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STEER AND TALL FESCUE PASTURE RESPONSES TO GRAZING INTENSITY
AND CHEMICAL SEEDHEAD SUPPRESSION

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Agriculture
at the University of Kentucky

By
Ben Michael Goff

Lexington, Kentucky

Co-Directors: Dr. Glen E. Aiken, Adjunct Professor of Crop Science
and Dr. William W. Witt, Professor of Crop Science

Lexington, Kentucky

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ABSTRACT OF DISSERTATION

STEER AND TALL FESCUE PASTURE RESPONSES TO GRAZING INTENSITY AND CHEMICAL SEEDHEAD SUPPRESSION

Tall fescue (*Lolium arundinaceum*) is the principal cool-season species within pastures of the southeastern USA and is known to have a mutualistic relationship with a fungal endophyte (*Neotyphodium coenophialum*) that produces the ergot alkaloids responsible for tall fescue toxicosis. Management of the reproductive growth of tall fescue is necessary, as the seedheads contain the highest concentrations of ergot alkaloids, and livestock have been documented to selectively graze these tissues. Recently, the herbicide Chaparral™ has been shown to be an effective method to prevent seedhead production in tall fescue pastures while also increasing steer gains at a low stocking rate. The objective of this study was to compare the impact of Chaparral on steer and pasture production under multiple grazing intensities (GI). Chaparral (0 and 140 g ha⁻¹) and two levels of GI (low: 3300±250 kg ha⁻¹ & moderate: 2500±250 kg ha⁻¹) treatments were arranged in a factorial combination as RCBD with three replications. Tall fescue seedhead densities were decreased ($P < 0.05$) within the Chaparral-treated pastures, but efficiency of the inhibition varied slightly between growing seasons. Chaparral-treated pastures had lower ($P < 0.05$) forage availabilities and contained forage with higher ($P < 0.05$) concentrations of crude protein (CP) and in vitro digestible dry matter (IVDDM) during both growing season. Steers within the Chaparral-treated pastures and low GI treatment had higher average daily gains (ADG). Carrying capacities (CC) were lowest and highest within the Chaparral-low GI and control-moderate GI treatments, respectively. Estimates of CC were not different ($P > 0.15$) between the Chaparral-moderate GI and control-low GI treatments. The higher ADG compensated for the lower CC of the Chaparral and low GI treatments and resulted in no difference ($P > 0.60$) in total gain per hectare (GPH) between grazing intensities and herbicide treatments in 2011. In 2012, the GPH were higher within the control and moderate GI treatments due to a lessening in the magnitude of difference between the herbicide and GI treatments. The effects of these treatments for alleviating symptoms of tall fescue toxicosis were inconclusive due to the low levels of ergot alkaloids production.

KEYWORDS: Tall Fescue Toxicosis, Tall Fescue, Herbicide, Chemical Seedhead Suppression, Grazing Intensity

Ben Michael Goff

25 September 2012

STEER AND TALL FESCUE PASTURE RESPONSES TO GRAZING INTENSITY
AND CHEMICAL SEEDHEAD SUPPRESSION

By

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25 September 2012

The work and achievement represented by this dissertation is dedicated to my grandfather, William Nelson Goff, my father, Mark Allan Goff, and my wife, Amber Renae Goff. The former two taught me what it takes to become a man, while the latter showed me how to become the man I want to be.

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LIST OF ABBREVIATIONS

ADG = Average Daily Gain
ASR = Average Stocking Rate
BFT = Back-fat Thickness
CC = Carrying Capacity
CP = Crude Protein
DF = Dead Forage
DOY = Day of Year
IVDDM = *In vitro* Digestible Dry Matter
GF = Green Forage
GI = Grazing Intensity
GPH = Gain per Hectare
NIRS = Near-infrared Spectroscopy
REA = Rib-eye Area
RFT = Rump-fat Thickness
TFA = Total Forage Availability
THI = Temperature Humidity Index

CHAPTER I: Introduction

Tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh. = *Schedonorus arundinaceus* (Schreb.) Dumort] is one of the principal cool-season species used as a forage within the USA, particularly within the subtropical southeast where no perennial cool-season grass was capable of persisting in grazing systems until the release of the cultivar ‘Kentucky 31’ (Hoveland, 2009). As a forage, tall fescue has been shown to produce similar yields as other cool-season grasses (Van Keuren, 1972; Austenson, 1963, Marten and Hovin, 1980) and is of comparable nutritive value (Bryan et al., 1970; Archer and Decker, 1977; Marten and Hovin, 1980). However, animal production is often reported to be lower on animals consuming tall fescue (Blaser et al. 1956; Hoveland et al. 1980). This decrease in animal performance was later shown to be due to ergot alkaloids produced by a fungus [*Neotyphodium coenophialum* (Morgan-Jones and Gams) Glenn, Bacon, and Hanlin] that lives within the intracellular spaces of the plant tissue (defined as an endophyte) (Bacon et al., 1977; Christensen and Voisey, 2007). Consumption of these alkaloids typically results in less weight gains, vasoconstriction, elevated body temperatures, and lower fertility, which are commonly termed as symptoms of tall fescue toxicosis (Strickland et al., 2009).

Current management strategies to alleviate tall fescue toxicosis are focused on preventing the production of the alkaloids or minimizing their intake by the animal (Roberts and Andrae, 2004). The release of endophyte-free (EF) cultivars of tall fescue soon after the discovery of the presence of the fungal endophyte increased animal production and health, but these cultivars lacked the persistence of the endophyte-infected (EI) varieties (Read and Camp, 1986 Bouton et al., 1993). This led to the development of tall fescue cultivars infected with a non-toxic endophyte (Bouton et al., 2002), which improved animal performance and health to levels comparable of the EF varieties, but with persistence similar to those of EI tall fescue (Parish et al., 2003; Nihsen et al., 2004). However, the cost of these novel endophyte (NE) varieties, along with the cost of re-establishment of EI pastures has led many producers to deem them as

uneconomical (Zhung et al., 2005). An alternative to establishing non-toxic tall fescues is to minimize the effects of the toxicosis by limiting the intake of alkaloids via dilution with other feed sources (Roberts and Andrae, 2004). Incorporating other species, such as legumes, or providing supplemental feeds are commonly recommended strategies to lessen the impact of the toxicity on EI tall fescue, although this may require a greater financial and management investment by the producer..

Ergot alkaloid concentrations are greatest within tall fescue seeds (Rottinghaus et al., 1991). The removal of the seedheads from pastures is another strategy to reduce the dosage of alkaloids received by grazing animals, as steers and yearling horses selectively graze upon these tissues (Aiken et al., 1993; Goff et al. 2012). While this is most commonly done by mowing, it often may be done late in the season after selective grazing of the seedheads has occurred. Additionally, the grazing of tall fescue seedheads may happen quickly, with near complete removal occurring over short period of time (Goff et al., 2012). Bransby et al (1988) reported that a higher stocking rate increased steer average daily gains (ADG) on EI tall fescue and attributed this to the removal of the apical meristems during grazing before their development into seedheads. Alternatively, several herbicides are known to inhibit floral development in forage grasses species (Moyer and Kelley, 1995; Glenn et al., 1980; Roberts and Moore, 1990; Reynolds et al., 1993). Since these herbicides suppress reproductive development in tall fescue, the amount of stem material from reproductive culms is also reduced, which improves forage nutritive value (Haferkamp et al., 1987; Sheaffer and Marten, 1986). Research demonstrating the efficacy of these herbicides on animal performance, especially at reducing the symptoms of tall fescue toxicosis is limited. Recently, Aiken et al. (2012) showed that Chaparral™, a herbicide produced by DowAgrosciences, reduced the emergence of seedheads in EI tall fescue pastures and the severity in the symptoms of tall fescue toxicosis, while improving forage nutritive value and steer ADG. However, tall fescue yield was reduced. Only one stocking rate (2.72 steers ha⁻¹) was evaluated within this study animal performance at stocking densities typically used in the

cattle industry is not known. Also, it is not known how the lower forage yield will affect the carrying capacity and total animal gain per area for the Chaparral-treated pastures. The primary objective of this study was to further evaluate the interaction between chemical seedhead suppression using Chaparral and grazing intensity on steer and pasture responses.

CHAPTER II: Literature Review

Tall Fescue

Origin and Adaptation

Tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh. = *Schedonorus arundinaceus* (Schreb.) Dumort] is a perennial grass that is common within cool-season pastures on the southeastern United States. A native to western Europe and north Africa (Buckner et al., 1979, Sleper and West, 1996), the exact date of its introduction is not known and is believed to have been introduced before 1800 through the importation of pasture seed mixtures (Buckner et al., 1979; Hoveland, 2009). Tall fescue was originally classified as a variant of meadow fescue [*Schedonorus pratensis* (Huds.) P. Beauv.], and production of this species was prevalent within the USA until the early 1900s when a rust (*Puccinia coronata* Cda.) outbreak reduced the acreage of meadow fescue, but had little effect on areas planted with tall fescue (Buckner et al., 1979). This outbreak, along with the release of the ‘Alta’ and ‘Kentucky 31’ cultivars in the 1940’s, led to its inclusion of tall fescue into pastures and hay fields of the USA.

Alta tall fescue was developed through a joint collaboration of the United States Department of Agriculture Research Unit (USDA-ARS) and Oregon State University (Buckner et al., 1979, Hoveland, 2009). It was one of the first forage cultivars to become registered by the American Society of Agronomy upon its release in 1940, and was widely accepted by producers of the northwestern USA (Buckner et al., 1979). The value of the Alta seed crop increased from \$31,000 in 1940 to over \$2.5 million 11 years later. Similar to Alta, Kentucky 31 gained wide acceptance from producers upon its release due to reputation as being a high-yielding, robust forage among producers. Kentucky 31 is an ecotype that was first collected by Dr. E.N. Fergus on the Suiter farm in Menifee County, Kentucky and was released by the University of Kentucky as a cultivar in 1943 (Buckner et al. 1979; Fergus and Buckner, 1972). There was a high demand from producers following its release because of its favorable agronomic properties. Seed production of the cultivar increased from 34,000 kg in 1946 to 5.7 million kg between 1951 and

1960 (Buckner et al., 1979). The area of tall fescue establishment in the USA increased from 16,000 ha in 1940 to over 14 million ha by 1979 largely due to the release of these cultivars (Buckner et al., 1979). More recent reports have estimated the total acreage of tall fescue to be approximately 35 million acres (Ball et al., 2007).

Tall fescue is adapted to a variety of growing environments, which is one of the reasons for its acceptance by producers. The area of adaptation for the grass ranges from northern Florida to southern Canada in North America (Burns and Chamblee, 1979; Belesky and West 2009). The production of tall fescue is limited in northern regions due to the potential for winter-kill within a stand. Burns and Chamblee (1979) reported winter kill damage ranged from 6% to complete loss of tall fescue in southern Manitoba and central Saskatchewan, respectively. These authors suggested that the upper limit for persistence of the species occurs approximately 100 miles north of the US-Canada border, but also noted that its survival depends on several other climatic factors besides low temperatures, such as snow cover. As with most cool-season species, the production of tall fescue is restricted under the high temperatures of the tropical regions of the USA, even under ample moisture conditions. Hoveland et al. (1974) demonstrated that the leaf expansion rate of tall fescue was depressed when plants were grown under day and night temperatures of 30 and 24°C compared to the 24 and 18°C that is more typical of the spring conditions within the temperate regions of the USA. These authors also showed that the number of days required for the appearance of new leaf tissues increased from 13 d with the 24/18°C temperature regime compared to 20 d with the 30/24°C treatment, further indicating that tall fescue growth is depressed under warmer temperatures. The use of tall fescue as a forage is limited west of 97°W due to limited moisture availability, except under irrigation conditions and within areas of the Pacific Northwest that receive large amounts of precipitation (Burns and Chamblee, 1979, Buckner et al., 1979, Sleper and West, 1996).

The primary area for tall fescue as a forage is the “transition zone” that occurs between the northern temperate and southern humid regions of the USA. Tall fescue has been cited as the

only cool-season grass species that will persist within pastures of the southeastern USA (Hoveland, 2009). One of the reasons for the greater persistence of tall fescue to this area is the grass's ability to tolerate the adverse soil conditions (Burns and Chamblee, 1979). The soils of the southeastern USA that are reserved for forage production are frequently acidic (pH ~5.5), shallow, and contain low concentrations of organic matter (Burns and Chamblee, 1979). Soil textures of these soils range from sandy to heavy clays, which translate to drainage classes of excessively drained and very poorly drained classes, respectively (Burns and Chamblee, 1979; USDA-NRCS, 1993). Tall fescue is tolerant of a wide range of soil pHs (4.7 to 9.5) (Cowan, 1956; Buckner et al., 1979), which aids in its establishment without a large requirement for correction of soil conditions. Shoop et al. (1961) reported that tall fescue tended to accumulate less Al internally than sericea lespedeza [*Lespedeza cuneata* (Dum. Cours.) G. Don], white clover [*Trifolium repens* L.], and redtop [*Agrostis gigantea* Roth], but also suggested that either liming to correct soil pH or the addition P fertilizers on acidic soils were required for acceptable yields. While not tolerant of the dry conditions of the sand-textured soils, tall fescue has been shown to tolerate times of high levels of soil moisture and inundation better than other cool-season species. Gilbert and Chamblee (1965) reported considerably reduced forage yields for white clover and orchardgrass after exposure to simulated flooding conditions at 18°C, whereas the yields of tall fescue were only slightly reduced following this inundation. The submersion of plants under temperatures of 32°C further decreased the yields of all species, with tall fescue producing higher yields at each time interval under the flooded conditions.

Forage Yields

Tall fescue is capable of producing forage yields that are similar or greater than other cool-season grass species. Van Keuren (1972) reported higher yields for tall fescue and Kentucky bluegrass [*Poa pratensis* L.] (5,626 and 5,088 kg ha⁻¹ respectively) in central Ohio compared to orchardgrass [*Dactylis glomerata* L.] (3,856 kg ha⁻¹) when harvested once annually in November. The author also reported greater total season yields for tall fescue when the grasses

were harvested two and three times annually (Tall fescue: 10,132 and 9,123 kg ha⁻¹ vs. Orchardgrass: 7,173 and 8,047 kg ha⁻¹; Kentucky bluegrass: 8,675 and 6,971 kg ha⁻¹). Austenson (1963) reported similar trends in western Washington between tall fescue and other species of cool-season grasses. Within this study, Alta tall fescue produced higher yields during the initial harvest than ‘S-143’ orchardgrass, ‘Drummond’ timothy [*Phleum pratense* L.], and common perennial ryegrass [*Lolium perenne* L.] during April, May, and June harvest dates. There was no difference between the yields of tall fescue and timothy when the first harvest was delayed until July, and was attributed to the later maturity of the cultivar of timothy. Orchardgrass produced greater yields from regrowth among the species; however, this did not translate to greater total seasonal yields. In Minnesota, Marten and Hovin (1980) reported higher yields for Kentucky 31 tall fescue (12,800 kg ha⁻¹) than ‘Northern’ orchardgrass (9,700 kg ha⁻¹), ‘Rise’ reed canarygrass [*Phalaris arundinacea* L.] (10,100 kg ha⁻¹), and ‘Sac’ smooth brome grass [*Bromus inermis* Leyss.] (8,700 kg ha⁻¹) during the year after establishment. Yields of orchardgrass and reed canarygrass exceeded that of tall fescue in succeeding years because of loss of the tall fescue stands and was believed to be due to the multiple harvests (2-4 annual harvest) used within the study (Marten and Hovin, 1980). Smooth brome grass produced similar forage yields as tall fescue during the second and third year of this study. Kentucky 31 tall fescue produced higher yields than ‘Boone’ orchardgrass in only one year of the five that the species were evaluated in Kentucky (Templeton et al., 1965).

The forage yields of tall fescue were generally accepted to have similar productivity as other cool-season species within simulated grazing studies, but were less consistent than other forage grass species when harvested as hay. Van Keuren (1972) reported no difference in the total season forage yields of Kentucky bluegrass (5,671 kg ha⁻¹), orchardgrass (5,986 kg ha⁻¹), and tall fescue (6,209 kg ha⁻¹) when the grasses were defoliated 5 to 6 times during the growing season. Hart et al. (1971) stated that the seasonal forage yield of Kentucky 31 tall fescue was greater than ‘Potomac’ orchardgrass when both species were clipped weekly to 5 and 10 cm, but

also reported considerable year-to-year variation in the yields of the grasses. There was no difference in yields of these species when harvested at 5 cm (6,000 and 6,140 kg ha⁻¹, respectively) in the first year of the study, but when harvested at 10 cm, orchardgrass produced higher yields than tall fescue (5,960 vs. 4,880 kg ha⁻¹). There was no difference in yields of the species when harvested at 10 cm in subsequent years, but tall fescue produced higher yields when harvested at 5cm in only the third year of the study (9,080 vs. 7,620 kg ha⁻¹). Templeton et al. (1965) reported no difference in the seasonal forage production of Kentucky 31 tall fescue and Boone orchardgrass when managed as pasture for five years, but showed higher yields for tall fescue (4,923 vs. 3,867 kg ha⁻¹) when the species were harvested to 6 cm at 14-day intervals. These authors also reported a greater weed content for the orchardgrass plots (937 vs. 300 kg ha⁻¹), which may suggest that tall fescue may be better suited to frequent defoliation than orchardgrass. Jung et al. (1974) reported comparable seasonal yields of three orchardgrass cultivars (Potomac, 'Pennlate' and 'Syn C') and Kentucky 31 tall fescue when the grasses were harvested five and eight times a season under two levels of N-fertilizer (3 annual applications of 56 and 112 kg ha⁻¹) without an appreciable loss of the stands. These two species also produced higher yields than multiple types of Kentucky bluegrass (common and a local ecotype), reed canarygrass (common, 'Iowa', and 'RC-1'), smooth brome grass ('Fox' and 'Saratoga') and timothy ('Climax'). All of the latter named species showed decreases in stand density under the cutting regimes (Jung et al., 1974).

Tall fescue is known for its ability to produce large amounts of forage growth during the fall, which is then deferred for grazing during the winter and early spring (referred to as 'stockpiling'). Bryan et al. (1970) demonstrated that tall fescue (4,418 kg ha⁻¹) produced more forage during the late fall than reed canarygrass (2,204 kg ha⁻¹) in central Iowa. Taylor and Templeton (1976) evaluated 'Kenblue' Kentucky bluegrass and Kentucky 31 tall fescue within stocking piling systems and compared different accumulation periods and N-fertilizer rates (0, 50, and 100 kg ha⁻¹). These authors reported tall fescue yields were consistently higher (1,414 –

3,843 kg ha⁻¹) than bluegrass (714 – 2,324 kg ha⁻¹) across all treatments. Archer and Decker (1977) compared the stockpiled yields Potomac orchardgrass and Kentucky 31 tall fescue in Maryland at three levels of N-fertilization (0, 50, and 100 kg ha⁻¹) and reported no difference in the yields between the species when harvested in October, after approximately a month of herbage accumulation. Tall fescue produced higher yields (3,709 and 3,069 kg ha⁻¹, respectively) than orchardgrass (3,153 and 2,465 kg ha⁻¹, respectively) if harvest was delayed until November and December, regardless of the fertility treatment. These authors also showed that tall fescue was capable of producing growth under lower soil temperatures than orchardgrass (Archer and Decker, 1977). Tall fescue yields ranged from 2,319-2,954 kg ha⁻¹ compared to 1,523-1,769 kg ha⁻¹ for orchardgrass when soil temperatures were maintained at 10°C,.

Nutritive Value

Marten and Hovin (1980) reported estimates of *in vitro* digestible dry matter (IVDDM) that were comparable between orchardgrass (660 g kg⁻¹), tall fescue (652 g kg⁻¹), and smooth bromegrass (651 g kg⁻¹). All of these species had greater IVDDM than reed canarygrass (620 g kg⁻¹). Similarly, Bryan et al. (1970) demonstrated that the *in vivo* digestibility of tall fescue was greater than reed canarygrass when the grasses were harvested in late July (626 vs. 541 g kg⁻¹) and early November (662 vs. 565 g kg⁻¹). The digestibility of reed canarygrass was greater when these species were harvested in June (633 vs. 555 g kg⁻¹), as it was harvested in a more immature stage than tall fescue and had not yet fully reached its reproductive stages (which resulted in fewer stems in the collected sample) (Bryan et al., 1970). Archer and Decker (1977) reported variable IVDDM differences between years with stockpiled orchardgrass and tall fescue. *In vitro* digestible dry matter was not different between these species when harvested in October (30 d) during the first year of the experiment. However, after 68 and 105 d of accumulation (mid-November and late December harvest, respectively), IVDDM was greater in the tall fescue forage (826 and 790 g kg⁻¹, respectively) than orchardgrass (779 and 730 g kg⁻¹, respectively). *In vitro* digestible dry matter was greater for orchardgrass (801 vs. 775 g kg⁻¹) during the November

harvest, and no difference was observed between the species during the October and December harvests in the second year of the experiment. The work of Taylor and Templeton (1976) suggests that tall fescue reserved for stockpiling maintained a greater digestibility (as estimated using a nutritive value index) during the winter than Kentucky bluegrass.

One of the most limiting aspects of forage nutritive value for animal production is crude protein (CP) and reports have demonstrated that tall fescue is often slightly lower in this component than other cool-season grasses. Austenson (1963) harvested orchardgrass, perennial ryegrass, tall fescue, and timothy when all species were in the vegetative stages (April) and reported CP concentrations of tall fescue were similar to ryegrass (142 and 141 g kg⁻¹, respectively) but lower than orchardgrass (163 g kg⁻¹) and timothy (180 g kg⁻¹). By the first of May, CP did not differ between orchardgrass, tall fescue, and ryegrass (98, 99, and 102 g kg⁻¹, respectively), and these three species were lower than timothy (119 g kg⁻¹) because of the later maturity of timothy. Crude protein concentrations of the timothy, ryegrass, and tall fescue forage were not different (80, 73, and 69 g kg⁻¹, respectively) and were higher than orchardgrass (58 g kg⁻¹) if harvest was delayed until mid-June. Marten and Hovin (1980) reported no difference in CP between orchardgrass and tall fescue averaged across three growing seasons and three cutting regimes (147 and 141 g kg⁻¹, respectively), and both of these species were lower than reed canarygrass and smooth brome grass (170 and 169 g kg⁻¹, respectively). Archer and Decker (1977) found higher CP concentrations in stockpiled orchardgrass than tall fescue (152 vs. 137 g kg⁻¹) when both species were harvested in later December. Similarly, Taylor and Templeton (1976) showed that CP of Kentucky bluegrass was greater than tall fescue at all dates of harvest, although the magnitude of the difference decreased later into the winter.

The “Forage Quality” Paradox

Animal performance from tall fescue has often been reported as being lower compared to animals consuming other species of forages despite having comparable nutritive values to other cool-season grasses,. Blaser et al. (1956) reported that steers grazing tall fescue pastures had

lower average daily gains (ADG) (0.40 kg d^{-1}) in Virginia compared to those grazing orchardgrass (0.49 kg d^{-1}). Steer weight gains were increased when white clover was interseeded into these pastures, but the trends in ADG remained the same between the species (orchardgrass: 0.54 ; tall fescue: 0.46 kg d^{-1}). However, the total live-weight gain per area (GPA) was not different between these species, and was a result of a higher carrying capacity for the tall fescue pastures ($1,016$ vs. $766 \text{ steer d ha}^{-1}$). The lower steer performance suggests that the intake of forage was lower for the steers grazing the tall fescue pastures since the forage yields were maintained at a similar level between pastures and the nutritive value is relatively comparable between species. Voluntary intake of steers grazing reed canarygrass pastures were higher than steers grazing tall fescue during the summer months (111.9 vs. $99.9 \text{ g kg live-weight}^{-1}$), although tall fescue forage was of higher nutritive value (*in vivo* digestibility: 626 vs. 541 g kg^{-1}) (Bryan et al., 1970). Similar trends in animal productivity were also reported for cow-calf and stocker operations by Van Keuren and Stuedeman (1979) and Spooner and McGuire (1979), respectively.

