frost seeding of red and white clover (same varieties and rates as in 2007) in cow paddocks in February 2009.

The normal grazing season spanned from approximately March to November each yr. During this time the 8 fescue-clover paddocks within each pasture were rotationally stocked, with the order and durations of stocking determined by the farm superintendent. From April through July, rotation decisions were based on rest days, with the rest periods increasing as forage growth slowed. A detailed description and analysis of the rotational stocking system is given by Emenheiser et al. (2014).

In each pasture, 4 of the 8 fescue-clover paddocks were stockpiled for winter grazing by cows. In July, the 4 paddocks to be stockpiled were stocked while the other 4 paddocks were rested. The stockpile paddocks were then fertilized with 67 kg/ha of N (urea) in mid-August and rested through the fall. Grazing of stockpiled forage began in mid to late-November and usually continued until January. With few exceptions, paddocks were given alternating stockpiling treatments in consecutive yr.

After forage stockpile was depleted, 1 of the 8 paddocks in each pasture was used for hay feeding from approximately January through the start of the grazing season in March or April. Occasionally under drought conditions, hay was fed in the fall, prior to grazing of stockpile in November. Hay was purchased or harvested elsewhere on the farm and did not originate from the pastures used for grazing in this experiment. The same paddock in each pasture was used for hay feeding each yr. Weight (kg) and duration (d) of hay feeding was recorded for each paddock from October 2007 through August 2012.

Cattle

The breeding program was designed to create 2 mature size classifications. Cows were considered either large (**LF**) or medium (**MF**) frame size (**FS**) based primarily on their sires, which were selected for divergent hip height (HH) EPD. A summary of EPD for sires used for artificial insemination (**AI**) in the 2 FS categories is presented in Table 5.1. Pastures were stocked with either 8 MF or 7 LF cows to provide approximately equal animal unit equivalents (AUE) per land area. A stocking rate of 1.4 to 1.5 AUE/ha was targeted.

Angus-cross cow-calf pairs (n=90) were used. Cows were between 3 and 17 yr of age, although most cows were 6 yr old. Replacement and first-calf heifers were developed elsewhere on the farm and were not considered in the analyses. Calving was targeted for March, and calves were stocked alongside their dams until weaning in September. Cows were culled annually at weaning for age and production. However, cows that failed to breed or that lost their calf were replaced immediately with a cow at the desired production stage from a spare herd maintained elsewhere on the farm. This was intended to maintain consistent stocking rates across replicates as much as possible.

At both breeding and weaning, cow body weight (**BW**, kg) and HH (cm) were measured. Cow body condition score (**BCS**, 9-point scale) was also assigned at these times, using guidelines described by Eversole et al. (2009). Calf weaning weight (**WW**, kg), HH, and age were recorded as well. Cow and calf data were available from weaning in 2007 to breeding in 2013. Simple mean, SD, minimum, and maximum values for cow and calf traits are presented in Table 5.2.

In 2007 to 2011, cows were synchronized for AI in late May or early June, followed by natural service clean-up bulls for approximately 60 d. In 2012, cows were synchronized for AI in early May. Cows were then re-synchronized, with those expressing heat in early June inseminated a second time. No clean-up bulls were used in 2012, thus the breeding season was approximately 30 d that yr. Calving began in March and typically ended in May.

Statistical analyses

Data were analyzed using the MEANS, GLM, and GLIMMIX procedures of SAS (SAS Inst. Inc., Cary, NC). Multiple comparisons of least squares means were made using a Tukey-Kramer adjustment.

Cow size and composition

Cow age in yr was recorded at each production stage (weaning or breeding). Cows with age ≥ 8 yr were combined into 1 age category. Records of cow BW, HH, and BCS at either breeding or weaning were assessed using a linear model of the general form:

$$Y_{ijklm} = \mu + F_i + C_j + (FC)_{ij} + S_{k(ij)} + R_l + A_m + (FA)_{im} + e_{ijklm} \quad [1]$$

where Y_{ijklm} was the response variable for a cow in FS F ($i = 1, 2$) and CS C ($j = 1, 2$) treatment groups, during yr R ($l = 1, \dots, 6$) and with age A ($k = 1, \dots, 6$), where $(FC)_{ij}$ and $(FA)_{im}$ were the FS by CS and FS by age interactions, respectively. The random terms included replicate S ($k = 1, 2, 3$) nested within the FS by CS interaction, and the residual error (e_{ijklm}). Because the individual cows within a pasture were not static throughout the experiment, a repeated measures design was not fitted.

Stocking rate

The total BW of cows stocked on each of the 12 pastures was also assessed at both weaning and breeding. In cases where other than 7 LF or 8 MF cow records were available at an event, the total BW was adjusted to reflect the appropriate number of cows for the FS category.

The general form of the linear model considered was:

$$Y_{ijkl} = \mu + F_i + C_j + (FC)_{ij} + S_{k(ij)} + R_l + e_{ijkl} \quad [2]$$

where Y_{ijkl} was total cow BW at either weaning or breeding, and other terms were as defined in Eq. 1. Cow stocking rates were calculated by dividing least squares means for the total cow BW on a pasture at either weaning or breeding by 6.47 ha.

Calf weaning weight

Individual phenotypes for calf WW were analyzed by fitting a linear model of the form:

$$Y_{ijklmn} = \mu + F_i + C_j + (FC)_{ij} + S_{k(ij)} + R_l + D_m + G_n + X_A \beta + e_{ijklmn} \quad [3]$$

where Y_{ijklmn} was the calf WW, with other terms those in Eq. 1 with the addition of dam age D ($m = 1, \dots, 6$), sex G ($n = 1, 2$), the design matrix X_A relating levels of the weaning age covariate to the calf to which they pertained, and β , the vector of linear regression coefficients. When calves were raised by a foster dam, the age of the foster rather than the biological dam was used.

Least squares means for individual calf WW obtained from Eq. 3 were multiplied by the number of cows stocked per pasture in the corresponding FS category. That total calf WW was then expressed as a proportion of the total cow weight in the respective pasture, which was multiplied (scaled) by the average total cow BW across all FS, CS and yr. These scaled total calf WW were expressed on a per ha basis as the measure of production efficiency.

Reproduction

Cows were evaluated by the success or failure to calve, either to the first AI or overall. These binomial events (0 for failure vs. 1 for success) were summed for each cow age category within each FS, CS, and yr combination. The proportions of cows that calved of those exposed, or that conceived to their first AI of those inseminated, were analyzed with a generalized linear model with a binomial distribution and a logit link. The model fitted was:

$$\text{logit}(Y_{ijlm}) = \mu + F_i + C_j + (FC)_{ij} + R_l + A_m + e_{ijlm} \quad [4]$$

where Y_{ijkl} was either the proportional calving rate to first AI or overall. The other terms were those in Eq. 1, with the addition of cow age category A ($m = 1, \dots, 6$). Given the different breeding protocol in the final yr, the fixed yr term also included variation attributable to the length of the clean-up period and(or) the number of times a cow was AI bred. However, those effects were not evaluated specifically due to confounding with a single yr. In preliminary analyses, the impacts of the AI sire to which a cow was first inseminated, and replicate, were considered. Neither defined variation in either of the binomial response variables ($P > 0.05$) and thus were excluded from the final model fitted. Linear and quadratic contrasts were estimated for the effects of cow age on calving success rates at first AI and overall.

