PERFORMANCE OF LIGHT VS. HEAVY WEIGHT STEERS GRAZING PLAINS OLD WORLD BLUESTEM AT THREE STOCKING RATES

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Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the degree of
DOCTOR OF PHILOSOPHY
July, 1999

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WEIGHT STEERS GRAZING PLAINS
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Thesis Approved:

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ACKNOWLEDGEMENTS

First, I want to thank the Lord for giving me the ability and strength to pursue and successfully accomplish my goals.

I thank Dr. Gerald Horn and Dr. Hebbie Purvis II for the opportunity to attend graduate school at Oklahoma State. I thank both of them for the financial support, both through my assistantship and grants to support research. They provided me with a lot of freedom in my research and continually challenged my intellectual ability. I had many opportunities and a wonderful educational experience here due in a large part to the mentoring and friendship of these two men. My family and I owe them a debt of gratitude.

Gratitude is also extended to other faculty members including; Dr. David Lalman and Dr. Sam Fuhlendorf who served as committee members, and Dr. Dave Buchanan and Dr. Mark Payton who were a source of encouragement and were always ready with an answer to my questions.

Many graduate students have been of great help to me, through their help and friendship as well as both answering and asking questions. Some of these are Dr. Steve Paisley, Dr. Hugo Arelovich, Dr. Jeff Hill, Brett Gardner, Tim Bodine, Alejandro La Manna, Ryan Reuter, Jeff Carter, and John Wheeler.

A graduate degree in Animal Science requires a substantial amount of research, much of mine was completed with the help of several herdsmen and lab technicians, without whose help much of the work may not have been accomplished. The list of these individuals includes, Ken Poling, Jim Counts, Steve Welty, Brock Karges, John Weir, Roy Ball, Maria Mottola, Donna Perry, and Carolyn Lunsford.

I owe a debt of gratitude to my parents, George and Connie Ackerman, for raising me with a desire to always do my best and never sell myself short. I thank them and my sisters, Gina, Mary and Amber for their support and encouragement. I also thank my wife's parents for their support and encouragement of myself and my family throughout my graduate career.

To my wife Gina, I owe an enormous thanks for her support, encouragement, and for always believing in me. She has followed me to many places around this country and has sacrificed time and financially in order to help me be successful. Both Gina and our daughters, Bridget and Shelby, were and are a source of encouragement. Without you three and your love, I never would have accomplished what I have over the past nine years.

Thank You and God Bless.

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CHAPTER I

INTRODUCTION

Warm season perennial grasses are a major source of forage for beef cattle enterprises in Oklahoma. These warm season perennial grasses are utilized to support summer grazing and for production of hay for stocker cattle and cow-calf operations. Old World bluestems are a species of warm season perennial grasses that have been introduced in Oklahoma and Texas. Many acres of Old World bluestem were planted during the implementation of the conservation reserve program (CRP). The use and contribution of Old World bluestems to beef production may increase when CRP lands are put back into production.

A major portion of the weight gained by beef animals prior to slaughter is attained after weaning, and in many cases, at least a portion of this post-weaning weight is gained from grazed forages (Gregory, 1972), Therefore, forages contribute to, or play a major role in beef production, both to support the production of the cow and for post-weaning gain of animals that are designated for harvest.

Hedrick (1972) describes the ideal beef animal as an animal which is capable of efficient conversion of feed grains and roughages into a maximum amount of meat that is acceptable to the consumer. Andersen (1978) and Klosterman (1972) concluded that size of animal, in relation to mature size and or breed type had little, if any, affect on productive and(or) economic efficiency. However, size or weight of cattle may greatly influence performance and ADG at different stages of the production cycle, particularly if the animal is in a rapid stage of growth.

Size of animal can become confused with, and is in many cases, closely linked to genetics or biological type of the animal. Some research has indicated that an animal which is genetically predisposed to have smaller mature size such as British breeds may be more suited to grazing operations than larger continental and mixed breeds (Andersen, 1978; Dickerson, 1978). In many cases, stocker cattle are a mix of breeds and frame types within breed. Therefore, initial weight of stocker calves when placed into a grazing program may be one of the most descriptive traits available for the prediction of gain and(or) performance.

Income per unit of land area is often closely related to gain per unit of area in stocker cattle grazing operations. Therefore, the relationship between stocking rate and type or size of steer may become an important factor in evaluating profitability. Much of the research conducted in the past was concentrated on yearling cattle that weighed 225 to 275 kg at the initiation of the trials. However, the average age and weight of summer stocker cattle has decreased in the past few years (Kail and Lusby, 1993; Purvis et al., 1996). Scott et al. (1988) reported gains of .84 kg/d for unsupplemented light weight (136 to 160 kg) calves grazing summer native range, and Kail and Lusby (1993) reported gains of unsupplemented calves in a similar production scenario to be .68 kg/d. Several studies have reported positive responses of these light calves to protein supplementation, possibly earlier in the growing season (forage) than older, heavier calves (Scott et al., 1988; Kail and Lusby, 1993; Purvis et al., 1996). Furthermore, several trials conducted at Oklahoma State University have evaluated gains of light weight early-weaned calves grazing winter wheat forage, Purvis et al. (1996) reported gains of .83 kg/d for these light weight calves while gains of approximately .92 kg/d for heavier, normal weaned calves are often observed in this type of production setting.

These trials have established that the potential exists for light-weight calves to gain at rates slightly less or similar to the gains of their heavier, older counterparts. However, little research has been conducted to compare gains of light vs heavy weight calves. Furthermore, there has been very little work, if any, conducted regarding the performance of these two sizes of calves on a equal body weight per unit area basis.

The stocking rate which will allow for, or derive the highest possible net income per unit of land area while not degrading or decreasing the long-term health of the forage base is an essential management consideration for grazing operations. A stocking rate which maximizes gain per animal or gain per unit of area often may not be ideal for maximal profitability and(or) maintenance of forage stand health. Therefore, the evaluation of animal performance and gain per unit area at several stocking rates may lend to the development of prediction equations and aid in setting stocking rates for optimal levels of forage use. The ability to select stocking rates which will allow for maximal productivity may help producers optimize economic profitability.

The objective of this study was to evaluate the gains of light and heavy weight calves grazing Plains Old World bluestem at three stocking rates during the summers of 1997 and 1998.

CHAPTER II

REVIEW OF LITERATURE

Old World Bluestem

Old World relatives of the American bluestems have been introduced into the western hemisphere, and interest has been stimulated in some of these introductions because of their apparent superiority to indigenous grass species (Celarier and Harlan, 1955). Possibly the first introduction of Old World bluestem (*Bothriochloa ischaemum)* into the United States was in California in 1917. The largest collection of Old World bluestems ever assembled in the western hemisphere was brought together at Stillwater, OK, and these grasses were grown and studied thoroughly (Celarier and Harlan, 1955).

Plains Old World bluestem (*Bothriochola ischaemum* (L.) Keng.) is a blend (equal proportions) of 30 strains collected from the mid-elevations of Afghanistan, Pakistan, India, Turkey, Iran, Kashmir, Iraq, and several nations from the former USSR. The purpose of blending was to buffer against possible insect and disease pests as well as to increase chances for adaptation and survival when used under various climatic and soil conditions. The Plains blend has been successfully established on thousands of acres throughout Oklahoma. Other varieties that have received some attention and have been used in Oklahoma include Caucasian, Granada, King Ranch, WW-Spar, and WW-Iron

Master. Of these varieties, Plains has proven to be the most popular and most widely used (Hodges and Bidwell, 1993).

A large number of acres of marginal farmland in Oklahoma were planted to Old World bluestem following the implementation of the conservation reserve program (CRP). Additionally, some producers have planted Old World bluestem as a forage source for current use in their grazing programs. Old World bluestem is quite useful for reclaiming abandoned farmland which has been degraded or depleted (Taliaferro et al., 1984). There were at least 388,461 hectares of former cropland placed into the CRP program in Oklahoma by 1988 (Hutson, 1988). Berg and Sims (1995) estimated that there were 2 million hectares of Old World bluestem established in Oklahoma and Texas by 1995. Therefore, it is apparent that this species of grass is of major importance in Oklahoma and Texas.

An obvious use for land set aside in the CRP program after the expiration of the program is beef production. Nutritive value of forage is a major concern for producers that raise stocker cattle during the summer months in the southern great Plains. Producers choices of forage types or species range from low input native species to intensively managed introduced species with greater input demands (Phillips and Coleman, 1995). Old World bluestem may be a valuable grass to add to forage managers alternatives for summer grazing.

In many cases, these Old World bluestems have been far superior to native species in productivity, persistence under use, aggressiveness, and, in some cases, forage nutritive value (Celarier and Harlan, 1955). Old World bluestems possess several characteristics that make them attractive as a summer grass such as drought tolerance, forage production, and grazing tolerance (Sims, 1988). Because of their crown structure, Old World bluestems are tolerant of continuous stocking at high stocking rates. In some cases, high stocking rates can result in more tillers per acre than low stocking rates (Christiansen and Svejcar, 1988). Old World bluestems possess the ability to tolerate many stresses without loss of stand (Taliaferro et al., 1984), including drought and intense grazing pressure.

Productivity

In general, the Old World bluestems are less palatable than many grasses native to North America; thus, it is recommended that these grasses be planted as pure stands so they can be managed separately from other forages (Dewald et al., 1985). Maximizing productivity of an monoculture such as Old World bluestem may require intensive management. Management of this grass may often differ from other warm-season species. Old World bluestem may often be roughly two weeks later to begin spring growth than other grasses, such as weeping lovegrass (Berg, 1993).

Plains Old World bluestem is intermediate in production, but is more adaptable to various conditions than other varieties such as the Caucasian variety (Dewald et al., 1988). Plains Old World bluestem is the most important species of Old World bluestems in the United States because of its ease of establishment, drought resistance, and winterhardiness (Sims and Dewald, 1982). Eck and Sims (1984), in a 36-year study conducted on the Rita Blanca National grassland in Dallam county, Texas, reported that *Bothriochloa ischaemum* not only survived over this time period, but had spread into adjoining plots where some other species of grass in the same study had died out. These workers also reported that Old World bluestem had greater forage production over time than Western Wheatgrass, Sideoats Grama, or Galleta grass in ungrazed plots. However, in grazed plots, the Galleta grass had the highest standing crop while Plains Old World bluestem was second.

Old World bluestem produces more forage/ha than native tallgrass prairie if it is managed properly (Horn et al., 1974); and of the species or mixes which have been evaluated, Plains appears to have the highest nutritive value (Horn and Jackson, 1979). Forage production data which has been collected indicates production in the range of 4,600 to 11,424 kg $\bullet$ ha^{-1} $\bullet$ $year^{-1}$ for Plains Old World bluestem (Sims, 1988). Plains Old World bluestem, when managed properly has the potential to produce large amounts of forage and gains at or near 220 kg/ha (Sims, 1988).

Coyne and Bradford (1985) reported that Old World bluestem produces more forage over a longer growing season than native tallgrass prairie grasses due primarily to a second growth period in late summer or early autumn, and can also withstand heavier grazing while maintaining annual productivity than tallgrass prairie pastures. Coyne and Bradford (1985) concluded that Old World bluestem can withstand heavier grazing pressure primarily due to the plants' ability to optimize canopy development and leaf area with a minimum amount of available biomass.

Gross pasture costs, in terms of dollars per acre are usually higher for improved pastures such as Old World bluestem because of fencing and fertilization costs. However, Phillips and Coleman (1995) observed that Old World bluestem pastures had lower total production costs in terms of dollars per steer than native tallgrass or bermudagrass pastures. These researchers observed that the opportunity for higher positive returns was greater for Old World bluestem than for bermudagrass pastures grazed with steers during the growing season.

Forage Nutritive Value and Animal Productivity

Old World bluestem forages will support high rates of gain early in the growing season (Coleman and Forbes, 1998). Phillips and Coleman (1995) observed greater gains per acre for Old World bluestem than either native range or bermudagrass. Similarly, Sims (1985) reported ADG of .72 and .81 kg for steers grazing native range and Old World bluestem, respectively. Coleman and Volesky (1994) collected data comparing the productivity of cows grazing two native range systems to cows grazing Old World bluestem. Cows in the Old World bluestem group had higher body condition scores and heavier weights in the spring which may indicate greater forage nutritive value if forage quantity was not limiting to productivity.

Many perceive the nutritive value of Old World bluestems to be very low in late summer and winter (Dabo et al., 1988). Furthermore, there seems to be a common conception that Old World bluestems have lower forage nutritive value year-round than many other forages, including native range. However, as mentioned previously, Phillips and Coleman (1995) observed lower production costs and higher potential for positive returns for Old World bluestem than native range. This advantage may primarily be due to greater overall forage production; however, forage nutritive value may also play a role.

Numerous trials have demonstrated the productive potential and quality of Old World bluestem, which, in many cases, was equal or superior to Oklahoma native ranges. Horn et al. (1974) reported higher CP and in vitro OM disappearance for Old World bluestem than for native range samples clipped during the summer. Furthermore, Gunter et al. (1991 and 1992) reported significantly higher CP and in vitro OM disappearance for Old World bluestem than for native midgrass prairie masticate samples during the months of June, August, and October.

Londono et al. (1981) reported in vivo DM digestibility of 60.7% for Plains Old World bluestem hay harvested in July near Woodward, OK. Ackerman et al. (1998 and 1999) reported CP values of 12.2% and 13.4% for Plains Old World bluestem for masticate samples collected throughout and averaged across the summer months near Stillwater in 1997 and 1998 respectively. Digestibility (IVOMD) values of these samples (65-70% of organic matter) were also higher than would be expected for a forage of "low nutritive value" during this time period. These data would refute the common perception that the nutritive value of Old World bluestem is poor during the summer.

Marston et al. (1993) reported CP content of 6.8% (DM basis) during the winter for Plains Old World bluestem masticate samples collected from south-central Oklahoma while Ackerman et al. (1997) observed CP content of 4.8% for Plains Old World bluestem and 5.2% for native range (DM basis) from masticate samples collected during January near Stillwater, OK. Thus, it would appear that the nutritive value of Old World bluestem is low during the winter and possibly late summer as would be expected during normal seasonal shifts in forage nutritive value. However, it may not be appreciably different than other warm-season forages during this time period.

Factors Affecting Nutrient Value of Grazed Forages

Season and Maturity

Stage of maturity and(or) season are the most important factors that influence forage digestibility, and thus forage nutritive value (Horn et al., 1974). Intake of forage may be closely associated to forage digestibility and lignin intake. Intake is positively related with digestibility, while lignin content is negatively correlated (Horn et al., 1979). Maturity of a forage may often correspond with an increase in lignin content which may negatively affect intake, and thus, animal performance (Corbett et al., 1963).

The nutritive value of Old World bluestem decreases with increasing maturity. This same characteristic is true of all grasses. For example, Ball et al. (1979) reported that in situ OM digestibility of native range varied from 17.7% for standing dry forage in December to 50.6% for live, growing forage in May. Nutritive value of forage may often decline within the growing season as maturity of forage plants increases. McCollum et al. (1990) observed declining CP and digestible OM and forage intake as the growing season progressed from May through August for native tallgrass prairie. As discussed previously, there is a perception that Old World bluestem is a poorer quality forage than other grasses, such as native tallgrass prairie. However, Lawrence (1995) observed a similar pattern in seasonal forage nutritive value between native tallgrass prairie and Plains Old World bluestem, and forage CP was greater for Old World bluestem during several months.

Horn and Taliaferro (1979) reported that neither Plains or Caucasian Old World bluestem had adequate CP to meet requirements for growth of beef calves in late summer. Furthermore, Coleman and Forbes (1998) reported minimal gains of steers grazing Plains Old World bluestem after July 18 and zero gains in late August and early September. Plains OWB, similar to all forages will decline in forage nutritive value as the growing season progresses.

The best use of forages is often attained by maximizing grazing when the forage is at its highest ratio of DM quanity:quality (Forwood et al., 1988). The rapid growth rate of Old World bluestem in spring is followed by seed production and a decline in green leaf proportion (Eck and Sims, 1984). Rapid rates of gain are often observed in early summer, then decline as maturity progresses Coleman and Forbes (1998). Due to maturation, seed production, and declining green leaf proportions, the nutritive value of unharvested and/or dormant forage is often low (Teague et al., 1996). Thus, as season progresses, both the nutritive value and quantity of forages decline (Hodges and Bidwell, 1993). Therefore, it would appear heavy stocking rates early in the growing season may be a valid option for maximizing productive use of Old World bluestem and possibly other grasses with similar forage nutritive value and growing seasons.

Grazing Pressure

The nutritive value of Old World bluestem is sensitive to proportion of green leaf mass and leaf to stem ratios (Teague et al. 1996). Grazing pressure and(or) level of grazing intensity may influence green leaf mass and leaf to stem ratios. Forbes and Coleman (1993) suggested that the management of Old World bluestem should attempt to maintain swards with as high a proportion of green leaf mass to stem as possible. Therefore, intensity of grazing and grazing system may have major influences on forage nutritive value of Old World bluestem as well as other forages. Decreasing leaf to stem ratios and CP content, coupled with increasing proportion of fiber constituents as forages mature emphasize the need to utilize management techniques that will maintain Old World bluestem grasses in a juvenile, actively growing state (Dabo, et al. 1988). To achieve optimal performance for growing livestock, forage must be kept in a vegetative, actively growing state (Taliaferro et al. 1984; Dewald et al., 1985). Bird et al. (1989) reported that the liveweight gain of steers grazing cool season perennial pastures was poorly related to forage mass, and that gains were related primarily to green forage mass.

Management strategies for Old World bluestem should aim to maintain swards with a high proportion of green leaf and green leaf mass (Forbes and Coleman, 1993). Old World bluestem requires heavy stocking after June 1 to maintain forage nutritive value (Anderson and Matches, 1983; Dabo, 1988, Johnson and Parsons, 1985). Light stocking may lead to patch grazing, thus, overall forage nutritive value late in the season may be poor in light stocked pastures. However, very heavily grazed pastures may also have lower forage nutritive value and quantity in comparison to moderately stocked pastures. Heavy stocking and(or) intense grazing may increase harvesting efficiency because it helps maintain the leafy condition of Old World bluestem. A greater proportion of leaf may be consumed by grazing animals than would be the case if the pastures were stocked lightly (Teague et al.,1996). Teague et al. (1996) observed increased proportion of live leaf and stems in pastures that had been grazed intensively. Additionally, Teague et al. (1996) reported increased CP content of clipped forage in intensively grazed, compared with less intensively grazed pastures. Frequent use of heavy stocking rates may stimulate plant growth and enhance forage nutritive value; however, plant vitality may be challenged (Taliaferro et al., 1984). Plains Old World bluestem may be more resistant to frequent defoliation than many other species, as demonstrated by stand persistence under frequent clipping (Teague et al., 1996). However, plants may be weakened by frequent defoliation, which may decrease total forage DM production (Taliaferro et al., 1984). Therefore, management practices should be designed to monitor forage nutritive value, animal performance, and stand health in order to sustain an adequate stand of forage while maximizing animal productivity. Increased forage or leaf production in response to grazing pressure is not a characteristic which is unique to Old World bluestem. However, research seems to suggest that Old World bluestem may be more responsive in a positive manner than other warm-season perennials such as native tallgrass prairie.