The discrepancy between the nutritive value and animal production has led some authors to define it as the “forage quality paradox” of tall fescue (Burns, 2009). It became known to producers that grazing tall fescue during the summer months often resulted in poor body condition of the animals and sometimes severe lameness, which collectively have become known as symptoms of tall fescue toxicosis. The exact cause of these symptoms remained unclear, although many researchers believed that they were due to an anti-quality component within the forage (Bush et al., 1979). Initial theories ranged from toxins derived from microbial actions in the rumen to alkaloids produced by either the plant or fungi, such as *Claviceps purpurea* (Bush et al., 1979). This was perplexing as other forage species, such as reed canarygrass, have been known to produce alkaloids without notable losses in animal production. To further complicate matters, animals grazing tall fescue continued to exhibit symptoms of tall fescue toxicosis without an appreciable amount of the sclerotia produced by the *Claviceps* fungi (Yates, 1962). Tall fescue was found in the late 1970’s to contain a fungi whose life-cycle occurs

entirely within the internal regions of the plant (later termed an ‘endophyte’), and it was found that this fungi produced ergot alkaloids that were responsible for the lower animal production on tall fescue pastures (Bacon et al. 1977; Hoveland et al., 1983).

Neotyphodium coenophialum

Discovery and Transmission

The presence of a fungal endophyte is not a condition unique to tall fescue and is widespread among other species of grasses. Bacon et al. (1986) estimated that over 125 species of grass are host to endophytes, and that all tribes of the Poaceae family except for five are known to be infected with endophytic fungi. The presence of the endophyte within tall fescue [*Epichloë typhina* (Fries) Tulasne, later reclassified as *Acremonium coenophialum* Morgan-Jones and Games, currently *Neotyphodium coenophialum* (Morgan-Jones and Games) Glenn, Bacon, and Hanlin] was first documented in New Zealand by Neill (1941), but its connection to the symptoms of tall fescue toxicosis went overlooked. Bacon et al. (1977) showed that tall fescue tillers collected from pastures where animals exhibited symptoms had a high frequency of infection with *N. coenophialum*, whereas pastures with no physical signs of the toxicosis were less frequently infected (< 50%). Subsequent grazing and feeding trials by Schmidt et al. (1982) and Hoveland et al. (1983) found a direct relationship between the presence of the *Neotyphodium* endophyte and symptoms of tall fescue toxicosis within cattle.

One reason for the long time interval between the discovery of the endophyte and its connection to tall fescue toxicosis is that there are no visual symptoms of *Neotyphodium*-infection of tall fescue tillers. The hyphae of the endophyte are vertically orientated between the cells of the intercellular regions of the plant tissue and are unbranched (Bacon et al., 1977). *Neotyphodium coenophialum* is not pathogenic and its hyphae do not penetrate the cell membranes or occur within the vasculature of the plant (Bacon et al., 1977; Christensen and Voisey, 2009). The endophyte is primarily found within the crown, leaf sheath, stem pith, and reproductive tissues of tall fescue and is not found within the roots or within the leaf blade of the

continental varieties of tall fescue, such as Kentucky 31 (Bacon et al., 1986; Christensen and Voisey, 2007). Unlike other genera of endophytes, such as the *Balansia* spp., reproduction of *N. coenophialum* is entirely asexual when the fungus is located within the plant and relies solely on the colonization of tall fescue seeds for transmission into succeeding generations (Neill, 1941; Bacon et al., 1986). *N. coenophialum* is located within the crown of established tall fescue during the early spring and colonizes the developing meristem. The endophyte then synchronizes its growth with the tissues of the plant before meristem elongation and continues to move upward intercalary extension (Christensen and Voisey, 2007; Christensen and Voisey, 2009). If the endophyte is not able to infect the young meristems before elongation of the cells, the hyphae are not able to later re-infect the tissues and results in endophyte-free tillers. The endophyte colonizes the ovary and following fertilization begins to infect the scutellum and embryo (Christensen and Voisey, 2009) leading to the propagation of endophyte-infected seeds.

Symbiosis with Tall Fescue

A mutualistic symbiosis exists between tall fescue and the *Neotyphodium* endophyte (Bacon et al., 1986, Belesky and West, 2009). The endophyte obtains nutrients, protection from external factors, and a means for dissemination from the plant, while the endophyte bestows the grass with a greater level competitiveness and tolerance to stresses which leads to improved persistence of endophyte-infected plants. Tall fescue pastures with low levels of endophyte infection (< 10%) do not tolerate grazing under low moisture levels in eastern TX and resulted in greater than 50% stand loss compared with a 4% stand loss with > 90% infection rate (Read and Camp, 1986). Similarly, Bouton et al. reported average stand densities of 0 and 27% for EF tall fescue varieties at two sites in southern GA compared to 91 and 64% for their EI counterparts. These studies, along with others, suggests that tall fescue infection with *Neotyphodium* is needed within pastures of the southeastern US (Belesky and West, 2009). Endophyte infection improves the competitiveness persistence of tall fescue primarily by altering the morphology of tillers and conferring greater tolerance to biotic and abiotic stresses (Belesky and West, 2009).

Altered Morphology and Competitiveness

Neotyphodium-infection has been shown to affect the growth characteristics of tall fescue, but the magnitude of the differences appears to be influenced greatly by the genotype of the tall fescue hosts. Hill et al. (1990) evaluated the growth characteristics and morphological variation of five Kentucky 31 clone pairs (i.e. EI and EF), and demonstrated that the yield and leaf area tiller⁻¹ were greater for the EI clones. However, within the first year of the experiment, the EF clones produced greater tiller numbers for three of the five clones. No difference in the production of tillers was detected between the clones during the second year of the study (Hill et al., 1990). These authors also showed that the crown in EI tillers was 7-11 mm deeper, and total crown size followed similar trends as tiller production (i.e. three EF clones greater during the first year and no difference during the second year). Belesky and Fedders (1996) reported more plant genetic variation of the alterations in tiller morphology when infected with *Neotyphodium coenophialum*. These authors reported that EI clones had higher yields and leaf mass tiller⁻¹ for one clone, but these parameters were higher for the EF form for the other clone pair used within the study. Endophyte infection produced greater tiller numbers for both of the clones within this study (Belesky and Fedders, 1996). Hill et al. (1991) demonstrated under field conditions that EI tall fescue had increased tiller numbers and higher yields, but the relative difference was again dependent upon the genotype of the tall fescue plant and growing environment. There was no difference between the yields of the spring harvest and tiller densities estimated during the fall for one EI and EF clone pair during the year of establishment, but yields and tiller populations were higher in the EI version of the two clone pairs used for both harvest dates in following years.

The potential for more tillers suggest that EI tall fescue would be more competitive and, therefore, productive than EF varieties. Belesky and Fedders (1996) found an interaction among the relative growth rate of tall fescue genotype, endophyte presence, and height of defoliation. These authors reported that EI was beneficial and increased yield and growth rate for one genotype when the plant was clipped to 5 and 10 cm weekly, while EI decreased the relative

growth of the other genotype of tall fescue under these treatments. There were minimal differences between EI and EF clonal pairs when left uncut. The genotypes that received the benefits of EI under defoliation were characterized as producing numerous, smaller tillers compared to those whose growth rate was depressed when infected with an endophyte under defoliation treatments, which produced fewer, but larger, tillers. The authors concluded that the latter clone would have had more herbage and photosynthetic tissue removed during defoliation and would also have fewer axillary buds to replace lost tillers and suggested that less intensive defoliation would be required to maintain EF of this genotype. Hill et al. (1991) suggested that the benefits of *Neotyphodium* infection of tall fescue were dependent upon the interactions among several factors, as the relative competitive advantage of EI tillers over EF not only depended on the genotype, but also varied considerably across years and growing environments.

Tolerance to abiotic stresses

One of the most commonly cited advantages for EI tall fescue is the ability to tolerate levels of moisture deficit that occur frequently during the summer months of the southeastern USA. Arachevaleta et al. (1989) reported that leaf tissue of both EI and EF Kentucky 31 tall fescue died when plants were placed under a high degree of moisture stress (soil matric potential = -0.50 MPa), but stated that the basal sheath areas of the EI plants remained photosynthetic and upon the return of adequate moisture EI produced 111% more regrowth than the EF plants. Endophyte-infected tall fescue also produced greater forage yields than EF plants under low and moderate levels of moisture stress (soil matric potentials = -0.03 and -0.05MPa, respectively), and tiller production was reduced as moisture deficit increased, regardless of infection status. West et al. (1993) used irrigation to develop a moisture stress gradient to compare the tolerance of EI and EF tall fescue. These authors showed that the tiller densities of both EI and EF stands decreased during the summer months under non-irrigated conditions, but reported that the EI stands recovered by the fall and produced similar tiller densities as the irrigated areas. There was a significant loss of the EF stand within both the irrigated and non-irrigated areas during the

following growing season. Forage yields followed similar trends as tiller densities for the EI and EF stands, with EI stands producing higher yields under all irrigation levels within the study. Belesky et al. (1989) reported similar trends for forage yields and persistence of EI and EF tall fescue clones subjected to moisture stress, but also reported that benefits received from endophyte-infection depended on genotype, as was previously discussed.

Several mechanisms were proposed to explain how *Neotyphodium coenophialum* aids in tall fescue persistence during times of moisture stress. Arachevaleta et al. (1989) reported that the leaf blades of EI plants tended to roll under the moderate and high levels of moisture stress, whereas leaves of the EF plants tended to remain flat and open under the same conditions. Leaf rolling is a common response to moisture stress among cool-season grasses and facilitates the reduction of transpiration losses (Johns, 1978). Previous research showed the importance of this trait to the survival of tall fescue under drought conditions (Frank et al., 1996). The endophyte has been implicated in cellular and physiological changes at the onset of drought conditions. Osmotic adjustment (i.e. the accumulation of solutes to lower the water potential) was greater for EI plants, which allowed these plants to maintain cell turgor longer and the quantity of osmotic adjustment was highly correlated ($r = 0.87$) with survival of tillers to the water deficit (Elmi and West, 1995). Richardson et al. (1992) reported mannitol, arabitol, and glucose accumulated within the sheaths and fructose and glucose within the leaf blade of EI tillers under moisture stress. The authors theorized that, in addition to contributing to the solute potential, these compounds may also act as a readily available substrate for metabolic conversion following the restoration of adequate levels of moisture, which partially explains the improved growth rate of EI tall fescue following drought.

Endophyte-infection has been shown to improve production and persistence of tall fescue under poor soil conditions (Belesky and West, 2009). The regions where tall fescue is the predominate forage are frequently have acidic soils with high concentrations of soil Al concentrations and low levels of available soil P (Belesky and West, 2009; Burns and Chamblee

1979). Shoop et al. (1961) reported higher yields for tall fescue compared to redtop and white clover without the addition of P_2O_5 , but showed that the forage yields of tall fescue were responsive to 45 and 360 kg P_2O_5 ha⁻¹ under non-limed and limed conditions, respectively. Malinowski et al. (2000) demonstrated that EI tall fescue was capable of increasing the relative growth rate under P-limited conditions, and showed that in select genotypes the P, Zn, and Cu concentrations were higher in EI plants. Malinowski and Belesky (2000) reported that EI plants released phenolic compounds into the rhizosphere that chelated Al, resulting in higher availability and intake of soil P. Endophyte-infected plants have shown to have a greater specific root length and total root mass under low P conditions than EF plants (Malinowski and Belesky, 2000).

Alkaloid Production

Infection of tall fescue with *Neotyphodium coenophialum* reduced herbivory of the plant by nematodes, insects, and grazing animals (West et al., 1988; Rowan et al., 1986), and is due to alkaloids produced by the endophyte. The endophyte is responsible for the production of pyrrolopyrazine, pyrrolizidine, and ergot alkaloids, while tall fescue produces diazaphenanthrene and indole alkaloids (Bush and Fannin, 2009). Although the plant-derived alkaloids (i.e. perloine) have some *in vitro* inhibitory effects at high concentrations on rumen bacteria (Bush et al., 1976), they are believed to not be associated with the symptoms of tall fescue toxicosis (Bush and Fannin, 2009) and aid in deterring predation by insects. Similar assessments of were made of the pyrrolopyrazine alkaloids (i.e. peramine), which have little activity on mammals (Bush et al., 1997; Bush and Fannin, 2009) but are important for control of insects, such as Argentine stem weevil in perennial ryegrass (Rowan et al., 1986; Rowan and Latch, 1994). The pyrrolizidine alkaloids (i.e. N-acteyllonline and N-formylloline) also deter insects (Bush et al. 1997; Bush and Fannin, 2009), but have only been shown to have some activity on animals only at concentrations greater than occur naturally from the symbiosis (Klotz et al. 2008).

Ergot alkaloids, such as lysergic acid and ergovaline, are believed to have the greatest activity on grazing animals and are thought to cause the symptoms of tall fescue toxicosis (Klotz,

et al., 2006; Klotz et al., 2007; Klotz et al., 2008). Ergovaline is the alkaloid produced at the highest concentrations by the endophyte, and may account for 84-97% of the total ergopeptide alkaloids produced (Lyons et al., 1986). The seasonal distribution of ergovaline concentrations are bimodal with peaks occurring during the spring and fall (Belekey et al. 1989; Bush and Fannin, 2009) due to ergovaline accumulation on reproductive and vegetative tillers, respectively. Rottinghaus et al. (1991) determined that ergovaline concentrations were highest within tall fescue seedheads, followed by the stem/sheath and leaf blades. Rogers et al. (2011) reported from a multi-state study that ergovaline concentrations increased in vegetative tillers throughout growing season.

Several management factors, such as N fertilizer and defoliation, may also have an impact on ergovaline concentrations. Lyon et al. (1986) demonstrated NO_3 and NH_4 fertilizers increased the total ergot alkaloid and ergopeptide concentrations within the sheaths of tall fescue in a greenhouse study. Similarly, Rottinghaus et al. (1991) reported 135 kg N ha^{-1} increased ergovaline concentration in tall fescue seedheads, leaf blades, and stems by, 66, 88, and 103%, respectively. Alkaloid production within the pseudostems of tall fescue plants was correlated with total nonstructural carbohydrate (TNC) and tissue N ($r > 0.73$) (Belesky and Hill, 1997). These authors also showed that ergovaline concentrations within leaf tissue peaked within 4 weeks of emergence and then decreased with further maturity. Belesky and Hill (1997) reported clipping weekly to 5 or 10 cm reduced the ergovaline content of regrowth compared to uncut controls and suggested that the decrease was the result of lower TNC concentrations within the plants. Similar results were reported by Bush and Fannin (2009) when tall fescue was clipped 5 cm every 21 days. Salminen et al. (2003) did not show as profound decreases in ergovaline concentrations for tall fescue mowed weekly, but reported increases in the concentration of other minor ergopeptides (ergonovine and ergocryptine).

Tall Fescue Toxicosis in Beef Cattle

Tall fescue toxicosis is of great importance to the beef cattle industry, because tall fescue forage is the predominate, and often sole, feed source within the southeastern USA where it is a primary species for cattle production. The total economic loss for tall fescue toxicosis within beef operations were estimated to be over \$600 million yr⁻¹ (Hoveland, 1993), with more current assessments estimating the losses to be over \$1 billion annually (Allen and Segarra, 2001). Producers began experience problems with animal health and productivity during the summer months shortly after the release of Kentucky 31 and Alta tall fescue (Hoveland, 2009). Animals grazing tall fescue pastures often had tenderness and swelling within the hoof region, and in extreme cases, sloughing off of the hoof. This condition eventually became known as “fescue foot” (Bush, et al., 1979). Cattle grazing tall fescue also experienced poor growth, less fertility, hair coat retention during the summer months, and often stand in shade or water to cool themselves because of higher body temperatures (Strickland et al., 2009). This “summer slump” in production along with “fescue foot” and “fat necrosis” (constriction of internal organs by necrotic adipose tissue) are now collectively known as symptoms of tall fescue toxicosis caused by the ergot alkaloids produced by the *Neotyphodium* endophyte (Strickland et al. 2009).

Ergot Alkaloid Effects on Animal Physiology

The physiological effects of the alkaloids on cattle must be described to understand the impact of EI-tall fescue on animal production. Ergot alkaloids induce vasoconstriction of the vasculature in cattle. Lysergamide caused contraction of the lateral saphenous vein and dorsal metatarsal artery at concentrations of 3×10^{-9} M and 1×10^{-7} M, respectively (Oliver et al., 1993). Klotz et al. (2006) reported a similar alkaloid, D-lysergic acid, had vasoconstrictive properties on bovine lateral saphenous vein *in vitro*, but higher concentrations were required (1×10^{-4} M) to stimulate contraction. These authors reasoned that lysergic acid likely had a minor role in the causation of the symptoms of tall fescue toxicosis. Ergovaline causes vasoconstriction at concentrations of approximately 1×10^{-8} M (Klotz et al., 2007; Klotz et al., 2008; Klotz et al.,

2010). The narrowing of the luminal area of veins elicited by ergovaline appeared to be irreversible at these concentrations as relaxation of the vein did not occur following the removal of the alkaloid (Klotz et al., 2007). Repetitive exposure to low concentrations of this alkaloid (1×10^{-7} M) led to an increasing contractile response. These results suggest that ergovaline tends to accumulate within the vasculature (Klotz et al., 2009) and exposure to low amounts of alkaloids may lead to negative long term effects on animal physiology and health.

Vasoconstriction leads to restricted blood flow throughout the animal, explaining the symptoms of tall fescue toxicosis associated with severe heat stress and fescue foot. Rhodes et al. (1991) reported that steers fed a high-alkaloid tall fescue seed diet ($1.18 \mu\text{g g}^{-1}$ ergovaline) experienced lower blood flow at the skin covering the ribs (5.6 vs. $11.2 \text{ ml min}^{-1} 100 \text{ g tissue}^{-2}$), brain cerebellum (95.4 vs. $121.7 \text{ ml min}^{-1} 100 \text{ g tissue}^{-2}$), duodenum (42.7 vs. $88.3 \text{ ml min}^{-1} 100 \text{ g tissue}^{-2}$), and colon (95.4 vs. $121.7 \text{ ml min}^{-1} 100 \text{ g tissue}^{-2}$) compared to steers consuming low-alkaloid seed diet ($< 0.05 \mu\text{g g}^{-1}$ ergovaline). There was also a tendency for lower blood flow rates at the pancreas (164.9 vs. $352.7 \text{ ml min}^{-1} 100 \text{ g tissue}^{-2}$) and kidneys (346.6 vs. $525.8 \text{ ml min}^{-1} 100 \text{ g tissue}^{-2}$) for steers consuming the high-alkaloid diet. Vasoconstriction is responsible for the elevated body temperatures and respiration rates observed in animals experiencing tall fescue toxicosis (Schmidt et al., 1982; Hoveland et al. 1983). Animals dissipate excess body heat through evaporative cooling and may not effectively regulate body temperature due to vasoconstriction when grazing EI tall fescue (Rhodes et al., 1991). Aldrich et al. (1993) reported higher rectal temperature for steers fed EI tall fescue seed than for steers receiving EF seed, regardless of the ambient temperature (22 and 32°C) the animals were exposed to. Skin vaporization (i.e. sweating) also was lower for steers receiving the EI treatment and placed in 32°C environmental chambers (47.1 vs. $87.2 \text{ kcal m}^2\text{h}^{-2}$). Similarly, Al-Haidary et al. (2001) showed consumption of an EI tall fescue diet (5 ng g^{-1} ergovaline) increased the amount of heat stress experienced by heifers, but the animals were partially able to adapt upon repeat exposure to elevated ambient temperatures.

The concentration of the hormone, prolactin, has been described as a “physiological marker” for tall fescue toxicosis (Waller, 2009). Prolactin is typically associated with mammary development and milk secretion in cows, but recently has been linked to a variety of other physiological responses in cattle, many which are linked to the physical symptoms of tall fescue toxicosis, such as gains and temperature regulation (Aldrich et al., 1993). Ergot alkaloids produced by *N. coenophialum* bind to dopamine receptors within the animal, thereby limiting the production of prolactin (Strickland et al. 2009). Hurley et al. (1980) reported higher serum prolactin concentrations for steers and heifers grazing nontoxic tall fescue pastures compared to those grazing EI-tall fescue (35.7 vs. 5.6 ng ml⁻¹). These authors also showed that prolactin concentrations increased when cattle consuming the nontoxic fescue were exposed to higher air temperatures, while the prolactin concentrations remained consistently low for cattle consuming toxic fescue.

Effects on Productivity of Stocker Operations

Hoveland et al. (1980) reported the first work relating the presence of the *Neotyphodium* endophyte and low animal performance in Alabama. These authors showed that tall fescue pastures with less than 20% of the tillers infected with the endophyte produced steer average daily gains (ADG) of 0.68 kg d⁻¹ compared to 0.45 kg d⁻¹ for steers grazing pastures with infection rates exceeding 80%. However, the study was not entirely conclusive as the less EI pastures had a large encroachment of dallisgrass [*Paspalum dilatatum* Poir.]. Schmidt et al. (1982) fed steers tall fescue seed and hay and reported lower ADG for steers fed the EI seed (0.20 kg d⁻¹) and EI hay (0.28 kg d⁻¹) diets compared to those fed EF feeds (0.90 and 0.66 kg d⁻¹ for the seed and hay diets, respectively). Further, endophyte infection of the feeds increased the feed-to-gain ratio (kg of feed required to produce a kg increase in body weight) for both the seed and hay diets (seed: 20.7 vs. 6.7 kg kg⁻¹; hay: 15.4 vs. 7.4 kg kg⁻¹), but did not estimate the level of significance on this data due to a lack of individual animal data (i.e. pens were fed as groups). Hoveland et al. (1983) reported similar trends in ADG between steers grazing tall fescue pastures

with < 5 and 94% infection rates (0.83 and 0.5 kg d⁻¹, respectively). Crawford Jr. et al. (1989) estimated a decrease of 0.07 kg d⁻¹ for every 10% increase in endophyte infection rate for steers grazing tall fescue pastures during the spring and summer from a regression of steer gain on pastures on increasing levels of endophyte infection. No relationship between steer ADG and infection rate was obtained for fall grazing and is most likely due to the animals being less heat-stressed under the cool temperatures of fall compared to the high temperatures of the spring and summer months.

Despite lower ADG, tall fescue pastures with high endophyte infection rates are typically reported to have higher carrying capacities (CC). Hoveland et al. (1983) reported that an increase of 175 steer d ha⁻¹ as the infection rate of the pastures increased from < 5 to 94%. Similarly, Chestnut et al. (1991b) reported an average of 1260 steer d ha⁻¹ for EI tall fescue pastures compared to 1089 steer d ha⁻¹ for EF pastures. The documented increase in CC for EI pastures may be due to reduced forage intake of the animals since the nutritive value of EI and EF tall fescue is similar (Burns, 2009). Chestnut et al. (1991b) reported higher forage intakes for steers grazing EF tall fescue (6.12 kg d⁻¹) compared to those grazing EI pastures (4.90 kg d⁻¹). Schmidt et al. (1982) reported the feed intake of tall fescue seed and hay was increased 36% and 8% when the endophyte was removed (seed: 6.41 vs. 4.14 kg d⁻¹; hay: 4.79 vs. 4.40 kg d⁻¹). In a controlled temperature environment, Aldrich et al. (1993) showed lower feed intakes for steers consume a EI tall fescue seed diet compared to a EF diet (3.33 vs. 3.89 %BW) when the animals were kept at 32°C, but reported no difference between the intakes when steers were housed in cooler conditions (22°C) (4.79 vs. 4.51 % BW). The authors reasoned that the lower feed intake for the EI seed diet under the higher temperatures was the result of the animals not being able to dissipate excess body heat, as steers on this feed produced less sweat and had higher rectal temperatures compared to the EF diet.