Minimum daily temperatures (MDTP), and daily temperature-humidity indexes (THI) as calculated by Amundson et al. (2006), were compiled for the first 21 d following the first AI date in each yr. Within each yr, the mean, minimum, maximum and variance of both MDTP and THI were calculated for the 21-d period. In addition, these variables were obtained considering only the first 9 d after AI. Data were compiled by breeding yr and assessed with a linear model where either first AI or overall calving rate were the response variables, and a single weather variable was fitted as a covariate. Those weather variables explaining significant variation in calving rates were then considered collectively, and the most important were identified using stepwise reduction.

Hay feeding

We evaluated both duration (d) and amount (kg) of hay feeding over each production yr, which began and ended with weaning. Weaning took place in mid-September when calves were

marketed and when most cull cows were removed and replaced; we standardized the production yr to extend from October 1 to September 30. An exception was the final yr, in which records ended in August. Duration of hay feeding was assessed 3 ways: the number of d hay was on offer in fall prior to use of stockpiled forage when weather necessitated hay feeding, in the winter after stockpile was depleted, and over the entire production yr. Total weight of hay fed over each production yr also was calculated for each pasture. Finally, the amount of hay fed per cow daily was calculated by dividing total hay fed (kg) by either 7 or 8 cows depending on FS classification, and the duration of hay feeding (d). These 5 response variables were evaluated fitting the linear model:

$$Y_{ijkl} = \mu + F_i + C_j + (FC)_{ij} + S_{k(ij)} + R_l + e_{ijkl} \quad [5]$$

where Y_{ijkl} was hay feeding response variable and other terms were those in Eq. 1. In order to reflect equivalent stocking rates among pastures, least squares means for total weight of hay fed in a pasture were scaled to the mean total cow BW of all FS and CS combinations obtained from fitting Eq. 2.

Net Returns

Revenues were calculated by multiplying the adjusted total WW for each FS+CS category by a sale price of \$2.76 / kg. This price was obtained as the 10-yr (2003 to 2012) average for 181.4 to 226.8 kg Virginia state graded feeder steer calves marketed in September (<http://www.vdacs.virginia.gov/marketnews/livestockstats.shtml>). Hay costs were calculated by multiplying adjusted total hay fed to a FS+CS category by a price of \$0.165 / kg (G. Groover, personal communication). Additional costs for FS or CS categories included: fence and forage establishment for the DC paddock; salt, mineral, vet, medicine, and other supplies for the

additional cow in MF pastures; and haulage and marketing of the additional MF calf. These costs were estimated from the Virginia Farm Business Management Livestock Budgets for spring calving beef cows with stockpiled fescue pasture (Eberly and Groover, 2013). Forage establishment and fencing costs for the FC paddocks were calculated from fescue (nil-ergot endophyte-infected), alfalfa, and high-tensile fencing budgets (Eberly and Groover, 2013), using the seeding and fertilizer rates described earlier; a square DC paddock with 80.6 m sides fenced with single-strand high tensile was assumed. Costs were subtracted from revenues to calculate net returns.

RESULTS AND DISCUSSION

Cow size and composition

BW

Least squares means for cow BW from Eq. 1 are presented in Table 5.3, for both weaning and breeding by FS, CS, and age categories. At both production stages, only FS, age, and yr defined variation in cow BW ($P < 0.0002$); the effects of CS, FS by CS interaction, and FS by age interaction were negligible ($P > 0.06$).

At weaning, LF cows weighed 42.0 kg (7.6%) more than MF cows ($P = 0.0002$). At 3 and 4 yr of age, cows were considerably lighter at weaning than older cows ($P < 0.0004$); after 6 yr of age no differences in BW were detected ($P > 0.52$). Cows were substantially heavier at weaning in 2009 as compared to other yr ($P < 0.0005$) with the exception of 2007.

At breeding, LF cows were 48.8 kg (8.7%) heavier than MF cows ($P < 0.0001$). Three- and 4-yr old cows were again noticeably lighter ($P < 0.0001$), with no differences in BW observed after 6 yr ($P > 0.37$). In 2013, cows were much lighter than in 2008, 2011, and 2012 ($P < 0.002$), and slightly lighter than in 2009 ($P = 0.09$), likely due to their earlier breeding and therefore shorter postpartum interval in 2013.

HH

Least squares means for cow HH from Eq. 1 are also presented in Table 5.3, for both weaning and breeding by FS, CS, and age categories. Only FS defined variation in HH within production stages ($P < 0.0002$). The LF cows were 2.0 cm (3.9%) taller than MF cows at both weaning and breeding ($P < 0.0002$). No effects of CS ($P > 0.17$), age ($P > 0.19$), yr ($P > 0.06$), or any interaction term ($P > 0.12$) on HH were observed at either production stage. Thus, HH appeared to be balanced across CS treatments, and did not change after a cow reached 3 yr old. The average HH of all cows did not change during the experiment, although it would be expected that the 2 FS categories became increasingly divergent for HH as the result of selection. However, because HH records were not available for all years, the FS by yr interaction was not investigated.

BCS

Least squares means at weaning and breeding for cow BCS from Eq. 1 are presented in Table 5.3 by FS, CS, and age categories. Age and yr were the only important factors that described variation in BCS at either production stage ($P < 0.001$). This suggests that cow BCS

was mostly a response to maturity and(or) seasonal variation among and within years, and was not strongly influenced by FS or CS, or their interaction ($P > 0.33$).

At both weaning and breeding, 3-yr-old cows were in poorer body condition than any other age ($P < 0.0001$). No age-related differences in BCS were detected at either production stage after a cow reached 5 yr old ($P > 0.52$). However, at breeding but not weaning, 4-yr-old cows also had lower BCS ($P < 0.001$) than older age categories. These results suggest a greater ability of 4-yr-old than 3-yr-old cows to regain body condition during lactation while on summer pasture.

Cows had higher BCS at weaning in 2011 than most other yr ($P < 0.04$). At breeding, cows were in substantially higher BCS in 2008 than in other yr ($P < 0.004$), and were in lower BCS in the final 2 yr of the experiment ($P < 0.01$). As with BW, the lower BCS at breeding in 2013 likely reflects the shorter postpartum interval resulting from breeding a month earlier than in other yr.

Stocking rate

Least squares means from Eq. 2 for the total cow BW stocked on pastures, as well as the corresponding stocking rates, are presented in Table 5.4. Most calculated stocking rates fell within the target range of 1.4 to 1.5 AUE/ha. However, despite the intent that differential stocking (7 LF vs. 8 MF cows) would result in equal total cow BW in all pastures, FS defined significant variation in total cow BW at both production stages ($P < 0.009$).

Pastures with MF cows contained 217.9 kg (5.2%) more total cow BW at weaning ($P = 0.002$), and 160.4 kg (3.7%) more total cow BW at breeding ($P = 0.009$), than LF pastures. This

was attributable to the 1 additional MF cow stocked per pasture, given that the individual mean BW for MF cows exceeded 7/8 that of LF cows (Table 5.3). Neither CS nor FS by CS interaction impacted total cow BW at either production stage ($P > 0.34$). When considering pairwise comparisons among pastures, least squares means for total cow BW in the LF+DC and LF+FC pastures differed only from the MF+DC ($P < 0.03$) and not MF+FC ($P > 0.06$) pastures at weaning. At breeding, no differences in total cow BW among pastures were observed, although the LF+FC vs. MF+DC comparison was approaching significance ($P = 0.054$). This result reflects the slightly smaller difference in BW in LF vs. MF cows at breeding vs. weaning (Table 5.3).

Year was important ($P < 0.0001$) in explaining total cow BW at weaning, and approached significance ($P = 0.07$) at breeding. Cows were substantially heavier at weaning ($P < 0.02$) in 2007 and 2009, as compared to most other yr. No difference in total cow BW among the 3 replications of each FS+CS combination was found at either production stage ($P > 0.14$).