Forbes and Coleman (1993) observed that changes in sward structure, primarily differences in green leaf mass, may limit forage intake. Proportion of green leaf appears to be the single most important component of the sward structure in regards to forage nutritive value within a growing season. Intensive grazing, or increasing stocking rate may stimulate forage productivity and diet quality. However, in many cases, heavy stocking rates simply decreased the quantity and (or) availability of leaves. When the quantity of leaves decreases, diet quality may also decrease. Chacon and Stobbs (1976) reported lower forage diet quality in heavy compared with lightly stocked tropical grass pastures, primarily due to decreases in leaf mass. Furthermore, Bird et al. (1989) observed decreased gains of steers grazing cool-season perennial mix pastures when proportion of green plant mass declined due to heavy stocking. Therefore, it is apparent that the response of forages to increasing grazing pressure will vary from one forage to another, and furthermore, the level of grazing pressure, in combination with seasonality, impacts the response of the plant in terms of level of leaf production.

Soil Fertility

Soil fertility can influence both forage nutritive value and quantity (Minson, 1971). Increasing forage yield with fertilization can increase animal gain per acre. Forage yield and beef production are related, however, the relationship appears to be quadratic and may be heavily influenced by stocking rate (Schultz et al., 1959). Old World bluestem will respond favorably to N fertilization, producing 9 to 23 kg of additional forage per .454 kg of actual N added (Hodges and Bidwell, 1993). Berg (1990 and 1993) reported substantial increases in forage production in fertilized Old World bluestem pastures. The range or variance in the influence of N fertilization on Old World bluestem production is dependant on several factors, including soil type and precipitation. Horn et al. (1974) reported that Plains Old World bluestem had the greatest increase in yield in response to N and P fertilization in comparison to weeping lovegrass, midland bermudagrass, or native range. Fertilization may also have positive impacts on forage nutritive value, for example, fertilization of Old World bluestem may increase CP content of the forage 2 to 5 percentage points during the growing season (Hodges and Bidwell, 1993).

Berg and Sims (1995) reported peak standing forage of unfertilized Old World bluestem to be 1,200 kg/ha while Old World bluestem paddocks which received 102 kg of N/ha averaged 6,900 kg/ha of forage production. Fertilization, timing of fertilization, and management of plant residue are all essential factors which contribute to appropriate management of a productive plot of Old World bluestem as well as other introduced forages.

Factors Affecting Liveweight Gain of Grazing Ruminants

Diet Selection

The gain of ruminants grazing forages is influenced by several factors, including diet selectivity. Ruminants that are able to select a diet from standing forage in a pasture may often have greater gain than animals which are fed forages, because feeding harvested forages to ruminants in pens or stalls may decrease selectivity. Hull et al. (1957) observed greater gains for sheep grazing forage than for those that were fed the same forage in a pen feeding situation.

Grazing ruminants often select diets of higher quality than can be hand clipped or harvested by other means (Johnstone-Wallace and Kennedy, 1944). Ruminants often select diets with higher proportions of leaf than stem, which may often have higher digestibility (%OM) and faster passage through the tract than stems due to rate of particle size reduction (Laredo and Minson, 1975; Alder and Minson, 1963).

Increasing passage rate may also have a positive influence on intake. Chacon and Stobbs (1976) reported that cows grazing tropical grasses consumed leaves first, followed by stems. When these cows began eating stems, bite size and intake declined. Alder and Minson (1963) conducted detailed botanical separation of samples clipped prior to, then immediately after grazing, and observed that cattle selected more digestible plant portions (leaves and stems). Although diet selectivity can be very difficult to estimate, it is apparent that gain of grazing animals is influenced by the animal's ability to select its diet. As the ability to selectively graze decreases, gains often decline.

<u>Stocking Rate</u>

Stocking rates are a fundamental aspect of land and forage resource management which have a large impact on forage, livestock, and economic responses to grazing (Gillen et al., 1992). In combination with diet selectivity, stocking rate can have major influences on animal gains. The ability of the animal to select a diet of its preference may decline as stocking rate increases and forage mass declines. Diet selectivity may be influenced by stocking rate, particularly when stocking rates are "heavy" (Chacon and Stobbs, 1976). It is very important to select a stocking rate which is "near optimum" or a rate which does not under- or over-utilize forage resources for the purposes of grazing research (Mott, 1960). Perhaps the most important factor in considering stocking rate is the effect of stocking rate on animal gains and(or) performance. The number of cattle per unit area for a period of time, or the stocking rate is perhaps the most important factor affecting individual animal performance (Paisley, 1998). Stocking rate is a major consideration when comparing systems or methods of management. Comparisons of systems are only valid at the optimum stocking rate or grazing pressure for each system (Hart et al., 1988).

Effects of Stocking Rate on Individual Animal Performance. Stocking rate has a tremendous influence on gain per animal and gain per acre (Riewe et al., 1963; Bird et al., 1989). Hart et al. (1988) observed decreasing ADG as stocking rates increased in a group of steers grazing native range in Wyoming. Arnold (1960) observed decreasing ADG of sheep as stocking rate increased. The effect of stocking rate on animal gains is usually negative; as stocking rates increase, gains decrease (Harlan, 1958). This negative relationship begins at a point which has been referred to as the “critical rate”.

The critical rate would be the stocking rate below which animal gains are independent of stocking rate (Hart, 1978). In other words, animal gains greater than this critical stocking rate are influenced by increasing stocking rate and gains below this rate are not influenced by stocking rate. Hart (1978) suggested that a critical rate does exist, and animal performance at stocking rates less than this point would be independent of stocking rate, however, the critical stocking rate is not a fixed point, it will move as season and grazing pressure dictate. Forage consumption per animal and animal gains often remain relatively constant until the critical stocking rate is reached. Forage consumption and animal performance is inversely related to stocking rate after this point (Petersen et al., 1965). Therefore, if the relationship between stocking rate and individual animal gain was graphically plotted, the relationship would not be linear. Climate, grass growth patterns, digestibility, and composition of available forage, all contribute to complicate this relationship (Connolly, 1976).

The existence of a critical rate has been disputed by some researchers. Jones and Sandland (1974) summarized data from 33 different pastures at various levels of stocking and observed a linear relationship between individual animal gain and stocking rate. Jones and Sandland (1974), therefore disputed the existence of a "critical point" as they observed no evidence of this point either in their work or in the trials they summarized to develop their equation. Numerous other reports have described a linear decline in ADG as stocking rate increased, suggesting the absence of a critical point or stocking rate (Hart et al., 1976 and 1988; Aiken et al., 1991; Gillen et al., 1992; and Coleman and Forbes, 1998). Furthermore, Riewe (1965) and Bransby et al. (1988) suggested that a linear function would characterize the relationship between animal performance and stocking rate over a limited range of grazing intensities. However, Noy-Meir (1978) suggested that a sigmoidally shaped curve best described this relationship. Coleman and Forbes (1998) reported a trend for a plateau of ADG at light stocking rates, then a hyperbolic decline as stocking rates increased.

Following their review in 1974, Sandland and Jones (1975) compared their linear model to those developed by others including a model developed by Owen and Ridgman (1968). They concluded that the relationship between gain per animal and stocking rate was linear; however, they included the statement "beyond the critical stocking rate". Therefore, if stocking rates below this critical rate or point are included, then the relationship observed probably will not be linear. Hart (1978) refutes the absence of a critical point. Most stocking rate studies show a simple linear decrease in animal gains as stocking rate increases, primarily because all stocking rates in these studies are greater than the critical rate. Hart et al. (1988) reported nearly constant gains of cattle below a critical rate then a linear decline in gains as stocking rates increased.

In further support of the concept that the relationship between stocking rate and ADG is not linear, Hart (1978) reported that the relationship between stocking rate and individual animal gain was not linear for many points in the grazing season. However, as the grazing season progressed, the curves shifted downwards, thus, the relationship over the entire grazing period was nearly linear. Furthermore, much of the work which has refuted the existence of a critical point was conducted over a relatively narrow range of stocking rates thus, it may be difficult to detect departures from linearity (Connolly, 1976).

It is important to realize that the effects of stocking rate on animal performance may not be easily identified early in the growing season. Hart (1978) stated that during the month of May, gain of grazing animals is independent of stocking rate. However, quality and/or quantity of forage may be reduced in higher or heavier stocked pasture by June, and gains may begin to decline (Hart, 1978). Therefore, critical stocking rate is not a single point, and is influenced by season and timing of grazing.

Riewe (1961) concluded that light stocking rates do not always produce the highest gain per animal. While individual animal gains are often greatest at lower stocking rates, a point is reached at which further reductions in stocking rate cannot result in increased gain per animal. This factor may be one of the primary reasons why the relationship between stocking rate and gain per unit area is not linear. The decline in gains past the critical point may often be linear, however, the portion of the curve where stocking rate no longer influences gains may be similar to a breakpoint, or a region where stocking rate no longer influences animal performance. Jones and Sandland (1974) refer to this portion of the relationship as a "plateau" in individual animal gains.

Forbes and Coleman (1993) suggest that light stocking rates early in the season result in tall, poor quality swards late in the season and, as a result of patchy grazing, herbage intake will decline to levels near heavily stocked pastures. Coleman and Forbes (1998) reported patch grazing in Old World bluestem pastures that were stocked lightly (2.5 steers/ha); the patch grazed areas were heavily utilized later in the grazing season. Thus, it appears that very light stocking rates can lead to some over-utilization of areas while theoretically maximizing individual animal performance. However, Coleman and Forbes (1998) observed decreased gains of steers in the light stocking rate in their study, possibly due to decreased forage nutritive value of the lightly grazed areas and decreased forage quantity in the heavily grazed areas. Conversely, very heavy stocking rates may lead to declining individual animal performance and over-utilization of the entire pasture. Therefore there may be some evidence to support the concept that the relationship may not be linear in some cases, both above and below the critical stocking rate.

Effects of Stocking Rate on Gain Per Unit Area. Gain per unit area is the product of the number of animals per unit area and gain per animal (Petersen et al., 1965). As stocking rates are increased, gain per animal often decreases, however gain per acre increases in most cases (Harlan, 1958; Phillips and Coleman, 1995; Coleman and Forbes, 1998). Increases in stocking rate can compensate for decreased individual animal gain; however, stocking rate can reach a point at which gain per acre begins to decrease (Riewe, 1961; Jones and Sandland, 1974; Hart et al., 1988). For example, Riewe et al. (1963) demonstrated that the point of maximum gain per ha was 4.02 and 2.89 steers per acre for steers grazing tall fescue and gulf ryegrass respectively. Gain per ha declined at stocking rates greater than these levels.

Therefore, the relationship between gain per unit area and stocking rate is not linear either. A curvilinear relationship has been described by Mott (1960), Riewe (1961), and Cowlishaw (1969). Similar to ADG, there have been numerous curves and regression equations reported. However, the basic point is that at light stocking rates, individual animal performance may be maximized, but gain/ha is not. As stocking rate is increased, gain/animal often declines but gain/ha increases to a point at which it will decline again. The point of maximum gain/ha is often past the point of maximum individual animal performance, or individual animal ADG will not be maximized at this point (Mott, 1961; Hart, 1978). After the point of maximum gain per unit area has been reached, there is often a drastic decline in this value, emphasizing the danger of stocking pastures at extremely heavy stocking rates (Harlan, 1958).

The primary concern of most beef producers is maximizing financial returns. Hart et al. (1988) reported that maximum financial return per acre lies at a point between maximum individual daily gain and maximum gain per acre. Therefore, it is apparent that stocking rate decisions have a major impact on financial returns. Indeed, stocking rate may often be one of the most important factors that can be managed by the producer (Redmon et al., 1995). Aside from animal factors, management of forage and overall land management are impacted heavily by stocking rate.

Forage Mass or Forage Allowance

Stocking rate often does not portray or account for grazing pressure, unless the actual amount of forage mass per animal is known (Guerrero et al. 1984). When the amount of forage available per animal decreases. gain per animal also may decline. For example, McCollum et al. (1990) reported declining forage OM intake as forage allowance decreased, this decline in intake was due in part to decreased diet digestibility and would probably lead to a decline in gains. Forage production varies from year to year and between seasons within a year. This fact presents further support for examining stocking rates as forage allowance, rather than forage mass. In this manner, one can analyze the response of animals to the actual amounts of forage available, rather than land area. For example, Hart et al. (1988) reported stocking rate as grazing pressure, or steer days per metric tonne of forage DM produced. This method of evaluating the relationship between forage mass and animal performance may be very important for research trials; however, implementation or application of this data in an applied or producer setting may be difficult in the absence of accurate, easily applied means for producers to measure and(or) monitor forage mass. Therefore, the individual researcher must weigh these facts prior to the initiation of trials in order to adequately meet the needs of conducting and communicating the research proposed.

However, forage mass may be very closely tied to stocking rate, as stocking rate is increased, forage mass will often decline. Petersen et al. (1965) suggested that the linear increase in gain per unit of area as stocking rates are increased will peak at the point at which total forage consumed is equal to the total forage available, and gain per unit of area would decline at stocking rates beyond this point. The relationship between forage mass and animal performance is not simple, factors such as ruminal fill, nitrogen status, and grazing behavior may alter or even decrease the impact of this relationship.

Allden and Whittaker (1970), Young and Corbett (1972), and Chacon and Stobbs (1976) observed increased grazing time as forage mass decreased. Increasing grazing time, in combination with declining intake, may both contribute to lower animal gains and(or) performance. The effects of forage mass on forage intake is discussed further in the intake section of this review.

Factors Influencing Forage Intake of Grazing Ruminants

The amount of forage ingested by a grazing animal is one of the largest determinants of performance. Forage intake may often account for greater variability in animal performance than other factors, such as forage digestibility (Mertens, 1994). Dry matter intake may constitute 65 to 75% of the variation in energy intake, while 20 to 30% may be attributed to differences in digestibility (Buxton et al., 1995). Estimation or prediction of forage intake is a difficult and complex procedure due to the wide array of factors which may impact or control the amount of forage a grazing animal consumes.

The 1981 NRC stated that consumption of less digestible, low-energy (often high fiber) diets is controlled by physical factors such as ruminal fill and digesta passage; whereas, consumption of highly digestible, high energy (often low-fiber, high-concentrate) diets is controlled by the animal's energy demands and by metabolic factors. Furthermore, research has indicated that intake of forage by ruminant animals is influenced by chemical composition, digestibility, and rate of digestion of the forage consumed as well as physical structure and composition of the forage available (McDonald et al., 1995). Food intake may often be influenced by metabolic stimuli or physiological status of the animal. However, the effects of these stimuli may be more pronounced in pen-fed than in grazing animals (Hodgson, 1985). Pittroff and Kothmann (1999) proposed an alternative to the afore-metioned hypothesis that intake is controlled by fill to a certain point then by metabolic factors thereafter, and proposed an integrated dynamic model of herbivore metabolism. They have proposed that fill may not be the primary control of intake, and propose that integrated metabolic mechanisms control intake in all situations. Therefore, it appears that there is still considerable work to be conducted in the area of intake regulation or that a firm, universally accepted model of intake regulation has not yet been elucidated.

Breed, or type of animal may influence intake because the urge to ingest food is driven by a genetically predetermined capacity to realize a potential for growth and milk production (Ketelaars and Tolkamp, 1992). Allison (1985) stated that body size and physiological status of the animal appear to influence forage intake to a greater extent than many other factors. It is clear that there are many factors which coincide or act in unison to influence or regulate intake of grazing animals.

Minson (1990) stated that the quantity of forage eaten by the grazing animal is controlled primarily by three factors: 1) the availability of suitable forage, 2) the physical and chemical composition of the herbage, and 3) the nutrient requirements of the animal. Allden and Whittaker (1970) and Jamieson and Hodgson (1979) concluded that intake of grazing animals is controlled by time spent grazing, rate of biting during grazing, and the weight of forage consumed per bite.

Forage Mass, Forage Allowance and Sward Height

Forbes (1988) concluded that sward height is the primary factor that limits intake in grazing animals. Several researchers, including Allden and Whittaker (1970) have found close relationships between sward height and forage intake. Jamieson and Hodgson (1979) observed a depression in intake of forage by beef calves when forage height decreased from 7.4 to 5.4 cm. Furthermore, there appears to be a maximum forage height above which forage intake no longer increases. For example, Coleman and Forbes (1998) reported the maximum forage height above which no increases in intake were observed was 41.7 cm for Old World bluestem.

Forage mass, which may often be expressed as the units of OM per unit area, is also an important characteristic of swards which may influence forage intake. Forage mass and sward height are often closely related, however, these two factors are often not reported together in the literature. Therefore, it may be necessary to consider the impacts of each factor on forage intake separately. Woodward (1936) reported declining intake and performance of dairy cows as forage mass declined below 1025 kg DM/ha. Minson (1990) reported that forage intake will decline when total forage mass is less than 2000 kg DM/ha. Chacon and Stobbs (1976) also reported decreased intake as forage mass decreased (reduction from 3408 to 1763 kg DM/ha).

Additionally, tiller density or the density of forage per unit area, which should be closely related to forage mass, will influence intake (Black and

Kenney, 1984). Hendricksen and Minson (1980) estimated that the point at which feed intake would decline was 1100 to 2800 kg DM/ha for cattle grazing temperate forage. Upon reviewing these papers, it becomes apparent that the response of intake and grazing behavior to declining forage mass varies from one forage to another and probably also differs between species of animal and state of maturity within species of forage.

Another means of describing the relationship between forage and animal performance may be forage allowance. Forage mass considers only forage per unit of area, whereas forage allowance considers forage allowed per animal as was discussed previously in the stocking rate section of this review. Decreasing forage allowance has similar effects on forage intake as declining forage mass. McCollum (1990) observed declining forage OM intake as forage allowance declined. Redmon et al. (1995) observed declining forage OM intake as forage allowance declined for steers grazing winter wheat pasture. Redmon et al. (1995) reported that daily intake of forage declined when forage allowance declined below 30 kg DM/100 kg BW.

Forage intake may decrease due to decreasing forage mass primarily because of a decline in the animals ability to ingest adequate amounts of forage due primarily to decreasing bite size (Stobbs, 1973; Chacon and Stobbs 1976; Forbes and Hodgson, 1985). Lower levels of forage mass will decrease the amount of forage an animal can ingest with each bite. Bite size appears to be the primary component or animal behavioral response that influences intake (Minson, 1990). Allden and Whittaker (1970) and Hendricksen and Minson

(1980) observed major decreases in bite size in response to declining forage mass. A more detailed description of the relationships between grazing time, rate of biting, and bite size will be included later in this review.

Numerous researchers, including Arnold (1960), Allden and Whittaker (1970), Young and Corbett (1972), and Chacon and Stobbs (1976) observed increased grazing time as forage mass decreased. However, in many of these studies, grazing time reached a peak or a maximum amount of time that the animals were willing to graze. After grazing time reached this peak, animals began to decrease time spent grazing as forage mass continued to decline. In other words, the effect of forage mass on grazing time is quadratic.

The relationship between forage intake and sward height is not linear. Other factors, including digestibility and gut fill, will limit intake at some point no matter how much forage is available. Furthermore, the relationship between these two factors is often dependant on species of grass, type of grazing animal, and possibly season.