It is known from the grazing trials that increases in CC may offset lower ADG and result in greater total gain per unit area (GPA) (Mott, 1960; Jones and Sandland, 1974). However,

grazing animals on EI tall fescue pastures do not always conform to these trends. Hoveland et al. (1980) reported lower GPA for tall fescue pastures with high endophyte infection rates ($> 60\%$: 360 kg ha^{-1}) than for pastures with low levels of endophyte ($< 20\%$: 450 kg ha^{-1}). These authors also reported similar trends in subsequent studies with the less infected pastures producing more GPA ($< 5\%$: 493 kg ha^{-1}) than pastures with high infection rates (94% : 384 kg ha^{-1}), despite the latter having a greater CC (593 and $768 \text{ steer d ha}^{-1}$) (Hoveland et al. 1983). In contrast to these studies, Bransby et al. (1988) reported higher GPA for tall fescue pastures with high endophyte infection rates ($> 70\%$). However, the greater GPA for high EI pastures only occurred under high stocking rates ($5.93 \text{ steers ha}^{-1}$) and under medium and low stocking rates (4.45 and $2.97 \text{ steers ha}^{-1}$, respectively) the low endophyte pastures produced similar or higher GPA. The authors did not observe a stocking rate effect on steer ADG within the EI pastures (Bransby et al., 1988).

Effects on Productivity of Cow-calf Operations

There is less research on the effects of tall fescue toxicosis in cow-calf operations due to higher research costs, but the impact of the endophyte is similar to stocker operations. Peters et al. (1992) reported lower forage intakes during the summer months for cows grazing EI tall fescue (Kentucky 31) in Missouri compared to those grazing EF tall fescue ('Mozark') and orchardgrass ('Hallmark') pastures (1.6 vs. 1.9 and 2.0% BW). Cows grazing the EI pastures had larger decreases in body weight (BW) (42 kg vs. 9 and 13 kg for Mozark and Hallmark, respectively) and produced less milk than their counterparts grazing the Mozark tall fescue and orchardgrass treatments. This resulted in lower calf ADG (0.72 kg day^{-1} vs. 89 and 88 kg day^{-1} for Mozark and Hallmark, respectively) and 205 d weaning weights (212 kg vs. 236 and 235 kg for Mozark and Hallmark, respectively) (Peters et al., 1992). Paterson et al. (1995) summarized several experiments and reported that ADG was consistently lower for cows grazing EI tall fescue and was negative (i.e. loss of body condition) for cows grazing EI treatments within four of the seven studies evaluated. Calf ADG and 205 d weaning weights were lower for EI tall fescue within all but one of these studies.

The effect of *N.coenophialum* on the reproduction efficiency is also a concern for cow-calf operations. Paterson et al. (1995) reported conception rates of 49-74% for cows grazing EI pastures compared to 78-95% for cows consuming nontoxic forages. Peters et al. (1992) reported lower conception rates for cows on EI pastures (72%) compared to those grazing a EF tall fescue (Mozark: 91%). The exact nature of this reduced fertility is not clear. Burke and Rorie (2002) reported no difference in concentration of pregnancy hormones (i.e. progesterone and estradiol) and follicular function for cows grazing EI and EF tall fescue, although there have been several studies showing a reduction in the concentration of pregnancy hormones for animals grazing EI tall fescue (Thompson and Studemann, 1993; Porter and Thompson, 1992). Burke et al. (2001) reported similar pregnancy rates and embryonic losses or pregnancy rates between 30 and 60 d of gestation for cows consuming EI and EF forages, and subsequent studies have suggested that pregnancy losses may occur within the first 6 days of embryo development (Schuenemann et al. 2005c; Waller, 2009). Research has emerged that suggest the reproductive issues associated with cattle grazing EI tall fescue may partially be explained by reduced fertility of bulls. Schuenemann et al. (2005a; 2005b) showed sperm morphology and motility did not differ for bulls fed toxic (ergotamine tartrate and EI tall fescue) and nontoxic diets, but reported that embryos fertilized *in vitro* with the former's sperm experienced a reduced embryo cleavage rates. Further development of the cleaved embryos into the eight-cell and blastocyst stages did not differ between treatments in these studies (Schuenemann et al. 2005a; Schuenemann et al. 2005b), which strongly implicates the responsibility of lower cleavage rates in the reduced fertility.

Management for Tall Fescue Toxicosis

Endophyte-infected tall fescue is still widely used within cattle production systems of the southeast because of its favorable agronomic benefits (i.e. drought tolerance, persistence under less intensive management, etc.) despite the potential negative impact on livestock production. Hence, it becomes important to develop management strategies to reduce the harmful effects of

the *Neotyphodium* endophyte. Current management strategies fall into two categories: inhibition of ergot alkaloids production and limiting the intake of ergot alkaloids by the animals (Roberts and Andrae, 2004). The use of EF varieties and novel endophyte (NE) (non-ergot alkaloid producing strains of *N. coenophialum*) strains are the primary methods to impede the production of ergot alkaloids, while incorporating additional forage species, providing supplemental feeds, preserving tall fescue, and the removal of seedheads are the most often used strategies to reduce the dosage of these alkaloids received by the animals (Roberts and Andrae, 2004).

Endophyte-free and Novel Endophyte Varieties

Researchers began to examine the use of EF varieties to increase pasture and animal production shortly after the discovery that *Neotyphodium coenophialum* was responsible for the symptoms of tall fescue toxicosis (Bacon et al., 1977; Hoveland et al., 1980). As previously mentioned, animal production from these varieties exceeds that from EI varieties, at least in the short-term. However, the EF varieties are more susceptible to environmental stresses and poor management conditions, leading to poor persistence of the stands. Read and Camp (1986) demonstrated the EF varieties of tall fescue could not tolerate medium-low grazing pressures in eastern Texas leading to greater than 70% losses of stands within two years. Bouton et al. (1993) reported similar losses within three years at two locations in southern Georgia, but reported better persistence of EF tall fescue genotypes that was comparable to EI varieties (95 vs. 97%) at a northern location within the state.

Hill et al. (1991) demonstrated that ergot alkaloid production depended not only on the presence of the endophyte, but also on the interaction between the endophyte and the plant. These authors compared the alkaloid production within a tall fescue genotype containing a naturally low-alkaloid producing endophyte (EDN2) and when the genotype was re-infected with a high-alkaloid producing endophyte (EDN11). Surprisingly, re-infection of the plant with the high-alkaloid endophyte (EDN11) did not translate to greater concentrations of ergot alkaloids, and after six months, the endemic endophyte (EDN2) actually produced more ergot alkaloids than

the introduced endophyte, indicating the endophyte-plant interaction may be a potential avenue of exploitation in reducing the toxicity of EI tall fescue. This later led to the development of NE varieties of tall fescue. Bouton et al. (2002) compared EF and EI versions 'Jesup' and 'Georgia' tall fescue, as well as forms of these genotypes that had been infected with NE, and reported that the forage yield and persistence of the NE forms were comparable to EI types, and both of these were greater than the EF plants. Also, these authors reported the body temperatures and serum prolactin concentrations for lambs grazing the NE tall fescue pastures that were similar to those grazing the EF forages, indicating that animals within the NE and EF pastures were not experiencing symptoms on tall fescue toxicosis (Bouton, et al., 2002).

Novel endophyte varieties of tall fescue has shown promise to improve animal performance within beef operations. In a multi-state review, Gunter and Beck (2004) estimated that using NE tall fescue varieties over EI improved steer ADG by 47%. Parish et al. (2003) reported that the steer ADG and GPA were similar for seven NE-tall fescue combinations to animals grazing EF pastures for fall and spring grazing (0.87 and 0.83 kg d⁻¹ & 212 and 366 kg ha⁻¹, respectively) for two locations in Georgia, with the production from both of these types of tall fescue being higher than steers grazing the EI pastures (0.49 and 0.40 kg d⁻¹ & 146 and 168 kg ha⁻¹, respectively). Steers grazing the EF and NE pastures also had greater concentrations of serum prolactin at the end of fall (15 ng ml⁻¹) and spring (119 ng ml⁻¹) grazing compared to the steers on the EI fescue (1.5 and 4.5 ng ml⁻¹, respectively) (Parish et al., 2003). Similar differences between NE and EI tall fescue varieties were reported in Arkansas and Missouri for stocker growth (ADG: 0.57 vs. 0.34 kg d⁻¹) and health (Serum Prolactin: 155 vs. 18 ng ml⁻¹; Rectal Temperature: 40.2 vs. 41.1°C) (Nihsen et al., 2004). Johnson et al. (2012) observed higher ADG and serum prolactin concentrations and lower rectal temperatures for steers grazing two varieties of tall fescue infected with NE compared to steers grazing EI Kentucky 31 pastures. These authors did not report any difference for these parameters between the NE cultivars. Watson et al. (2004) reported that the ADG of cows and calves increased when allowed to graze NE tall

fescue, resulting in a greater body conditioning score for the cows and higher weaning weights of calves (246 vs. 222 kg). Although cows grazing NE pastures had calves with higher birth weights (38.6 vs. 32.7 kg), these authors observed no further reproductive benefit from the NE tall fescue (calving rate = 94% for both varieties) and was attributed to breeding earlier in the spring (i.e. cooler conditions) and the cows having no prior exposure to EI tall fescue and having good body condition at the time of breeding (Watson et al., 2004). Looper et al. (2009) showed that grazing NE tall fescue pastures improved the reproductive capacity in bulls compared with those grazing EI tall fescue. Sperm produced by bulls grazing NE pastures had greater motility and better morphology than those bulls on EI pastures (Looper et al., 2009), but no difference in the percentage of live sperm was observed between the two treatments.

Incorporation of Other Forage Species and Supplemental Feeds

One of the most frequent methods to mitigate the negative impacts of EI tall fescue is to incorporate other forage species, usually clover, to dilute the concentration available within the total amount of available forage. Blaser et al. (1956) reported establishing white clover into EI tall fescue pastures slightly improved ADG, but was not significant when average across growing seasons (0.40 vs. 0.46 kg d⁻¹). Lusby et al. (1990) grazed steers on tall fescue pastures with high and low endophyte infection rates, as well as an EI tall fescue-clover mixture, in Oklahoma and showed that the steers grazing the EI tall fescue-clover mixture and tall fescue pastures with low infection rates had higher body weights at the end of the grazing season compared to those on the high-EI pastures (398 and 394 vs. 348 kg, respectively). Steers grazing EI tall fescue-clover mixtures also had elevated body temperatures that were similar to those grazing the high-EI pastures (39.5 and 39.6.4 °C, respectively) and were higher than steers grazing the low-EI pastures (39.3°C). Chestnut et al. (1991b) reported when clover occurred within stands at greater than 15%, steer ADG were improved on EI tall fescue pastures, but showed that several indicators of tall fescue toxicosis were not different between EI pastures and EI tall fescue-clover mixtures (Rectal temperatures: 41.2 vs. 41.0°F; Hair coat rating: 3.6 vs. 3.8, on a scale of 1-5

with 5 indicating an extremely rough, matted hair coat). These authors also reported an improvement in steer ADG and decrease in the severity of tall fescue toxicosis symptoms when 'Midland' bermudagrass (*Cynodon dactylon* (L.) Pers.) was included in the pastures, although this severely reduced the percentage of tall fescue by 24 to 74%.

Another alternative method to alleviate the decline in production from grazing tall fescue during the summer months is to provide additional sources of feedstuffs during this period. Aiken et al. (2006) reported a decrease in rectal temperatures in late June when steers (with and without steroid implants) were placed on bermudagrass pastures. Steer rectal temperatures were only slightly higher than normal after 10 days on the bermudagrass (39.8 and 39.6 °C, respectively). The serum prolactin concentrations of steers grazing the tall fescue pastures in the study were initially 28.9 ng ml⁻¹ when moved to the bermudagrass, and increased during their time on nontoxic forages without reaching a plateau, indicating that animals were beginning to recover from the toxicosis. Aiken and Piper (1999) either moved steers to eastern gamagrass [*Tripsacum dactyloides* (L.) L] pastures or supplemented them on EI tall fescue with a broiler litter-corn diet (2.27 kg head⁻¹) during the summer months in Arkansas. Steers grazing the eastern gamagrass pastures had higher levels of serum prolactin and sleeker hair coats than those that were maintained on EI tall fescue with supplementation, which suggest that during periods of high ambient temperatures it may have been more effective to completely remove animals from EI pasture rather than providing supplemental concentrate feeds (Aiken and Piper, 1999). However, Carter et al. (2010) reported that feeding soybean hulls (2.3 kg head⁻¹) was effective in maintaining steer growth on EI tall fescue pastures, as ADG (0.95 vs. 0.72 kg d⁻¹) and serum prolactin concentrations (103.5 vs. 42.5 ng ml⁻¹) were increased compared to steers not receiving the supplemental feed. The use of steroid implants (Synovex[®] S: 200 mg progesterone-20 mg estradiol) had an additive effect with feeding soybean for steer ADG (1.23 kg d⁻¹) in this study, but had little further effect on serum prolactin concentrations.

Preserving Tall Fescue Forage

The preservation of EI tall fescue as hay or silage has been shown to reduce the toxicity of the forage through the oxidation of alkaloids during the curing process. Roberts et al. (2002) reported that harvesting EI tall fescue for hay decreased the concentration of ergot alkaloids by 70% (373 vs. 1240 ng g⁻¹ for fresh forage), and that preserving the forage as silage only slightly decreased the concentration of alkaloids (972 ng g⁻¹). These authors further showed that the ergovaline concentrations decreased when the forage was harvested hay, ammoniated hay, or silage compared to green forage (Roberts et al., 2011). The total ergot alkaloid concentrations also decreased when the forage was conserved as hay or ammoniated hay, but concentrations increased for silage (Roberts et al., 2011). Since an immunoassay was used to quantify the total ergot alkaloid concentrations, the increase in total ergot alkaloids during the ensiling process was the result of ergovaline degradation that left the epitope for the antibody used within this method intact (Roberts et al., 2011). Chestnut et al. (1991a) reported that feeding ammoniated EI tall fescue hay to lambs resulted in serum prolactin concentrations that were similar to the concentrations found in lambs fed EF hay (110 and 91 ng ml⁻¹), and lambs within both of these treatments had higher prolactin concentrations than those fed EI hay (59 ng ml⁻¹). The forage intake (2.7 and 2.4 vs. 1.8 % body weight) and ADG (148 and 120 vs. 93 g d⁻¹) were higher for lambs consuming the EF and ammoniated EI hays compared to the EI hay. Similar to the harvest of EI tall fescue as hay, Kallenbach et al. (2003) showed that the toxicity of stockpiled EI tall fescue decreases as grazing was delayed until early spring. These authors reported that ergovaline concentrations within stockpiled tall fescue decline approximately 85% between mid-December and early March.

Removal and Inhibition of Seedheads

The removal or prevention of tall fescue seedheads is a management strategy that may easily be incorporated into cattle operations (as these plant tissues contain the highest amount of ergot alkaloids) (Rottinghaus et al., 1991). Mowing is effective, but it often occurs too late in the

growing season and allows cattle the opportunity to consume seedheads. Goff et al. (2012) showed that cattle began to selectively graze tall fescue seedheads shortly after their emergence from the boot stage, and near total removal occurred within a matter of weeks. Geldings and steers selectively removed approximately 50% of tall fescue seedheads in pastures with varying levels of endophyte infection rates (Aiken et al., 1993). Bransby et al. (1988) reported that increasing stocking rates on tall fescue pastures with high endophyte infection rates (> 70%) increased ADG compared to other stocking rates. However, this occurred at only one location within the study, and no statistical analysis was provided. The authors rationalized that the higher stocking rates at this location may have improved forage utilization on the pastures, which allowed for the removal of apical meristems by the steers before their development into seedheads. At low stocking rates, less meristems were removed and resulted in a greater number of seedheads within the pasture, which would lead to a large dose of alkaloid and lower ADG if consumed by the steers. Other researchers examining multiple stocking rates on tall fescue have reported inconclusive or no effects of higher stocking rates reducing symptoms of tall fescue toxicosis. Aiken and Piper (1999) reported no linear response in ADG or serum prolactin concentrations for steers grazing EI tall fescue pastures (3.0 to 6.0 steers ha⁻¹). However, steers within this study were either removed from EI pastures or received supplementation before a significant amount of heat stress would have occurred. Aiken et al. (2006) reported no response in steer ADG to four stocking rates (3.0 to 6.0 steers ha⁻¹) when steers did not receive a steroid implant. However, these authors reported a linear decline for ADG with increasing stocking rates for steers within the steroid implant treatment, which is a more typical animal response for the grazing of cool-season forages (Mott, 1960; Jones and Sandland, 1974). There was no effect of stocking rate on serum prolactin concentrations for the implanted steers, but concentrations increased with lower stocking rates for the non-implanted steers. The authors hypothesized that the forage became mature and unpalatable at low stocking rates and the forage intake was likely greater at the higher stocking rates and led to an intake of greater concentrations of alkaloids. No

mention was made to the amount of tall fescue seedheads present within the latter two studies (Aiken and Piper, 1999; Aiken et al. 2006).

Use of Plant Growth Regulators on Forages

The use of herbicides to reduce reproductive growth in grasses has been prevalent within the turf industry for many years, but only a few chemicals examined for suitability within the forages industry. Undersander (1986) reported that mefluidide [N-[2, 4-dimethyl-5[[trifluoromethyl) sulfonyl] amino] phenyl] acetamide] reduced the heading percentage of wheat [*Triticum aestivum* L.] (60 vs. 96%) when applied during early spring (18 March) at 280 g ha⁻¹. Lower rates of the mefluidide or earlier application had no effect on the heading percentage. Haferkamp et al. (1987) showed that mefluidide applied at three rates (0.14 to 0.42 kg a.i. ha⁻¹) reduced the seedhead density of crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.] with the highest chemical rates reducing the densities by 91%. These authors also stated that the seedheads present with the mefluidide -treated forage were smaller and misshaped. Although the presence of seedheads was not explicitly measured, Sheaffer and Marten (1986) reported that mefluidide (0.42 kg ha⁻¹) increased the leaf stem⁻¹ ratios of five cool-season species (tall fescue, Kentucky bluegrass, orchardgrass, smooth brome grass, and reed canarygrass). These authors also showed environmental variability on the effectiveness of the herbicide to suppress reproductive growth when applied 24 September, 28 April; and 13 May. All applications increased the leaf stem⁻¹ ratios of the forage (2.1, 2.5, and 2.6 vs. 0.9 for control, respectively) in the first year, but only the early spring date increased the ratio of the grasses during the second year (2.1 vs. 0.8). Roberts and Moore (1990) found similar results with amidochlor [N-[(acetylamino) methyl] 2-chloro-N-2, 6-diethylphenyl] acetamide] applied to tall fescue at 1.12 kg a.i. ha⁻¹ in the spring. The authors reported that the herbicide reduced the number reproductive culms from approximately 250 seedheads m⁻² to 75 seedheads m⁻² during the first year of the study, but found no effect the following year. Reynolds et al. (1993) reported clethodim [(E,E)-(±)-2[1[[3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one] reduced

the seedhead densities of tall fescue, with greatest inhibition coming from rates of 22.4 g a.i ha⁻¹ and with crop oil (2.3 L ha⁻¹) as a surfactant (35, 14, and 0 seedheads m⁻² for November, March, and April applications vs. 240 seedheads m⁻² for control). Moyer and Kelley (1995) reported mefluidide (280 g ha⁻¹), imazethapyr [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethy-3-pyridinecarboxylic acid] (35 and 70 g ha⁻¹), and metsulfuron [2-[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid] (6.3 and 8.4 g ha⁻¹) reduced the number of seedheads produced by Kentucky 31 and 'Fawn' tall fescue when applied during the early spring in Kansas and reduced seedhead densities by 91, 83, and 67%, respectively, when applied at their highest rates. These authors also showed the inhibitory effects of metsulfuron was offset by that the addition of 2,4-D [(2,4-dichlorophenoxy)acetic acid] (140 g ha⁻¹) as the seedhead densities of this mixture did not differ from the controls (387 vs. 488 seedheads m⁻²) and were higher than when metsulfuron was applied alone (260 seedheads m⁻²). Aiken et al. (2012) applied ChaparralTM (9.45% metsulfuron and 62.13 % aminopyralid [4-amino-3, 6-dichloro-2-pyridinecarboxylic acid]) at rates of 140 g ha⁻¹ and found the herbicide, on average, reduced the seedhead densities of tall fescue pastures from 90.6 to 6.3 seedheads m⁻².

The suppression of seedheads in forages results in lower forage yields during the initial harvest because of a loss of reproductive stems, but there has been little evidence to show any carryover effects in the regrowth of the forage. Glenn et al. (1980) reported lower yields for tall fescue treated with mefluidide at 0.28 and 0.56 kg ha⁻¹ when harvested 21 days after application (3338 and 3987 vs. 4614 kg ha⁻¹ for control areas), but found no difference in the yields after 29 d of regrowth (50 d after initial herbicide treatment) (582, 493, and 538 kg ha⁻¹, respectively). During the second year of the study, only the 0.56 kg ha⁻¹ treatment had lower yields than the control for the first harvest (1238 vs. 1715 kg ha⁻¹), and no differences were observed in the yields of the regrowth (50 d; 71 d after mefluidide application). Further, these authors showed that mefluidide (0.28 kg ha⁻¹) reduced forage yield harvested two weeks following application at two early dates (1 and 15 April), but not for two later dates (29 April and 13 May) (Glenn et al.

1981). Sheaffer and Marten (1986) reported mefluidide (0.42 kg ha^{-1}) reduced the yields of five cool-season grasses (average across species) when applied in the fall ($2,300 \text{ kg ha}^{-1}$), early spring ($1,500 \text{ kg ha}^{-1}$), and late spring ($1,800 \text{ kg ha}^{-1}$) (Control: $3,100 \text{ kg ha}^{-1}$), but no difference between the total seasonal forage yield (3 harvest) between the control and fall application ($6,500$ vs. $5,900 \text{ kg ha}^{-1}$) which were only slightly higher than seasonal yields from the early and late spring applications ($5,300$ and $5,500 \text{ kg ha}^{-1}$, respectively). In the following year of this experiment, only the yields from the early spring application was lower than the control ($2,400$ vs. $4,800 \text{ kg ha}^{-1}$) for the first harvest, and no difference of the total seasonal yields was found between treatments. Roberts and Moore (1990) reported lower forage yields for tall fescue during the first harvest following the application of $1.12 \text{ kg a.i. ha}^{-1}$ of amidochlor to tall fescue pastures, but also observed no difference in the yields of the regrowth. Reynolds et al. (1993) and Moyer and Kelley (1995) also experienced lower forage yields from application of clethodim, mefluidide, imazethapyr, and metsulfuron, but did not estimate yields of forage regrowth. Aiken et al. (2012) showed lower forage yields for Chaparral-treated pastures, but reported that the magnitude of the difference varied between grazing seasons.

There is typically an increase in forage nutritive value because lower amounts of stem materials are present within the herbage treated with seedhead suppressing herbicides. Glenn et al. (1980; 1981) reported mefluidide-treated tall fescue maintained higher CP concentrations and lower cellulose concentrations over the growing season. Haferkamp et al. (1987) reported higher CP, *in vitro* digestible organic matter (IVDOM), and ash content, as well as, lower neutral detergent fiber for mefluidide-treated crested wheatgrass. Similar trends in CP, NDF, and IVDDM were reported for forages treated with amidochlor, clethodim, imazethapyr, and metsulfuron (Roberts and Moore, 1990; Moyer and Kelley, 1995; Reynolds et al., 1993; Aiken et al. 2012). Aiken et al. (2012) found that the CP concentrations of leaf blade and sheaths of vegetative tillers were greater within Chaparral-treated pastures than control areas (180 and 110 vs. 157 and 85 g kg^{-1}), but reported no IVDDM differences for these tiller components (818 and

733 vs. 806 and 742 g kg⁻¹). These authors also showed there was no clear trend for water soluble carbohydrate (WSC) as this parameter varied between herbicide treatments, seasons, and morphological components. Robb et al. (1982) showed the initial harvest and regrowth of mefluidide-treated tall fescue had higher *in vivo* digestibilities (658 vs. 593 g kg⁻¹), and that mefluidide-treated forage from the initial harvest had greater N and NDF digestibilities when fed to lambs (N Digestibility: 59.6 vs. 56.3%; NDF Digestibility: 58.8 vs. 58.2%).