Calf weaning weight

On average, calves were weaned at 181 (SD = 16) d of age, weighing 219 (SD = 31) kg. Mean calf HH was 42 (SD = 2) cm. Weaning age was younger than the 205-d industry standard (BIF, 2010). This was done to fit the experimental timetable of a collaborating university and provide steer calves with a 42-d backgrounding period prior to transportation for stockering and finishing studies. All fixed effects in Eq. 3 explained considerable variation in calf WW ($P < 0.0001$) except for CS ($P = 0.16$) and the FS by CS interaction ($P = 0.97$), which were still fitted to correctly account for replication ($P = 0.04$).

Calf WW from LF cows was 12.0 kg (5.6%) heavier than from MF cows ($P = 0.03$). Giving calves access to a designated creep paddock with improved forages did not increase WW substantially ($P = 0.16$). Calves had considerably heavier WW ($P < 0.0006$) in 2009 than in all other yr except 2010 ($P = 0.07$). Steer calves were 16.6 kg (7.9%) heavier at weaning than heifer calves ($P < 0.0001$). Calves reared by 3- and 4-yr-old cows (the youngest cows in our system) had significantly lighter WW than all other age categories ($P < 0.02$), but no effect of rearing dam age on WW was detected after cows reached 5 yr old ($P > 0.38$).

In Table 5.5, least squares means from Eq. 3 for calf WW in each of the 4 FS+CS combinations, as well as total calf WW reflecting the number of cows in that pasture category, are presented. No differences in mean WW among FS+CS combinations were observed, although the LF+DC vs. MF+FC comparison was approaching significance ($P = 0.08$). This suggests that potential differences in cow age, calf sex, and weaning age among pastures ($P < 0.0001$) may have negated the important main effect of FS ($P = 0.03$) on mean WW, although no systematic differences in these 3 variables among pastures were found among pastures ($P > 0.24$). The 12.0 kg heavier WW of LF vs. MF calves is also partially explained by the difference (6.3 kg) in EPD for WW of the sires used for each FS category (Table 5.1).

The effect of total calf WW on overall stocking rate at weaning was also considered. To account for the unknown impact of calf grazing on cow paddocks in FC vs. DC categories, cow stocking rates in Table 5.4 reflect 6.47-ha pastures for both FC and DC categories, although only 5.83 ha in DC pastures was truly available to cows. Without more regular weighing of calves, tracking of time spent in creep paddocks (Tracy et al., 2012), or measurement of forage intake by calves, calculation of overall stocking rates at points prior to weaning would be difficult.

However, at weaning, overall stocking rates (including both cows and calves) ranged from 1.96 AUE/ha in LF+DC pastures to 2.10 AUE/ha in MF+FC pastures, in our system.

A critical metric for the hypotheses we tested was the total weight of calves weaned per land area among the FS and CS treatment groups. Of particular interest was whether the heavier mean WW for LF vs. MF calves would offset the lower number of LF calves expected per pasture, when LF and MF cows were stocked at equivalent rates. Total WW values presented in Table 5.5 reflect least squares means from Eq. 3 for WW in each of the 4 FS+CS combinations, multiplied by the appropriate number of cows stocked, and hence calves weaned, per pasture for the respective FS category. However, as shown in Table 5.4, pastures differed across FS categories for the total cow BW stocked at weaning. Adjusted total WW (kg/ha) for each FS+CS combination are therefore presented in Table 5.5. Production efficiency, as defined by saleable product produced per land area, is best assessed with this measurement for our cow-calf system.

In general, the advantage in mean WW of LF calves did not compensate for the 1 fewer calf weaned from LF vs. MF pastures. When stocked equally, MF cows produced more kg/ha of total WW than LF cows, regardless of CS. The MF cows produced 7.0 and 7.4 kg (2.8 and 3.0%) more kg/ha of WW than LF cows in DC and FC systems, respectively. An advantage in WW kg/ha was also gained with DC vs. FC systems, although this difference was not as substantial (6.5 to 6.9 kg, or 2.6 to 2.8% more) as that due to cow FS. Overall, the combination of MF cows and DC creep systems resulted in the greatest WW production efficiency (261.0 kg/ha).

Reproduction

Using Eq. 4, overall mean calving rate was 79.3%, and 53.9% of cows calved to their first AI. Only yr was important in explaining variation in either measure of reproductive success ($P < 0.02$). Still, cow age approached significance in explaining overall calving rate ($P = 0.10$) or first AI calving rate ($P = 0.07$). However, least squares means for age were clearly parabolic, and an important quadratic effect was observed for both overall and AI calving rate ($P = 0.03$ and 0.02 , respectively). Overall calving rate increased from 73% in 3-yr-old cows to a peak of 89% in 6-yr-old cows, then decreased to 76% in 8-yr and older cows. The AI calving rate was 49% and 45% in 3- and 4-yr-old cows, respectively, and then increased to 66% in 6-yr-old cows before decreasing to 46% in 8-yr and older cows. In general, despite no significant ($P > 0.10$) linear differences between pairwise age comparisons, 6-yr-old cows had the highest rate of reproductive success. Furthermore, young (3- to 4-yr-old) and old (8-yr-old and greater) cows were the least likely to breed, particularly via AI. The tendency toward lower reproductive rates in 4-yr-old vs. 3-yr-old cows was not statistically significant ($P > 0.99$). However, were 2-yr-old cows also included in this experiment, it would not be particularly surprising if the calving rates were lower in 3- vs. 2-yr-old cows due to the apparent challenges for young cows to regain body condition after calving (Table 5.3).

Comparison of overall and AI calving rates for the 6 yr are presented in Fig. 5.1. Differences in reproductive success among all breeding yr ($P < 0.02$) were primarily influenced by exceptionally high calving rates in 2009. Although overall calving rates approached the 2007 average for mature cows in the East region of the United States (88%; http://www.aphis.usda.gov/animal_health/nahms/beefcowcalf/index.shtml), calving rates to the first AI were generally poor. This result is unsurprising given the potential for heat stress (Amundson et al., 2006), fescue toxicosis (Porter and Thompson, 1992), and(or) the interplay of

the 2 (Burke et al., 2001) to negatively affect reproductive rates in this region in the summer, which was likely compounded by the lack of shade in our system. With the assumption that forage endophyte content was reasonably constant throughout the experiment, investigation of annual differences in weather during the breeding season, and their effect if any on calving rates, was of interest.

When considered the 21-d period following the first AI date each yr, as suggested by Amundson et al. (2006), none of the summary statistics considered – mean, minimum, maximum or variance for MDTP and THI – explained variation in overall calving rate ($P > 0.24$). Only the minimum THI for the 21-d period was important in explaining AI calving rate ($P = 0.04$). When considering only the first 9 d after AI (W. E. Beal, personal communication), these variables again explained no variation in overall calving rate ($P > 0.39$), but several were highly influential predictors of AI success. When fitted singly, maximum MDTP, and mean, minimum, and maximum THI explained 80.2, 77.5, 76.7, and 80.3% of variation in AI calving rate, respectively ($P < 0.02$). When these 4 variables were fitted simultaneously as covariates in a linear model with AI calving rate as the response, maximum MDTP and minimum THI remained after stepwise reduction. The model containing these two effects explained 94.8% ($P = 0.01$) of variation in yearly AI calving rates.