Sward Structure

One of the factors that influences forage intake is sward structure. Forbes and Coleman (1993) concluded that changes in sward structure, particularly in the proportion of green leaf mass to stems, influenced intake of Old World bluestem. Forage intake was more closely related to green leaf mass than any other sward characteristics. Laredo and Minson (1975) also observed differences in intake of leaf vs stem fractions of tropical grasses. Therefore, it would appear that the quantity of leaves and leaf:stem ratio of available forage are factors that play a major role in controlling intake of grazing animals. As mentioned previously, in a study concerning the effects of defoliation on grazing behavior of steers, Chacon and Stobbs (1976) noted declining intake and decreased DM of pastures with increasing grazing pressure. These authors also reported a decline in leaf available for grazing from 1140 to 194 kg DM/ha.

Grazing Behavior

Time spent grazing influences energy expenditure of grazing animals. Energy expenditure of grazing animals varies dependant upon the costs of attaining forage (Osuji, 1974). Energy expended while grazing may be largely influenced by grazing time. Energy expended during consumption of feedstuffs, both forage and concentrate, is highly correlated to the amount of time spent eating, and is more related to time spent eating than amount of feed ingested (Susenbeth et al. 1998). Therefore, grazing time will have major impacts on the energy expenditure of a grazing animal. Forage availability is one of the major factors that influences grazing time, and as a result, also influences energy expenditure. Initial decreases in forage mass will often result in increased time spent grazing.

Fatigue, while not being a major consideration for pen-fed cattle, is a factor that may sometimes influence intake of grazing cattle (Chacon and

Stobbs, 1976). Declining forage mass may increase energy expenditure while simultaneously causing a decline in intake if the decline in forage mass is severe. In other words, as forage mass continues to decline, grazing time may decrease due to fatigue and less willingness to graze, leading to a further decline in intake. The combination of these factors will have a negative affect on animal gains.

As forage mass and(or) forage allowance decrease, grazing time often increases (Allden and Whittaker, 1970). Forage mass was the primary factor which influenced grazing time in sheep as reported by Arnold (1960). Ackerman et al. (1998) observed increased grazing time with increasing stocking rate and decreased standing crop, which coincided with decreased ADG of steers grazing Old World bluestem. Similarly, Young and Corbett (1972) observed increased grazing time from 8.2 to 12.3 hours as forage mass decreased from 2800 to 370 kg DM /ha. Lofgreen et al. (1957) observed increased grazing time of steers grazing alfalfa. As the number of days in the pasture increased, they attributed this increase in grazing time to decreasing forage mass and forage allowance which increased the amount of time required to selectively graze. When forage mass is reduced to less than 2000 kg DM/ha for, there is a reduction in bite size, this reduction is only partially offset by increases in grazing time and rate of biting, therefore, total forage intake often declines (Minson, 1990).

However, Jamieson and Hodgson (1979) observed decreasing grazing time with decreasing forage mass, possibly due to large decreases in forage mass. Decreased forage intake due to declining forage mass may only be partially compensated for by increased grazing time (1996 NRC). As was discussed previously, fatigue may play a role in intake regulation when forage mass is at such a low point that animals will not maintain intake.

The quantity of forage consumed by an animal each day depends on time spent grazing, the rate of biting, and the size of each bite (Stobbs, 1973; Bailey and Bishop, 1975; Minson, 1990). Bite size appears to be the primary component that can influence intake. However, bite size is entertwined with grazing time, and there appears to be an upper limit on the amount of time an animal will spend grazing each day (Minson, 1990). This upper limit may depend on many factors, including type and condition of forage, the animals physiological state, and many other factors. Chacon and Stobbs (1976) observed increased grazing time, decreased intake per bite, and increased number of bites as forage mass of tropical pastures decreased. However, as defoliation or the decrease in forage mass increased near the end of their trial, grazing time began to decline. The decline in gazing time that the authors observed may have been due to the large decline in available leaf that was mentioned previously. Therefore, forage nutritive value may have decreased to the point at which rumen-reticular fill became a major factor in limiting intake. This is in agreement with results reported by Redmon et al. (1995) who observed decreased intake with decreased herbage allowance. However, fecal output was not different, therefore, degradability and rumen fill may have been limiting intake, rather than ability to ingest forage.

Increases in grazing time and rate of biting may compensate for decreases in bite size, depending on the availability of forage or the severity of the limitations of forage availability. However, this response is dependant upon the level of forage mass, or how severe the limitation of forage mass is. Chacon and Stobbs (1976) concluded that the major factor which influenced intake of forage was bite size, and although cows increased grazing time and rate of biting, intake still decreased with less forage mass. Furthermore, numerous papers have reported that as depressions in forage mass become severe, grazing time and rate of biting decline and intake will decline even further.

There are many factors which can influence or alter intake of forage or other types of feed. One of the factors which may not often be considered is behavior. The extent of understanding of the effects of animal behavior on animal performance is modest at most (Curtis and Houpt, 1983). Tribe (1950) demonstrated that unsupplemented ewes spent more time grazing than supplemented ewes. However, when supplemented and unsupplemented ewes were placed in adjacent pastures, the supplemented ewes were stimulated to graze longer. Perhaps this effect could also occur in stocking rate trials. Animals in a light stocking rate treatment may be stimulated to spend longer periods of time grazing than they normally would by their counterparts in a heavy stocking rate treatment across the fenceline.

Composition of Forage and Rumen Fill

As mentioned in the previous section, the composition of forage or the ratio and quantity of green, actively-growing forage to dry, dormant forage is an important consideration when considering the effects of forage availability on forage intake. The relationship between intake and forage composition has been studied extensively in green, growing pastures. As noted by Minson (1990), intake is more closely related to allowance of green, growing forage than total forage on offer. However, during periods of forage dormancy, intake may be more closely related to forage digestibility and nitrogen status of the animal and(or) ruminal microorganisms than forage mass. Dormant forages are often low in nitrogen. Animals consuming dormant forage often experience a N deficiency, and providing the animal with supplemental N often increases dry matter intake (Egan and Moir, 1965; McCollum and Horn, 1990).

As discussed previously, physical limitations on intake occur when the animal eats until its rumen is full (Buxton et al., 1995). Intake of forage is closely related to reticulo-rumen fill, which is associated with digestibility as well as fiber content of the ingested forage. The fiber content of ingested forage will have some influence on rate of passage of material out of the rumen (Allison, 1985). Intake of dry matter may be limited by digestibility and rate of digestion of ingested nutrients (Ketelaars and Tolkamp, 1992). In conditions where forage mass is not limiting, the forage intake of grazing cattle may be related to digestibility of the herbage consumed (Hodgson and Wilkinson, 1968; Hodgson et al. 1977; Minson, 1990; Allison, 1985). Hodgson et al. (1977) demonstrated this relationship with intake of low quality hays by calves grazing temperate swards. The lower the quality of the hay, the less the calves consumed. Herbage intake is directly related to digestibility, rate of passage, and rumen fill (Blaxter et al., 1961).

Rate of digestion is not always be the primary controller of intake. Rate of passage is not predetermined by rate of digestion, passage or ruminal dilution rate may act independently of rate of digestion. Intake of forage is closely related to structural or cell wall content of the ingested portion. The amount of cell wall in the ingested forage will have a major influence on rate of passage, and thus, rate of intake (Van Soest, 1982). Proportion of cell wall constituents and the amount of time required to decrease particle size of a forage are also important controllers of intake. Therefore, the relationship between rate of digestion and rate of passage plays an important role in intake regulation (Allison, 1985). When a ruminant is consuming low quality forage, fill often remains constant, while intake is controlled by passage rate or flow of particulate matter out of the rumen. Therefore, dry matter intake and rumen retention time are inversely related (Thornton and Minson, 1973). However, fill may not always remain constant, animal related factors such as pregnancy may alter capacity and fill. Therefore, considering passage rate as the primary controller of intake while assuming a constant level of fill may not be a valid assumption in all cases (Allison, 1985).

The prime physical factor of a plant that influences intake is the rate at which it is broken down into particles small enough to escape the rumen (Minson, 1990). This factor is readily apparent in the differences of intake of ground and long-stemmed hay. Fine grinding can increase intake of hay, presumably through effects on digesta passage (Galyean and Goetsch, 1993). However, grinding and pelleting may also have negative affects on ruminal digestibility through increased passage rates and decreased digestibility (Horn and McCollum, 1987). Furthermore, leaf vs stem ratio may also influence intake. Minson (1990) discussed comparisons of leaf vs stem intakes in which digestibilities of the two fractions were similar while intake was greater for the leaf fraction. Hendricksen et al. (1981) and Minson (1990) suggest that differences in intake of leaf vs stem fractions may not be due to differences in digestibility between the two fractions, but rather, differences in particle sizes and the rate of reduction of particle size, with the stem fraction having the larger particle size, higher structural cell wall content, and longer ruminal retention time.

Palatability

Palatability of feedstuffs may often be overlooked when considering intake. Ruminants often are selective as to what they consume, they may often consume leaf in preference to stem portions of forage, or they may prefer one species of forage to another. It is difficult to discern if these differences are due to palatability or simple ease of consumption. Measurement of palatability is very difficult because it is often difficult to discern if differences in feed consumption are due to true palatability and acceptability of a feedstuff, or some other factor (Ketelaars and Tolkamp, 1992).

Chemostatic Regulation

The current beef cattle NRC (1996) suggests several equations for use in prediction of forage intake. These equations however, are primarily based on energy content of the diet, and the authors of the NRC suggests that more research needs to be conducted in order to accurately model and predict the intake of grazing ruminants.

Ingestive behavior may also be related to chemostatic changes in the animal in relationship to dietary influences such as ME intake. Variation in circulatory levels of cholecystokinin, glucose, and other factors will both initiate and terminate feeding behavior (Curtis and Houpt, 1983). However, the influence of these control mechanisms on intake may often be relatively slight for ruminants consuming forages in comparison with ruminants consuming highly-digestible, high-energy concentrate feedstuffs (NRC, 1981).

Forage intake may also be related to metabolizability of diets, the more metabolizeable a diet, the greater the intake will be, in other words, metabolizable energy content and forage intake are positively related (ARC, 1980). Voluntary intake often increases with increasing diet digestibility, however, in some cases, there is a point where increasing digestibility will not result in further increases in intake (Allison, 1985). Conrad (1966) suggested the existence of a point of DM digestibility (68%) at which the influence of physical regulation of intake declines and the influence of physiological or chemostatic factors increases for cattle consuming corn:corn silage based diets. However, this relationship may not exist with high forage/lower energy diets. As discussed previously, the capacity of the rumen, stretch and fill receptors, and digesta passage rates also influence the intake of a grazing ruminant.

Animal Requirements

Nutrient requirements, are influenced to a great extent by physiological state. As mentioned previously in Minson's (1990) three factors which control intake, the third factor described was nutrient requirements, nutrient requirements often influence intake. For example, a lactating cow will increase intake due to the nutrient demands of lactation (Ketelaars and Tolkamp, 1992; Buxton et al., 1995; Olson, 1998). However, it is not completely clear whether this increase in intake following parturition is due to increased requirements or removal of restraints on gut capacity or a combination of both (Ketelaars and Tolkamp, 1992). Additionally, the fatness of ruminant animals, and(or) the ratio of fat to lean muscle influences intake, for example. In very fat animals, intake tends to stabilize as body weight increases (McDonald et al., 1995). Therefore, intake of grazing animals is not based solely on ruminal fill, forage mass, and energy content of the diet, but physiological influences may often play a role in control of intake.

Environment

Environmental influences, such as variation in temperature, also influence intake. Feed intake will increase as temperatures fall below the thermonuetral zone, and decrease with temperatures above the thermonuetral zone (Morrison, 1983; NRC, 1996). These adaptations due to environment appear to be driven primarily by changes in ruminal motility and corresponding energy requirements (Ketelaars and Tolkamp, 1992). However, there is some disagreement with the simple effects of temperature on grazing time. Adams et al. (1986) observed decreased grazing time of beef cows when they experienced extreme cold temperatures. Photoperiod may also influence intake as intakes are generally greater in months with longer daylengths (NRC, 1981).

Factors Affecting the Performance of Animals of Different Size or Weight

Some of the factors which may influence performance of grazing ruminants are species, live weight, and age (Seman et al., 1991). Animal size, as influenced by genetics, age, and(or) previous nutrition is a primary determinant of animal performance, including rate of gain.

Intake

There are differences of opinion regarding the relationship between body size and intake in the literature. Some authors have concluded that intake is not related to body size, rather, it is directly related to maintenance requirements, in other words, animals will eat to their requirement, regardless of their body size. However, others have reported that gut size is the primary factor related to intake. A smaller animal with a smaller gut and proportionally higher maintenance requirements per unit of body weight may require a higher quality diet than larger animals (Ketelaars and Tolkamp, 1992). Large animals may often be less selective grazers and they often retain food longer, and digest food to a greater extent which allows them to have greater ME intake on the same diet than smaller animals (Illius and Gordon, 1991).

Some ruminants such as concentrate selectors have smaller ruminal capacity, perhaps similar to that of a young, light weight grass and roughage eater. Concentrate selectors regularly consume a diet of higher quality due a decreased ability to digest cell wall components and lesser ruminal capacity (Church, 1988). Perhaps, the young, light weight ruminant is somewhat similar to the concentrate selector in this respect. However, this relationship may not be supported by the fact that ruminal volume of cattle increases with body weight at a decreasing rate. The relationship of rumen volume to body weight is approximately: rumen volume = body weight$^{.57}$ (Owens and Goetsch, 1988). Therefore, the young ruminant may often have a larger rumen in proportion to its body size than its adult counterparts. Indeed young, light weight calves have been observed to consume feed in amounts that would seem very unlikely for a larger more mature animal. For example, Purvis and Lusby (1996) observed DM intakes of approximately 2.9% of BW for 105 kg early-weaned calves consuming a total mixed ration. Similarly, Paisley and Horn (1996) observed DM intakes of a total mixed ration of approximately 3.1% of BW for 121 kg early-weaned calves.

Therefore, it appears that small, or more likely young ruminants consume more feed per unit of body weight, which may be related in a large part to the fact that the smaller animals rumen is larger in proportion to its body weight. Additionally, smaller lighter steers have been observed to consume more forage as a percentage of body weight than larger steers. Ackerman et al. (1998) observed forage (OWB) OM intakes of 3.2% of live weight for 141 kg steers in comparison to OM intakes of 2.5% of live weight for 265 kg steers. Paisley et al. (1998) reported forage (wheat pasture) OM intakes of 2.8% of liveweight for 157 kg steers. Similarly, Adams et al. (1987) observed greater intakes as a percent of body weight for small (446 kg BW) than large (574 kg BW) cows.

However, the larger animals consume more feed when expressed as absolute amounts. Zoby and Holmes (1983) observed greater forage intakes for large cattle (cows and steers: 631 kg BW) than light steer calves (164 kg BW).

However, the lighter animals consumed more forage in relation to metabolic body weight than the heavier animals. These workers postulated that smaller cows may have been compensating for a higher energy requirement per pound of live weight with increased appetite.

Allison (1985) suggested that within a breed, intake is more closely related to age than live weight. It may be very difficult to separate the effects of age and increasing body weight on forage intake. This concept is further supported by the data of Hunter and Siebert (1986) who observed linear decreases in intake of forage both as a percentage of live weight and metabolic body weight for both Angus and Brahman steers as body weight increased from approximately 100 to 500 kg.

The previous discussion applies primarily to growing animals. Mature animals may eat proportionally similar quantities of feed among species and body weights. Adenuga et al. (1990) observed intake of lactating dwarf goats to be similar to that of lactating cattle and sheep when expressed as multiples of maintenance. However, a review of literature leads to the conclusion that there are still some different viewpoints regarding the relationship between body size/weight differences and intake. It would seem that the relationship between maintenance requirements, fasting heat production, and intake are the primary factors which drive these differences (Ketelaars and Tolkamp, 1992).

Some researchers have reported that size of animal is of somewhat less importance to ADG and feed conversion in the feedlot segment of the cattle industry. Klosterman (1972) reviewed several trials for which he investigated feedyard performance of cattle of differing biological types and sizes and concluded that biological size and weight of animals have little influence on feed efficiency. Anderson (1978) also reported that biological size of cattle had very little, if any significant impact on feed efficiency; and therefore, little impact on economic returns of cattle in feedlots. However, when these two authors referred to "size" of an animal, they were referring to mature weights and the differences in mature weights of different breeds of cattle, not necessarily different weights of cattle of similar biological type. Conversely, Brown et al. (1973) observed that body weight and body length were closely related to feed consumption and feed conversion in a group of yearling Hereford bulls.

Ingestive Behavior

Allison (1985) suggested that younger animals may select a higher quality forage diet, resulting in faster food passage. Arnold (1981) found that five-month old lambs consumed diets of higher digestibility and nitrogen content than their older counterparts while grazing subterranean clover. Horn (1979) reported that calves tend to select a higher quality diet than cows when both were grazing bermudagrass. Although there were no significant differences in intake as a percentage of metabolic body weight, Bae et al. (1983) reported that rumination time, eating, and total chewing time were less for animals of larger metabolic body weight when consuming a medium quality hay. Forwood et al. (1991) observed increased bolus weights of masticated, ingested forage in heavy (533 kg) compared with light (280 kg) steers consuming both growing and dormant tall fescue:red clover mix pastures. Furthermore, Zoby and Holmes (1983) observed increased bite size for heavy compared with light steers grazing perennial ryegrass during the growing season. These researchers speculated that the size of the larger steers' head and associated oral cavity allowed for the larger size of bolus. The heavier steers may have been able to ingest and chew more forage at one time than the lighter steers. Age of animal, and possibly body size, may influence efficiency of chewing (Church, 1998). Therefore, differences in grazing behavior and energy expended to consume forage, in combination with differences in rumen capacity and overall ability to select and ingest forage, may lend to differences in ADG and other measures of performance between light and heavy cattle.

Erlinger et al. (1990) observed increases in grazing time for larger, heavier animals when comparing 387 kg cows to 589 kg cows at similar levels of forage allowance. However, Zoby and Holmes (1983) reported longer grazing times for small (164 kg BW) in comparison with heavy (631 kg BW) steers. Differences in diet selection, in combination with forage intake and grazing time, may impact performance of light vs heavy cattle. Zoby and Holmes (1983) reported a trend for greater diet selection as well as grazing time of light vs heavy steers.

Overall individual performance of small, less mature cattle may be less than larger, more mature cattle. Some researchers have found evidence that young, light weight calves are particularly sensitive to changes in gazing management and(or) forage availability (Leaver, 1970). However, Jamieson and Hodgson (1979) concluded that substantial changes in herbage allowance had similar affects on young, light weight calves (< 150 kg) as larger cattle. Therefore, there appears to be some disparity in the concept of the relationship between body size or weight and age of cattle and the grazing environment, such as forage mass and quality.

Maturity and (or) Body Composition

Stage of maturity may also influence gains of cattle of different sizes. As an animal matures, the proportion of gain composed as fat increases as an animal nears maturity. Lean muscle accretion will peak when empty body weight is 744 kg or when empty body fat equals 36.2% of BW (Owens et al. 1995). Body composition is highly correlated with fasting heat production and nutrient requirements (Baker et al. 1991). A older, more mature animal may often have lower maintenance energy requirements as a proportion of body weight due, in part, to a higher proportion of body fat. However, rate of gain of more mature animals may be slower because muscle tissue gain is energetically less costly than fat tissue gain (Webster, 1980).