There is less information in the literature on the impact of chemically suppressing reproductive growth on animal production despite various improvements in nutritive values. Allen et al. (1983) reported mefluidide applied to orchardgrass (0.22 and 0.28 kg ha⁻¹) did not improve steer live-weight gains (101, 105, 103 kg for 0, 0.22, and 0.28 kg ha⁻¹ mefluidide treatments, respectively), but forage nutritive value and production was limited by dry condition. Wimer et al. (1986) showed mefluidide applied to smooth bromegrass pastures (0.28 kg ha⁻¹) improved the seasonal weight gains of cows (99 vs. 68 kg ha⁻¹), while calf gains were improved in the first year of the study (171 vs. 146 kg ha⁻¹). Calf gains were similar during the second year (103 vs. 96 kg ha⁻¹); with calves on the mefluidide-treated forage only having higher gains during July of this grazing season. Most of the gains within the cows came during the summer months of grazing. Cow and calf gains were greater or similar for the control pasture during May, June (1983), and September, but cows grazing the mefluidide-treated pastures lost less weight during June (1982), July, and August, resulting in great seasonal gain. The authors also attributed the better maintenance of the cows body condition during the summer was due to the forage within the control pastures becoming mature and of low nutritive value, whereas the mefluidide-treated pastures were composed primarily of immature, vegetative tillers (Wimer et al., 1986). Similarly, Turner et al. (1990b) reported similar concentrations of IVDOM and CP for mefluidide-treated and control tall fescue until early summer months when the latter forage became mature, resulting in lower nutritive value. These authors also reported higher forage intakes for heifers fed mefluidide-treated hay and higher weight gains for these heifers and steers grazing mefluidide-

treated pastures (Turner et al., 1990a). Steer ADG was increased (0.93 kg d^{-1}) when animals were allowed to graze tall fescue pastures receiving Chaparral compared to the controls (0.63 kg d^{-1}) (Aiken et al., 2012). There was also a reduction in the severity of the symptoms of tall fescue toxicosis for steers grazing within the Chaparral-treated pastures, with lower rectal temperatures (40.8 vs. 41.3°C) and higher concentrations of serum prolactin (100.7 vs. 47.4 ng ml^{-1}) than steers grazing the control forage.

It is well-documented in the literature that chemical suppression of forage reproductive growth leads to improved nutritive value of the forage, with a few studies suggesting that this translates in higher animal gains. However, these studies compare animal production at one stocking rate, and since the relationship between stocking rate and animal gains is dynamic (Mott, 1960; Jones and Sandland, 1974), chemical seedhead suppressions studies need to be evaluated at multiple stocking rates to ensure trends in production are consistent across other grazing intensities. Since forage yields are also reduced by the herbicide, there is a possibility that forage availability may become limiting within herbicide-treated pastures at higher stocking densities and result in lower gains compared to control pastures. Subsequently, at low stocking densities grazing pressures may become reduced enough in control pastures that steers may selectively graze a diet that is of similar nutritive value to the herbicide-treated pastures (Turner et al., 1990b), resulting in similar gains between treatments. The effect of chemical seedhead suppression to reduce the severity of tall fescue toxicosis symptoms has also only been examined within one preliminary study (Aiken et al., 2012). The effectiveness of herbicides to alleviate fescue toxicosis should also be examined at multiple grazing pressures, as there is circumstantial evidence that suggests similar responses may be obtained by using higher stocking rates (Bransby et al., 1988).

CHAPTER III: Materials and Methods

Site and Layout

This research was conducted at the University of Kentucky (UK) C. Oran Little Research, near Versailles, KY on a McAfee silt loam (Fine, mixed, active, mesic Mollic Hapludalf) and a Maury-Bluegrass silt loam (Fine, mixed, active mixed, mesic Typic Paleudalf) complex. Tall fescue with multiple types of endophyte- infection was sprayed two times with glyphosate at 4.68 L ha⁻¹ on 31 August 2009 and 18 March 2010 (Johnson et al., 2012). Endophyte-infected Kentucky 31 (infection rates = 82 and 73% for 2011 and 2012, respectively) tall fescue was planted on 19 March 2010 at 28 kg of pure live seed (PLS) ha⁻¹. Areas of poor tall fescue emergence during the spring 2011 were reseeded at the same rate on 14 September 2011. The study area was fertilized annually with 78 kg N ha⁻¹ which was applied on 28 March 2011 and 16 March 2012.

The experimental area consisted of twelve 1.0 ha pastures, and pastures were blocked according to the average slope and dominate soil type. Two levels of grazing intensity and two herbicide treatments were arranged in as a 2 x 2 factorial design and were randomly assigned to pastures within the blocks. Herbicide treatments consisted of Chaparral™ (DowAgrosciences, Indianapolis, IN) (62.13 % aminopyralid [4-amino-3,6-dichloro-2-pyridinecarboxylic acid] and 9.45% metsulfuron-methyl [methyl 2-[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoate]) applied at 0 or 140 g ha⁻¹ (metsulfuron: 13.2 g ha⁻¹, aminopyralid: 87.0 g ha⁻¹) on 7 April 2011 and 19 March 2012. Pastures not receiving Chaparral received Milestone™ (40.6% aminopyralid) at 220 g ha⁻¹ (aminopyralid: 89.3 g ha⁻¹) on the same dates. All herbicides were applied with 0.25% NIS (Activator 90, Loveland Products Inc., Greeley, CO). Each herbicide treatment was grazed with variable stocking rates to target 3,300 or 2800 ± 280 kg DM ha⁻¹ of available forage maintained during the season for the low and moderate grazing intensities, respectively.

Steers were allowed to graze pastures for 74 days (5 May 2011 to 14 July 2011) and 84 days (3 April 2012 to 26 June 2012). A variable stocking rate was used in the study to give an estimate of the carrying capacity for each treatment. Each year three “tester” steers were allowed to graze each pasture for the entire grazing season, while “grazer” steers were added or removed when forage availability exceeded or was less than the targeted goal for each grazing intensity treatment. When not assigned to a tall fescue pasture, grazer steers were maintained on an adjacent pasture of bermudagrass [*Cynodon dactylon* (L.) Pers.] interseeded with rye [*Secale cereal* L.], and annual ryegrass [*Lolium multiflorum* Lam.]. Tester animals in 2011 consisted of Angus crossbred steers (initial body weight (BW): 264 ± 22.3 kg). Tester steers in 2012 were composed of Hereford, Charolais, and Angus steers (initial BW: 316 ± 16.1 kg) due to the limited availability of one specific breed, with each individual breed equally represented among treatments. Steers were blocked according to initial body weights (i.e. light, middle, and heavy) and were randomly assigned to treatments within a given block. Steers were maintained according to UK-International Animal Care and Use Committee (IACUC) protocol #2011-0797 and were vaccinated for blackleg (Alpha 7/MB™-1, Boehringer Ingelheim Vetmedica Inc., St. Joseph, MO) and respiratory infections (Vista®Once SQ, Intervet Inc., Millsboro, DE) and received steroidal implants (Synovex® S: 200 mg progesterone-20 mg estradiol, Fort Dodge Animal Health, Fort Dodge, IA) at the beginning of the season. Steers were dewormed with moxidectin (Cydectin®, Fort Dodge Animal Health, Fort Dodge, IA) as needed throughout the grazing season.

Pasture Responses

Forage Availability

Forage availability was estimated approximately every two weeks beginning on 10 May 2011 and 23 April 2012 according to the disk meter method described by Bransby et al. (1977). The compressed canopy height was measured at 50 random locations within a pasture with a 1.9 kg disk (diameter: 33 cm) that was allowed to float freely on a graduated shaft. A calibration

curve was developed to convert the measured canopy heights into estimates of available forage by harvesting the forage under the area of these disks (0.09 m²) at three locations per pasture on 31 May 2011, 14 July 2011, 7 May 2012, and 18 June 2012. Forage was placed in a forced air oven at 65°C for two days to correct for moisture content. It was necessary during 2012 to correct for dead plant material within these calibration areas and was done by predicting this percentage with near infra-red spectroscopy (NIRS). After drying, forage samples were ground to pass through a 1-mm screen with a cyclone mill (UDY Corp., Fort Collins, CO) and scanned with a Foss 6500M NIR (Foss NIRSystems Inc., Laurel, MD). Materials collected for the estimation of botanical composition of the pastures (see below) were also used to develop NIRS calibration curve. These materials were hand-separated to determine the percentage of dead and green forage within the sample before being remixed and ground to 1-mm with a cyclone mill. A regression between the spectral scans and percentage of dead material was determined using a partial least squares approach. Samples were scanned between wavelengths of 400 to 2500 nm with light scatter corrected for by standard normal variant (SNV) transformation and detrending of the spectra. Mathematical treatments for the regression were chosen based on its ability to produce a low standard error of calibration (SEC), standard error of cross validation (SECV), and high minus the variance ratio (1 – VR). Spectral outliers were identified as having a global H-statistic greater than 3. Suitability of the regression was evaluated by predicting the percent dead materials from these calibration samples. The disk meter calibration samples collected on 7 May and 18 June 2012 were ground to pass through a 1-mm sieve and their percentage of dead and green forage determined using the NIRS calibration curve. These estimated percentages were then used to derive separate relationships between compressed canopy height with dead and green forage availabilities.

Forage Nutritive Value and Ergovaline Concentration

Forage samples were collected from three 0.9 m² quadrats (2.54 cm stubble height) within each pasture on the dates when forage availabilities were estimated every two weeks beginning on 10 May 2011 and 23 April 2012. Approximately 50 reproductive tillers (No Chaparral treatment, only) and 50 vegetative tillers (all treatments) were collected from pastures and separated into their morphological components (leaf blades, leaf sheaths, stem, seedheads) on 11 May 2011, 17 June 2011, 20 April 2012, and 5 June 2012. Samples were then stored at -20°C until frozen and lyophilized using a Botanique Model 18DX48SA freeze dryer (Botanique Preservation Equipment Inc., Phoenix, AZ). Samples were ground to 4 mm with a Wiley mill (Thomas Scientific, Swedesboro, NJ) after drying. A sub-sample of this course ground material was taken and ground through a 1-mm screen using a cyclone mill.

In vitro digestible dry matter (IVDDM) was determined using the filter bag method described in Vogel et al., 1999. Approximately 0.25 g of sample was placed in pre-weighed ANKOM F5 Filter bags (ANKOM Technology, Macedon, NY). Twenty four samples were placed into a Daisy II incubator (ANKOM Technology, Macedon, NY) jar assembly with 1600 ml of buffer solution (Vogel et al., 1999) and 400 ml of rumen fluid collected from cannulated Holstein steers being fed a corn silage-alfalfa diet. A fiber bag containing an alfalfa (*Medicago sativa* L.) standard, as well as an empty bag to account for any potential loss bag material that may occur during digestion, were also added to each jar assembly. Samples were allowed to digest within the incubator for 48 hours at 41°C before being washed with a neutral detergent solution at 100 °C using an ANKOM 200 fiber analyzer (ANKOM Technology, Macedon, NY) for one hour to remove microbial matter. Samples were dried for 12 h at 41 °C and weighed to determine the amount of forage lost to digestion.

Concentration of water soluble carbohydrate (WSC) was determined using a method based on the ferricyanide method used by Dairy One (Ithaca, NY) (Aiken et al., 2012). Approximately 0.25 g of sample was placed into a 50 ml centrifuge tube with 25 ml of distilled

water and placed on a rocking shaker at 50 rpm for three hours. Next, the tubes were centrifuged and a 2 ml aliquot of the supernatant placed into a 20 ml glass test tube. One milliliter of 1N H₂SO₄ was placed into each test tube and the tubes were placed into a 100 °C water bath for 20 minutes. After cooling, 0.5 ml of 1N NaOH was added to the tube and mixed. A 0.5 ml aliquot of this mixture was removed and placed into a fresh 20 ml test tube with 10 ml of a potassium ferricyanide solution (K₃Fe(CN)₆: 0.774 g/L; Na₃PO₄: 38.0 g/L) and placed back into the water bath for 15 minutes. After cooling, the solution was transferred to a cuvette and the absorbance read at 420 nm with a Beckman Coulter DU 800 UV-VIS spectrophotometer (Beckman Coulter Inc., Brea, CA.) The WSC concentration of the forage was determined using a standard curve from the absorbance of 0, 200, 400, 600, 800, and 1000 ppm of glucose solution.

Nitrogen content of the forage was determined via combustion with a Leco FP-215 N Analyzer (LECO Corp., St. Joseph, MI.) and was converted to crude protein (CP) by multiplying by 6.25. Ergovaline concentrations were determined by Dr. L.P. Bush's laboratory using a modification of the HPLC method described in Yates and Powell (1988). Reported concentrations of ergovaline are the sum of it and its isomer, ergovalinine.

Other Parameters

The botanical composition of the pastures was estimated on 31 May 2011 and 28 May 2012 using a double-sampling technique (Ortega-Santos, 1990). The percentages of tall fescue, orchardgrass, and other species were visually estimated from 30 random 0.09 m² quadrats (25 quadrats per pasture were taken in 2012) in each pasture. A curve was developed to correct for visual bias by harvesting and hand separating three quadrats per pasture to determine the actual percentage of each species. The amount of dead material was also estimated during this separation in 2012 to use as a correction factor in the estimation of forage availability (see above), but was excluded as a component of the botanical composition. The dead material was discarded during 2011. The endophyte infection rate of pastures was determined by an immunoblot assay kit (Agrinostics Ltd. Co., Watkinsville, GA) from 25 vegetative tall fescue

tillers collected on 1 June 2011 and 5 June 2012. The carrying capacity (CC) of each treatment was estimated by determining the number of days tester and grazer steers were on specific pastures and are reported as the number of steer grazing days ha⁻¹. Tall fescue seedhead densities were estimated by counting the number of reproductive culms within 30 0.25 m² quadrats on 16 June 2011 and 22 May 2012.

Steer Responses

Average daily gain (ADG) of tester steers was determined from weights taken at the start and end of the grazing season. Steers were weighed following a 12 to 14 hours fast to minimize potential variation from the amount of material within the rumen. Rectal temperatures and blood samples were collected from the tester steers on 6 June 2011 and 22 May 2012 and at the end of grazing. Blood samples were collected from the jugular vein and were centrifuged at 3,000g to separate the serum from blood cells. Serum samples were stored at -20°C until shipment to Dr. N. Schrick's laboratory at the University of Tennessee where the concentration of prolactin was estimated using radioimmunoassay (Bernard et al., 1993). Rectal temperatures were taken with a TM99A digital thermometer (Cooper-Atkins Corp., Middlefield, CT.). Carcass-related traits were determined at the end of the grazing season for tester steers using an Aloka SSD-500V (Hitachi Aloka Medical, Ltd., Tokyo, Japan) ultrasound with a 3.5-MHz linear array transducer (UST 6049). Scans were taken with the transducer between the 12th and 13th ribs to estimate the rib-eye area (REA) and back-fat thickness (BFT). Scans of the rump-fat thickness (RFT) were collected between the hip and rump. Estimates of these parameters were determined from images using Blackbox Pro 5000 image capturing system (Biotronics Inc., Ames, IA). The amount of total animal gain per area (GPA) was determined by the multiplication of the tester ADG by the CC.

Statistical Analysis

Data were analyzed as a RCBD with three replications using PROC Mixed in Statistical Analysis Software (SAS) (v.9.2, SAS Institute Inc., Cary, NC). Blocks, as well as its interactions, were considered random effects, while herbicide treatment and grazing intensity and their interactions were analyzed as fixed effects. Years was also analyzed as a fixed factor because treatments were re-randomized between growing seasons. Covariance analysis was used to determine the effect of herbicide, stocking rate, and their interaction on the calibration regressions used for the determination of forage availability and botanical composition, and the number of regression developed chosen accordingly based on the significance of these factors. Repeated measures analysis was conducted on estimates of forage availability and nutritive value to determine covariance between dates during the growing season. Because of the reestablishment of tall fescue in sparse areas of the pastures between the 2011 and 2012, treatments were randomly reallocated to the pastures before the 2012 grazing season and thus parameters measured over multiple years were not considered as a repeated measure. A 1st order autoregressive (AR(1))covariance structure was used for analysis of total forage availability in 2011, while a compound symmetry (CS) structure was used for the total and green forage availabilities during the 2012 growing seasons. Dead forage availability in 2012 was analyze using a heterogeneous AR (1) covariance structure. No temporal correlation detected within the estimates of forage nutritive value and these samples were analyzed as a split plot in time, with the herbicide treatment and stocking rate combination as the whole plot and sampling date as the sub-plot. Degrees of freedom were adjusted using the Satterthwaite approximation to minimize Type I error rates on repeated measures (Little et al., 2006). Mean comparisons among treatments was done using the /PDIFF option of LSMEANS in SAS, and comparison of trends in repeated measures done using regression method described by Little et al., 2006.

Climatic Data

A weather station was not at the location so climatic data from College of Agriculture weather station located in Lexington, KY (approximately 21 km east) was used to describe variation seasonal climatic trends. A temperature-humidity index (THI) was used to provide an estimate of the heat stress experience by the steers during the grazing season and was derived according to Tarazon-Herrera et al. (1999) as:

$$\text{THI} = 0.45T + 0.55TH - 31.9H + 31.9$$

Where:

T = maximum daily temperature (°F)

H = maximum relative humidity/100

CHAPTER IV: Results and Discussion

Climatic Conditions

The climatic conditions of Lexington, KY for the 2011 and 2012 growing season, as well as a 10-Yr average for the site, are summarized in Figures. 4-1, 4-2, and 4-3. The average monthly temperatures of 2011 were approximate to the 10-Yr average (Figure 4-1), although April and July temperatures were slightly above average (14.6 vs. 13.7 °C and 26.3 vs. 24.6 °C, respectively). The early spring of 2012 exhibited higher than normal temperatures (March: 13.8 vs. 8.6 °C), but returned to more typical conditions during April and June (Fig. 4-1). The average monthly temperature was also slightly elevated during May of 2012, but the magnitude was not as great as during March (May: 20.6 vs. 18.3 °C). A larger amount of precipitation was received during the spring of 2011 (Figure. 4-2), particularly in April when the site received more than double its average precipitation (323 vs. 135 mm). The summer months (June and July) received slightly less than average precipitation (Figure. 4-2), but received 175 mm more overall precipitation during 2011. The 2012 growing season was drier than average (Figure. 4-2), with a precipitation deficit of 272 mm occurring by the end June. The temperature-humidity index (THI) was higher than average during the early spring (March and April) and summer (July) of 2011, but was similar during the late spring and early summer (May and June) of this growing season (Figure. 4-3). The THI was higher in March of 2012 (65.9 vs. 56.2), but was comparable to average conditions during April. May and June in 2012 had THI that were slightly below and above average, respectively (Figure. 4-3).

Botanical Composition

Covariance analysis indicated that year, herbicide treatment, and grazing intensity did not affect ($P > 0.40$) the relationship between the predicted and actual estimates of species composition, and accordingly, calibration samples were pooled to derive one regression for the tall

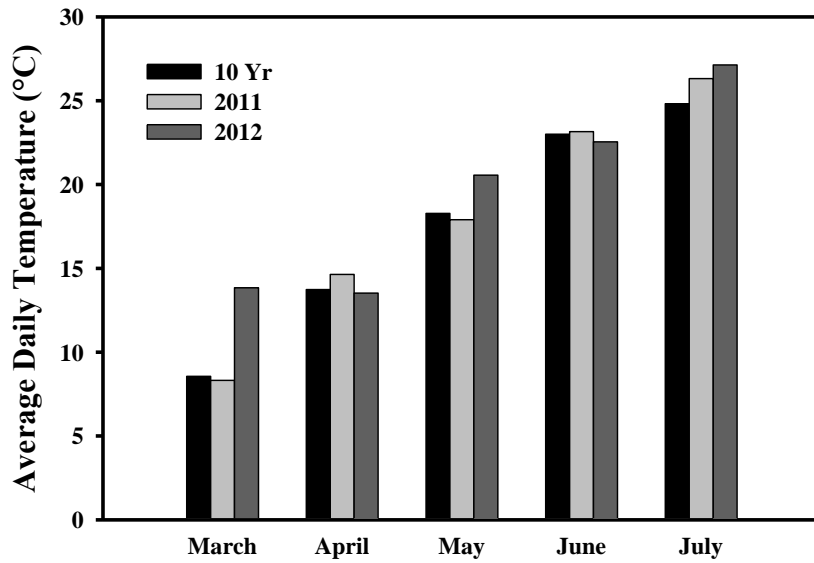


Figure 4.1. Average monthly ambient temperatures (°C) for Lexington, KY during the 2011 and 2012 growing season. 10 Yr = 10 year site average.

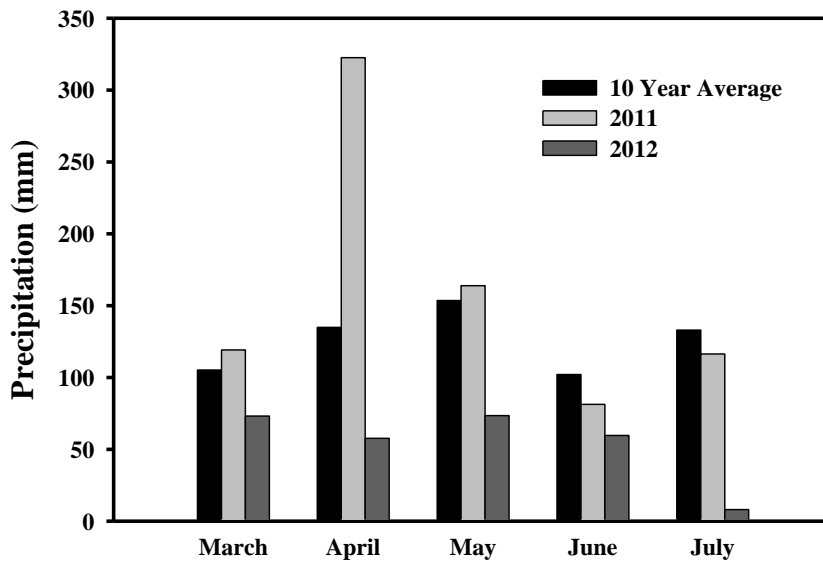


Figure 4-2. Monthly precipitation (mm) for Lexington, KY during the 2011 and 2012 growing season. 10 Yr = 10 year site average.

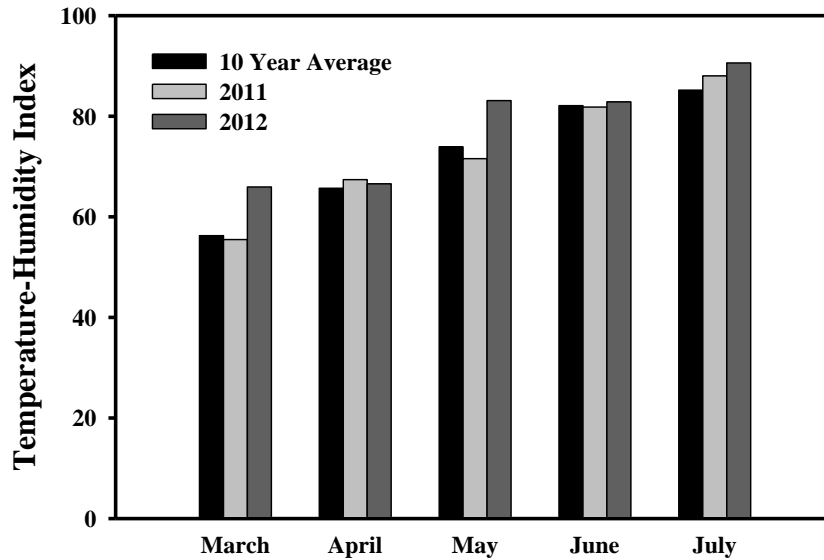


Figure 4.3. Average monthly temperature-humidity index (THI) for Lexington, KY during the 2011 and 2012 growing season. 10 Yr = 10 year site average.