Values for maximum MDTP and minimum THI for the 9 d following initial AI in each of the 6 breeding seasons are shown in Fig 5.2. Because of their different scales, yearly values are expressed as percentage deviations from the 6-yr mean. Years with the greatest AI calving rates (i.e., 2009 and 2012) were also characterized by the lower than average maximum MDTP and minimum THI. Early June temperatures were unseasonably low in 2009, and AI began in early May 2012. In 2012, there was little improvement in overall calving rate gained from a second

AI, likely due in part to the high success rate to the first AI. It appears that a substantial advantage in AI success, as well as overall calving rate, can be gained by shifting the AI date earlier and(or) to coincide with milder climatic conditions.

Hay feeding

In an average yr, 12.7 ($SD = 1.5$) kg of hay was fed to each cow daily for 99 ($SD = 28$) d. That implies that for about 9 mo of the yr and well into winter, our rotational stocking system with fall stockpiling produced adequate forage to maintain the herd, as Allen et al. (1992) found for a similar system. Emenheiser et al. (2014) analyzed forage availability in the same paddocks used for our experiment, and reached a similar conclusion.

Least squares means for days of fall, winter, and total hay feeding from Eq. 5 are shown by yr in Fig. 5.3. Despite the overall effectiveness of the forage system, total d of hay feeding varied appreciably across the 5 production yr ($P < 0.0001$). Total duration of hay feeding was similar ($P > 0.18$) only between 2009 with 2008 and 2010, indicating that hay feeding was subject to substantial annual variation. The number of d in which hay was fed over the entire production yr generally decreased annually, which may reflect that the forages seeded in 2007 continued to establish throughout the experiment. Both fall and winter hay feeding also varied considerably with yr ($P < 0.0001$). Years with the longest hay feeding period over the entire production yr (2007 and 2008) were also characterized by more d of hay feeding during the fall than other yr ($P < 0.01$). Fall hay feeding implies that grazing pressure exceeded forage availability prior to the grazing of stockpiled forage due to uncontrollable weather conditions.

Increased fall hay feeding in 2008 may reflect the unseasonably low average daily precipitation after June of that yr (Emenheiser et al, 2014).

Duration of hay feeding, considered in the fall, winter, and over the full production yr, was also affected by FS ($P < 0.03$). Hay was on offer in MF pastures for 12 d (12.9%) longer than in LF pastures. The majority of these days were in the winter (7 d), although MF cows required nearly 48% (5d) more hay feeding in the fall than LF cows ($P = 0.03$). This suggests that the greater stocking rate in MF vs. LF pastures (Table 5.4) made it more likely for MF cows to deplete the forage available on pasture, when confined to 4 of 8 paddocks prior to grazing stockpile. No effect of CS ($P > 0.09$), FS by CS interaction ($P > 0.08$), or replication ($P > 0.42$) on total, fall, or winter hay feeding days was found.

Only yr explained variation in hay fed per cow daily. Considerably less hay was fed per cow d^{-1} in 2011 than in all other production yr ($P < 0.05$), consistent with the results shown in Fig. 5.3. Given no significant difference in the number of hay feeding days among CS ($P = 0.26$), this result reflects the greater total weight of hay fed in DC vs. FC pastures, considering all years. Most likely, this is attributable to the greater stocking density, at least after weaning, on cow paddocks within DC vs. FC pastures due to the presence of the designated creep. The difference among LF and MF cows for hay fed daily was negligible ($P = 0.10$). Therefore, given a mean of 12.7 kg d^{-1} , pastures with 8 MF vs. 7 LF cows were fed about 14% more hay daily (101.6 vs. 88.9 kg d^{-1}).

Only FS ($P = 0.001$) and yr ($P < 0.0001$) were important in explaining variation in the total weight of hay fed. Overall, 1866.4 kg (22.2%) more hay was fed in MF than in LF pastures ($P = 0.001$). Least squares means for total weight of hay fed for each FS+CS combination are shown in Table 5.6. These means are also adjusted to a constant stocking rate, using the total

cow BW in the corresponding pasture at weaning from Table 5.4. After adjustment for cow BW, the MF+DC combination required the most total kg of hay over an average production yr. Therefore, the pastures producing the greatest calf WW per land area (Table 5.5) also required the most hay.

Net returns

Comparative budgets for each of the 4 FS and CS treatment combinations, assuming an equal cow stocking rate, are shown in Table 5.7. Revenues were greatest for the MF+DC system, which had the greatest WW production efficiency (Table 5.5). However, this system also had the greatest costs due to the establishment of the DC paddock and the maintenance of an additional cow. As a result, MF+DC pastures resulted in the smallest net returns to the cow-calf enterprise. The FS and CS treatment combination that had the highest net returns for our experiment (LF+FC) was actually the combination with the lowest WW production efficiency (Table 5.5).

Because no differences in reproductive rates among the FS or CS treatment combinations were detected ($P > 0.49$), the budgets reflect no difference in cull cow revenues, and no differential replacement costs for open cows or additional AI costs for those less likely to conceive. It also seems that the mean stocking rate in this experiment allowed all cows to meet their nutritional needs throughout each of the production yr evaluated (Emenheiser et al., 2014). If the grazing pressure was increased to the extent that cows were unable to meet their requirements, our expectation is that larger cows with greater nutritional needs (NRC, 2000) would be more likely to demonstrate reduced reproductive performance.

In summary, our analyses revealed greater differences in costs than in revenues among FS and CS treatment, when we considered all pastures to be equivalently stocked to the mean stocking rate of this experiment. Therefore, net returns to similar cow-calf enterprises are most effectively increased by minimizing costs.

Conclusions

A rotational stocking system with fall stockpiling of native tall fescue can support nutritional needs of a spring calving cow-calf operation well into the winter, such that minimal hay feeding is required. Genetic selection for divergent HH resulted in differences in both cow FS and BW, and larger cows weaned larger calves with heavier WW at the same age. Despite lighter individual WW, when cows were stocked at equivalent rates, MF cows produced more total calf WW (kg WW/ha) than LF cows. This advantage in production efficiency was attributable to more cows stocked on the same land area. With modest stocking rates, no differences in calving rates were detected among the treatment groups. When cow stocking rate was equivalent, more total kg of hay was fed in pastures containing MF vs. LF cows. Because these pastures also produced more total calf WW, we attribute the differences in hay feeding in part to greater grazing pressure from the calves during the summer. Despite lower revenues, LF+FC systems resulted in the largest net returns to our cow-calf enterprise due to lower total costs than other FS and CS treatment combinations. The results of this study strongly suggest that cow-calf producers seeking to increase net returns to a similar enterprise are well-served to pay attention to costs. For the factors we evaluated, choices based solely on improving WW production efficiency had an undesired effect on the bottom line in our system.

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Table 5.1. Expected Progeny Difference (EPD) for bulls used for artificial insemination of the 2 cow size categories¹

Frame Size	Yearling hip height (cm)	Yearling weight (kg)	Weaning weight (kg)	Birth weight (kg)	Calving ease (%) ²
Large (LF)	1.6	45.6	24.4	0.8	6.6
Medium (MF)	-0.9	32.7	18.1	-0.3	11.6
Difference (LF-MF)	2.5	12.9	6.3	1.1	-5.0

¹The EPD summarized were obtained from the American Angus Association sire evaluation (<http://www.angus.org/Angus.aspx>) in May, 2012.

²Expressed as a difference in the percentage of unassisted births. A higher value indicates greater calving ease in first-calf heifers.

Table 5.2. Simple mean, SD, minimum and maximum values for cow and calf traits¹

Variable	Mean	SD	Min	Max
Cows ²				
Age (yr)	6.3	2.6	3.0	17.0
BW (kg)	582.5	77.6	333.8	780.2
HH (cm)	52.1	1.7	48.0	56.0
BCS (points)	5.8	1.2	2.0	8.0
Calves ³				
WW (kg)	219.1	30.8	122.5	312.1
HH (cm)	41.6	1.7	38.0	46.5
Age (d)	181.0	16.3	121.0	211.0

¹HH= Hip Height.