Animals which have greater accretion of lean as a proportion of gain and overall body weight may have higher maintenance requirements (Tess, 1984). However, efficiency of muscle tissue gain is approximately four times greater than fat because of the greater amount of water which is stored with muscle than fat (Owens, et al. 1995). Therefore, the energetic efficiency of gain per unit of body weight gained decreases as the animal increases in age (Webster, 1980). However, it is interesting to note that a mid-maturity calf (ex: 250 kg BW) will often gain weight more rapidly than a young calf (150 kg BW). This difference in rate of gain often occurs despite the lesser efficiency of gain (Webster, 1980) for the heavier calf. Gains expressed as a percentage of live weight are often greater for light weight animals, therefore greater numerical live weight gains for heavier animals may simply be a function of mass rather than efficiency.

Maintenance requirements of a lean animal are greater than the maintenance costs of a fatter animal at the same stage of physiological maturity and production as demonstrated by Thompson et al. (1983) with crossbred cows. However, increased maintenance requirements because of lean tissue as a proportion of live weight may not apply to animals of different physiological maturity. Possibly, the efficiency of lean tissue gain is large enough to outweigh the negative relationship between lean muscle mass and maintenance requirements in young, growing animals.

Efficiency of gain is greatly influenced by stage of maturity, and feed efficiency is usually nearly constant for cattle until they reach approximately one-third of their mature size after which it begins to decline (Webster, 1980). Rate and efficiency of gain will decline as the animal nears physiological maturity as fat and energy content of gain increases (Lofgreen and Garrett, 1968). Weight gains at this point of maturity contain an increasing proportion of gain as fat and a smaller proportion as lean and bone (Crooker et al., 1991.)

Genotype

Animals of different genetics (ie: Angus vs Simmental) may have different mature sizes. Therefore, two animals of similar weights may have vastly different body composition. Genetics have some influence on gains of grazing cattle. Consequently, when reviewing research concerning gain performance of cattle of varying sizes, it is important to consider breed of cattle as well as weight differences. A lot of research has been conducted, such as that reported by Frisch and Vercoe (1984), comparing gains, intake, and other factors of animal performance and behavior between cattle of different genotypes. Ferrell and Jenkins (1987) observed different maintenance energy requirements on a metabolic body weight basis for cows of different genotypes. Once again, this type of data may not lend much to the discussion or study of performance differences of cattle of similar breed type and age.

One problem with much of the data concerning performance of different sizes or weights of cattle is the fact that often ages of the cattle in the trials are unknown and(or) not reported. Therefore, some research that has compared "young", immature animals to "mature" animals may be confounded by age. For example, Zoby and Holmes (1983) reported herbage intake and grazing behavior of mature cows, "large" steers (631 kg BW and 69 months of age), "medium" steers (439 kg BW and 19 months of age) and "small' steers (164 kg body weight and 7 months of age). Although this work may be of interest in studying the effects of age and maturity on grazing behavior, the results may not be applicable to interpreting or investigating the differences in gains between groups of stocker cattle of different weights. Age is a factor that may influence forage intake as older animals typically consume more feed per unit of body weight, and thereby may often have greater ADG (NRC, 1996). However, this statement or observation may be an artifact of compensatory growth. Furthermore, older, more mature cattle may have less disease stress and overall health difficulties which may allow them to increase their rate of gain. Consequently, it is somewhat difficult to compare performance of cattle of different weights across trials.

Summary of Review of Literature

Maximizing and sustaining income of grazing cattle enterprises in Oklahoma and other states is important to the livelihood of many cattleman. Old World bluestem, particularly the Plains variety, has and may have increasingly larger impacts on the economy of beef cattle production as a source of forage for summer stocker programs. Therefore, management of this grass may also increase in importance.

Research concerning performance of different sizes and(or) weights of cattle in grazing programs may be timely in light of current economic conditions and increasing numbers of small, light weight cattle in these programs. Further investigation of the relationship between stocking rates, performance, and income of light vs heavy weight calves is warranted. Additionally, investigation of why differences in performance occur may add to the base of scientific knowledge regarding the performance of grazing animals. It is apparent that stocking rate, intake, and grazing time are interrelated in their effect on animal performance. Furthermore, there is currently ongoing debate about what factors control, or regulate forage intake. Research in this area may also contribute to increasing the base of scientific knowledge.

Continued investigation of grazing animals may improve efficiency of food production in an increasingly competitive market and a world in which demands for food will continue to increase. Production of food for human consumption from forages in an efficient manner may help agriculture to meet these increasing demands for high quality foods.

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CHAPTER III

PERFORMANCE, FORAGE INTAKE, AND GRAZING TIME OF LIGHT VS HEAVY WEIGHT STEERS GRAZING PLAINS OLD WORLD BLUESTEM AT THREE STOCKING RATES

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ABSTRACT: Gains of light and heavy weight calves grazing Plains Old World bluestem at three stocking rates were evaluated during the summers of 1997 and 1998. Initial weights of mixed breed light weight steers (LHT) were 141 ± 17 kg in 1997 and 160 ± 23 kg in 1998. Initial weights of mixed breed heavy weight steers (HWT) were 265 ± 17 kg in 1997 and 248 ± 13 kg in 1998. Initial stocking rates for both sizes of steers were: light; 392 kg of live weight/ha, moderate; 504 kg of live weight/ha (increased to 616 kg live weight/ha in 1998), and heavy; 840 kg of live weight/ha. Data were analyzed as a 2 x 3 factorial with year as a random variable. A significant year x steer type x stocking rate interaction was observed for ADG and gain/ha (GHA) data. However, no two-way interactions were detected, therefore, ADG and GHA data are reported as steer type within year and stocking rate by steer type within year. Heavy steers had greater ($P <$ .05) ADG than LHT steers during both years; 1.01 vs 1.21 kg/d during 1997 and .72 vs .78 kg/d during 1998 for LHT and HWT steers, respectively. Forage intake (g/kg BW) was greater ($P =$ .05) for LHT (31.1) than HWT (27.6) calves. Light weight calves had lower ($P =$ .001) residual forage allowance than HWT calves; 18.2 vs 26.2 kg forage/kg BW for LHT and HWT steers, respectively. Grazing time (min/d: 1998 only) was greater ($P = .05$) for LHT (665.5) than HWT (624.3) steers. Forage CP and DOM were slightly greater ($P < .05$) for HWT vs LHT cattle. A linear decline in ADG was observed ($P < .07$) as stocking rates increased for HWT steers in 1997 and LHT steers in 1998. However, ADG did ($P > .30$) not decline with increasing stocking rate for LHT calves during 1997 or HWT calves during 1998. Forage intake was ($P > .10$) not different among stocking rates, however, residual forage allowance decreased ($P < .05$) as stocking rate increased. Grazing time was ($P < .05$) greatest for steers in the moderate and heavy stocking rates. Forage DOM decreased ($P < .05$) as stocking rate increased. Both LHT and HWT steers had ($P < .05$) lower ADG at all three stocking rates during 1998 compared with 1997. Gain per hectare was ($P < .05$) greater for LHT than HWT calves at all three stocking rates during both years. Gross return/ha was greater for LHT than for HWT steers during both years. Despite having had lower ADG, LHT steers had greater GHA and gross return/ha than HWT steers during both 1997 and 1998.

Key Words: Cattle, Stocking Rate, Old World Bluestem.

Introduction

Two factors that may influence performance of grazing ruminants are live weight and age (Seman et al., 1991). Body size and(or) weight of grazing cattle may influence grazing behavior and forage intake; therefore, live weight gain may depend, in part, on body size. If stocking rates are based on units of live weight per hectare, light weight calves may offer the opportunity to stock more steers per hectare. However, young, light weight calves may be particularly sensitive to changes in grazing management and(or) forage availability (Leaver, 1970). Investigation of the effects of stocking rate on gains of steers of different body weights may help identify what size or weight of calf can provide the greatest net return from grazed forages.

Old World bluestem is one of the main warm season grasses that has been planted on marginal farmland in Oklahoma (Berg and Sims, 1995). The nutritive value of Old World bluestem declines rapidly as they mature, therefore, this forage must be kept in a vegetative and actively growing stage in order to achieve optimal performance of growing livestock, (Dewald et al., 1985). One method of maintaining this actively growing condition may be manipulation of stocking rate. However, increasing stocking rates may have negative effects on forage nutritive value and quantity as well as weight gain of cattle.

Identification of optimal stocking rates for maximizing stocker cattle weight gain per ha should aid in making decisions regarding management of Old World bluestem pastures. Furthermore, monitoring the effects of stocking rate on forage nutritive value, intake, and residual standing crop may aid in making management decisions. The objectives of this study were to determine the effects of increasing stocking rate on the live weight gain and gain/ha of light and heavy steers grazing Plains Old World bluestem.

Materials and Methods

Research Site

The study site was located at the Bluestem Research Range 11 km southwest of Stillwater, OK. The primary soil types at this site are: Coyle Loam, Coyle-Lucien complex, Grainola-Lucien complex, Renfrow loam, Stephenville-Darnell complex, Stephenville fine sandy loam, and Zaneis loam. Plains Old World bluestem (*Bothriochloa ischaemum* L. Keng:OWB) was seeded and established at this site in 1989. Total precipitation for the months of May, June, July, and August was 50.3 cm during 1997, and 38.2 cm during 1998. The historical average precipitation for this site during these months is 49.3 cm. Nitrogen fertilizer was applied at a rate of 112 kg/ha and an herbicide (Grazeon P+D®, 2,4-D + Picloram, Dow AgroSciences, Indianapolis, IN) was applied to OWB pastures early in the growing season each year. A total of 105 ha of OWB was separated into 12 pastures of approximately 8.7 ha in size. Dormant residual forage was removed via winter grazing trials prior to the growing season each year.

Treatment Design

Year 1. Two-hundred and fourteen mixed breed light weight steers (LHT: average initial wt: 141 ± 17 kg SD) and 115 mixed breed heavier weight steers (HWT: average initial weight: 265 ± 17 kg SD) were used during year one. Initial stocking rates were: light (LS) 392 kg live weight/ha, moderate (MS) 504 kg live weight/ha, and heavy (HS) 840 kg live weight/ha. The trial was initiated May 28, 1997 and final weights were recorded on August 8, 1997. Steers were removed on this date because of contractual agreements regarding delivery to the owner on August 12.

Year 2. One-hundred and ninety-three mixed breed light weight steers (LHT: initial wt: 160 $\pm$ 23 kg SD) and 126 mixed breed heavier weight steers (HWT: initial weight: 248 $\pm$ 13 kg SD) were used during year two. Initial stocking rates were: light (LS) 392 kg live weight/ha, moderate (MS) 616 kg live weight/ha, and heavy (HS) 840 kg live weight/ha. The moderate stocking rate was increased by approximately 112 kg BW/ha in order more evenly space the three stocking rates. The trial was initiated May 15 and final weights were recorded on August 31, 1998. The length of the trial was extended 40 d during 1998 in order to graze OWB throughout the duration of the growing season.

All stocking rate by cattle type combinations were replicated twice resulting in a total of twelve groups, and steers were randomly assigned to treatments on the initial weigh date. At initial processing, steers received a Synovex-C® implant during year one, and a Ralgro implant during year two. Steers had ad-libitum access to water and salt throughout the trial.

Sampling Procedures

In an attempt to equalize fill across treatments, all steers were placed in the same tallgrass prairie pasture four days prior to both initial and final weigh dates. Approximately 12-16 hours prior to weighing, cattle were moved to a small holding area without access to feed and water.

All forage nutritive value, OM intake, and forage mass collection techniques were conducted in the same manner during both 1997 and 1998. Diet samples were collected monthly in June, July, and August during 1997 and May, June, July, and August during 1998. Eight ruminally cannulated steers (average body weight: 242 ± 11.3 kg SD) were placed in the pastures approximately 7 days prior to each collection period to allow for adaptation to the OWB. Ruminal fistulation surgeries were conducted by clinicians at the Oklahoma State University Veterinary Hospital and all surgical and experimental procedures were approved by the University Animal Care Committee in accordance with the recommendations of the Consortium (1988). Forage nutritive value samples were collected by removing reticuloruminal contents, allowing animals to graze for 1.0 to 1.5 h, then removing the masticate from the rumen and replacing reticuloruminal contents (Lesperance et al., 1960). Two ruminally cannulated animals were assigned to each pasture and 4 pastures were sampled per day for 3 days, the two samples collected from each pasture were composited within pasture for analysis of forage nutritive value.

Residual forage mass of each pasture was estimated in August by hand clipping. Five .1 m^2 quadrats were clipped to approximately 2.5 cm of height in each pasture, and clipped samples were then dried at 55°C and allowed to air equilibrate prior to weighing.

Forage OM intake was estimated once in August using intraruminal (Captec Chrome for Cattle; CAPTEC (NZ) Ltd., Auckland, New Zealand) controlled release chromium boluses. Four steers in each cattle type x stocking rate combination were given a Captec bolus. Fecal samples were collected once daily for 4-d following a 6-d adaptation period. Chromium content of feces was used to estimate fecal output, DOM (in vivo digestible organic matter) and fecal output were used to estimate forage OM intake. Grazing time was estimated during 1998 using vibracorders. Vibracorders were placed on two steers (both LHT and HWT) in each of the stocking rates and grazing time was recorded over 7 d. The first day of recording was not included in the mean grazing time, allowing one day for adaptation to the collars.

Laboratory Analysis

Oven dried (55°C) masticate and fecal composite samples were ground in a Wiley mill to pass a 2-mm screen and were analyzed for DM and ash. During year one, N content of masticate samples was analyzed as Kjeldahl N (AOAC 1996). In year two, a combustion technique (Leco NS-2000, St. Joseph MI: AOAC, 1996) was utilized for N analysis. Masticate samples were analyzed for NDF and ADF using the methods of Goering and Van Soest (1970).

A 48-h in vitro procedure similar to the method of Goering and Van Soest (1970) was used to estimate masticate OMD. In order to determine OMD, .5 g of masticate sample was incubated in buffered ruminal fluid for 48 h. Samples were frozen immediately following the 48 h incubation in order to halt microbial activity. Samples were thawed and an NDF extraction was performed on the residue. The post-NDF residue was then ashed. In vitro OM disappearance was calculated using the organic matter content of the original sample and the NDF residue. These in vitro values were then converted to in vivo values by regressing the in vitro disappearance values of standards on the known in vivo digestibility of those same samples. The resulting regression equation and OM concentrations of initial samples were used to convert masticate in vitro OMD to in vivo digestible organic matter (DOM).

Preparation of fecal samples for determination of chromium concentration was conducted in a manner similar to Williams et al. (1962). Fecal samples were ashed then digested in a solution of phosphoric acid-manganese sulfate and potassium bromate. Chromium concentration of fecal composite samples was determined using a Perkin-Elmer Model 400 Atomic Absorption Spectrophotometer (Perkin-Elmer, Norwalk, CT).

Statistical Analysis

Steer ADG, gain/ha (GHA), OM intake, grazing time, and residual forage mass data were analyzed using the GLM procedure of SAS (1992) as a replicated 2 x 3 factorial arrangement of treatments. Year was included in the model as a random variable. Measures of forage nutritive value were analyzed as repeated measures within the 2 x 3 factorial using the MIXED procedure of SAS (1992). Least squares analysis and the P-DIFF procedure of SAS were used to separate treatment means when a significant ($P < .05$) F-Test was detected. A significant year x cattle type x stocking rate interaction was observed ($P < .10$) for ADG and GHA data. However, no two-way interactions were detected ($P > .24$), therefore, ADG and GHA data are reported as steer type within year and stocking rate by steer type within year. Regression and indicator (dummy regression) analyses were conducted using PROC REG of SAS (1992) to determine the response of ADG and GHA of both steer types as stocking rate increased as well as the difference in response between LHT and HWT steers.

Economic Analysis

Gross returns to summer grazing were calculated by multiplying the weight gain of steers by the value of weight gain for each size of steer. Value of weight gain was calculated using the 10-year, seasonally adjusted Oklahoma City National Stockyards purchase and selling prices for medium-frame, No. 1 steers (Trapp, 1999). Trapp (1999) reported base prices for cattle in 45.4 kg increments, therefore, regression analysis was used to develop price equations in order to more precisely predict purchase and selling prices for the weights of steers in this trial on a kg basis rather than the large 45.4 kg increments. Linear regression of prices for steers ranging from 136 to 454 kg resulted in an r^2 of .93 and an Sy•x of 1.46; the prediction equation was Y = 54.50 - .0239x. Addition of a quadratic term to the equation increased the r^2 to .998, the Sy•x was .22, and the prediction equation was $Y = 68.08 -.0716x + .0000381x^2$. Therefore, the second (quadratic) equation was used to adjust values as it increased the accuracy of prediction.

Results and Discussion

ADG: Light vs Heavy Steers

Average daily gains were greater ($P < .01$; Table 1) for HWT than LHT steers during both years. Differences in ADG may have been driven by differences in forage nutritive value, forage intake, or grazing time between LHT and HWT steers.

Body size and or weight of the grazing ruminant may have some influence on grazing behavior and forage intake. Larger, heavier, and more mature animals may have different grazing behavior, and thus may often have different forage intake, diet selection, and performance than lighter, less mature animals (Bae et al., 1983). Furthermore, larger animals may have greater total rumen capacity, and therefore, have the ability to consume more total forage mass than smaller animals. Illius and Gordon (1991) suggested that large animals may often be less selective grazers, however, they often retain food longer, and will digest food to a greater extent which may allow them to have greater ME intake while consuming a similar diet as smaller animals. However, the data reported by Illius and Gordon (1991) was collected from African ruminants ranging from 3.7 to 1000 kg and may not apply to the range of weight differences between groups of steers in the current study. All of these factors may enable a larger, more mature ruminant to have greater performance than young, light weight ruminants. In the current study, comparisons of performance are limited to growing animals, not immature vs mature animals. In this context, level of maturity of LHT vs HWT steers is an important consideration. As an animal grows, body weight increases in a sigmoidal fashion (Webster, 1980). Light and HWT steers in this study may have been at different stages of growth during the trial, and as Webster (1980) stated, the ratio of retained energy to weight gain declines throughout growth. Therefore, the LHT steers may have been gaining weight more efficiently, despite having lower ADG, simply because of their stage of growth in relationship to HWT steers. In support of this concept, the LHT steers tended (*P* = .07; Table 1) to have greater season-long gain as a percentage of body weight than HWT steers.

Forage Intake: Light vs Heavy Steers

Forage intake (g/kg BW) of LHT steers was greater (*P* = .01; Table 2) than HWT steers. Similar to the current study, Zoby and Holmes (1983) observed greater forage intake for light (steer calves, 164 kg BW) vs heavy (cows and steers: 631 kg BW) cattle when expressed as g/kg BW. Greater forage intake as a proportion of BW for light weight cattle may be expected when considering the relationship of BW to rumen volume: rumen volume = body weight$^{.57}$ (Owens and Goetsch, 1988). The young ruminant may often have a larger rumen in proportion to its body size than older counterparts which may allow the younger animal to consume greater quantities of forage as a percentage of BW as was observed for LHT vs HWT steers.