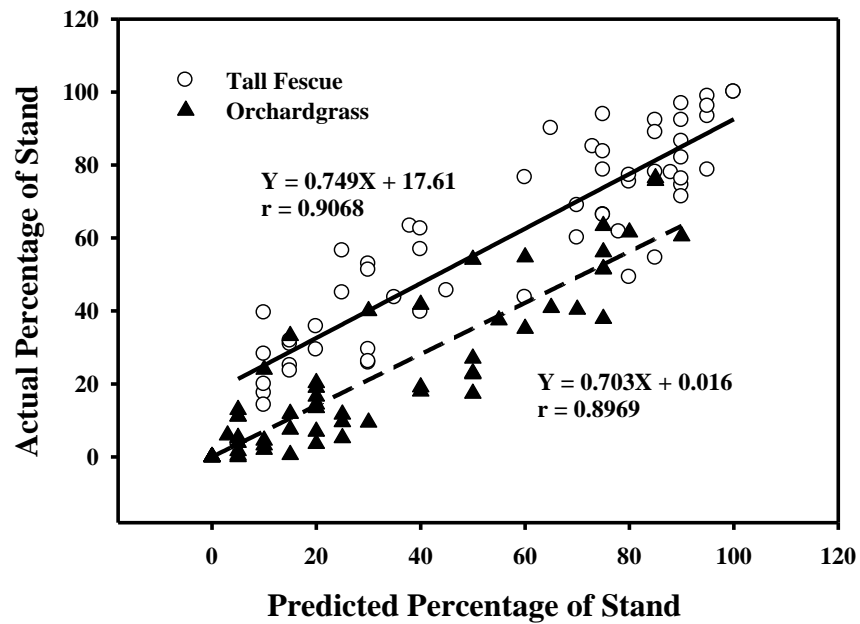


Figure 4-4. Regressions between visually-predicted and actual percentage of tall fescue and orchardgrass within double-sampling calibration samples.

fescue and orchardgrass components (Figure. 4-4). The relationship between the visually-predicted estimates and their actual percentage within mixture was linear ($P < 0.05$) for both tall fescue ($r = 0.9065$) and orchardgrass ($r = 0.8964$). A satisfactory relationship ($r < 0.60$) was not obtained for the other species present within the pastures and their presence was determined as the remaining percentage following the subtraction of the tall fescue and orchardgrass estimates. This fraction was composed primarily of Kentucky bluegrass [*Poa pratensis* L.], crabgrass [*Digitaria spp.*], common chickweed [*Stellaria media* (L.) Vill.], purple deadnettle [*Lamium purpureum* L.], henbit [*Lamium amplexicaule* L.], and buckhorn plantain [*Plantago coronopus* L.] in 2011. Kentucky bluegrass, crabgrass, and buckhorn plantain comprised the other species during 2012. The amount of tall fescue was lower ($P < 0.05$) within Chaparral-treated pastures (62.1 vs. 70.0%). There was also a tendency ($P = 0.10$) for a higher percentage of tall fescue within the moderate GI pastures (68.8 vs. 63.4%). Orchardgrass populations did not differ ($P > 0.30$) between herbicide treatments or grazing intensities, and averaged 14.5% across years and treatments. The amount of other species present within the pastures varied between herbicide treatments and years. A greater percentage ($P < 0.01$) of the other species of vegetation within the Chaparral-treated pastures compared to the control pastures (24.4 vs. 10.6%) in 2011. However, no differences between these treatments existed during the 2012 growing season (22.3 vs. 18.6%, respectively).

Botanical composition was determined on a dry matter basis, it is expected that the use of Chaparral would lower the tall fescue biomass due to the inhibition of reproductive growth and corresponding loss in dry matter. Aiken et al. (2012) similarly reported a reduction in tall fescue of approximately 15% in Chaparral treatments within a tall fescue-Kentucky bluegrass mixture, but tall fescue composed greater than 50% of the pastures. The reduction in tall fescue within this study was not as great and may be due to differences in the maturity of the stands. In the current experiment, pastures consisted of relatively new stands of tall fescue (~ 2 years), and were partially reseeded following the first year of grazing. This would have likely negated any

additive losses of tall fescue that would have occurred from multiple grazing periods. Multiple other species of grass adapted to the environmental and management conditions, such as Kentucky bluegrass, would be present within older stands due to their encroachment over time. Any incident that would reduce the competitive ability of tall fescue, such as chemical suppression, may have resulted in an increase in their occurrence within the pasture. Although no difference was observed in the botanical composition of the Chaparral-treated pastures between years, the increase in the percentage of other species within the control pastures may have been the result of this encroachment of Kentucky bluegrass. The tendency for less tall fescue within the lower GI may be the result of localized grazing of the steers within these pastures (i.e. spot grazing). Animals tend to select a diet containing portions of the plant with the greatest nutritive value under low grazing pressures, and as the forage matures, may return to previously grazed areas to consume the high-quality vegetative regrowth (Cid and Brizuela, 1998). This type of grazing will deplete the carbohydrate reserves of the tillers and lead to plant death in these areas and eventually the encroachment of other species. There is also a chance that the accumulation of reproductive growth may have shaded developing tall fescue tillers, and led to fewer tillers with reduced vigor (Briske, 2007). This would have possibly led to the colonization of these areas by species more adapted to these conditions (i.e. Kentucky bluegrass) and is another possible explanation for the increased presence of other species within the control pastures during the second year of the study. This preference for the consumption of vegetative tissues may have also led to their greater removal within the Chaparral-treated pastures and result in lower estimates of tall fescue.

Seedhead Densities

Chaparral reduced tall fescue seedhead densities within treated pastures, but its effectiveness varied between years ($P < 0.05$). Chaparral reduced ($P < 0.01$) seedhead densities by 92.3% (4.2 vs. 54.6 seedheads m^{-2}) in 2011, while in 2012 the number of seedheads was reduced by 69.5% (38.0 vs. 124.6 seedheads m^{-2}). Although seedhead densities were measured

later in the growing season in 2011, the estimates were taken after relatively the same number of days grazing (42 and 48 d for 2011 and 2012, respectively), indicating that longer exposure to the steers did not account for the lower number of seedheads during 2011. Similar variability for the effectiveness of chemical seedhead suppression between years has been reported (Haferkamp et al., 1987; Sheaffer and Marten, 1986; Moyer and Kelley, 1995), but authors did not offer cause of the irregularity. Roberts and Moore (1990) credited the lack of a response in seedhead densities to amidochlor in the second year to the inherently low number of reproductive tillers during the growing season. The authors hypothesized that the reduced reproductive growth within the plots was the result of fewer tillers produced during the fall caused by unknown management factors.

The exact cause of the lower efficacy of Chaparral in 2012 is unclear. It is possible that the higher seedhead densities within the Chaparral-treated pastures in 2012 may simply be the result of more overall seedheads produced during this year. However, Aiken et al. (2012) reported Chaparral consistently reduced seedhead densities to < 8 seedheads m^{-2} , despite variable seedhead densities within control pastures that were similar to those seen within the current study. Warmer temperatures during the early portion of the spring in 2012 (Figure 4-1) may have produced more herbage at the time of application, which may have lessened the absorption of herbicide into vernalized tillers or its subsequent translocation to the site of action. Similarly, the higher temperatures may have resulted in the tillers being more physiologically active earlier at the time of treatment and allowed the plants to internally metabolize the herbicide quicker. Olson et al. (2000) reported wheat [*Triticum aestivum* L.] and jointed goatgrass [*Aegilops cylindrica* Host.] metabolized 100 and 60% of the sulfonylurea herbicide, sulfosulfuron, [1-(4, 6-dimethoxypyrimidin-2-yl)-3-(2-ethanesulfonylimidazo [1, 2-a] pyridine-3yl) sulfonylurea] after 48 hours when the plants were maintained at day/night temperatures of 25/23°C. Greater than 95% of the herbicide remained intact within both plants when the temperatures were decreased to 5/3°C. Similarly, Gallaher et al. (1999) reported higher temperatures (30/20°C) increased the metabolization of nicosulfuron [2-[[[(4,6-dimethoxy-2-pyrimidinyl)arnino]car-

bonyl]amino]sulfonyl]-N,N-dimethyl-3-pyridinecarboxamide] in corn [*Zea mays* L.] and primisulfuron [2-[[[[[4,6-bis(difluoromethoxy)-2-pyrimidinyl]amino]carbonyl]amino]sulfonyl]benzoic acid] and broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster] by approximately 20% compared to cooler conditions (20/10°C).

Forage Availability

Disk Meter Calibrations

Separate regressions were created for each growing season since year was determined to affect ($P < 0.05$) disk meter calibrations. Disk meter calibrations for each individual herbicide and grazing intensity treatment were needed in 2011 (Figure. 4-5), while one regression accurately described the relationship between total forage availability (TFA) and disk meter heights in 2012 (Figure. 4-6). The presence of a dense layer of dead material from the previous grazing season was collected with the calibration samples led to erroneously high estimates of TFA in 2012 (Figure. 4-6, 4-10, 4-11). To correct for this, near-infrared reflectance spectroscopy (NIRS) was used to quantify the amount of senescent material within the calibration samples, and was based on a calibration derived from the dead material obtained from estimation of pasture botanical composition. A summary of this calibration equation is provided in Table 4-1. Near-infrared reflectance spectroscopy accurately detected the presence of dead material within the calibration samples (SEC = 0.98; SECV = 0.504; 1-VR = 0.72, equivalent to the R^2 of cross-validation). This resulted in an adequate prediction equation (SEP = 3.93; $R^2 = 0.88$) that was equivalent to or exceeded previous reports of dead herbage with NIRS (Coleman et al., 1985; Marten et al., 1989). As with the TFA, one regression was necessary to describe the relationship between the amounts of green forage (GF) and disk meter heights (Figure. 4-7). Separate regressions were required to predict the amount of dead forage (DF) within the herbicide treatments (Figure. 4-8). A linear relationship was adequate to describe the relationship between disk meter heights and the various estimates of forage yields ($r > 0.75$; Figures 4-5 to 4-8).

Table 4-1. Summarization of near-infrared reflectance spectroscopy (NIRS) calibration for the percent dead material contained within 2012 disk meter calibration samples. SEC = standard error of calibration, SECV = standard error of cross validation, 1-VR = 1 minus the variance ratio, SEP = standard error of prediction, R^2 = coefficient of determination for predicted samples.

Percent Dead Material	Math Treatment	n	Mean	SEC	SECV	1-VR	SEP	R^2
	2,5,5,2	32	62.58	0.98	5.04	0.72	3.93	0.88

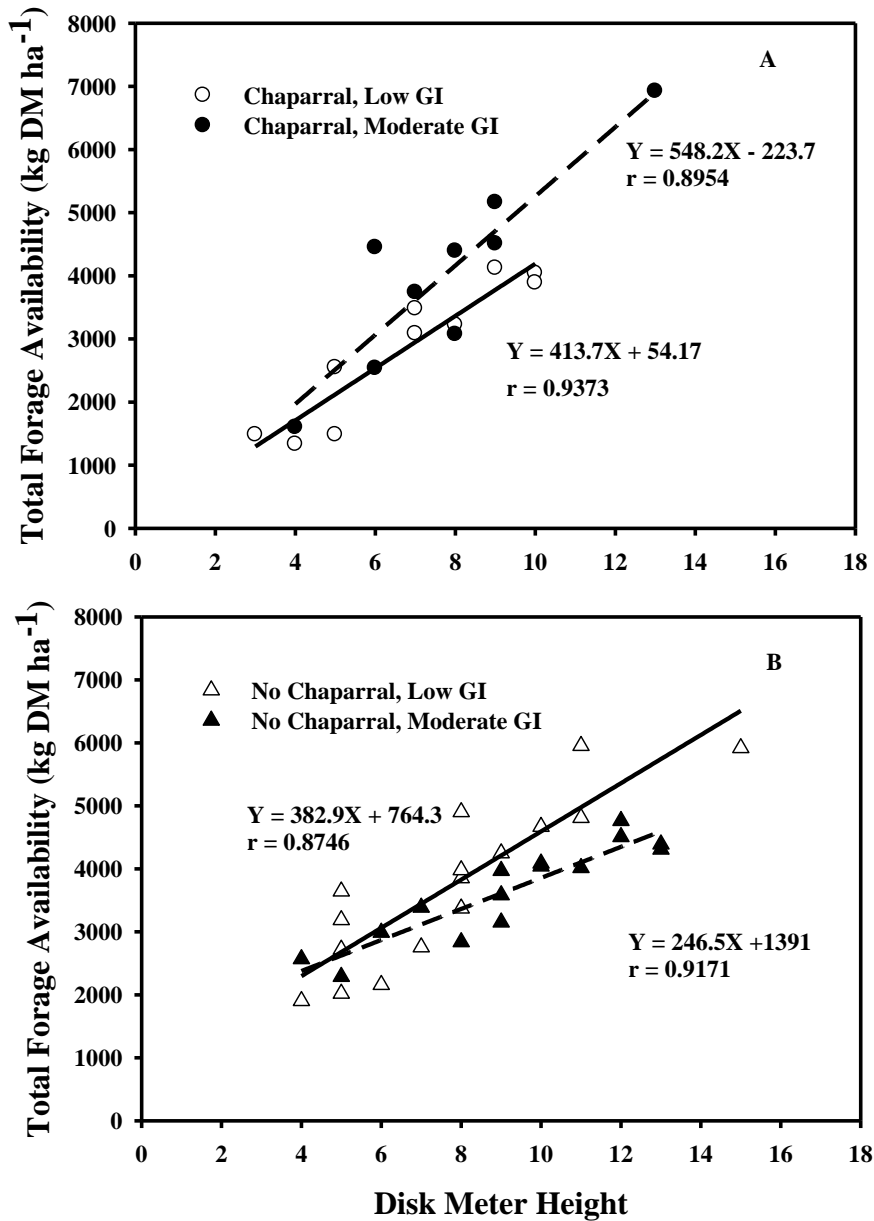


Figure 4-5. Relationships between total forage availability (kg DM ha⁻¹) and disk meter height for herbicide-grazing intensity (GI) treatments during the 2011 growing season with Chaparral (A) and No Chaparral (B) treatments.

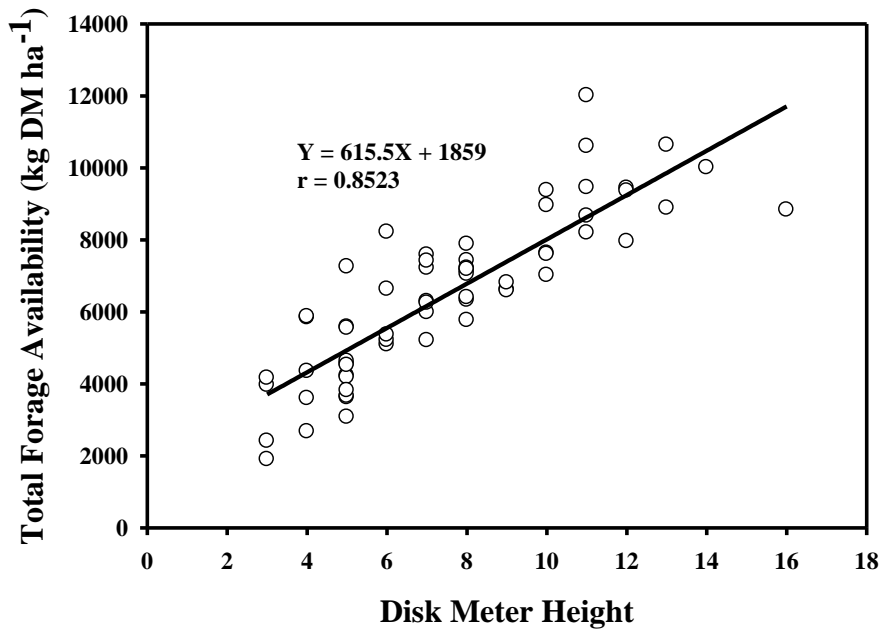


Figure 4-6. Relationship between total forage availability (kg DM ha⁻¹) and disk meter height during the 2012 growing season.

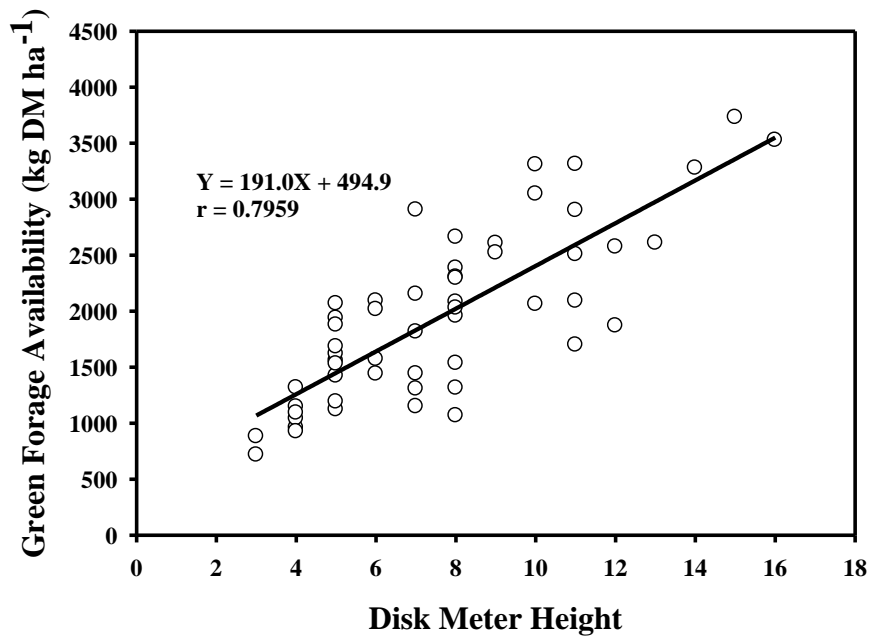


Figure 4-7. Relationship between the amount of green forage (kg DM ha⁻¹) and disk meter height during the 2012 growing season.

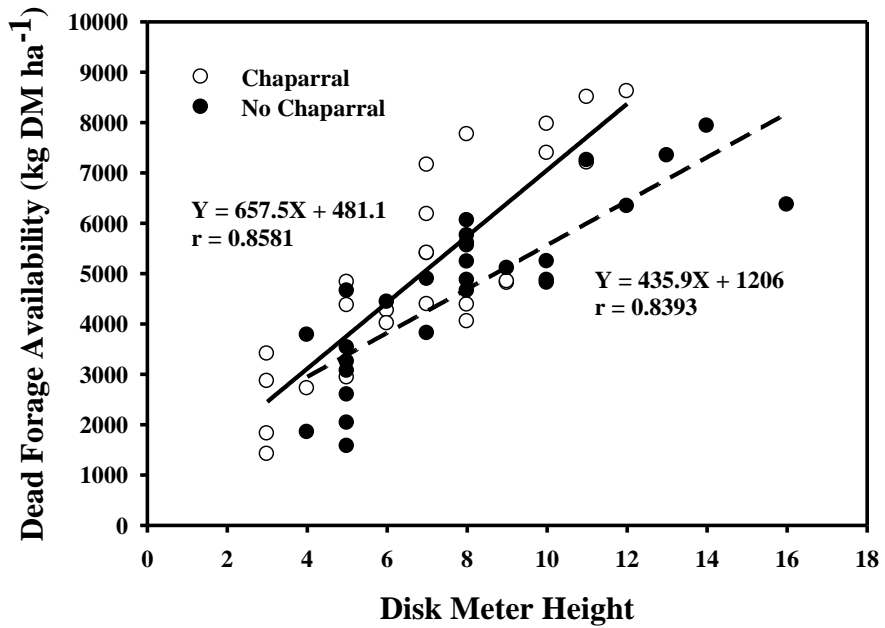


Figure 4-8. Relationships between the amount of dead forage (kg DM ha⁻¹) and disk meter height for herbicide treatments during the 2012 growing season.

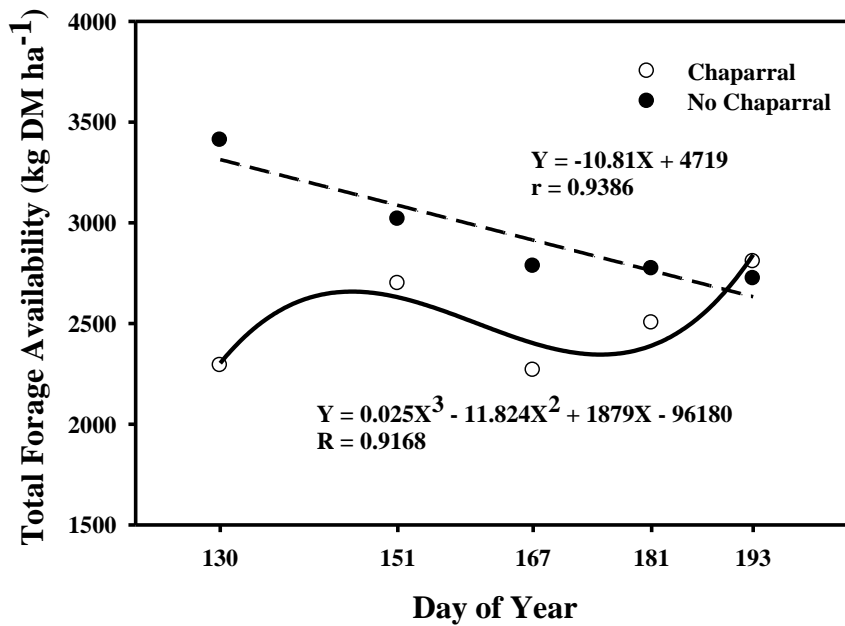


Figure 4-9. Trends in total forage availability (kg DM ha⁻¹) for herbicide treatments during the 2011 growing season.

2011 Growing Season

Grazing intensity did not affect TFA in 2011 ($P > 0.30$), while herbicide treatment varied with day of year (DOY) ($P < 0.01$; Figure. 4-9). The lack of a GI effect on TFA may be explained by two factors. First, it was apparent early within the grazing season that heavy stocking within Chaparral-treated pastures would lead to stand deterioration, and in the loss of one replicate of the Chaparral-moderate GI treatment. This led to the conservative addition of grazer animals throughout the remainder of the season. Additionally, the late start of grazing in 2011 resulted in forage within the control pastures being in the reproductive stages of growth when cattle were placed into the pastures. Although a higher ($P < 0.01$) average stocking rate (ASR) occurred within moderate GI pastures (4.96 vs. 3.48 steers ha⁻¹), the steers did not consume enough of the accumulated stem materials to result in significant differences in TFA. Total forage availability decreased linearly ($P < 0.05$, $r = 0.9386$) within the control pastures, while also exhibiting a cubic ($P < 0.05$; $R = 0.9168$) trend within the Chaparral-treated pastures. The regular adjustment of stocking densities, in conjunction with favorable growing conditions in the spring of 2011 (Figure. 4-1 and 4-2), may have led to the cubic trend in TFA in Chaparral-treated pastures. Stocking densities were lessened after DOY 167 in anticipation of the decreased summer production that is common to cool-season forage (i.e. “summer slump”). Instead, the ample moisture led to the continued accumulation of growth within the Chaparral-treated pastures. Total forage availability was initially lower ($P < 0.05$) within Chaparral-treated pastures, but did not differ from the control pastures at DOY 181 and 191 (Figure. 4-9; $P > 0.10$).

2012 Growing Season

Grazing intensity and herbicide both affected TFA in 2012 ($P < 0.05$; Figure. 4-10 and Figure. 4-11, respectively). As expected, the ASR was higher ($P < 0.05$) within the moderate GI treatment (4.96 vs. 3.48 steer ha⁻¹). Total forage availabilities decreased linearly ($P < 0.01$) within both the low and moderate GI treatments ($r = 0.9824$ and 0.9445 , respectively), with the decline of the moderate GI treatment proceeding at a greater rate ($P < 0.05$; Figure. 4-10). Total

forage availability was lower ($P < 0.01$) within the moderate GI pastures. Similar to 2011, TFA decreased linearly ($P < 0.01$; $r = 0.9969$) within the control pastures, and displayed a cubic trend ($P < 0.05$; $R = 0.9455$) within the Chaparral-treated pastures (Figure. 4-11). However, TFA was consistently lower ($P < 0.10$) within the Chaparral treatments at all dates in 2012.

The availabilities of green forage (GF) within the pastures followed similar trends as TFA for the grazing intensity and herbicide treatments (Figures. 4-12 and 4-13). There was more GF ($P < 0.01$) within the low GI pastures (Figure. 4-12). Green forage declined linearly within both grazing intensity treatments ($r = 0.9824$ and 0.9445 for low and moderate GI, respectively), but the low GI maintained higher levels of GF across the growing season. The amount of GF declined linearly in the Chaparral-treated and control pastures ($P < 0.01$; $r = 0.7962$ and 0.9969 , respectively) throughout the grazing period. Green forage initially declined in the Chaparral-treated pastures and reached a plateau at approximately DOY 141 (Figure. 4-13). The amount of GF was higher within the control pastures at all dates, except for DOY 169 ($P > 0.10$).