²Includes all cow measurements from weaning 2007 to breeding 2013.

³All calf traits measured at weaning, 2007 to 2012.

Table 5.3. Least squares means for cow body weight, hip height, and body condition score within frame size, creep system, and age categories at both weaning and breeding

	Weaning ¹			Breeding ²		
	BW (kg)	HH (cm)	BCS	BW (kg)	HH (cm)	BCS
Frame Size ³						
LF	593.7 ^a	53.4 ^a	6.0 ^a	612.3 ^a	52.8 ^a	5.6 ^a
MF	551.7 ^b	51.4 ^b	6.0 ^a	563.4 ^b	50.9 ^b	5.7 ^a
Creep System ⁴						
DC	573.5 ^c	52.6 ^c	6.0 ^c	590.0 ^c	51.9 ^c	5.7 ^c
FC	571.8 ^c	52.2 ^c	5.9 ^c	585.8 ^c	51.7 ^c	5.7 ^c
Age (yr) ⁵						
3	478.5 ^e	51.8 ^e	5.0 ^e	477.4 ^e	51.1 ^e	4.4 ^e
4	547.7 ^f	52.2 ^e	5.8 ^f	550.9 ^f	51.9 ^e	5.3 ^f
5	581.8 ^g	52.6 ^e	6.2 ^f	603.5 ^g	52.2 ^e	6.0 ^g
6	600.1 ^{g,h}	52.9 ^e	6.3 ^f	622.9 ^{g,h}	52.1 ^e	6.2 ^g
7	615.1 ^h	52.5 ^e	6.4 ^f	635.4 ^h	51.7 ^e	6.0 ^g
≥8	612.8 ^h	52.5 ^e	6.1 ^f	637.0 ^h	52.1 ^e	6.1 ^g

¹Measured in fall, 2007 to 2012.

²Measured in spring, 2008 to 2013.

³Large (LF) or Medium (MF).

⁴Forward (FC) or Designated (DC).

⁵The ≥8 category includes cows with a maximum age of 17 yr.

^{a-h}Within a column and factor, values with common superscripts do not differ ($P = 0.05$).

Table 5.4. Least squares means for total cow body weight on pastures by frame size and creep system, and corresponding cow stocking rates

Production Stage ¹	Frame Size ²	Creep System ³	Total Cow BW (kg) ⁴	Stocking rate (AUE/ha) ⁵
Weaning	LF	DC	4202.8 ^a	1.43
		FC	4185.9 ^a	1.43
	MF	DC	4433.7 ^b	1.51
		FC	4390.9 ^{a,b}	1.50
Breeding	LF	DC	4385.8 ^c	1.49
		FC	4319.0 ^c	1.47
	MF	DC	4526.4 ^c	1.54
		FC	4499.3 ^c	1.53

¹Weaning in fall, 2007 to 2012, breeding in spring, 2008 to 2013.

²Large (LF) or Medium (MF).

³Forward (FC) or Designated (DC).

⁴Reflects either 7 LF or 8 MF cows per 6.47-ha pasture.

⁶One animal unit equivalent (AUE) = 454 kg.

^{a-c}Within a production stage, values with common superscripts do not differ ($P = 0.05$).

Table 5.5. Least squares means for calf weaning weight (WW), total WW, and WW production efficiency adjusted to a constant cow stocking rate, by frame size and creep system¹

Frame Size ²	Creep System ³	Mean WW (kg)	Cows per pasture ⁴	Total WW (kg)	Adj. Total WW (kg) ⁵	WW Production Efficiency (kg/ha) ⁶
LF	DC	229.3 ^a	7	1605.1	1643.5	254.0
	FC	222.2 ^a	7	1555.4	1599.0	247.1
MF	DC	217.5 ^a	8	1740.0	1688.8	261.0
	FC	210.0 ^a	8	1680.0	1646.5	254.5

¹Weaning in fall, 2007 to 2012. Mean weaning age = 181 d.

²Large (LF) or Medium (MF).

³Forward (FC) or Designated (DC).

⁴Reflects either 7 LF or 8 MF cows per 6.47-ha pasture.

⁵Adjusted to constant total cow BW at weaning (Table 5.4; mean = 4303.3 kg).

⁶Considers adjusted total WW and 6.47-ha pastures.

^aMean WW did not differ among FS+CS combinations ($P = 0.05$).

Table 5.6. Least squares means for total weight of hay fed and hay fed per cow daily, for 4 frame size and creep system combinations over 6 production years¹

Frame Size ²	Creep System ³	Hay fed per cow (kg/d ⁻¹)	Total hay fed (kg)	Adj. Total hay fed (kg) ⁴	Hay fed per ha (kg/ha) ⁵
LF	DC	13.1 ^a	8997.7 ^{a,b}	9212.9	1423.9
	FC	12.3 ^a	7827.5 ^a	8047.0	1243.8
MF	DC	12.3 ^a	10366.0 ^b	10061.2	1555.1
	FC	12.1 ^a	10192.0 ^b	9988.7	1543.9

¹A production yr was defined from October 1 to September 30.

²Large (LF) or Medium (MF).

³Forward (FC) or Designated (DC).

⁴Adjusted to constant total cow BW at weaning (Table 5.4; mean = 4303.3 kg).

⁵Considers adjusted total hay fed and 6.47-ha pastures.

^{a-b}Within a column, values with common superscripts do not differ ($P = 0.05$).

Table 5.7. Comparative budget analysis assessing net returns to the cow-calf enterprise for 4 combinations of frame size and creep system factors¹

Item	Frame Size and Creep System Treatment ²			
	LF		MF	
	DC	FC	DC	FC
REVENUES³				
WW Revenue	\$4,529.12	\$4,406.48	\$4,653.95	\$4,537.38
TOTAL REVENUES	\$4,529.12	\$4,406.48	\$4,653.95	\$4,537.38
COSTS⁴				
Hay	\$1,523.32	\$1,330.54	\$1,663.58	\$1,651.60
Fence	\$528.00		\$528.00	
Forage Establishment	\$138.88		\$138.88	
Salt and Mineral			\$14.96	\$14.96
Vet and Medicine			\$19.27	\$19.27
Supplies			\$2.00	\$2.00
Haul Calves			\$3.75	\$3.75
Market Calves			\$17.78	\$17.78
TOTAL COSTS	\$2,190.20	\$1,330.54	\$2,388.22	\$1,709.36
NET RETURNS⁵	\$2,338.92	\$3,075.94	\$2,265.73	\$2,828.03
Net Returns per hectare ⁶	\$361.50	\$475.42	\$350.19	\$437.10

¹Adapted from VA Farm Business Management Livestock Budgets (Eberly and Groover, 2013).

² Large (LF) or Medium (MF) frame size; Forward (FC) or Designated (DC) creep system.