Forage intake when expressed as kg/steer, was greater (*P* = .01; Table 2) for HWT steers. Similarly, Zoby and Holmes (1983) observed greater forage intakes (kg/d) for large cattle in the study mentioned previously. Total food consumption (kg/steer) was greater, this increased consumption may have contributed to greater ADG attained by HWT vs LHT steers.

Forage Mass and Forage Allowance: Light vs Heavy Steers

Residual forage mass (kg/ha: Table 2) was greater (*P* = .10) for HWT (7602) than LHT (6246) steers. Forage intake will decline when total forage mass is less than 2000 kg of DM/ha (Minson, 1990) over a wide range of forages. Forage mass of OWB was never below 2000 kg/ha at any stocking rate for either LHT or HWT steers; therefore, one may conclude that forage mass should not have impacted steer performance in the current study.

Forage allowance or grazing pressure may be a more accurate description of the relationship between the amount of forage available and animal performance than forage mass (Mott, 1960). Residual forage allowance (kg residual DM/kg final liveweight) was greater (*P* = .01: Table 2) for HWT than LHT steers in the current study. Forage intake (g/kg BW) of LHT steers was greater, which may have contributed to the reduction in residual forage allowance between LHT vs HWT steers at equal stocking rates (kg BW/ha). However, forage allowance did not negatively impact forage intake (g/kg BW) of LHT in comparison to HWT calves. Coleman and Forbes (1998) used “put and take animals” and weekly forage mass estimations to maintain target levels of forage mass and herbage allowance between treatments. Weekly monitoring and maintenance of forage allowance in the manner used by Coleman and Forbes (1998) may be a more appropriate method of investigating the effects of stocking rate on animal performance than initial BW assignment as was used in the current study. However, data collected from the current study may accurately approximate what would occur in a production situation, whereas, the “put and take” method may not.

Grazing Time During 1998: Light vs Heavy Weight Steers

Grazing time was measured during 1998 only. Forage mass and(or) allowance may often impact the amount of time an animal must spend grazing in order to maximize its intake (Arnold 1960). As mentioned previously, the difference in residual forage allowance between steer types was not great enough to result in a decrease forage intake for LHT steers. However, LHT steers spent more time grazing (P = .05: Table 2) than HWT steers. An increase in time spent grazing for LHT calves may be expected in light of the fact that they had greater intake as a percentage of BW and lower residual forage allowance than HWT steers. The combination of increased grazing time and lower absolute intakes of forage of similar quality may have contributed to lower gains for LHT vs HWT calves. However, harvesting efficiency, expressed as grams of forage OM intake • kilogram BW^{-1} • min of $grazing^{-1}$ did not differ (P > .35; Table 2) between LHT vs HWT steers. The similarity in harvesting efficiency between LHT vs HWT steers may suggest a similar amount of energy expended while consuming forage despite decreased forage allowance and greater intake and grazing time for LHT cattle.

Forage Nutritive Value: Light vs Heavy Steers

Forage nutritive value values were combined across months and years for analysis of differences in forage nutritive value values between steer types and stocking rates. Crude protein (12.4 vs 13.2 % of OM for LHT and HWT steers respectively) and DOM (65.5 and 66.4 % of OM for LHT and HWT steers respectively) content of masticate samples collected from pastures grazed by

HWT steers tended to be ($P < .07$) greater than LHT steers. It would appear that the higher level of forage intake observed for LHT steers resulted in lower residual forage allowance and the ability of LHT steers to select diets of equal quality to HWT steers may have been reduced. Crude protein content of the forage was adequate to support gains of HWT steers that were observed throughout the trial both years (NRC, 1996). However, LHT steers would have required CP levels of at least 14.1 % (NRC, 1996) to support gains at levels (> 1 kg/d) equal to the HWT steers during 1997. Calculated weight gains were greater than observed for LHT calves during both years (Table 1). However, the differences in DOM content of forage between LHT and HWT steers was numerically small and may have had minimal impacts on steer gains.

Stocking Rate: ADG

There was a significant interaction ($P < .05$) in the response of LHT and HWT steers to stocking rate between years because of the differences in the response of LHT and HWT cattle to stocking rates between years. As stocking rate (kg/ha) increased, ADG of HWT steers decreased ($P = .06$; $Y = 1.48 - .0005x$, $Sy{\bullet}x = .09$, $r^2 = .62$) linearly during 1997 (Figure 1). However, there was ($P = .40$) not a linear relationship between ADG and stocking rate for LHT steers during 1997, therefore, a prediction equation and supporting statistics were not reported. A linear decrease ($P = .03$; $Y = .85 - .0003x$, $Sy{\bullet}x = .03$, $r^2 = .73$) in ADG was observed as stocking rate increased for LHT calves during 1998 (Figure 2), but there was ($P = .35$) not a linear relationship between these variables for HWT steers during 1998, thus, a prediction equation and supporting statistics were not reported for HWT steers during 1998. Declining ADG resulting from increasing stocking rate has been well established in the literature (Jones and Sandland, 1974; Hart et al., 1976). More specifically, Coleman and Forbes (1998) reported significant declines in season-long gains of steers grazing Plains OWB as stocking rates increased. Therefore, a decline in ADG as stocking rate increased would be expected for both LHT and HWT steers independent of year to year variation. However, the interaction regarding the relationship between steer type and stocking rate among years makes it difficult to draw conclusions regarding the response of LHT or HWT weight steers to increasing stocking rate.

Stocking Rate: Forage Intake, Residual Forage Mass and Allowance, and Forage Nutritive Value

Mean forage intake, forage mass, and residual forage allowance data were pooled across steer type and year because no significant ($P > .19$) two or three way interactions were detected in these variables. Forage intake did not differ ($P = .45$: Table 3) among stocking rates. Therefore, a decline in ADG would not be expected to be due to differences in forage intake among stocking rates. Residual forage mass (kg/ha) did not differ ($P = .13$: Table 3) between the LS and MS rates, however, residual forage mass ($P < .02$) for the HS rate was less than both the LS and MS rates.

Residual forage allowance, g/kg BW was different ($P < .05$: Table 3) among all three stocking rates with the LS rate having the highest and the HS rate the lowest forage allowance, while the MS rate was intermediate. During

1998, steers in the LS rate spent ($P < .02$; Table 3) less time grazing (min/d) than steers in the MS or HS rates, while grazing time was ($P = .72$) similar between the MS and HS rates. The energy expended during consumption of feedstuffs, both forage and concentrate, is highly correlated to the amount of time spent eating. Energy expenditure is more related to time than amount of feed ingested (Susenbeth et al. 1998). The decline in residual forage allowance may have resulted in increases in grazing time which may have had some negative impacts on ADG as stocking rate increased. However, the increases in grazing time were not large enough to alter ($P > .10$: Table 3) harvesting efficiency among stocking rates. Therefore, it may be possible that this slight increase in grazing time, although statistically significant, may not have been great enough to have major affects on energy expenditures.

Declining ADG as stocking rate increases may often be due to decreasing forage nutritive value. However, the only forage nutritive value factor which differed among stocking rates in the current study was DOM which declined ($P < .05$) as stocking rate increased (67.1, 65.9, and 65.1% of OM for LS, MS, and HS respectively). The differences were slight and affects on steer performance due to declining DOM of this magnitude should have been minimal.

Stocking Rate: Gain Per Hectare

Gain/ha increased ($P < .05$) as stocking rate increased for both LHT and HWT steers during 1997 and 1998. Gain per unit of area is the product of the number of animals per unit of area and gain per animal (Petersen et al., 1965). As stocking rates are increased, gain per animal often decreases, however, gain per acre increases (Harlan, 1958; Phillips and Coleman, 1995). A significant ($P = .06$) steer type x stocking rate x year interaction was observed for GHA which may have been due in part to the difference in the MOD stocking rate between years. Therefore, GHA data are reported as steer type x stocking rate within year (Figures 3 and 4).

Plains Old World bluestem, when managed properly, has potential to produce large amounts of forage, enough forage, in fact, to allow for gains at or near 220 kg/ha (Sims, 1988). Gain/ha for both LHT and HWT steers in the HS rate was greater than 220 kg/ha during both years, and was greater ($P < .05$) for LHT than HWT steers at all stocking rates. Gain/ha increased ($P < .05$) at a greater rate as stocking rate increased for LHT as compared with HWT steers as was detected by indicator regression analysis. Therefore, GHA was not only greater at each stocking rate for LHT cattle, but the difference in GHA between LHT and HWT steers increased as stocking rate increased. The combination of greater GHA and greater rate of increase in GHA as stocking rate increased resulted in an advantage of light weight cattle in terms of total GHA despite the fact that the ADG of light cattle may often be less than older, heavier cattle. Increases in stocking rate can compensate for decreased individual animal gain via increases in GHA. However, stocking rate can reach a point at which gain per acre begins to decrease (Riewe, 1961; Hart et al., 1988). In the current study, GHA did not decline for either steer type at any stocking rate during either year and gains continued to increase linearly, therefore stocking rate did not exceed the potential for increased gain at any point.

Gross Returns per Hectare

Light weight steers had a higher value of weight gain than HWT steers during both years. Purchase and selling weights, adjusted base prices, seasonal indexes, season-long gains, and the calculated value of gain for both LHT and HWT steers are reported in Table 4. Light weight calves had higher value of gain during both 1997 and 1998 (Table 4). The combination of greater GHA and higher value of gain for LHT calves resulted in larger gross returns/ha for LHT than HWT steers at all three stocking rates during both years (Figure 5).

ADG: 1997 vs 1998

Average daily gain for both LHT and HWT steers at all three stocking rates was greater ($P < .05$) during 1997 than 1998 (Table 1). However, ADG exceeded that reported by Coleman and Forbes (1998) for steers grazing Plains OWB during both years. The decline in gain for 1998 may have been influenced, in part, by differences in precipitation and temperature between the two years. During 1997, precipitation was above average in the months of June, July, and August, while precipitation was below average during these three months during 1998 (Figure 6). However, residual forage mass (kg/ha: Table 5) and residual forage allowance (g/kg final BW: Table 5) were ($P > .10$) not different between 1997 and 1998. Therefore, any affects of precipitation on animal performance may be due to impacts of precipitation on forage quality, rather than quantity. Additionally, there were 41 more days (9 vs 50 d for 1997 and 1998 respectively) during the trial period with temperatures equal to or greater than 35° C during 1998 than 1997. Temperatures equal to or greater than 35° C may cause significant declines in forage intake (NRC, 1981). Additionally, the extension of the grazing season to August 31 during 1998 (compared with August 8 during 1997) may have contributed to the decline in gains between 1997 and 1998. Comparatively, Coleman and Forbes (1998) reported rapid rates of gain from mid-May to approximately July 18 and minimal gains from July 18 to September. Season-long gains in the current study may have declined during 1998 due to declining forage quality late in the growing season.

Forage Nutritive Value: 1997 vs 1998

Forage nutritive value may often have a direct impact on animal gains. In the current study, all forage nutritive value components measured were different ($P < .05$) between the two years (Table 5). Neutral detergent fiber and ADF content of masticate samples was greater ($P < .05$), and DOM content was less ($P = .02$) during 1998 compared with 1997. Hodgson and Wilkinson (1968) reported that forage OM digestibility had greater impacts on forage intake and performance of Jersey heifers than forage allowance. A decline in DOM would have negative impacts on gains unless the steers were able to consume more forage during 1998. Intake of forage is often closely related to rumen-reticular fill, which is associated with digestibility as well as fiber content of the ingested forage (Allison, 1985). However, forage intake was not different between the two years, therefore, lower DOM during 1998 did not alter forage intake. An increase in ADF content may often lead to lower forage intake, however, intake was not altered by increasing ADF or any other forage component during 1998 in comparison with 1997. Crude protein content of masticate samples was higher during 1998 than 1997. This is a disparity in comparison to other nutritive value factors. However the difference was slight (12.2 vs 13.4 % of OM for 1997 and 1998, respectively, and the CP content of the forage should have been adequate to support the observed levels of gain for HWT steers during both years, but may have been slightly deficient for LHT calves during 1997 (NRC, 1996). The variation in forage nutritive value components between the two years may have been due, in part, to the differences in temperature and precipitation between summers. Therefore, the combination of temperature and forage nutritive value differences between the summers of 1997 and 1998 may have contributed to the lower gains observed during 1998.

Implications

Light weight steers had lower ADG than heavier weight steers during both years at all stocking rates. However, gain/ha was greater for light weight steers than heavier weight steers at all stocking rates when stocked at equal kg BW/ha. Increased gain/ha and increasing slope of gain/ha for light weight steers, coupled with a higher value of gain resulted in greater gross returns/ha. Light weight steers have the potential to have greater gross returns/ha when they are stocked at similar rates (kg BW/ha) as heavier steers.

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Table 1. Initial and final weights, and ADG of light vs heavy weight steers during 1997 and 1998

	1997[a]	SE	1998[b]	SE
Light:				
No. steers	214	--	115	--
Initial Wt. (kg)	141	1.2	160	1.4
Final Wt. (kg)	210	2.3	239	2.6
ADG (kg)	1.01[ef]	.022	.72[df]	.025
Calculated ADG[c]	1.33	--	.90	--
Gain, % BW	39.2[g]	.67	39.0[g]	.67
Heavy:				
No. steers	193	--	126	--
Initial Wt. (kg)	265	1.2	248	1.2
Final Wt. (kg)	347	2.3	333	2.3
ADG (kg)	1.21[eg]	.022	.78[dg]	.022
Calculated ADG[c]	1.15	--	.94	--
Gain, % BW	26.9[ef]	.67	29.2[df]	.67

[a]Gains calculated based on a 69 d grazing period.

[b]Gains calculated based on a 109 d grazing period.

[c]ADG calculated using DOM as TDN; converted to NEm and NEg, table maintenance requirements, and live weight gain equations from the 1984 NRC.

[de]Means in a row without common superscripts differ ($P < .02$).

[fg]Means in a column without common superscripts differ ($P < .01$).

Table 2. Forage OM intake, grazing time, harvesting efficiency, residual forage mass, and residual forage allowance of light vs heavy steers.

	Steer Type[a]		
	Light	Heavy	SE[b]
Forage OM intake g/kg BW	31.1[f]	27.6[e]	1.23
Forage OM intake, kg/steer	7.3[e]	9.5[f]	.41
Grazing time; min/d[c]	665.5[f]	624.3[e]	11.94
Harvesting efficency[d]	.04	.05	.004
Residual forage mass, kg/ha	6246.0[g]	7602.0[h]	546.4
Residual forage allowance; kg/kg final BW	8.26[e]	11.87[f]	1.21

[a]Initial weights pooled across years: 151 kg for light and 256 kg for heavy weight steers.

[b]Standard error of the means.

[c]1998 grazing time only.

[d]Grams of forage OM intake • kg BW^{-1}• minute of $grazing^{-1}$ based on 1998 values only.

[ef]Means within a row without common superscripts differ ($P < .05$).

[gh]Means within a row without common superscripts differ ($P = .10$).

Table 3. Forage OM intake, grazing time, harvesting efficiency, residual forage mass, and residual forage allowance of steers in the light, moderate, and heavy stocking rates.

	Stocking Rate[a]			
Item	Light	Moderate	Heavy	SE[b]
Forage OM intake, g/kg BW	29.3	29.2	29.6	1.51
Forage OM intake, kg/steer	8.5	8.1	8.6	.51
Grazing time; min/day[c]	598[e]	672[f]	665[f]	14.6
Harvesting efficency[d]	.04	.04	.04	.005
Residual forage mass, kg/ha	8822.0[f]	7285.0[f]	4948.0[e]	757.4
Residual Forage Allowance; kg/kg final BW	16.3[g]	9.5[f]	4.5[e]	1.54

[a]Stocking rates: 392 and 840 kg initial live weight/acre for light and heavy stocking rates, respectively; moderate stocking rate = 504 and 616 kg initial live weight/acre for 1997 and 1998, respectively.

[b]Standard error of the means.

[c]1998 grazing time only.

[d]Grams of forage OM intake • kg BW^{-1}• minute of $grazing^{-1}$ based on 1998 values only.

[efg] Means within a row without common superscripts differ ($P < .05$).

Table 4. Adjusted purchase and selling prices, seasonal indexes, season-long gain, and calculated value of gain of light and heavy weight steers during 1997 and 1998.

Steer Type	Year	Body Weight	Adj. Price ($/45.4 kg)[a]	Seasonal Index[b]	Seasonally Adj. Price($/45.4 kg)	Gain[c]	Value/ Gain[d]
Light	1997						
	purchase	141	109.15	103.0	112.42		
	selling	210	95.14	100.1	95.23	68.5	60.00
Heavy	1997						
	purchase	265	86.62	103.7	89.83		
	selling	347	78.60	101.7	79.93	82.5	48.00
Light	1998						
	purchase	160	104.86	103.0	108.01		
	selling	239	90.43	101.0	91.33	78.0	57.00
Heavy	1998						
	purchase	248	89.01	103.7	92.30		
	selling	333	79.64	101.7	80.99	84.8	48.00

[a] Calculated from ten-year average base price structure reported by Trapp (1999), adjusted according to: $Y = 150.11 -.1579x + .000084x^2$, $Sy{\bullet}x = .22$, $r^2 =.998$.

[b]Seasonal price indexes for each weight range during April and August (Trapp 1999).

[c]Season-long gains for respective steer weight groups.

[d]Value of gain ($/45.4 kg) = (selling wt. x (adjusted selling price x seasonal index)) – (purchase wt. x (adjusted purchase price x seasonal index))/gain.

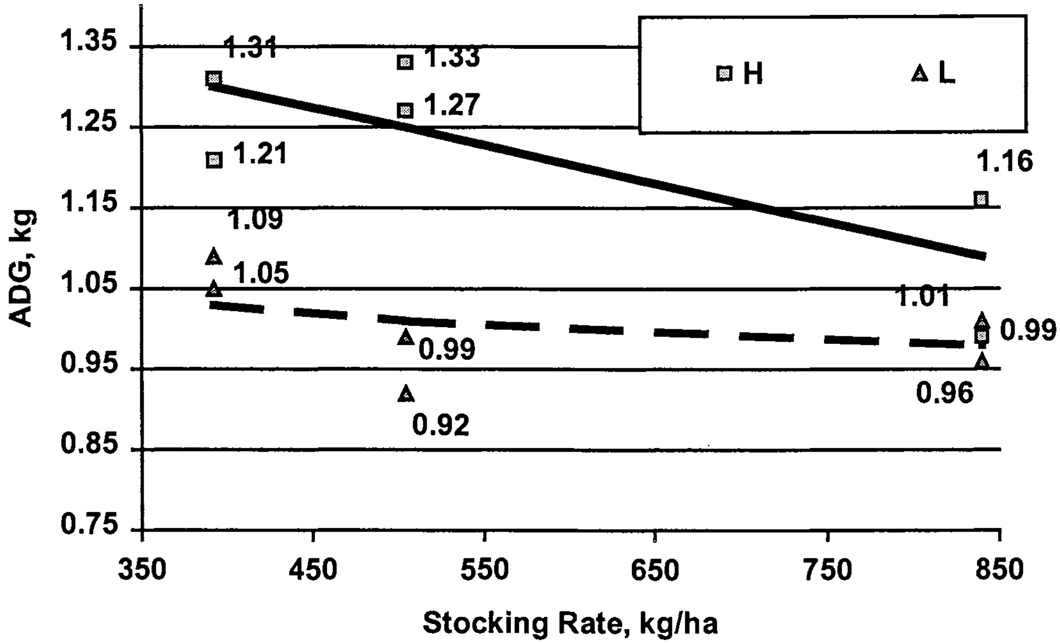
Table 5. Chemical composition and residual forage mass of old world bluestem during 1997 and 1998[a].