There was a tendency ($P = 0.09$) of an herbicide-GI interaction on the amount of DF within the pastures (Figure 4-14). There was no difference ($P = 0.38$) in the amount DF within the Chaparral-moderate GI and control-moderate GI treatments (4360 and 4526 kg ha^{-1} , respectively). However, the Chaparral-low GI treatment tended to have slightly higher amounts of DF ($P = 0.12$; 5610 kg ha^{-1}) than control-low GI (5311 kg ha^{-1}), and likely resulted from the herbicide hindering physiological activity within the initial growth of the forage. It was common to collect vegetative tillers that were entirely encased in senescent leaf tissues within this treatment, and it is possible that the drier conditions of this growing season may have slowed the decomposition of the dead tissues (Meentemeyer, 1978). The lower amounts of DF within the

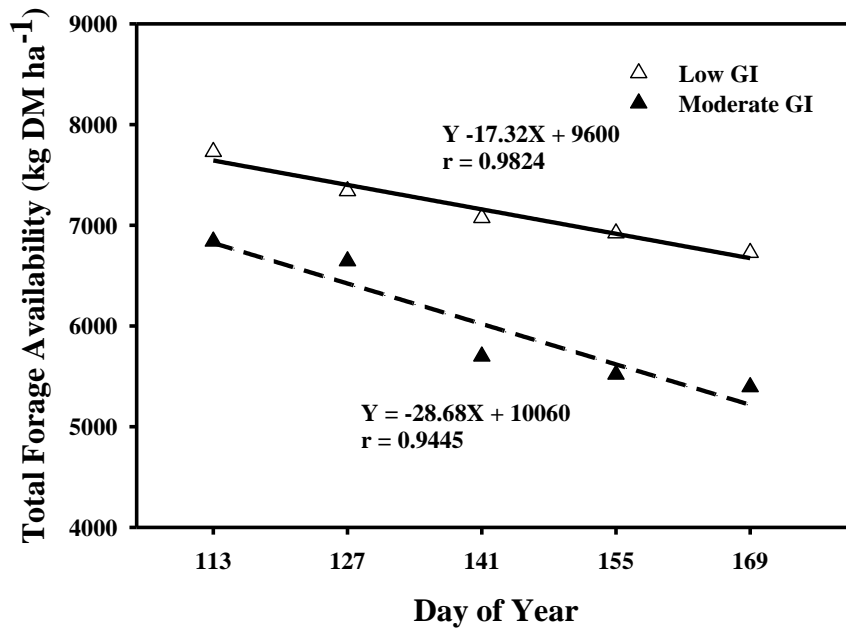


Figure 4-10. Trends in total forage availability (kg DM ha⁻¹) for grazing intensity (GI) treatments during the 2012 growing season.

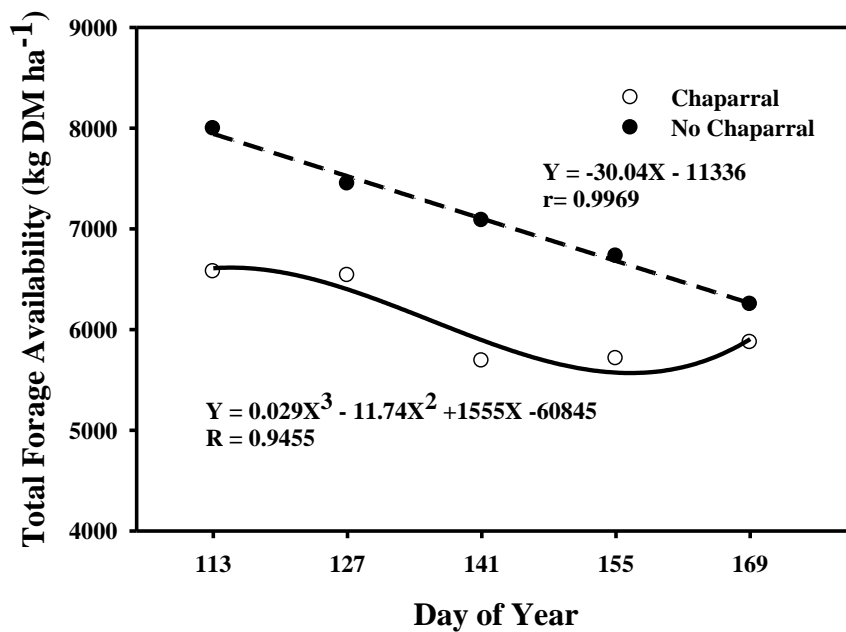


Figure 4-11. Trends in total forage availability (kg DM ha⁻¹) for herbicide treatments during the 2012 growing season.

Chaparral-moderate GI treatment was likely either the result of greater consumption by the animal or accelerated decomposition rate (Naeth et al., 1991; Shariff et al., 1994). Higher degrees of forage utilization within these pastures may have increased the decomposition of senescent tissues by allowing more light and moisture (i.e. dew) to reach the soil surface.

The amount of DF decreased linearly ($P < 0.01$) within both the low and moderate GI ($r = 0.9621$ and 0.9297 , respectively), with DF in the latter treatment decreasing at a greater rate ($P < 0.01$; Figure. 14-15). The amount of dead forage was higher ($P < 0.01$) within the low GI pastures, and is due to greater amounts of mature forage. Once grasses have progressed into the late stages of seed development, the leaf and stem tissues of the reproductive growth begin to senesce and would be considered as part of the dead fraction by the NIRS. Forage utilization would likely be higher in the moderate GI treatment and contain less of this senescent reproductive growth. The amount of DF within the herbicide treatments varied considerably throughout the grazing season (Figure. 4-16). As with the other estimates of available forage, DF demonstrated linear ($P < 0.01$; $r = 0.9969$) and cubic ($P < 0.01$; $R = 0.9455$) trends within the control and Chaparral-treated pastures, respectively. There was no difference ($P > 0.10$) in the amount of DF between the herbicide treatments until DOY 169, when more DF ($P < 0.01$) was observed within the Chaparral-treated pastures (4766 vs. 4316 kg ha⁻¹). It is not known why there was more DF within the Chaparral-treated pastures at this date, but may have to do with the previously mentioned dry conditions leading to the slower litter decomposition rates.

Although most chemical seedhead suppression studies report forage yields (typically lower for herbicide-treated forage), few have reported forage yields under grazing conditions. Wimer et al. (1986) reported that TFA was lower within mefluidide-treated smooth brome grass pastures grazed with cow-calf pairs (0.6 pairs ha⁻¹) and, when averaged across the season, mefluidide-treated pasture produced approximately one-third of the TFA from the control pastures. Aiken et al. (2012) reported lower TFA for Chaparral-treated pastures during the first year of the study, but showed that warmer temperatures in the spring resulted in comparable TFA

between herbicide treatments during the spring of the second year. As previously mentioned, favorable growing conditions combined with conservative stocking were believed to be partly responsible for similar TFA within the Chaparral-treated and control pastures in 2011. Chaparral-treated pastures were stocked more assertively in 2012, and resulted in TFA being lower compared to the control pastures at all dates.

Few reports exist in the literature of the effect of chemical seedhead suppression on the green and dead portions of the available forage. Wimer et al. (1986) briefly mention the presence of chemical burns on the forage following mefluidide applied during the early spring. Similarly, Aiken et al. (2012) reported a 2 to 3 week lag period in forage production within Chaparral-treated when the forage was chlorotic with lower growth rates. Moyer and Kelley (1995) visually estimated the degree of chemical injury to tall fescue and found that chlorosis ranged from slight to near complete chlorosis with desiccation of leaf tissue. Such reports suggest that Chaparral may result in the loss of additional tall fescue forage, other than reproductive growth. However, the differences in DF varied considerably between the two herbicide treatments (Figure. 4-16) with no apparent trend, and were likely elevated due to the presence of the thatch and dry conditions of the growing season. In addition, the amount of GF present within the treatment on any date would not be considered limiting (i.e. $< 900 \text{ kg ha}^{-1}$) to animal production (Dougherty and Collins, 2003).

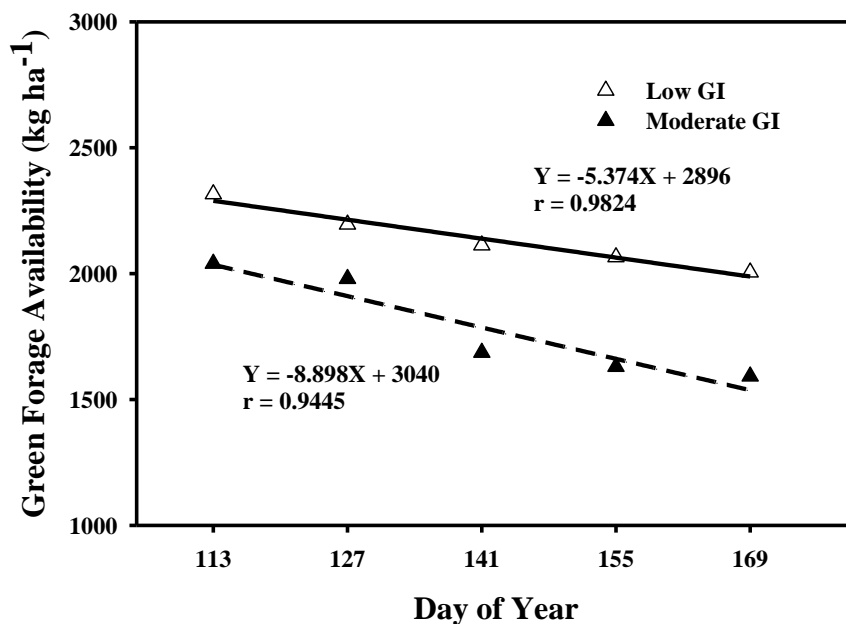


Figure 4-12. Trends in the amount of green forage (kg DM ha⁻¹) for grazing intensity (GI) treatments during the 2012 growing season.

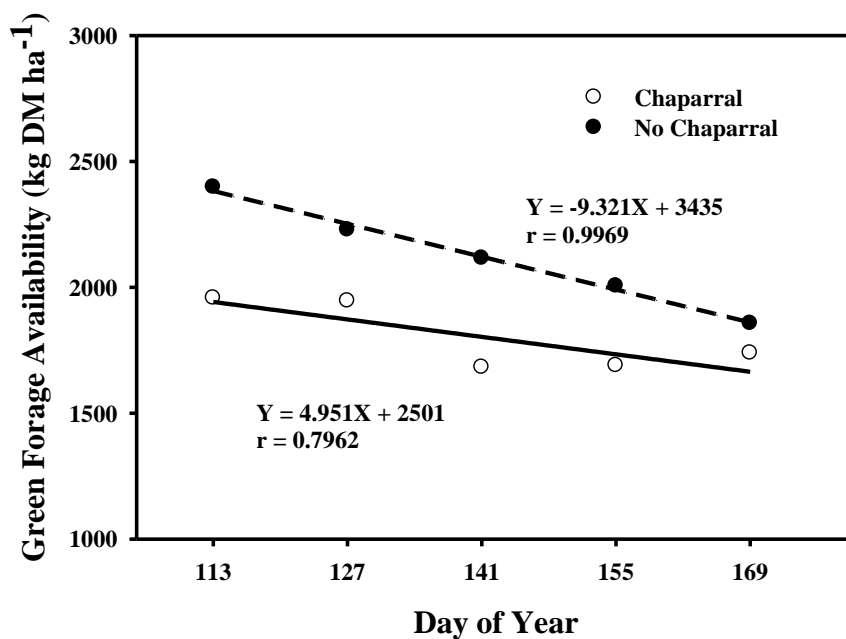


Figure 4-13. Trends in the amount of green forage (kg ha⁻¹) for herbicide treatments during the 2012 growing season.

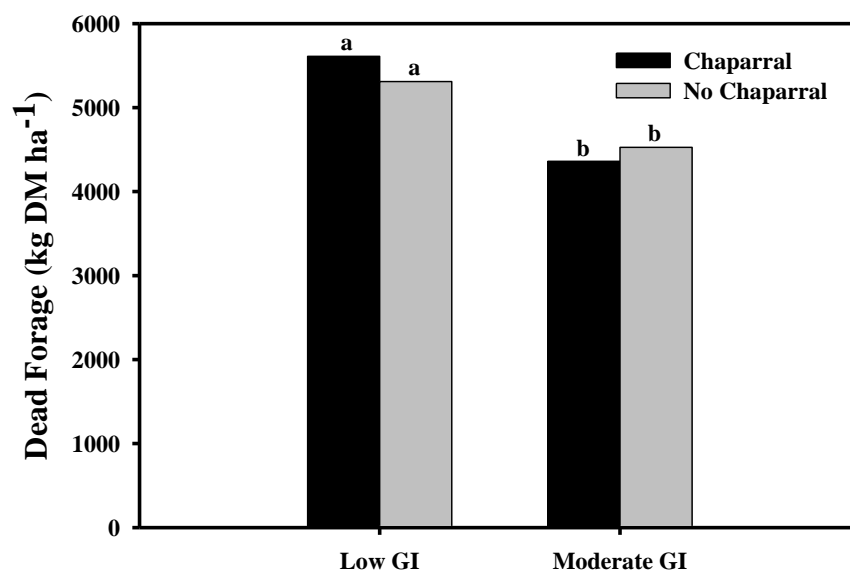


Figure 4-14. Amount of dead forage (kg DM ha⁻¹) within herbicide and grazing intensity (GI) treatments during the 2012 growing season. Letters represent difference in means across treatments at $P < 0.05$ level.

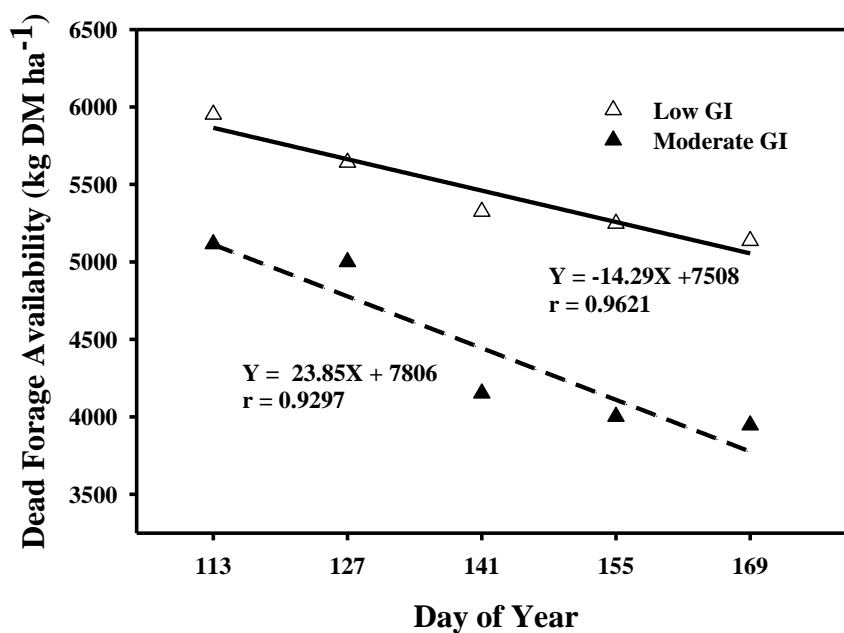


Figure 4-15. Trends in the amount of dead forage (kg DM ha⁻¹) for grazing intensity (GI) treatments during the 2012 growing season.

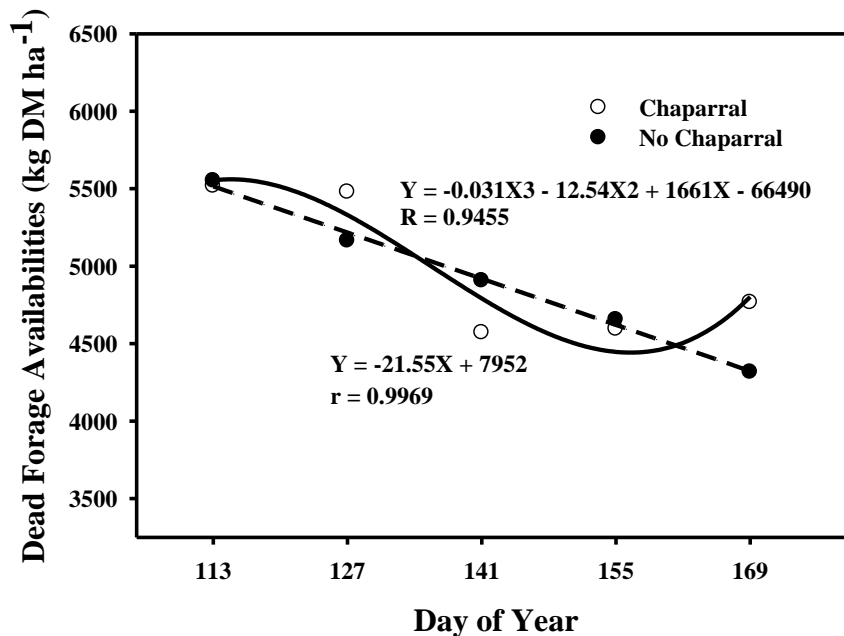


Figure 4-16. Trends in the amount of dead forage (kg DM ha⁻¹) for herbicide treatments during the 2012 growing season.

Forage Nutritive Value

Whole Tillers

Chaparral-treated forage contained greater ($P < 0.05$) concentrations of CP (Figure 4-17). Crude protein decreased curvilinearly in Chaparral-treated and control forage in 2011 ($R = 0.9394$ and 0.9910), and reached relatively stable concentrations at DOY 167 (Figure 4-17). Crude protein concentrations in 2012 remained approximately the same ($P > 0.10$) within the herbicide treatment throughout the growing season (Figure. 14-17). The difference between the treatments was about 40 g kg^{-1} at each date ($\sim 40 \text{ g kg}^{-1}$), which suggested that the improvement in CP was attributed to the inhibition in tall fescue reproductive growth from Chaparral. Stems are inherently low in CP, while young vegetative tissues contain high levels of CP (Collins and Fritz, 2003). The increase in CP resulting from chemical suppression of reproductive growth is common in these types of studies (Wimer et al., 1986; Moyer and Kelley, 1995; Roberts and Moore, 1990). Glenn et al. (1980) showed that mefluidide increased CP concentration of tall fescue forage by 25 g kg^{-1} nearly two months following application. Aiken et al. (2012) reported

higher CP concentrations within forage of Chaparral-treated pastures, particularly later in the growing season when forage within the control pastures had entered the reproductive stages. These authors also reported higher CP concentrations for vegetative tillers collected from Chaparral-treated pastures compared to those from control pastures. This suggests that the higher forage CP concentration within Chaparral-treated pastures may be due to more than the presence of stems (Aiken et al., 2012), and is discussed further within the next section.

Grazing intensity also affected forage CP concentrations, but the impact of the treatment varied between years of the study ($P < 0.05$; Figure. 4-18). Crude protein decreased in a similar curvilinear manner within both GI treatments in 2011 ($P < 0.05$, $R = 0.9697$ and 0.9899 for low and moderate GI, respectively), but did not differ ($P > 0.20$) between treatments on any date. Forage CP within the low GI pastures declined linearly in 2012, ($P < 0.10$; $r = 0.9081$) throughout the grazing period, but remained fairly constant ($P > 0.10$) within the moderate GI (Figure. 4-18). Significant differences ($P < 0.05$) in CP concentrations between these treatments were not observed until DOY 141 and remained higher ($P < 0.05$) within the moderate GI until the end of the grazing period. The lack of CP response to grazing intensity in 2011 was due to the previously discussed later date for the initiation of grazing and the conservative stocking adjustments during this growing season. The improvement in CP concentrations with the moderate GI during 2012 was likely to have greater forage utilization. Higher stocking densities result in more grazing pressure which results in animals being less selective of their diet and consume lower quality components, such as stems (Chacon and Stobbs, 1976). The removal of reproductive growth stimulates the regrowth of vegetative tillers from axillary buds near the crown of the grass. Utilization of the forage was greater within the moderate GI during 2012 because grazing was initiated earlier in the growing season and allowed the steer to graze immature reproductive tillers. This prevented the accumulation of low quality and unpalatable growth within these pastures that occurred in the low GI pastures and within the control pastures of 2011.

There was also a tendency ($P = 0.06$) of an herbicide-grazing intensity interaction among forage CP concentrations. When averaged across growing seasons, CP concentrations were highest ($P < 0.01$) within Chaparral-treated pastures, and did not differ ($P > 0.70$) between grazing intensities of this herbicide treatment (143 vs. 144 g kg⁻¹, for Chaparral-low GI and Chaparral-moderate GI, respectively). Crude protein concentrations within the control pastures were higher ($P < 0.01$) within the moderate GI pastures (104 g kg⁻¹) than the low GI pastures (94 g kg⁻¹). As previously discussed, forage CP concentrations may be improved with higher grazing intensities through higher degrees of forage utilization and removal of reproductive tissues. This reproductive growth was inhibited by Chaparral and CP would likely be near the peak concentrations and further increases were not obtained by improving forage utilization.

Grazing intensity did not affect ($P > 0.30$) water soluble carbohydrate (WSC) concentrations within the forage, while the effect of herbicide treatment varied between growing seasons (Figure. 4-19). Forage WSC concentrations showed curvilinear decreases for both the control and Chaparral-treated pastures in 2011, ($P < 0.05$; $R = 0.9927$ and 0.9936 , respectively), but were not different between the treatments during DOY 149 and 180 (Figure. 14-19). Water soluble carbohydrate concentrations were higher ($P < 0.10$) at DOY 132 and 195 within the Chaparral-treated pastures. Similarly, forage WSC concentrations declined curvilinearly for both herbicide treatments in 2012 ($P < 0.05$; $R = 0.9108$ and 0.9481 for Chaparral and control treatments, respectively). However, the control pastures tended to have higher WSC concentrations, and were significantly higher ($P < 0.10$) than the Chaparral-treated pastures on DOY 127 and 141. Although there are not many reports on the effect of chemical seedhead suppression on forage WSC concentrations, trends within 2012 contradict what has been reported. Aiken et al. (2012) reported higher forage WSC concentrations within Chaparral-treated pastures, which were attributed to the low WSC concentrations of the reproductive tillers within the control pastures.

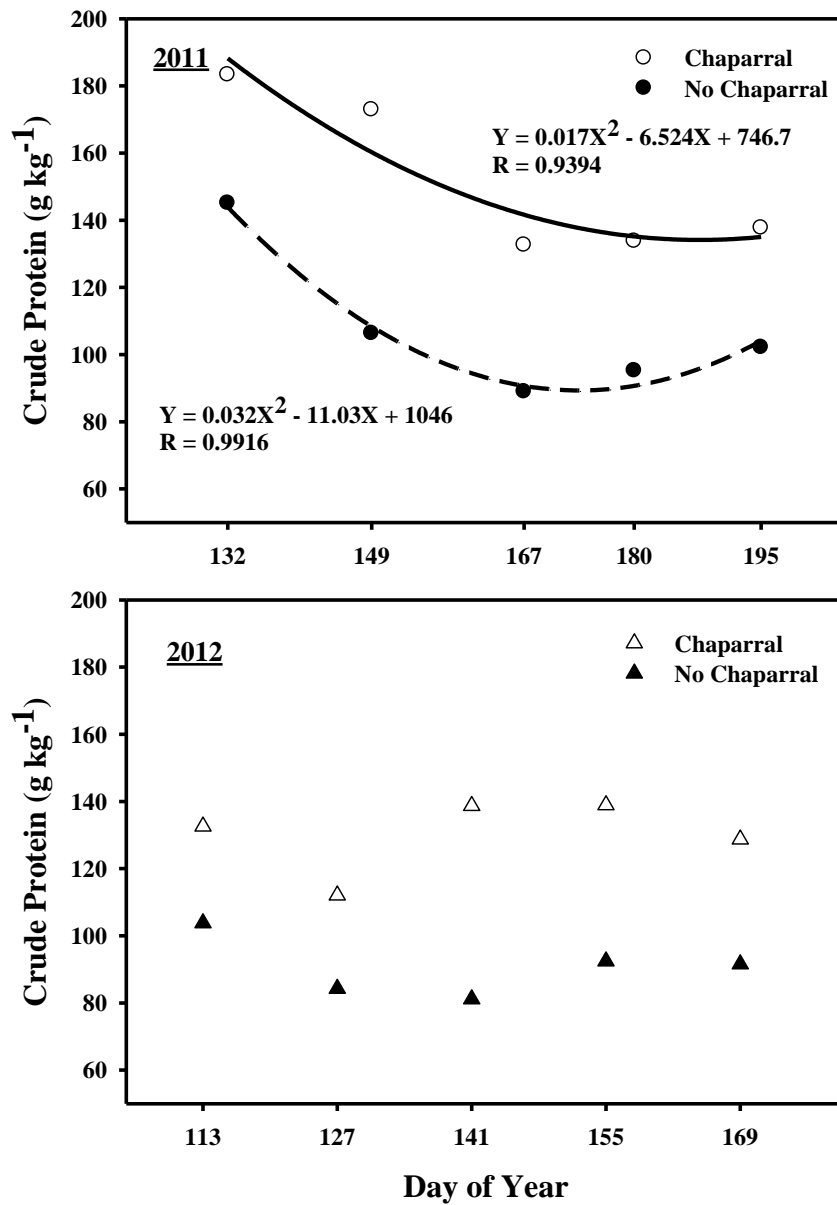


Figure 4-17. Trends in forage crude protein concentrations (g kg^{-1}) for herbicide treatments during 2011 and 2012 growing seasons.