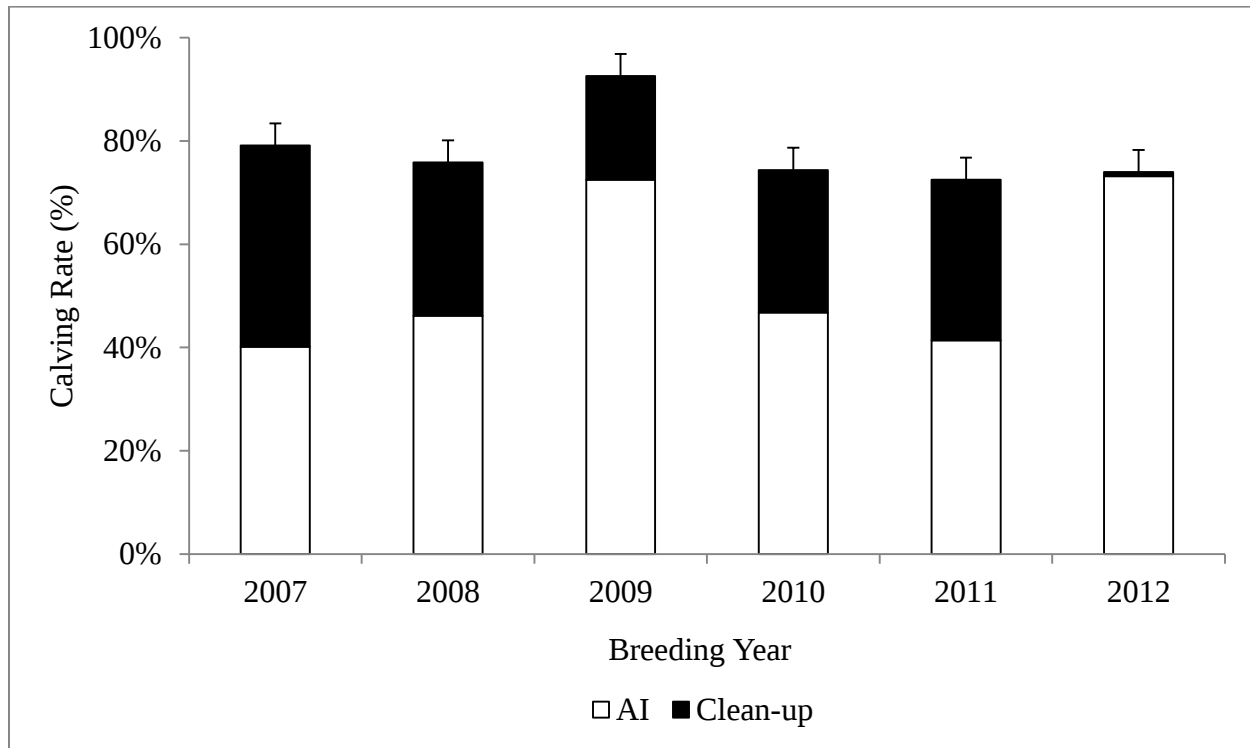
³Considers adj. total WW (Table 5.5) and sale price of \$2.76 / kg.

⁴Considers adj. total hay fed (Table 5.6) and hay cost of \$0.165 / kg. See Methods for other assumptions.

⁵Total revenues minus total costs.

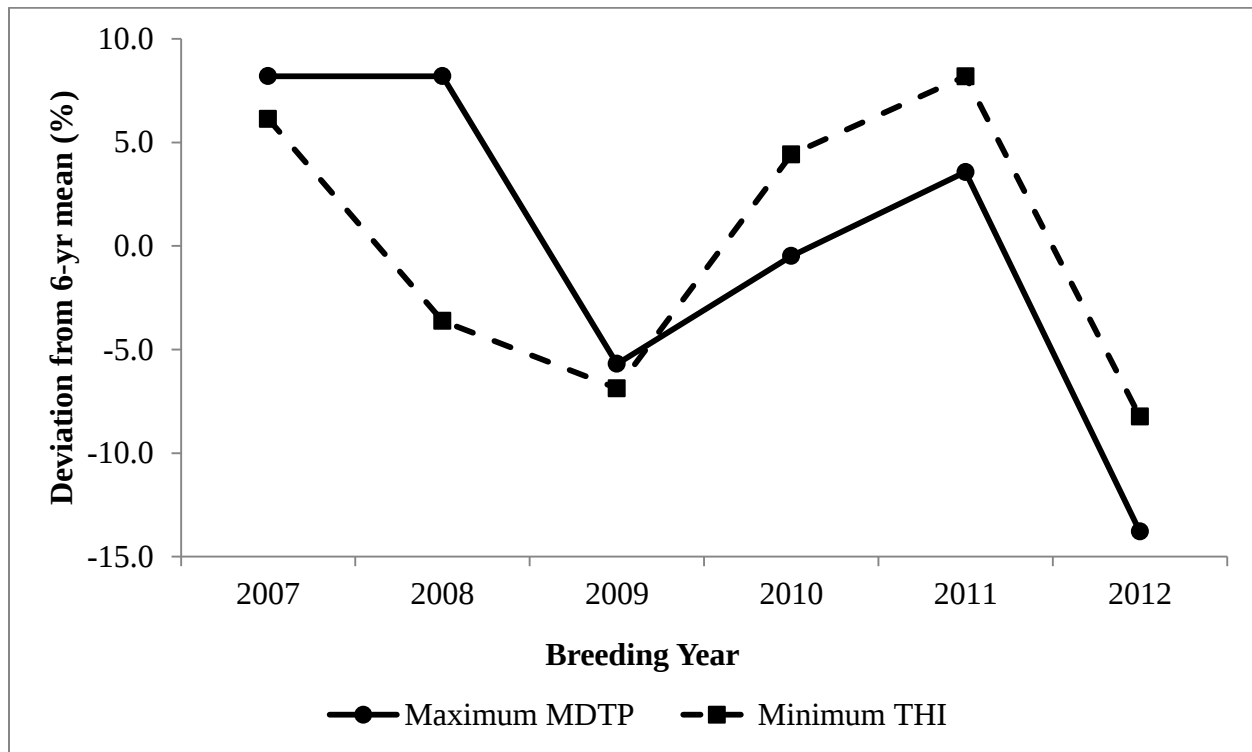
⁶Considers 6.47-ha pastures.

Figure 5.1. Least squares means for overall and AI calving rates during each of 6 years¹



¹In 2007 to 2011, cows were artificially inseminated once in late May or early June, followed by cleanup bulls. In 2012, cows were artificially inseminated during milder climatic conditions in early May, followed by a second AI if heat was detected in early June. No natural service cleanup bulls were used in 2012.