Item	Year 1997	Year 1998	SE[b]
CP	12.2[c]	13.4[d]	.25
NDF	81.4[c]	82.9[d]	.36
ADF	42.0[c]	52.3[d]	.27
DOM	69.5[d]	62.5[c]	.34
Ash	10.6[d]	9.6[c]	.35
Residual forage mass, kg/ha	7445.0	6403.0	546.40
Residual forage allowance, g/kg final BW	11.1	9.1	1.21

[a]Values expressed as a percentage of OM: pooled across all pastures within year.

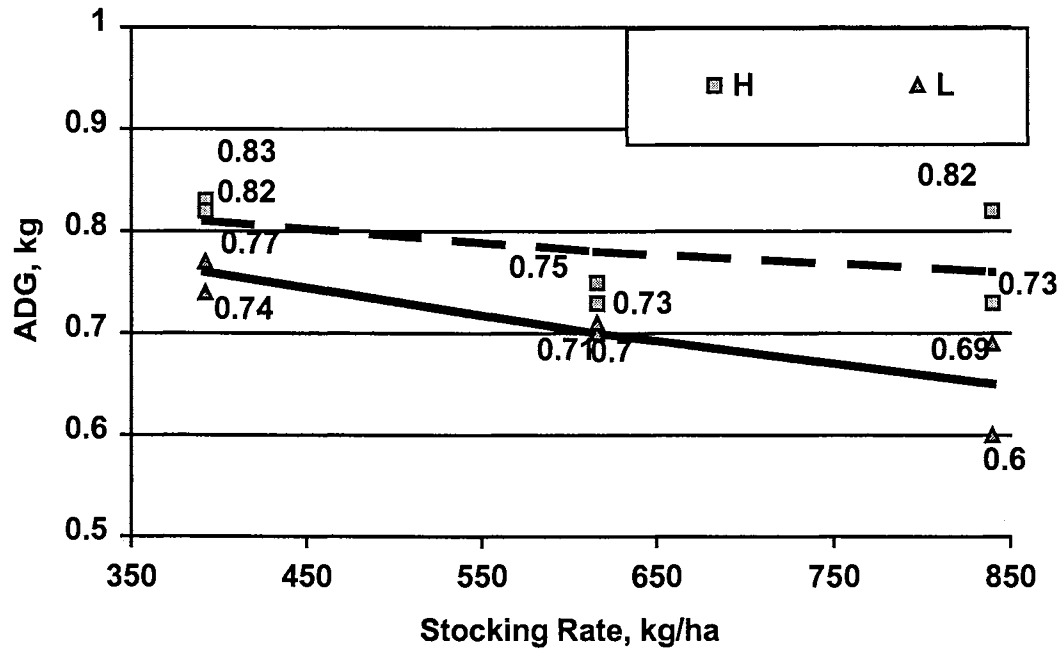
[b]Standard error of the means.

[cd]Means within a row without common superscripts differ ($P < .06$).



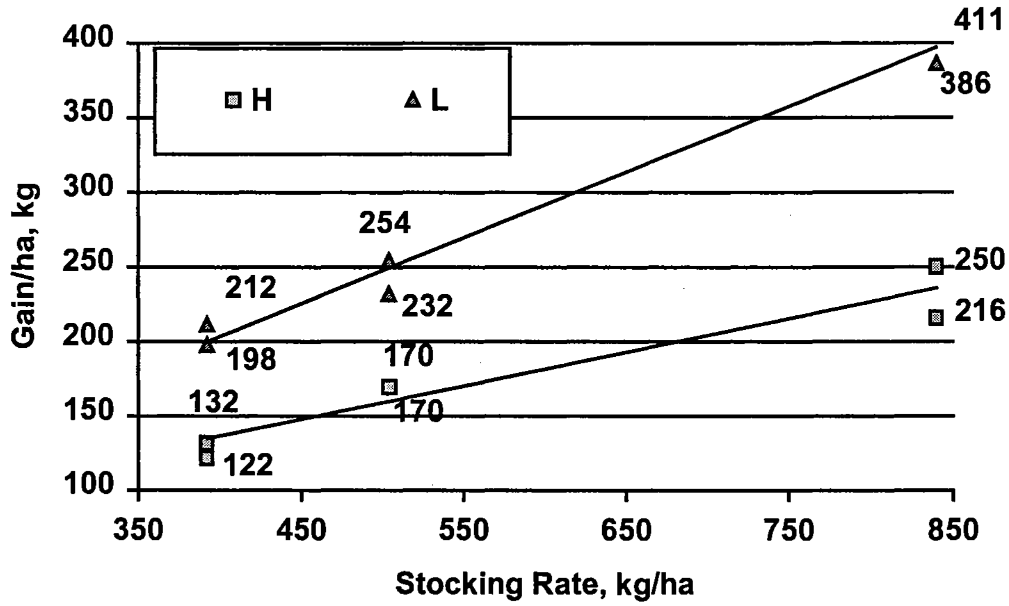
Y = 1.48 - .0005x HWT Steers (*P* = .06): Sy•x = .09, r^2 = .62

Figure 1. Relationship between ADG and stocking rate for light and heavy steers during 1997.



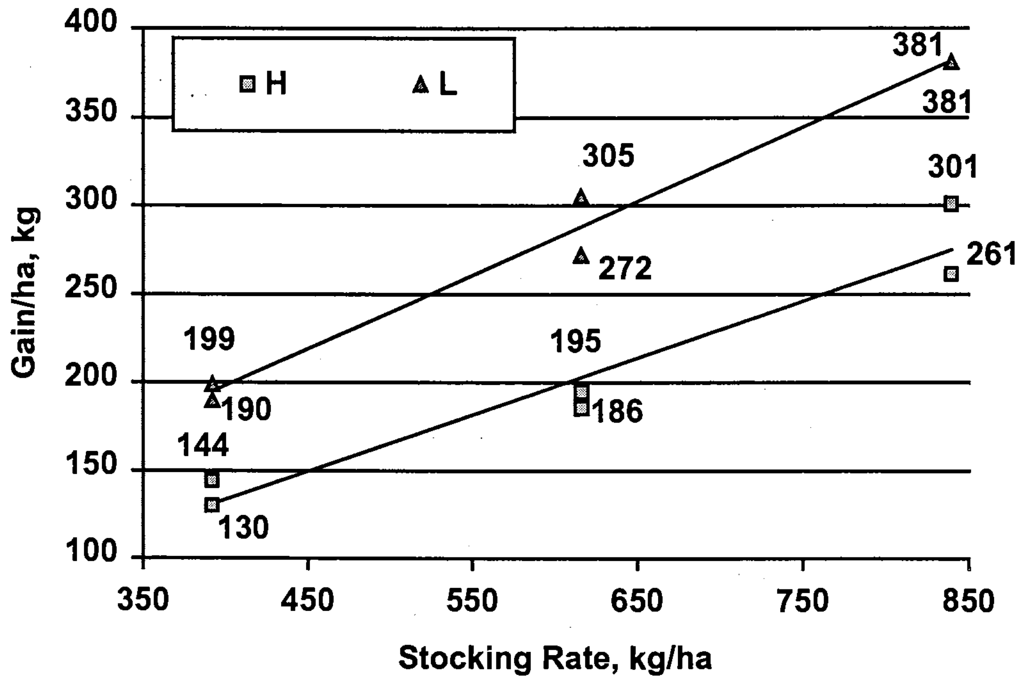
Y = .85 - .0003x LHT Steers (P = .03): Sy•x = .03, r^2 = .73

Figure 2. Relationship between ADG and stocking rate for light and heavy steers during 1998.



Y = 46.07 + .23x HWT Steers (P = .002): Sy•x = 15.4, r^2 = .92
Y = 28.27 + .44x LHT Steers (P = .001): Sy•x = 14.1, r^2 = .98

Figure 3. Relationship between gain/ha and stocking rate for light and heavy steers during 1997.



Y = 5.23 + .32x HWT Steers (P = .002): Sy•x = 18.8, r^2 = .94
Y = 31.69 + .42x LHT Steers (P = .001): Sy•x = 12.0, r^2 = .98

Figure 4. Relationship between gain/ha and stocking rate for light and heavy steers during 1998.

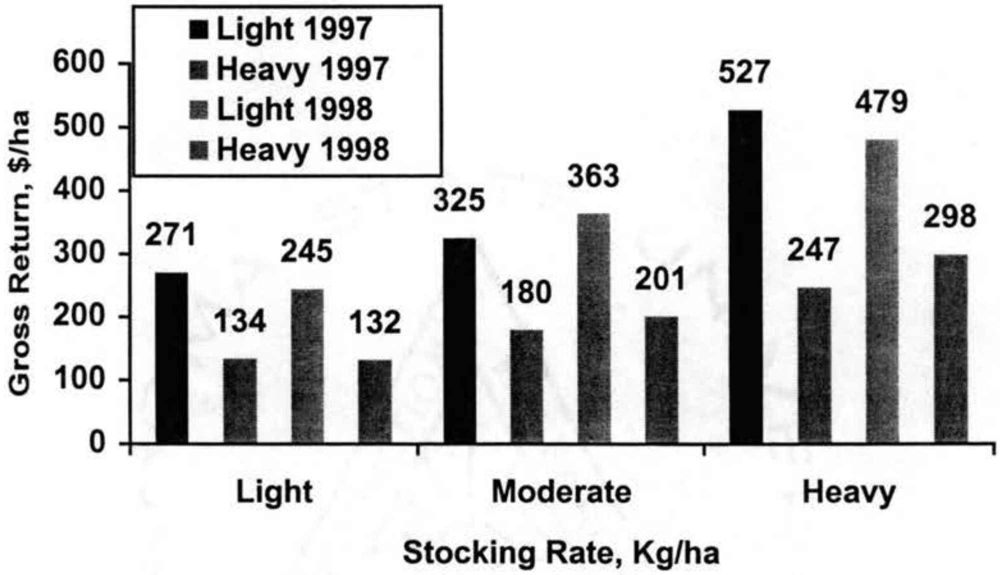


Figure 5. Gross return ($/ha) of light vs heavy steers during 1997 and 1998.

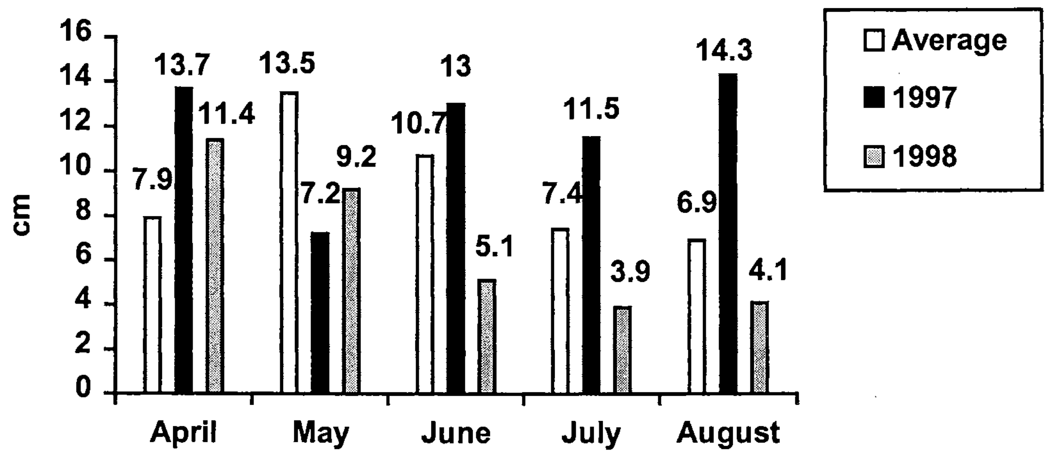


Figure 6. Precipitation for the months of April, May, June, July, and August during 1997 and 1998 at the Marena site of the Oklahoma Mesonet system near the bluestem research range and the historical average for Payne county Oklahoma.

CHAPTER IV

ESTIMATION OF FORAGE MASS OF OLD WORLD BLUESTEM USING A VISUAL OBSTRUCTION MEASUREMENT TECHNIQUE

C. J. Ackerman, H. T. Purvis II, G. W. Horn, M. E. Payton, L. T. Vermeire, S. I. Paisley, and T. N. Bodine

ABSTRACT: A visual obstruction technique and hand clipped quadrats were used to develop prediction equations for estimating forage mass (kg DM/ha) of Plains Old World bluestem during the summers of 1997 and 1998. The technique used was a modification of a procedure developed in Kansas during the 1970's. This technique estimates visual obstruction using a pole which is marked incrementally along its length. When the pole is placed vertically in a sward and observed from a distance of 4 m, visual obstruction, or the amount of the pole which is obscured from view by standing forage, can be estimated. In order to estimate forage mass of Old World bluestem, 120 visual obstruction measurements (VOM) were recorded (60 each year) and one .1 m^2 quadrat was clipped at the same point where each VOM was recorded. Linear regression analysis was used to investigate the relationship between VOM and clipped forage mass and to develop equations for the prediction of forage mass using VOM. Regression analysis indicated (P < .05) a significant linear relationship between VOM and clipped forage mass. The r^2 values for regression of VOM on clipped forage mass were greater than .50 for both years. The slopes of the regression lines for the two years were (P > .10) not different, indicating a similar relationship between VOM and clipped forage mass during both years.

However, the intercepts of the two lines were different ($P < .05$), indicating a difference in overall DM between the two years, therefore, the data was not pooled across years. The visual obstruction measurement technique has potential for practical use in estimating forage mass of Plains Old World bluestem, additional data collected over several years may increase the accuracy of the prediction equations. Users of these types of techniques to estimate forage mass should exercise caution and be sure that the validation of the technique was specific to the forage type for which it is to be applied and that validation was conducted over several years under various environmental conditions.

Key Words: Old World Bluestem, Visual Obstruction Measurement, Forage Mass.

Introduction

Estimation of forage mass is an important factor in grazing management. Accurate estimation of forage mass allows producers and researchers to accurately set and monitor the impact of stocking rate on forage growth and productivity. Clipping and weighing forage is the most accurate method of determining forage mass, but the time and labor required may limit its use, especially for producers (Harmoney et al., 1997). Robel et al. (1970) developed a method for measuring forage mass using a marked pole that may require significantly less time and labor than hand clipping techniques. An equation was developed by these workers that describes the relationship between visual obstruction measurements and the weight of vegetation clipped from quadrats. The technique proved to be accurate and they observed an r^2 of .95 between clipped vegetation and visual obstruction measurements for Kansas native grasses. Michalk and Herbert (1977) observed an r^2 value (visual obstruction vs clipped vegetation) of .80 for growing lucerne using a technique similar to the procedure developed by Robel et al. (1970). Harmoney et al. (1997) reported an r^2 value of .63 for a combined regression of several different types of forages using visual obstruction measurements. These reports established a potential for using this technique to develop prediction equations for the estimation of forage mass in several different types of forages. However, as suggested by Harmoney et al. (1997), the accuracy of this method may vary from one forage species to another. Therefore, the technique should be validated for each species for which it is to be used to estimate forage mass.

The objective of this study was to evaluate the relationship between visual obstruction measurements and clipped forage mass for Plains Old World bluestem, and develop equations for prediction of forage mass using the pole developed by Robel et al. (1970).

Materials and Methods

Study Site.

The study site was the Bluestem Research Range located 11 km southwest of Stillwater, OK. The forage at this site is Plains Old World bluestem (*Bothriochloa ischaemum* L. Keng). Visual obstruction samples were collected during August of 1997 and 1998 from twelve pastures. These twelve pastures had been assigned to a stocking rate trial from May through August during both years. Initial stocking rates were: light; 392 kg of live weight/ha, moderate; 504 kg of live weight/ha (increased to 616 kg live weight/ha in 1998), and heavy; 840 kg of live weight/ha.

Description of Robel Pole.

The pole developed by Robel et al. (1970) was described as a round pole (3 cm diameter x 150 cm height) which was marked with brown and white paint at alternating decimeters. The mid-point of each decimeter was marked with a narrow black stripe which made it possible to distinguish half-decimeters. These workers determined that the most accurate (r^2 = .95) readings of visual obstruction were made at 1 m of height and 4 m away from the pole. Therefore, in order to establish exact distances for observation, 4 m of string were attached to the top of the large pole and the top of a second, smaller pole at 1 m of height on both poles. Using this smaller pole, one can extend the string to its full length and sight on the larger pole which is placed vertically in the sward from a height of 1 m. The pole used in the current study was modified by separating the lower

5 decimeters into quarter decimeters (2.5 cm) with black tape marks. Additionally, alternating red and white paint rather than brown and white was used.

Data Collection:

During August of 1997 and 1998, 60 visual obstruction measurements (VOM) and clipped samples were collected from 12 separate pastures (5 samples/pasture) each year. At each sampling site, a VOM was recorded and a .1 m^2 quadrat clipped to approximately 2.5 cm above the soil surface. Clipped samples were taken at the same point or area as the VOM by placing the back side of the clipping frame against the base of the Robel pole and extending the long portion of the clipping frame in the same direction that the VOM was recorded. Clipped samples were dried at 55°C for approximately 72 h and weighed. Monthly precipitation data was recorded by the Oklahoma Mesonet system at the Marena site which is within 1 km of the study site.

Calculations.

All clipped forage weights were converted from g/m^2 to kg/ha. Pasture was the experimental unit in this study, therefore, individual observations were pooled within pasture. Pasture means were then used for development of regression equations.

Statistical Analysis.

Regression and indicator (dummy regression) analyses were conducted using PROC REG of SAS (1992) to determine the relationship between clipped weights and VOM and to examine the relationship between the slopes and intercepts of the regression lines for each year.

Results and Discussion

Total precipitation at the study site during 1997 and 1998 was greater than the historical average for Payne county Oklahoma (Figure 1). However, precipitation during 1997 was above average in the months of June, July, and August, while precipitation was below average during these three months during 1998 (Figure 2).

Coleman and Forbes (1988) reported that herbage height of Plains OWB was highly correlated with herbage mass. An r^2 of .95 was observed in their study, which may support the use of VOM for estimating forage mass of Plains Old World bluestem. The r^2 for the linear relationship between clipped forage mass and VOM in the current study was .60 for 1997 and .57 for 1998, which may indicate a slightly greater accuracy for the 1997 prediction equation. These r^2 values are similar to the values reported by Harmoney et al. (1997). These workers compared clipped weights of pure or mixed stands of alfalfa, big bluestem, birdsfoot trefoil, Kentucky bluegrass, red clover, smooth bromegrass, switchgrass, and tall fescue to VOM measurements and observed a r^2 of .63 for all forage types combined. The r^2 observed by Harmoney et al. (1997) using VOM was greater than the r^2 observed for other forage mass estimation techniques including a rising plate meter and a canopy height stick.

The results of regression analysis indicated ($P < .05$) a linear relationship (Figures 3 and 4) between forage mass and VOM for both years. However, the equations derived from the two years had ($P = .03$) different intercepts, resulting in a different prediction equation for each year. This difference in the intercepts of the prediction equations between the two years may likely be related to the large difference in precipitation between the summers of 1997 and 1998. The increase in forage DM/ha observed for 1998 may have been an artifact of sampling technique. Green forage was not separated from dry, dead forage, and there may have been more forage mass/ha due to lower levels of precipitation in 1998. In other words, the forage may have been more mature and(or) had a higher DM content, resulting in increased forage mass during 1998.