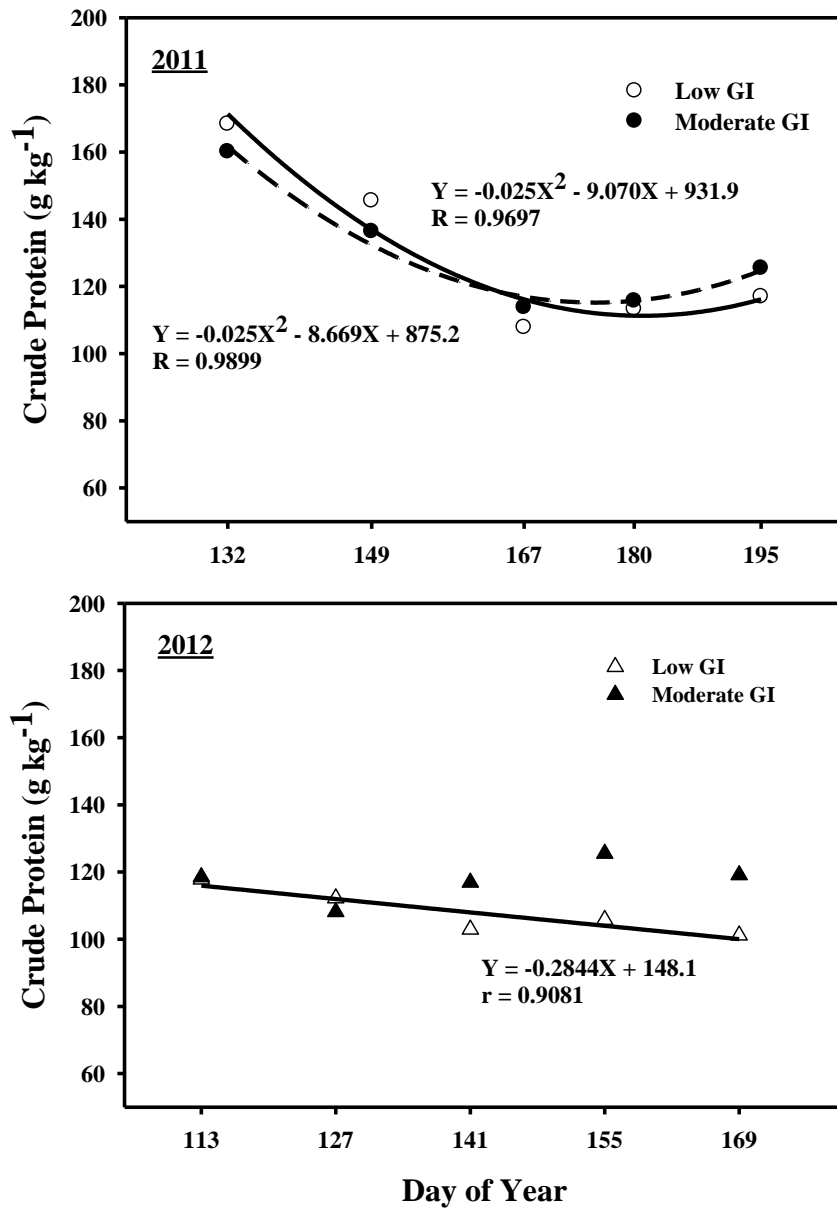


Figure 4-18. Trends in forage crude protein concentrations (g kg^{-1}) for grazing intensity (GI) treatments during 2011 and 2012 growing seasons.

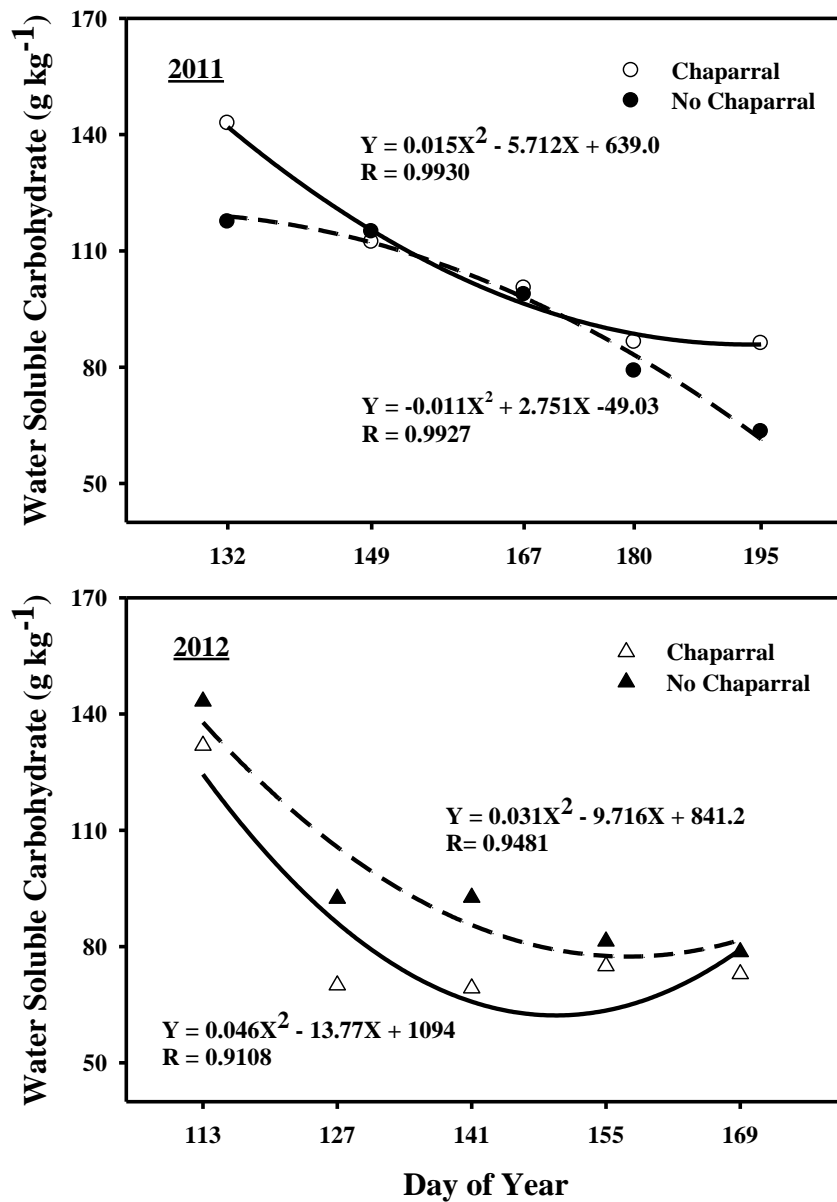


Figure 4-19. Trends in forage water soluble carbohydrate concentrations (g kg^{-1}) for herbicide treatments during 2011 and 2012 growing seasons.

The concentrations of WSC within forages are known to respond to a variety of environmental factors, soil moisture and ambient temperatures. Smith and Jewiss (1966) reported that higher temperatures reduced WSC within the crown of timothy. Blaser et al. (1966) hypothesized that a decrease of WSC concentrations in plants exposed to higher ambient temperatures was due to respiration rates exceeding the photosynthetic rate of the plant. Photosynthesis proceeds at a reduced rate due to the closure of stomata and instability of electron transport as temperature increases beyond the optimum range (Taiz and Zeiger, 2006). Respiration rates continue to increase as temperatures increase, and may potentially reduce levels of stored energy (i.e. WSC) if photosynthetic rate is decreased to a high degree. Although low soil moisture was reported by some to increase WSC concentration within forage (Brown and Blaser, 1970), others have been shown that WSC may initially increase when exposed to dry conditions, and eventually decrease as the length of the drought is extended (Volaire and Thomas, 1995). Thus, the prolonged dry conditions (Figure. 4-2), in addition to the elevated summer temperature (Figure. 4-1), may have led to the lower WSC concentrations within the Chaparral-treated pastures. It is possible that the reproductive growth within the control pastures may be a “buffer” against these conditions, possibly by absorbing solar radiation higher within the canopy or by creating a boundary layer (i.e. a higher-humidity layer of air) near the soil surface that may have reduced evapotranspiration.

Herbicide treatment effects on *in vitro* digestible dry matter (IVDDM) differed between growing seasons ($P < 0.05$; Figure. 4-20), while GI did not influence ($P > 0.40$) digestibility of the forage. *In vitro* digestible dry matter decreased in a quadratic manner ($P < 0.05$) for the Chaparral-treated and control pastures during both growing seasons. Concentrations of IVDDM decreased until approximately DOY 167 and 141 within 2011 and 2012, respectively (Figure. 4-20). *In vitro* digestible dry matter was higher in 2011, ($P < 0.01$) for forage collected within Chaparral-treated pastures on all dates, but was only higher within these pastures after DOY 141 in 2012. The lower IVDDM of forage within the control pastures is the result of the presence of

reproductive growth within these pastures. The concentrations of structural carbohydrates, such as cellulose and hemicelluloses, are greater within stems compared to the leaves and sheaths of vegetative tissues, and are less degradable within the digestive system of the ruminants (Moore and Hatfield, 1994). Digestibility of reproductive tissues is further reduced by the continued deposition of these carbohydrates and lignin with the cell wall as the plant matures. Lignin, a phenolic conglomerate bound to hemicelluloses, reduces digestibility by impeding access to the carbohydrates by the degrading microbes (Jung and Deetz, 1993).

Improvements in forage IVDDM is a common trend among chemical suppression of seedheads studies. Wimer et al. (1986) reported that IVDDM of smooth bromegrass from mefluidide-treated pastures was higher than forage from control pastures (600 vs. 555 g kg⁻¹) when averaged across season. However, these authors reported that IVDDM was initially similar or greater (due to chemical burn) within the control pastures during the growing season, and believed the ensuing decrease of IVDDM within the pastures was due to the accumulation of reproductive growth. Similarly, Turner et al. (1990b) reported that forage *in vitro* digestible organic matter was similar between mefluidide-treated and control pastures during May, but mefluidide-treated pastures maintained higher concentrations of IVDOM later in the season as reproductive tillers developed within the control pastures. Aiken et al. (2012) also reported that IVDDM of forage was similar between control and Chaparral-treated pastures, and that forage IVDDM decreased in the control pastures at the onset of reproductive growth. These trends aid in explaining the comparable IVDDM of forage collected from the herbicide treatments during the first two harvests of 2012 (Figure. 4-20). On these dates, reproductive tillers either had not developed within the control pastures or were within the pre-boot stage when the concentration of structural carbohydrates and lignin were low. With continued development of these tillers, IVDDM declined in accordance with increase of these cell wall components.

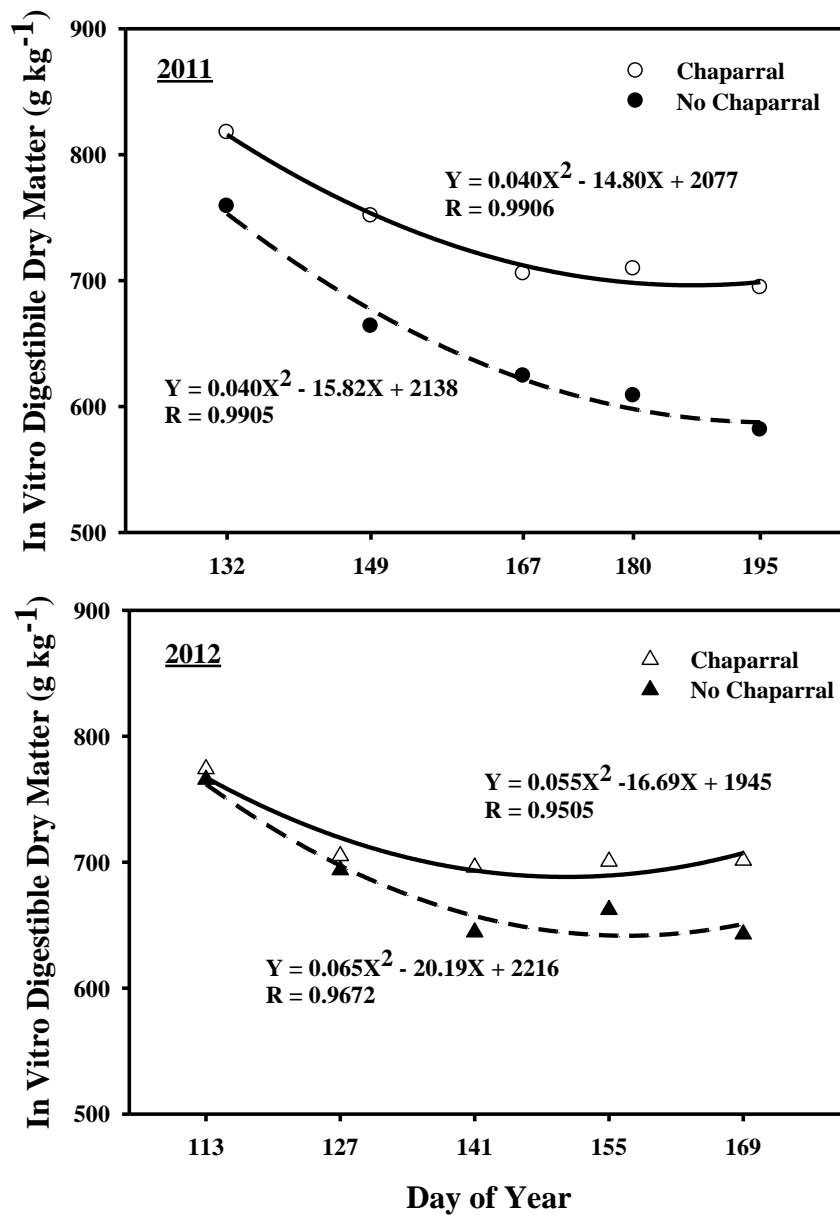


Figure 4-20. Trends of *in vitro* digestible dry matter (g kg⁻¹) of forage within herbicide treatments during 2011 and 2012 growing seasons.

Tiller Morphological Components

The nutritive values of vegetative and reproductive tiller morphological components from the control pastures are summarized in Table 4-2. Grazing intensity did not affect ($P > 0.15$) the nutritive value of the components. Several trends common among the respective components agree with existing knowledge of forage nutritive value and plant anatomy (Collins and Fritz, 2003). In general, leaf tissues (blades and sheaths) were of the highest forage nutritive value, followed by the seedheads and stems, respectively (Table 4-2). Similarly, vegetative tissues were of better quality than their respective reproductive counterparts. More specifically, CP concentrations were highest ($P < 0.05$) in leaf blades (vegetative and reproductive) and seedheads, followed by the leaf sheaths (vegetative and reproductive). The stems of the reproductive tillers contained the lowest ($P < 0.05$) CP concentrations. Concentrations of IVDDM were highest ($P < 0.05$) among vegetative leaf sheaths and were lowest ($P < 0.05$) for reproductive leaf sheaths and stems (Table 4-2). Seedheads and leaf blades (vegetative and reproductive) were intermediate to these two groups, with the reproductive leaf blades being lower ($P < 0.05$). Vegetative leaf sheaths also contained the highest ($P < 0.05$) concentrations of WSC, followed by stems, and finally the other morphological components (Table 4-2). Cool-season grasses store carbohydrate reserves within their stem bases (Brown and Blaser, 1970; MacAdam and Nelson, 2003), which explains the higher WSC concentrations within the vegetative leaf sheaths and stems as the tissues function in the storage and translocation of nonstructural carbohydrate. The higher concentrations of WSC within the vegetative leaf sheaths also explain the higher IVDDM of these tissues as these carbohydrates are readily degraded within the rumen (Moore and Hatfield, 1994). Although stems also contained high WSC concentration, their estimates of IVDDM were lower than other tissues due to higher lignin and cellulose concentrations.

Nutritive values decreased in tiller components as the growing season progressed. Crude protein concentrations decreased ($P < 0.05$) in reproductive leaf blades and stems during both

years, and in the vegetative tiller components and seedheads of 2011 (Table 4-2). Concentrations of CP remained consistent ($P > 0.10$) in vegetative leaf sheaths and seedheads of 2012 and reproductive leaf sheaths during both growing season. Interestingly, CP concentrations increased ($P < 0.05$) within vegetative leaf blades during 2012. Concentrations of WSC were unchanged ($P > 0.10$) for most tiller components, except for decreases with later dates for the stems in 2011 and reproductive leaf blade and sheaths in 2012 (Table 4-2). Water soluble carbohydrates concentrations also increased ($P < 0.05$) in the vegetative leaf sheaths during both growing seasons, and likely due to the accumulation of carbohydrates reserves within the plant. Forage IVDDM decreased ($P < 0.05$) within the reproductive tiller components in both years (Table 4-2). Vegetative leaf blades also showed a decrease in IVDDM with later dates in 2011, but were not different between the two dates of 2012 (Table 4-2). The decline of CP, WSC, and IVDDM concentrations in the reproductive tiller components were likely the result of the deposition of cell wall components (i.e. lignin and cellulose) as the plant matures.

The nutritive values of vegetative tiller morphological components were compared between Chaparral-treated and control pastures to evaluate if there were additional nutritive value benefits from Chaparral (i.e. other than inhibiting reproductive growth). Herbicide treatment did not affect WSC concentrations ($P > 0.05$) within the vegetative tillers except in vegetative leaf sheaths on 30 April 2012 (Table 4-3). On this date, WSC concentrations of the leaf sheaf were higher ($P < 0.05$) within the control pastures, and may be due to the vegetative tillers within the Chaparral-treated pastures not yet fully replenishing their stored reserves following the Chaparral treatment as no difference was observed later in the growing season (Table 4-3). Vegetative leaf sheaths contained higher WSC concentrations ($P < 0.05$), but exhibited variable trends across growing season. No difference in WSC concentrations was observed between dates in 2011 for the vegetative leaf sheaths ($P > 0.25$); however, these components increased during the later date of 2012 ($P < 0.05$) and may be explained by the variation of the start of grazing between growing season. Tillers were collected after 27 d of grazing in 2012, compared to after 6 days of grazing

Table 4-2. Nutritive value of morphological components of vegetative and reproductive tillers collected from control pastures across grazing intensities. IVDDM = in vitro digestible dry matter, CP = crude protein, WSC = water soluble carbohydrate. Letters refer to a difference ($P < 0.05$) in the means between dates within a given year and tiller component.

	2011					
	IVDDM		CP		WSC	
	----- $g\ kg^{-1}$ -----					
	<u>11 May</u>	<u>17 June</u>	<u>11 May</u>	<u>17 June</u>	<u>11 May</u>	<u>17 June</u>
<u>Vegetative Tillers</u>						
<i>Blade</i>	837a	723b	159a	135b	110a	129a
<i>Sheath</i>	798a	797a	87a	67b	168a	221b
<u>Reproductive Tillers</u>						
<i>Blade</i>	815a	692b	187a	111b	108a	95a
<i>Sheath</i>	639a	564b	85a	80a	106a	79a
<i>Stem</i>	710a	505b	51a	33b	186a	120b
<i>Seedhead</i>	754a	698b	153a	129b	73a	70a
	2012					
	IVDDM		CP		WSC	
	----- $g\ kg^{-1}$ -----					
	<u>30 April</u>	<u>5 June</u>	<u>30 April</u>	<u>5 June</u>	<u>30 April</u>	<u>5 June</u>
<u>Vegetative Tillers</u>						
<i>Blade</i>	712a	712a	111a	129b	110a	107a
<i>Sheath</i>	758a	773a	68a	70a	153a	254b
<u>Reproductive Tillers</u>						
<i>Blade</i>	751a	572b	144a	80b	128a	63b
<i>Sheath</i>	597a	523b	64a	61a	138a	81b
<i>Stem</i>	647a	520b	58a	30b	176a	153a
<i>Seedhead</i>	742a	679b	132a	129a	83a	86a

in 2011. The longer exposure to grazing in 2012 may have allowed for the removal, and the subsequent regrowth, of portions of the tillers, which lowered the concentrations of WSC reserves within the vegetative sheaths of the plant. Water soluble concentrations in vegetative leaf blades did not differ between dates ($P > 0.25$) on either herbicide treatments.

Crude protein concentrations were higher ($P < 0.05$) in the leaf blades of vegetative tillers compared to the sheath tissues. This difference in CP concentrations reflects the comparative function between the types of tissues. Leaf blades function primarily in the capture of solar energy and its conversion to chemical energy through photosynthesis, whereas in cool-season grasses, the purpose of leaf sheaths is to provide structural support to the leaf blades and storage of carbohydrate reserves within vegetative tillers, and hence does not have as large of a metabolic requirement for active proteins as the blades. As with the whole tiller samples, CP concentrations were higher ($P < 0.05$) in the components of vegetative tillers collected from the Chaparral-treated pastures (Table 4-4), and may represent a conservation of nutrients from the inhibition of reproductive growth. Aiken et al. (2012) reported similar trends in CP concentration of vegetative tillers from Chaparral-treated and control pastures, and reasoned that because tall fescue plants allocated resources to the production of reproductive tillers, a larger amount N was partitioned to the vegetative growth and accumulated within these tissues.

The concentrations of CP of the tiller components decreased ($P < 0.05$) during later dates of both growing seasons except for, as previously mentioned, tillers collected from control pastures on 5 June 2012 (Table 4-4). Crude protein concentrations remained constant ($P > 0.30$) and increased ($P < 0.05$) for the vegetative leaf sheaths and blades, respectively, compared to earlier in the growing season. Although CP concentrations of the tiller components were still higher in the Chaparral-treated pastures, their overall decreasing trend in 2012, compared to the control pastures, may provide support to the earlier hypothesis that forage within these pastures were more exposed to the hot, dry climatic conditions of this growing season than the control pastures. Crude protein concentrations may decrease as the result of high temperatures or low

soil moisture conditions for an array of reasons: scavenging of carbon backbones for respiration, repartitioning of nutrients to underground structures, dilution increased lignin concentrations, etc.; and the maintenance or increase of CP concentrations indicates that these tissues were experiencing less stress. Although it is not possible to know the exact nature of the reduction in CP concentrations in the control pastures, it may have been the result of reproductive tillers providing shade or somehow reducing moisture loss (Buxton and Fales, 1994).

Grazing intensity also affected CP concentrations in the vegetative tiller components. Crude protein concentrations were higher ($P < 0.05$) in leaf blades (156 g kg^{-1}) and sheaths (90 g kg^{-1}) from vegetative tillers collected in the moderate GI pastures compared to low GI pastures (144 and 83 g kg^{-1} , respectively). Although there was no indication of year and GI interaction ($P = 0.26$), the significance of the GI main effect was likely driven by the more assertive stocking of steers during the 2012 growing season (Figure. 4-17). Pastures receiving the moderate GI treatment were stocked heavily at the start of grazing in this growing season, and within many pastures reduced the amount of reproductive growth. More N was likely available for redistribution to the vegetative tiller components with less reproductive tillers serving as sinks.