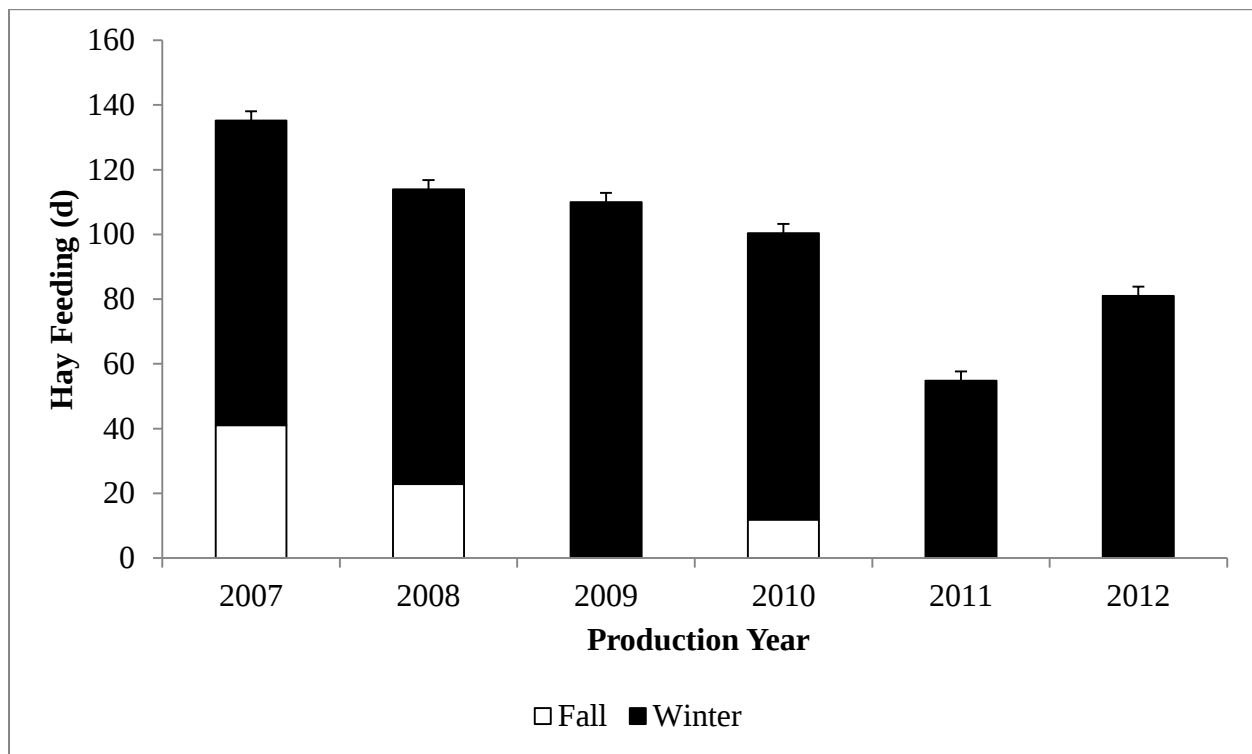
Figure 5.2. Annual percentage deviations from 6-yr overall mean for maximum minimum daily temperature (MNTP, °C) and minimum temperature-humidity index (THI), for the 9-d period beginning on the initial AI date each breeding year^{1,2}



¹Variables adopted from Amundson et al. (2006). MNTP = minimum daily temperature (°C); THI = temperature humidity index. Weather factors considered over the 21-d postbreeding period recommended by these authors had little impact on calving rates in our study. We instead considered the 9-d period following the initial AI event (W.E. Beal, personal communication).

²See Fig. 5.1 for a depiction of reproductive success during these yr. Maximum MDTP and minimum THI for the 9-d post-breeding period explained 80.1 and 76.7% of variation in AI calving rate, respectively ($P < 0.02$).

Figure 5.3. Least squares means for days of fall, winter, and total hay feeding during each of 6 production years^{1,2}



¹A production yr was defined from October 1 to September 30.

²All yr differed for total hay days ($P < 0.01$), except 2008 vs. 2009 and 2009 vs. 2010.

CHAPTER 6: SYNTHESIS AND CONCLUSIONS

SUMMARY OF HYPOTHESES

Several important goals of the research were accomplished. Each of the Chapters 3 to 5 has been or soon will be submitted for publication. Chapter 5 was broad enough in scope that its content may be subdivided and published as 2 papers. Perhaps more importantly, however, this research answered several important questions for the cow-calf sector as part of Virginia Tech's contribution to a comprehensive and collaborative analysis of pasture-based beef production systems in the Appalachian region. Results are summarized in the context of the hypotheses stated in Chapter 1:

Pasture

With respect to Hypothesis 1, we developed statistical models to describe forage dynamics that were simple enough to be fitted, and that were robust across multiple response variables. While the number of days grazed in the previous rotation or immediately prior to the sampling event were not always influential, the number of days since a paddock was last grazed (REST) was quite useful, and its interactions with month, stockpiling, hay feeding, and associated interactions were well-investigated and proved informative as well. With regard to Hypotheses 2 and 3, stockpiling had a more important effect on forage growth and quality than hay feeding. The analyses revealed a comprehensive story of the effects of stockpiling, not just in the paddocks that had been designated for winter grazing, but in those that were not stockpiled

as well. The negligible effects of hay feeding both supported the findings of other studies and added reassurance that winter hay feeding as practiced in this study was a suitable management strategy. Finally, investigation of Hypothesis 4 led to the conclusion that the forage system was able to meet the nutrition needs of the cattle grazing as part of it.

Ultrasound scanning

The Ultrasound Guidelines Council (UGC) statistics we reported to test Hypotheses 5 and 6 were mostly within an acceptable range or had no established standard of comparison. We therefore failed to reject both hypotheses to support our conclusion that experienced ultrasound technicians can scan mature beef cows to estimate body composition traits with acceptable precision and accuracy. When evaluating Hypothesis 7, there is little doubt that animal variation has a strong influence on UGC statistics in cows, particularly those relating to prediction accuracy.

Beef production

With respect to Hypothesis 8, we found no differences in reproductive efficiency among frame size categories. However, the medium-framed cows clearly had an advantage in total weight of saleable calf produced per land area, despite disadvantages in individual mean calf weight. As we suspected, this was attributable to a greater number of cows (and hence calves) per area when stocking rates were equivalent to the large frame category. We did not, however, find an advantage for either creep system in terms of the calves' weaning weights when testing

Hypothesis 9. Numerically greater weaning weights were observed from calves given access to a designated creep with improved forages, but the differences were not statistically significant. When evaluating net returns to the cow-calf enterprise for Hypotheses 10 and 11, we found that creep system, more so than frame size, was important in determining the bottom line. The added cost of establishing a designated creep with improved forages was not justified because it did not result in calves that were significantly heavier at weaning. Also, despite greater revenues from medium frame cows, these were exceeded by the cost of the additional cow and calf in that frame size category. We therefore concluded that of the systems we evaluated, large frame cattle in a forward creep system resulted in the greatest net returns to the enterprise.

DISCUSSION AND SYNTHESIS OF WORK

The research described in Chapter 3 was both a logical starting point for describing the system, as well as a particular challenge given my background and the complexity of the forage dynamics. A particular triumph in this research was the successful use of days covariates to describe a paddock's status in the rotation on a sampling date, when the paddocks vary in the duration and order in which they are grazed. These 2 stipulations are reality for most grazing systems except controlled academic experiments. The results, specifically an understanding of the factors influencing forage dynamics and the implication that cattle's nutritional needs were met by the system, laid the groundwork for almost the entirety of Chapter 5.

Rotational stocking systems are challenging to describe, and the high-order interactions among variables are difficult to interpret and present. Fig 3.1 shows what many textbook introductions to stockpiling do not: forage accumulation in some paddocks requires greater

pressure placed on others. Fig 3.5 is a unique pictorial that shows how paddock rest had a different effect on forage accumulation, in different stockpiling treatments, at different times of the year. While neither of these concepts is particularly revolutionary, they are both commonly overlooked.

The research in Chapter 3 was not without its weaknesses. The overall experiment was designed to evaluate systems at the pasture level, and thus each individual paddock was only sampled monthly. With our focus at the paddock level, the power of our statistical analyses was limited by the single sampling. However, the amount of field and lab work required for such sampling was already astronomical, and thankfully we were still able to describe, with reasonable significance, the instantaneous changes in paddocks at different points in the rotation. If nothing else, this, coupled with the many interactions with other factors, provided a case against the common practice where rotational systems are considered a static unit of total area, with description averaged over all paddocks or limited to the 1 that contains the cows at the time.

Given the considerable impact of the weather covariates and particularly precipitation, a major area of interest that was not fully investigated is the risk associated with the management strategies as rainfall varies. Unfortunately, the size of the data, the single forage sampling of paddocks, and the many other important interactions limited our ability to test many interactions with precipitation without overfitting. Also, the assumption that temperature, rainfall, soils, etc. were equitable across paddocks was troublesome. I do believe that assessing risks due to weather when certain management practices are employed, is the logical direction in which to continue this work. It was never our intention, however, to evaluate management *per se*.