The differences in the prediction equations between years may indicate a need for further collection of data. The Sy•x values were 1607.1 for 1997 and 1561.6 (kg) for 1998 which may indicate a similar variability among samples collected during the two years. This variability does appear to be large; therefore, more samples collected within each experimental unit should help to decrease this variability and increase the accuracy of the equation. Lower 95% confidence intervals are reported in figures 5 and 6. When using the modified Robel pole to detect a VOM, an individual could use these lower confidence intervals as a conservative estimate and be 95% sure that the actual forage mass would be equal to or greater than the level reported for the corresponding VOM reported in figures 5 and 6. Collecting visual obstruction measurements and clipped weights for regression analysis over a series of years with wide differences in precipitation and other climatic conditions should strengthen the resulting equations and render the predictions more accurate.

Despite the fact that intercepts for the two years were different, the slopes of the regression lines were (P = .90) similar, which indicates a similar relationship between clipped forage mass and VOM for each year. This similarity of slopes between the two years may be a further support the validity of this technique.

Stage of growth may be an important consideration when developing equations to predict forage mass. Although samples were not collected in different seasons, it is possible that separate equations may be needed for summer vs winter stages of growth. Further research should improve the accuracy of these equations. Additionally, there is a need to validate these equations with separate clipped weights collected in concurrence with the VOM and clipped weights used to develop the equations.

Implications

Data collected during the summers of 1997 and 1998 indicate that there is potential for using visual obstruction measurement for estimation of forage mass of Plains Old World bluestem. This should merit further research of this technique. However, it is important to emphasize that this technique, and others like it, should be validated over a number of years under a variety of climatic and grazing situations in order to ensure accuracy of prediction.

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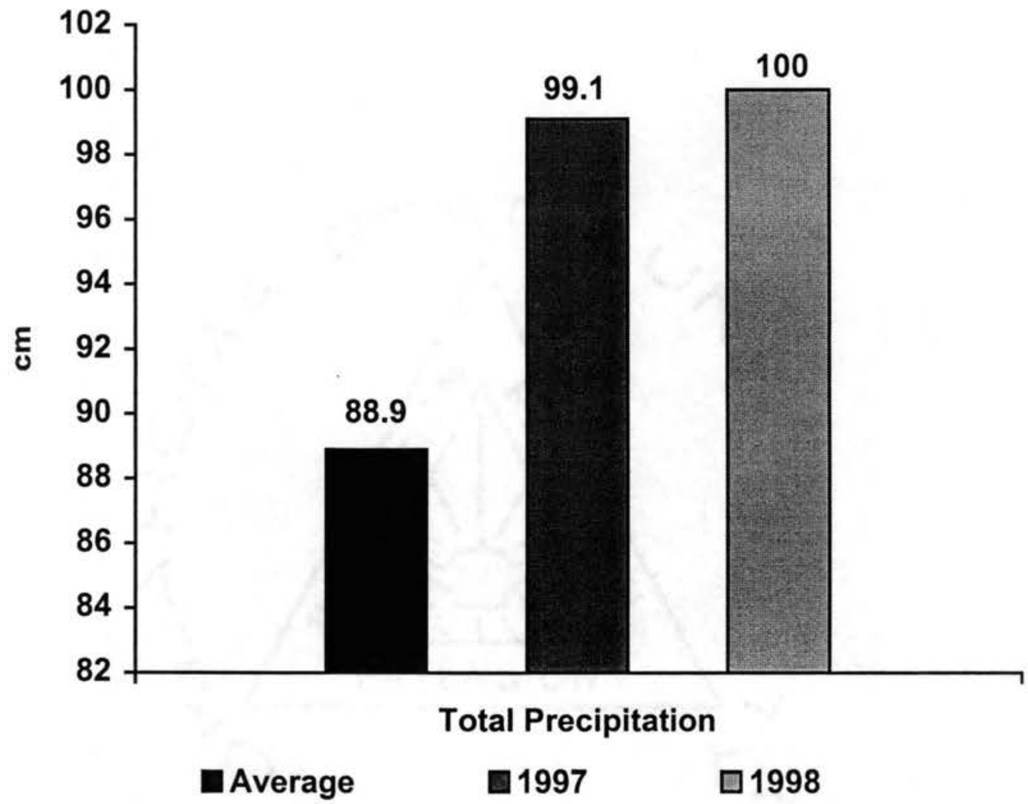

Figure 1. Precipitation totals for 1997 and 1998 recorded by the Marena site of the Oklahoma Mesonet system near the bluestem research range and the historical average for Payne county Oklahoma.

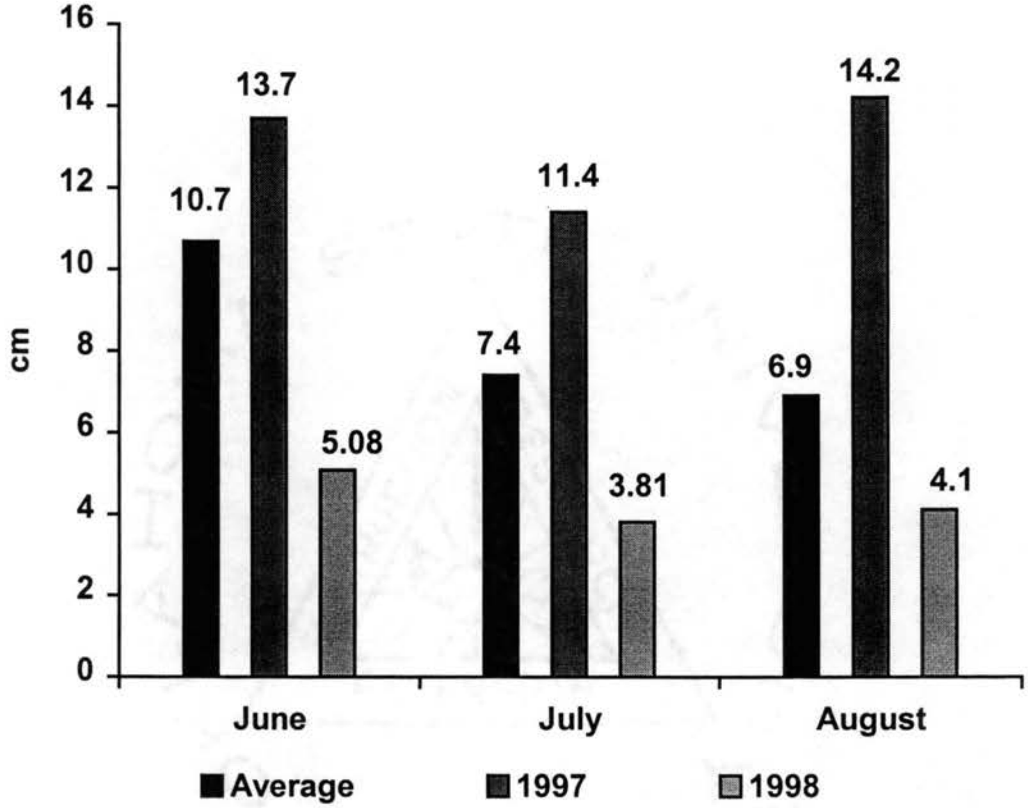

Figure 2. Precipitation totals for June, July, and August during 1997 and 1998 recorded by the Marena site of the Oklahoma Mesonet system near the bluestem research range and the historical average for Payne county Oklahoma during those months.

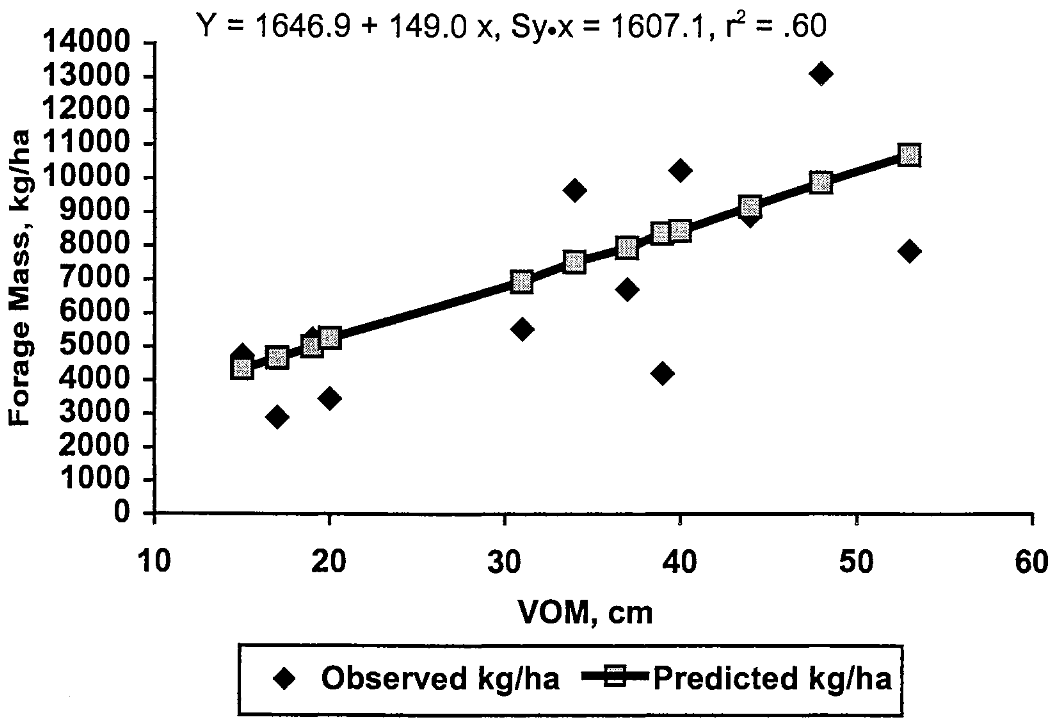

Figure 3. Relationship between forage mass and visual obstruction measurement for Plains Old World bluestem during August of 1997.

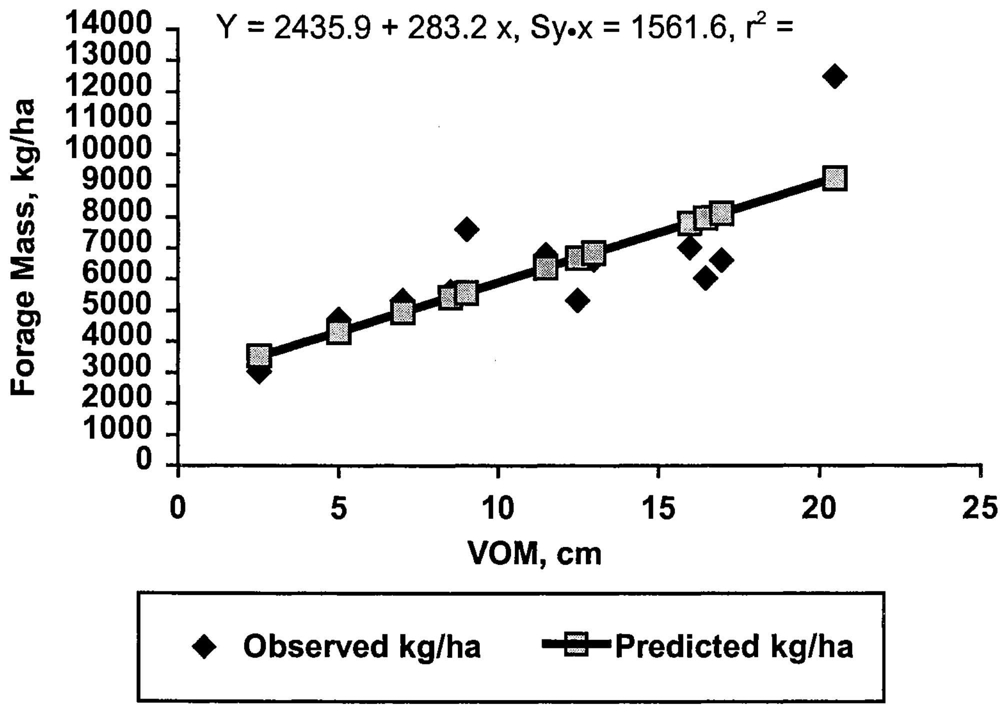

Figure 4. Relationship between forage mass and visual obstruction measurement for Plains Old World bluestem during August of 1998.

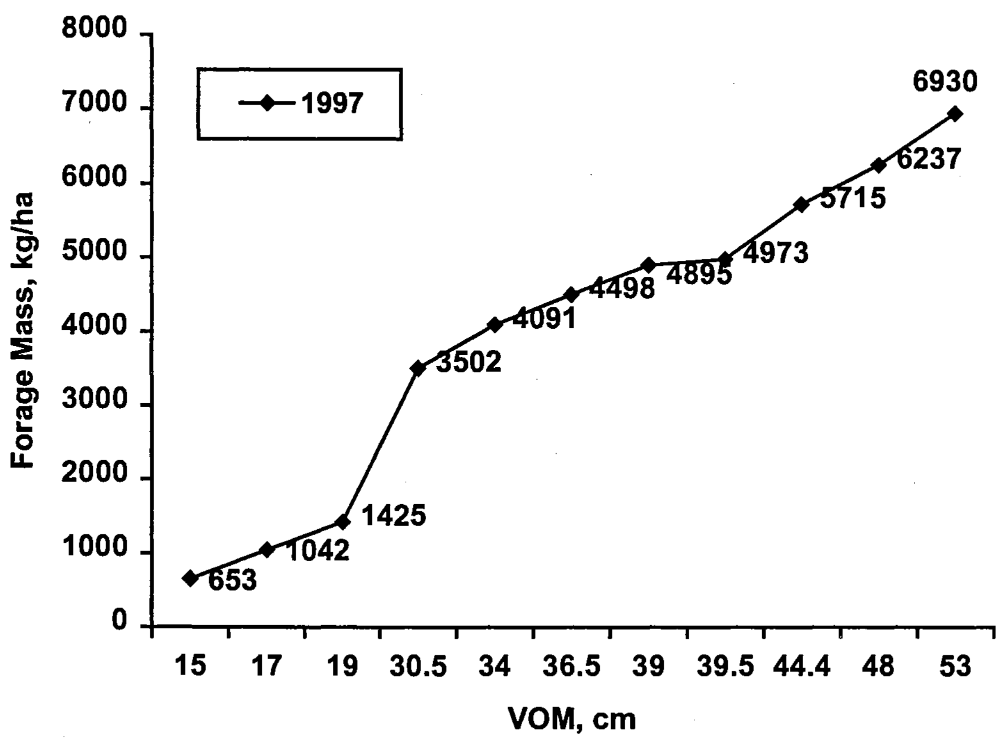

Figure 5. Confidence intervals (95%, lower confidence intervals) as an estimate of the minimum amount of forage mass to expect at each level of visual obstruction measurement for 1997.

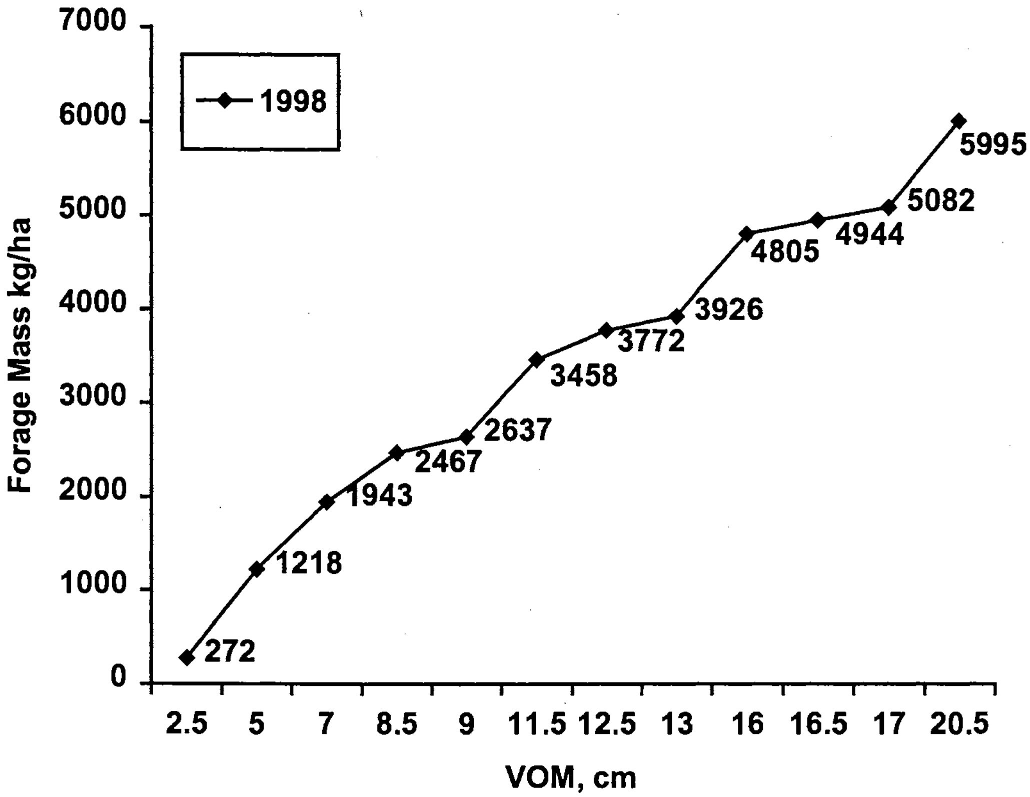

Figure 6. Confidence intervals (95%, lower confidence intervals) as an estimate of the minimum amount of forage mass to expect at each level of visual obstruction measurement for 1998.

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APPENDIXES

APPENDIX A

Climatological Data

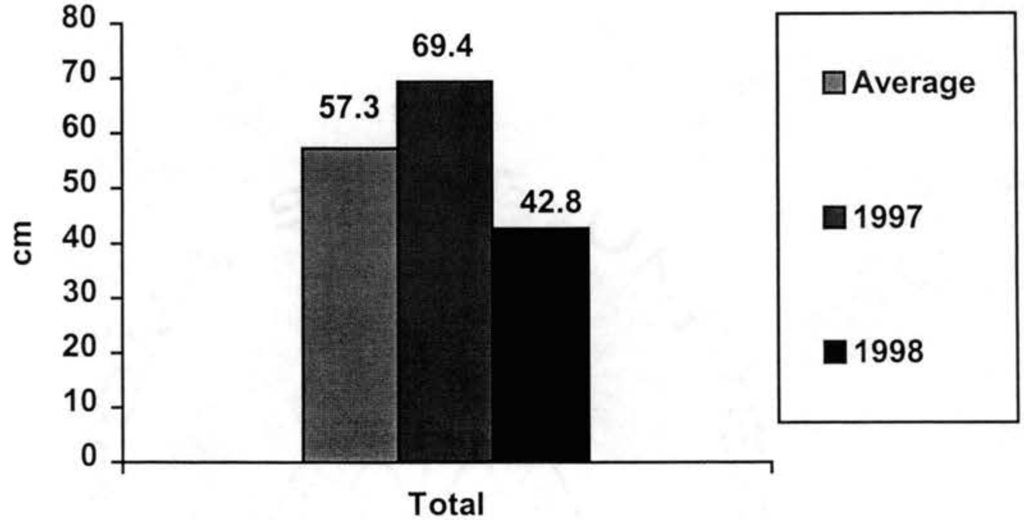

Figure 1. Total precipitation for the months of April through August recorded by the Marena station of the Oklahoma mesonet system, and the ten-year average for Payne county Oklahoma.

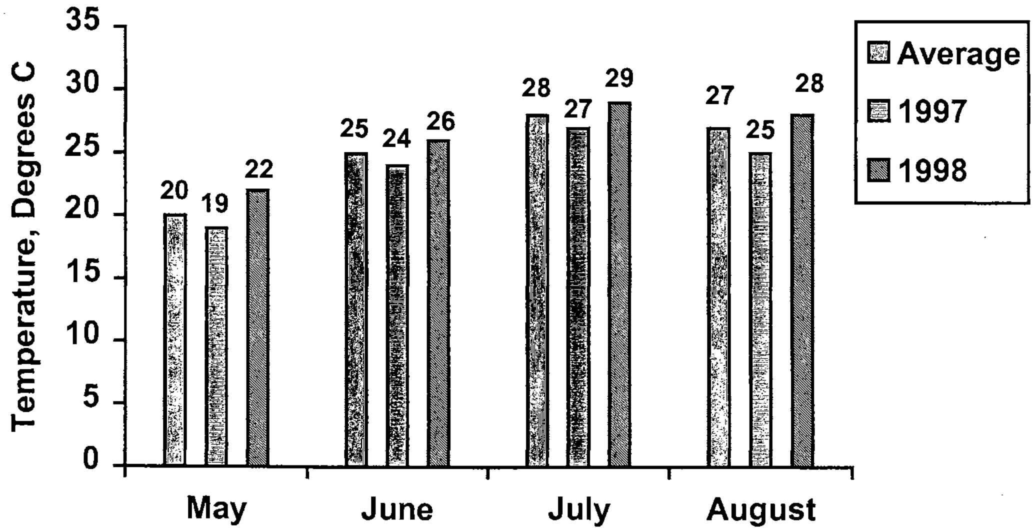

Figure 2. Average temperatures during the months of May, June, July, and August recorded by the Marena station of the Oklahoma mesonet system, and the ten-year average for Payne county Oklahoma.

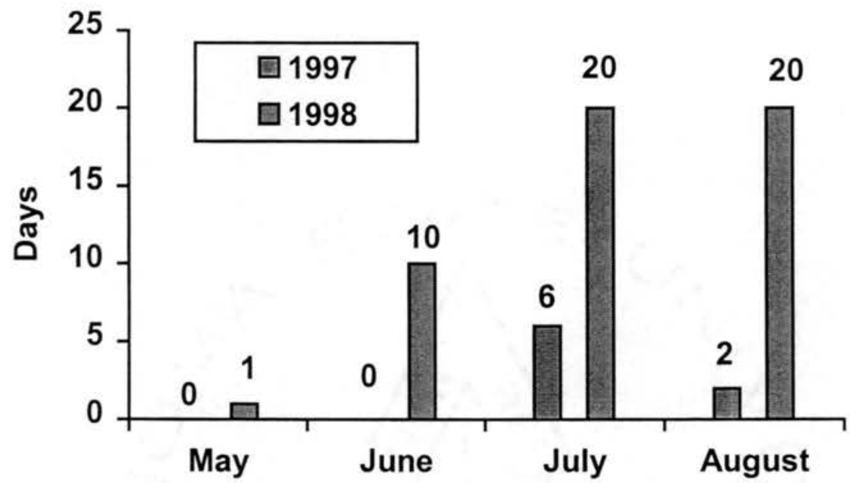

Figure 3. Number of days with temperatures equal to or greater than 35°C during 1997 and 1998 in the months of May, June, July, and August recorded by the Marena station of the Oklahoma mesonet system.

APPENDIX B

Crude protein and digestible organic matter of forage masticate samples collected from pastures grazed by Light vs Heavy weight steers, and degradable and undegradable intake protein as a percentage of CP for the months of June, July, and August during 1997 and 1998. Interaction terms, and forage nutritive values for 1997 and 1998 by month

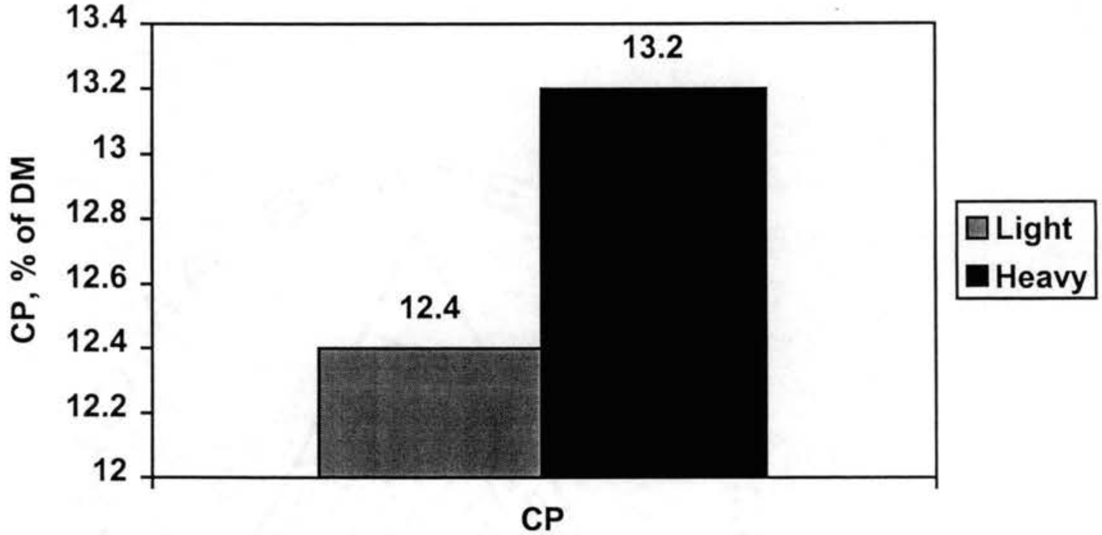

Figure 1. Crude protein of forage masticate samples collected from pastures grazed by Light vs Heavy weight steers.

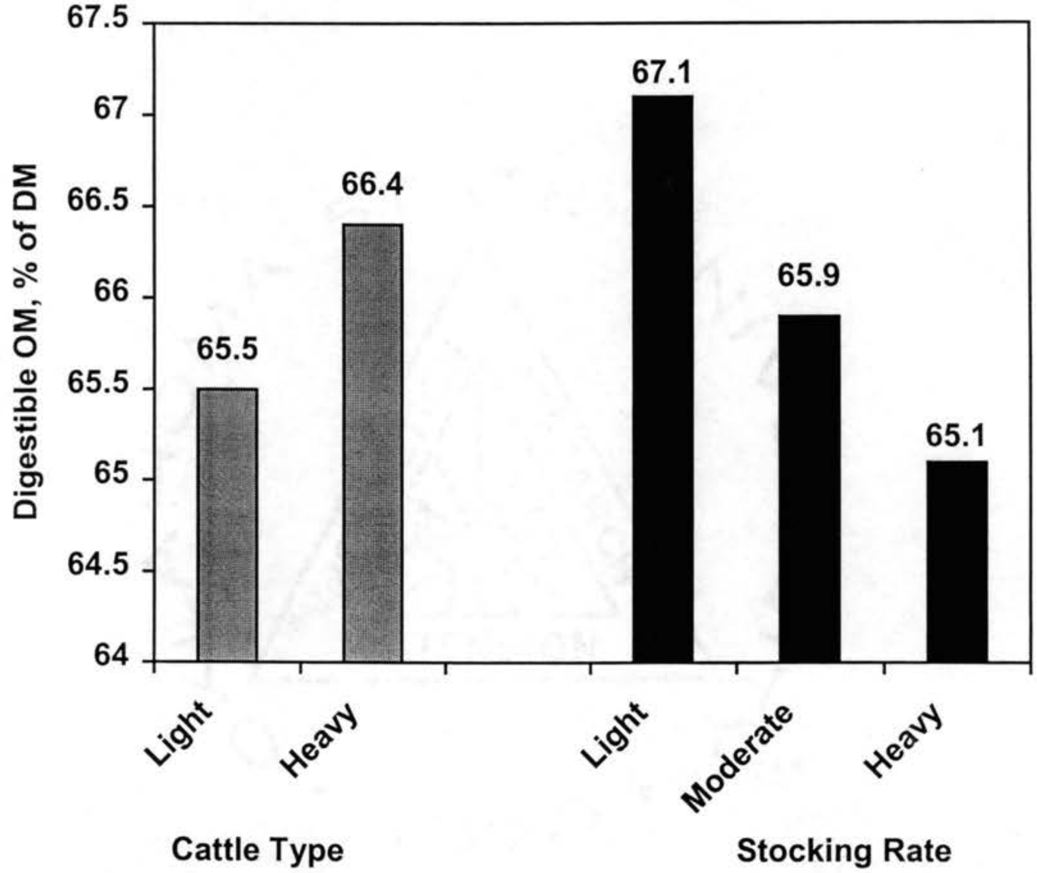

Figure 2. Digestible organic matter of forage masticate samples collected from pastures grazed by Light vs Heavy weight steers.

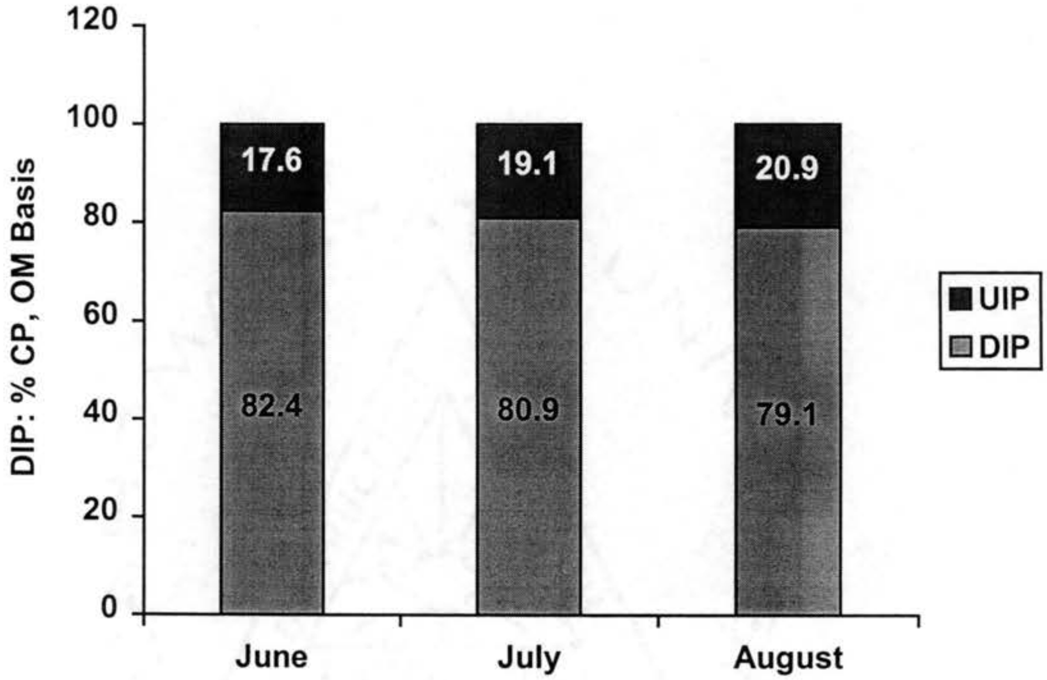

Figure 3. Degradable and undegradable intake protein as a percentage of CP for the months of June, July, and August 1997.

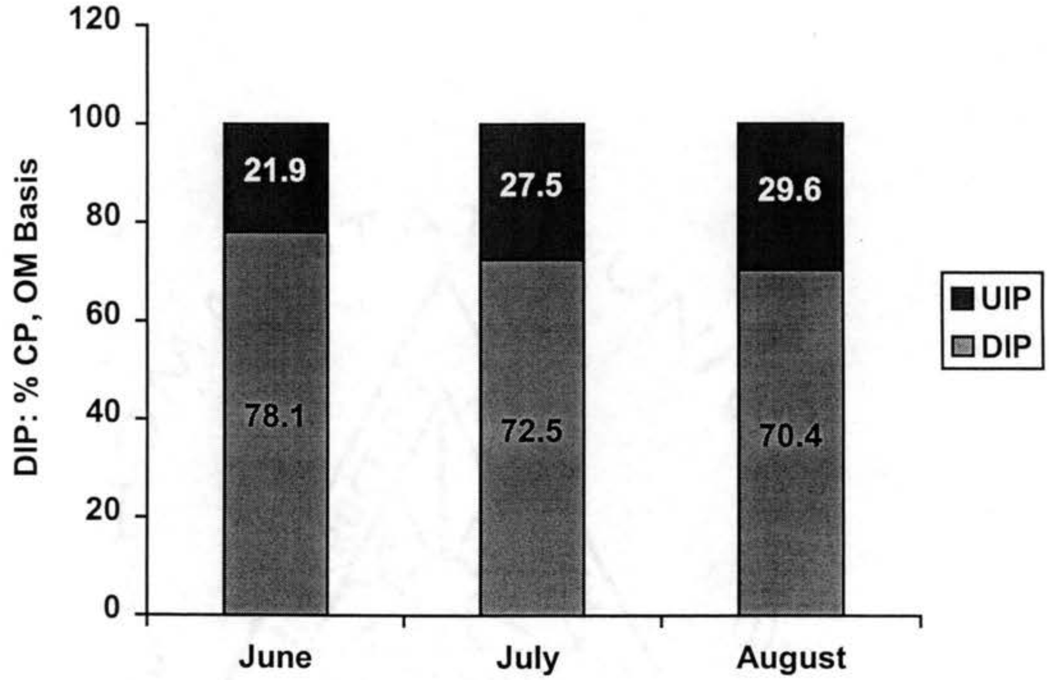

Figure 3. Degradable and undegradable intake protein as a percentage of CP for the months of June, July, and August 1998.

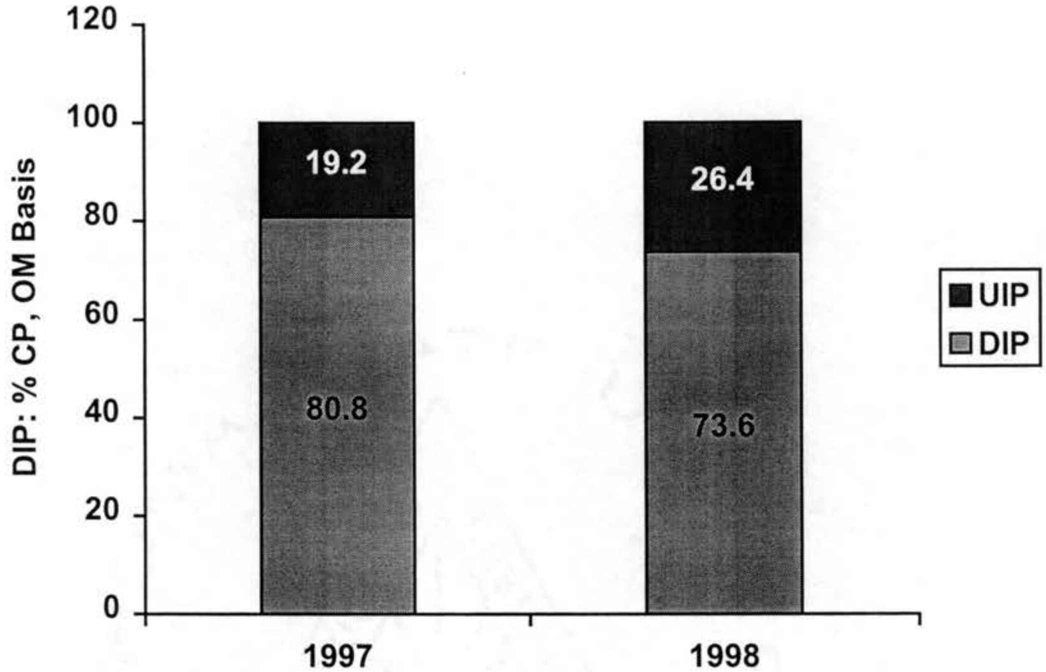

Figure 3. Degradable and undegradable intake protein as a percentage of CP averaged across the months of June, July, and August during 1997 and 1998.

Table 1. Interactions observed (statistical analysis) for ADG, gain/ha, forage intake, residual forage mass, and 1998 grazing time.

Item	Source[a]	P-value
ADG	year x type x rate	.06
	year x rate	.66
	year x type	.24
	type x rate	.68
Gain/ha	year x type x rate	.06
	year x rate	.63
	year x type	.52
	type x rate	.31
Forage Intake	year x type x rate	.91
	year x rate	.27
	year x type	.78
	type x rate	.34
Residual Forage Mass	year x type x rate	.56
	year x rate	.41
	year x type	.86
	type x rate	.29
Grazing Time	type x rate	.19

[a]Type = Cattle type, light and heavy; rate = stocking rate, light, moderate and heavy.

Table 2. Interactions observed (statistical analysis) for the nutritive quality components, CP, ADF, NDF, and in vivo digestible organic matter.

Item	Source[a]	P-value
CP	year x type x rate x month	.53
	year x rate	.74
	year x type	.21
	year x month	.001
	type x rate x month	.40
	rate x month	.79
	type x month	.22
	type x rate	.80
ADF	year x type x rate x month	.001
	year x rate	.41
	year x type	.83
	year x month	.001
	type x rate x month	.001
	rate x month	.39
	type x month	.001
	type x rate	.75
NDF	year x type x rate x month	.13
	year x rate	.20
	year x type	.76
	year x month	.80
	type x rate x month	.20
	rate x month	.22
	type x month	.12
	type x rate	.74
DOM	year x type x rate x month	.30
	year x rate	.85
	year x type	.16
	year x month	.01
	type x rate x month	.18
	rate x month	.65
	type x month	.38
	type x rate	.27

[a]Type = Cattle type, light and heavy; rate = stocking rate, light, moderate and heavy.
[b]Digestible Organic Matter.

Table 3. Forage nutritive value of Plains Old World bluestem masticate during 1997 and 1998[a].

	1997				1998				
Item	June	July	August	SE	May	June	July	August	SE
OM	88.4	89.8	90.0	.60	88.5	88.7	90.6	91.9	.60
Ash	11.6	10.2	10.0	.60	11.5	11.3	9.4	8.1	.60
CP	14.7	10.7	11.2	.43	14.5	16.2	14.1	9.9	.43
DIP, % CP	82.2	81.0	79.0	1.77	81.1	78.0	72.5	70.4	1.01
NDF	82.9	80.8	80.4	.63	75.5	84.0	82.7	82.0	.63
ADF	41.2	42.7	42.1	.46	49.2	49.1	56.5	51.4	.46
DOM[b]	63.0	72.7	72.7	.59	61.9	62.5	62.4	62.4	.59

[a]Values pooled across 12 pastures, 2 samples in each pasture, totaling 24 samples for each month.
[b]Digestible Organic Matter.

VITA

Callan J. Ackerman

Candidate for the Degree of

Doctor of Philosophy

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