Perhaps the greatest weakness of Chapter 3 was that cow weight data had not yet been compiled at the time of analysis. The paper was therefore written with the assumption that

pastures were equally stocked at a rate of 1.39 AUE/ha. Analysis of actual cow weights in Chapter 5 revealed that this assumption was incorrect on several levels: pastures containing medium frame size cows were stocked more heavily than those with large frame cows, and actual stocking rates ranged from 1.43 to 1.54 AUE/ha. We also did not consider calf weights as part of the stocking rate, or nutrient requirements, in Chapter 3. However, with the 2.7-fold excess of available nutrition at the most limiting time of the year, it is unlikely that re-analysis would result in a different conclusion as to the effectiveness of the forage system.

In Chapter 4, we were fortunate to be able to employ a simple, powerful design and produce a well-balanced, nearly complete, and well-organized data set. Of the 3 chapters, the experiment in Chapter 4 was the narrowest in scope, and yet may potentially have the most far-reaching implications. A larger validation study for beef cow carcass ultrasound was not found. Many of the statistics we reported had not been previously reported for cows; in those respects I feel this work will make a valuable contribution to the literature. While the conclusion that ultrasound was suitable for cows was perhaps not particularly surprising, some of the results and implications for the contribution of animal variation were indeed.

Prior to beginning analysis for chapter 4, we suspected a substantial animal effect on precision and accuracy statistics, but certainly did not fully appreciate its extent. While the study was not large enough to fully dissect how the animals themselves were affecting the statistics we reported, the implication that ultrasound accuracy is more influenced by variation among animals than among experienced technicians is an important one. A similar variance partitioning approach is likely warranted in younger cattle and other species to make certain that approaches to technician certification are appropriate. If the UGC statistics are found to be overwhelmingly reflective of variation in animals (rather than among technicians) as they were in our study, a

shift in paradigm is likely warranted. Better strategies may include bounds placed on the variation among animals used for certification events, or adjustment of the statistics for technicians to account for animal variation in the test population.

Of the 3 chapters, Chapter 4 is the one for which I have the fewest criticisms. Certainly, the design would have been more powerful had there been a greater number of technicians or cows, and the results more directly applicable the other chapters had actual body composition been measured. However, in addition to the expense involved, a larger experiment or one that involved dissection, would have been difficult to conduct under time and facility constraints. Another inevitable weakness of the design in Chapter 4 was the need to harvest cows in 3 groups, stratified by fatness. If there was any potential for carcass measurements to change in an animal between scanning and slaughter that were related to BCS or backfat thickness, our analyses as conducted would have overlooked that potential.

An implication of Chapter 4 that presents an important consideration for Chapter 5 is the relative imprecision of body condition scoring. We also clearly demonstrated that BCS reflected differences in muscling as well as fat, and is less predictive of carcass fatness than ultrasound. While the use of carcass backfat thickness as a proxy for body composition is debatable, it does appear that there is potential for ultrasound to more precisely explain differences in composition, which may contribute to differences in performance, in cows. It was the original intent of the research to include ultrasound information with Chapter 5, and I am greatly disappointed that we were not able to do so due to time constraints. My belief is that ultrasound may have helped us to detect differences in reproductive capacity among the cows, which would have added to the scope of our economic analyses in Chapter 5.

Still, Chapter 5 offers a comprehensive analysis of the production efficiency and net returns for the SVAREC cow-calf system. Its most important result, likely, is the finding that systems that maximized weaning weight per land area also resulted in the least net returns. This is likely an important consideration, given current industry emphasis. Another important finding, which is underplayed because reproductive differences were not detected among the treatment groups, is the use of just 2 weather variables to explain 95% of the variation in AI calving rate for the years evaluated. While the study lacked the size and scope for a comprehensive reproduction trial, a finding as striking as this has fairly obvious implications for management of risk: attempting to breed cows on hot fescue in the heat of summer is a long bet. Given more years of data on more cows to evaluate the potential net returns gained from shifting the breeding season to when climatic conditions were milder, even a 5% increase in calving rate would have likely made a tremendous impact on the comparative budget sheet, after the loss in calf weight weaned, and/or the costs of purchasing a bred replacement cow, were accounted for.

Perhaps the greatest challenge given the experimental design in Chapter 5 is that the system did not allow cows to fail, or when they did they were immediately replaced. Although the reasons for this were obvious from a financial standpoint, it also made it difficult to describe true risks for the producer without making considerable assumptions. Mercifully, the detection of no differences in reproductive rates, which may in part be a consequence of cows being replaced in the system, allowed us to avoid much of the area where the experimental design would have presented a real challenge. Even so, it appeared that the stocking rates used in the experiment were low enough ubiquitously that no cow or calf was particularly challenged nutritionally. Had there been differences in capacity for maternal milk, for example, greater pressure on the system could have quickly translated into divergence in weaning weights. Another limitation of Chapter

5 was that the large and medium frame cows were not tremendously different. While it was clear among the cows that we analyzed that the large frame category was more profitable, there is an inherent danger in generalizing those results to other populations or enterprises when the mean difference between cow types was only 42kg. Finally, the ability of the conclusions for Chapter 5 to generalize to other cow-calf operations in the region is limited by the fact that heifers and cows younger than 3 yr old were not considered as part of the system. If differences existed in age at puberty among the classes, or if the trend we observed toward lower BCS in 3-yr-old cows could somehow be explained by their records from earlier in life, it is possible that these differences would have influenced the conclusions we made as to which combination of cow type and production system was the best strategy.

APPLICATIONS

To some extent, the answers provided by systems research like this are less applicable than the additional questions they raise, because the real value of the effort is in the added (and often unconventional) thought it requires. In other words, systems research is never “finished,” because the system itself is a continuously evolving entity that requires evolution in return. Thus, when seeking to develop sustainable systems--whether biological, economic, or academic--being knowledgeable is often less important than being inspired to continually improve. While this research provides some useful answers to important questions, my real hope is that it inspires continued efforts toward the greater goals.

A substantial amount of groundwork for the use of cow ultrasound in beef improvement and valuation, and for the development of better technician certification guidelines in younger cattle and other species, is provided in Chapter 4. I hope that our findings, particularly those with

regard to the effects of animal variation, will be used by several industries in the near future to assure that their certification standards for ultrasound technicians are sufficiently, and consistently, rigorous. The implications summarized in Chapters 3 and 5 of this research are likely suitable for direct application to similar cow-calf enterprises. Producers seeking to better understand the dynamics of a forage system, or to manage for more effective systems, might gain perspective from the distilling of complexity--or merely the depiction of effective management methods--that were provided. Although Chapter 5 likely offers several important considerations for cow-calf producers, its economic implications may be of greatest value. I certainly do not expect the conclusions about frame size or creep systems from our study to be universally true, but I hope they will inspire some thought. Caution against maximization of production efficiency is somewhat counterintuitive, and certainly uncommon, with regard to current views on calf weaning weight.

Ultimately, work focused almost entirely on cow-calf enterprises that sell feeder calves at weaning in no way provides a comprehensive solution for the whole of pasture-based beef systems in Appalachia. In order to foster the thriving regional economy that the overarching systems project desires, all aspects of the system must work in harmony. The production system must not only focus on its outputs, but on maintaining the health of the land and its non-renewable resources. Even if a particular cow type or creep system is the most profitable for a cow-calf producer, if it results in calves that gain inefficiently during the stocker or finishing phase, or that yield a product that does not satisfy consumer preferences or willingness to pay, the economic sustainability of the entire system is compromised. The key to proper application of this work, then, lies in careful collaboration among all phases of the industry, which extend not just from cow-calf to finishing, but from soil to consumer.