Unlike WSC and CP concentrations, the IVDDM concentration of the vegetative tiller components was variable between herbicide treatments (Table 4-5). Vegetative leaf sheaths collected from Chaparral-treated and control pastures had similar ($P > 0.50$) concentrations of IVDDM on all dates tillers were collected, and increased at the later date of 2012, which is consistent with an increase of highly digestible WSC (Moore and Hatfield, 1994) during this period (Table 4-3). Leaf blades IVDDM concentrations decreased during 2011, and were higher ($P < 0.05$) in the Chaparral-treated pastures on 17 June 2011. It is not known why the vegetative leaf blades of the control pastures were lower in IVDDM. Several authors have reported that shading may lower forage IVDDM (Blair et al., 1983; Navarro-Chavira and McKersie, 1983). Although the overall impact of these environmental factors is often debated (Buxton and Fales, 1994), it may be possible that the shading from reproductive tillers may have increased cell wall

Table 4-3. Water soluble concentrations (g kg^{-1}) of vegetative tiller components from Chaparral-treated and control pastures. Letters refer to a difference ($P < 0.05$) in the means between dates within a given year and tiller component.

Water Soluble Carbohydrate				
----- g kg^{-1} -----				
2011				
<u>11 May</u>		<u>17 June</u>		
	Chaparral	No Chaparral	Chaparral	No Chaparral
<i>Blade</i>	101a	110a	95a	129a
<i>Sheath</i>	193a	168a	218a	221a
2012				
<u>30 April</u>		<u>5 June</u>		
	Chaparral	No Chaparral	Chaparral	No Chaparral
<i>Blade</i>	91a	110a	123a	107a
<i>Sheath</i>	106a	153b	239c	254c

Table 4-4. Crude protein concentrations (g kg^{-1}) of vegetative tiller components from Chaparral-treated and control pastures. Letters refer to a difference ($P < 0.05$) in the means between dates within a given year and tiller component.

Crude Protein				
----- g kg^{-1} -----				
2011				
<u>11 May</u>		<u>17 June</u>		
	Chaparral	No Chaparral	Chaparral	No Chaparral
<i>Blade</i>	203a	159b	156b	135c
<i>Sheath</i>	125a	87b	79bc	67c
2012				
<u>30 April</u>		<u>5 June</u>		
	Chaparral	No Chaparral	Chaparral	No Chaparral
<i>Blade</i>	162a	111b	153c	129d
<i>Sheath</i>	111a	68b	86c	70b

Table 4-5. In vitro digestible dry matter concentrations (g kg^{-1}) of vegetative tiller components from Chaparral-treated and control pastures. Letters refer to a difference ($P < 0.05$) in the means between dates within a given year and tiller component.

In Vitro Digestible Dry Matter				
----- g kg^{-1} -----				
2011				
	<u>11 May</u>		<u>17 June</u>	
	Chaparral	No Chaparral	Chaparral	No Chaparral
<i>Blade</i>	841a	837a	754b	723c
<i>Sheath</i>	808a	798a	805a	797a
2012				
	<u>30 April</u>		<u>5 June</u>	
	Chaparral	No Chaparral	Chaparral	No Chaparral
<i>Blade</i>	753a	712b	746ab	712b
<i>Sheath</i>	723a	758ab	783b	773b

lignin concentrations and lowered IVDDM within the vegetative leaf blades of the control pastures. Any negative effect of shading from reproductive growth in 2012 may have been offset by the additional benefits of shielding against the hot, dry conditions.

Steer Performance

Animal Gains and Carrying Capacities

Steer average daily gain (ADG) response differed between years, and averaged 0.69 and 1.05 kg d^{-1} during the 2011 and 2012, respectively. The higher gains during 2012 are likely the result of animals being exposed to the less stressful environment (Figures. 4-1 and 4.3). With higher temperatures, animals may reduce grazing times which reduces the forage intake of the animals, and subsequently, weight gain (NRC, 1996). Although temperatures were higher in the spring of 2012 (Figure. 4-1), animals were removed from pastures before July when the greatest amount of heat stress occurs (Figure. 4-3) on the animals. Additionally, the grazing season was terminated in June of 2012, while steers were allowed to graze until mid-July during the 2011 growing season. Thus, the steers evaluated in 2012 growing season were not exposed to higher temperatures that typically occur during the summer. The use of continental breeds of

cattle (i.e. Charolais, Limousin, etc.) during 2012 may also partially be responsible for the higher ADG, since these breeds have higher growth rates compared to the British breeds of cattle (i.e. Angus) (Mason, 1971; McAllister et al., 1976).

Steer ADG was affected by herbicide treatments ($P < 0.05$), with steers grazing the Chaparral-treated pastures gaining 0.95 kg d^{-1} , compared to 0.79 kg d^{-1} for steers on the control pastures. The higher ADG of the steers within the Chaparral-treated pastures was attributed to greater forage nutritive value (Figures 4-17, 4-19, and 4-20) that resulted from the inhibition of reproductive growth, as there is little evidence that animals within treatments were experiencing symptoms of tall fescue toxicosis (see below). Aiken et al. (2012) similarly reported increases in ADG for steers grazing Chaparral-treated pastures, and also partly attributed the improved animal gains to the better maintenance of forage nutritive value within pastures during the grazing season. Wimer et al. (1986) demonstrated that cows grazing mefluidide-treated pastures maintained higher body weights across the season, which was believed to be due to the higher forage quality within these pastures resulting in the dams losing less weight during the summer months.

Similar to the herbicide treatments, GI also affected ($P < 0.05$) steer ADG. Average daily gains were higher ($P < 0.05$) for steers on the low GI treatment (0.95 kg d^{-1}) compared to the moderate GI (0.79 kg d^{-1}), and is typical response for stocking rate studies (Mott, 1960; Jones and Sandland, 1974). Animals are able to selectively graze plant tissues that maximize the nutritive value (i.e. leaf tissue) of the forage under low grazing pressures, which result in a higher quality diet and better animal performance (Mott; 1960; Blaser et al., 1959; Bryant et al., 1965). Increases in stocking pressures create greater competition for available forage. Animals are then forced to be less selective in their diet and will consume plant tissues that are of lower nutritive value (i.e. stem), lowering animal performance (Mott; 1960; Blaser et al., 1959; Bryant et al., 1965).

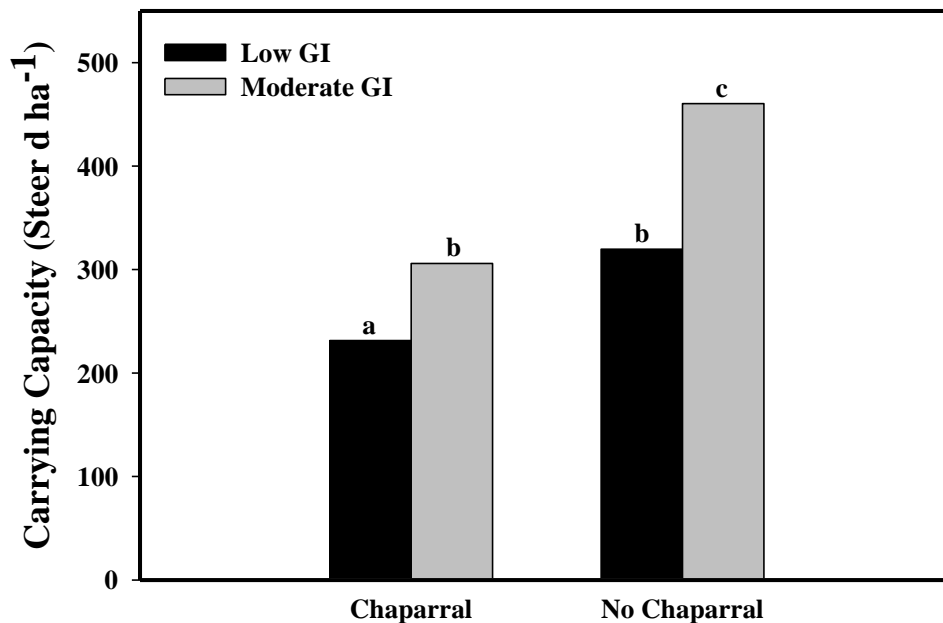


Figure 4-21. Seasonal carrying capacities (steer d ha⁻¹) for herbicide and grazing intensity (GI) treatments. Letters refer to a significant difference ($P < 0.05$) in the means across herbicide and GI treatments.

Herbicide treatment and GI had an interactive effect ($P < 0.05$) on the estimated carrying capacity (CC) of each pasture (Figure. 4-21). Moderate GI pasture had higher ($P < 0.01$) CC within both herbicide treatments, and was the direct result of the greater stocking densities imposed on these treatments. There was no difference ($P > 0.40$) between the CC of the Chaparral-moderate GI (300 steer d ha⁻¹) and the control-low GI (320 steer d ha⁻¹) treatments (Figure. 4-21). The Chaparral-low GI (232 steer d ha⁻¹) and control-moderate GI (460 steer d ha⁻¹) had the lowest and highest estimates of CC, respectively. This indicated that despite lower forage yields within Chaparral-treated pastures (Figures. 4-9, 4-11, and 4-13), similar levels of forage productivity (as measured by days of grazing), may be obtained by increasing stocking rates. Stocking rates within the Chaparral-treated pastures may not be as high as control pastures without noticeable stand deterioration. As noted previously, there were issues with overgrazing of the Chaparral-treated pastures during the first growing season. If stocking densities are

increased within Chaparral-treated pastures, producers should do so cautiously and may consider alternative grazing systems (i.e. rotational grazing) that promote tall fescue persistence allowing adequate periods of rest between grazing intervals.

The effect of herbicide treatment on gain per hectare (GPH) varied between growing seasons ($P < 0.05$; Figure. 4-22). There was no difference in 2011 ($P > 0.70$) the GPH for Chaparral-treated and control pastures (203 vs. 193 kg ha⁻¹). However, GPH was higher for both treatments during the 2012 growing season, with the control pasture producing higher ($P < 0.01$) GPH than the Chaparral-treated pastures (414 vs. 313 kg ha⁻¹). The variability of GPH trends between herbicide treatments and years represents the interplay between steer ADG and pasture CC (i.e. $GPH = ADG * CC$). The improvement in ADG in for steers grazing Chaparral-treated pastures compensated for lower CC to result in no difference in GPH (Figure. 4-22). The higher GPH in 2012 reflects a lessening in the magnitude of differences in steer ADG between the two herbicide treatments (1.08 and 1.02 kg d⁻¹ for Chaparral-treated and control pastures, respectively) during this growing season. The improvement of steer ADG in this growing season was not sufficient to compensate for the lower CC in Chaparral-treated pastures, which resulted in lower GPH (Figure. 4-22).

The response of GPH to the GI treatments mirrors that of the herbicide treatments ($P < 0.05$; Figure. 4-23). There was no difference ($P < 0.70$) in GPH between the low and moderate GI pastures in 2011 (203 vs. 193 kg ha⁻¹), while the moderate GI treatment had higher ($P < 0.01$) GPH than the low GI treatment in 2012 (Figure. 4-23; 411 vs. 311 kg ha⁻¹). The higher ADG of steers within the low GI treatment compensated for the lower CC (Figure. 4-21) of the treatment in 2011, but did not during 2012 due to the similar steer ADG of the low and moderate GI treatments. The differing trends of GPH and GI during the different years may also, at least partially, be due to the variation in stocking decisions between the two growing seasons, with the conservative stocking of steers in 2011 leading to comparable GPH between the moderate and low GI treatments. Gain per hectare has been described as a curvilinear response to increases in

stocking rates (Mott, 1960; Jones and Sandland, 1974). Gains increase with stocking rate to a maximum GPH, after which animals gains decline due to limited forage availability (i.e. overgrazing). The optimum stocking rate is sometimes defined as a range near the maximum GPH where GPH increases or decreases at a diminishing rate to the left and right of the maximum GPH (Mott, 1960). It is likely, that during 2011, both levels of GI were within this range, resulting in similar GPH. In 2012, the distance between the two levels of GI on this theoretical graph may have been larger due to the more assertive stocking of the pastures, and resulted in significantly different GPH.

Carcass-Related Traits

Growing season and herbicide treatment independently affected ($P < 0.05$) the ribeye area (REA) and back fat thickness (BFT) of the steers, but were unaffected by GI ($P < 0.40$). Steer REA and BFT were higher during 2012 compared to 2011 (REA: 59.3 vs. 47.9 cm²; BFT: 3.94 vs. 2.77 mm), and is likely due to the higher ADG of the steers during this growing season (Figure 4-21). Steers grazing the Chaparral-treated pastures also had larger REA and BFT compared to those within the control pastures (REA: 56.4 vs. 50.8 cm²; BFT: 3.54 vs. 3.17 mm), and is most likely due the higher forage nutritive value within these pastures. As previously mentioned, IVDDM and CP were higher within Chaparral-treated pastures by the end of each grazing season (Figure. 4-17 and 4-20), which translates into more available energy and protein available for animal growth, respectively. Crude protein concentrations of 120 g kg⁻¹ and total digestible nutrients (TDN) of 700 g kg⁻¹ (TDN is an estimate of the forage digestibility that is highly correlated to IVDDM; Collins and Fritz, 2003) are often considered the minimum requirement for developing steers (NRC, 1996). The forage within the Chaparral-treated pastures never decreased below these thresholds

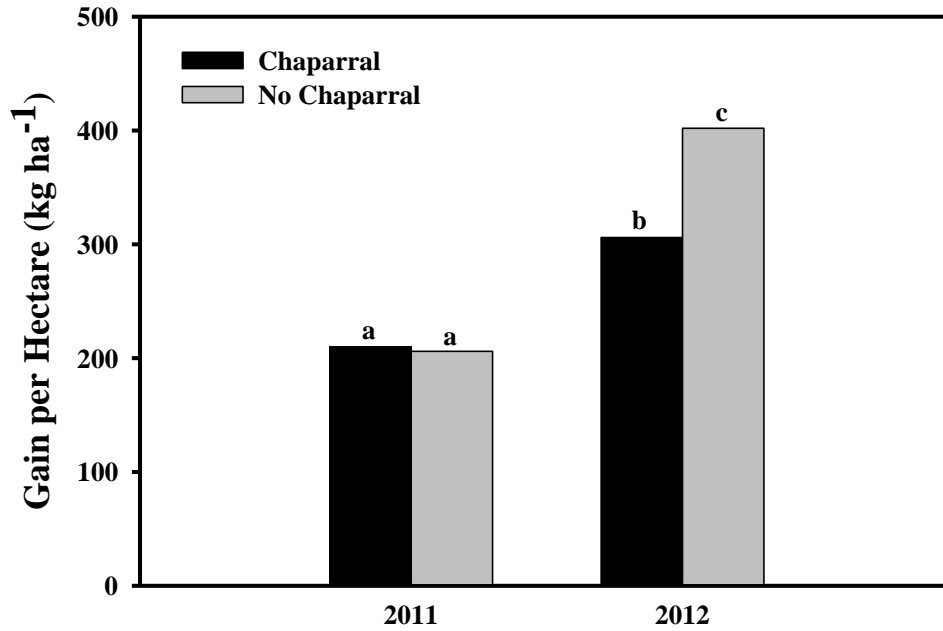


Figure 4-22. Gain per hectare (kg ha⁻¹) for steers grazing herbicide treatments during 2011 and 2012 growing seasons. Letters refer to a significant difference ($P < 0.05$) in the means.

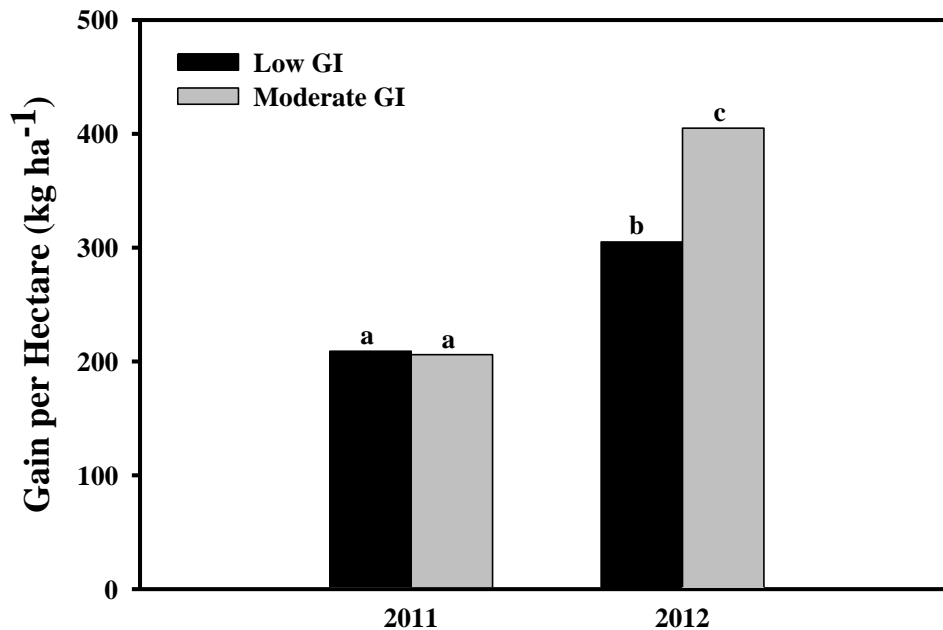


Figure 4-23. Gain per hectare (kg ha⁻¹) for steers grazing the grazing intensity (GI) treatments during 2011 and 2012 growing seasons. Letters refer to a significant difference ($P < 0.05$) in the means.

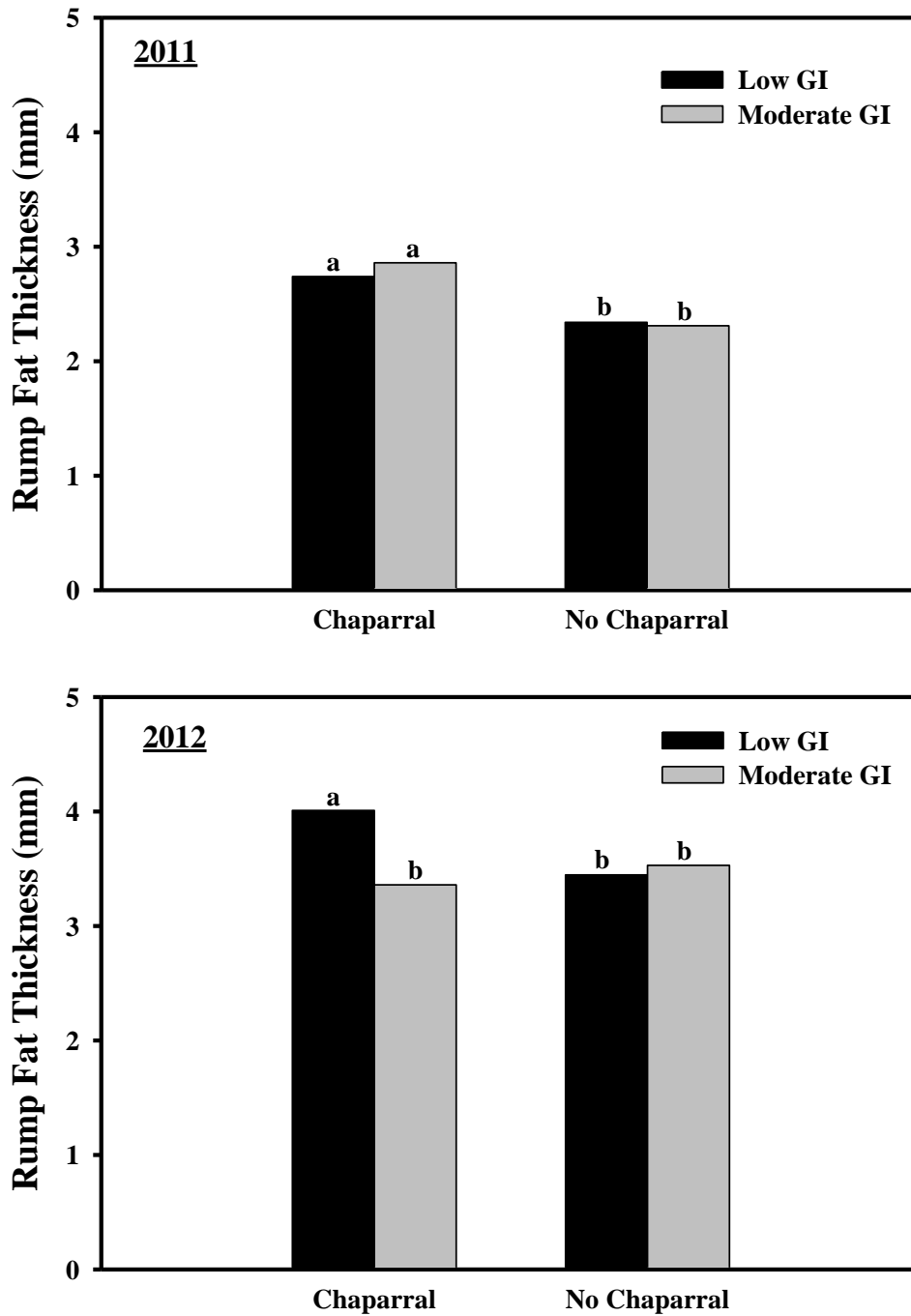


Figure 4-24. Rump fat thickness (mm) of steers on the herbicide and grazing intensity (GI) treatments. Letters refer to a significant difference ($P < 0.05$) in the means.

in either growing season, while forage within the control pastures usually was below these levels by DOY 149.

In contrast to REA and BFT, steer rump fat thickness (RFT) varied ($P < 0.05$) between growing season, herbicide treatment, and GI (Figure. 4-24). In 2011, steers in the Chaparral-treated pastures (2.72 and 2.81 mm for low and moderate GI, respectively) had greater ($P < 0.01$) RFT than steers grazing the control pastures (2.34 and 2.31 mm for low and moderate GI, respectively), and no difference ($P > 0.60$) was found between GI within a given herbicide treatment (Figure. 4-24). During 2012, RFT was higher for all herbicide-GI treatments, which was due to the larger animals and higher gains as previously noted for this growing season. Rump fat thickness did not differ ($P > 0.30$) between the low and moderate GI treatments of the control pastures (3.44 and 3.53 mm, respectively), but was higher ($P < 0.05$) within the Chaparral-low GI treatment (4.00 mm) compared to the Chaparral-moderate GI treatment (3.36 mm). The RFT of steers on the latter Chaparral treatment was not different than those on the control pastures ($P > 0.30$). Since forage availability or the parameters of forage nutritive differ between the Chaparral-low GI and Chaparral-moderate GI treatments, the difference in RFT may be the result of variation in their selective grazing. Increasing grazing pressures result in the consumption of lower quality diets, and since the Chaparral-low GI treatments carried fewer animals (Figure. 4-21) steers within this treatment were able to select a more nutritious diet that likely resulted in more fat deposition. This trend was not observed in 2011 due to the conservative stocking of the Chaparral-moderate GI treatment.

Ergovaline and Symptoms of Tall Fescue Toxicosis

Although pastures had high endophyte infection rates in both growing seasons (82 and 73% for 2011 and 2012, respectively), ergovaline production was unusually low. Ergovaline concentrations of the whole tiller samples was below the detection limits of the HPLC method ($\sim 0.01 \mu\text{g g}^{-1}$), and concentrations were only able to be measured within a limited number of samples when tillers were separated into their morphological components. The ergovaline

Table 4-6. Ergovaline concentrations ($\mu\text{g g}^{-1}$) of tiller components from Chaparral-treated and control pastures during 2011 and 2012 growing seasons (17 and 5 June, respectively).

	Ergovaline			
	$\mu\text{g g}^{-1}$			
	2011		2012	
	Chaparral	No Chaparral	Chaparral	No Chaparral
<u>Vegetative Tillers</u>				
<i>Blade</i>	0.01*	BD†	0.12*	BD†
<i>Sheath</i>	0.04*	0.10*	0.75*	0.12
<u>Reproductive Tillers</u>				
<i>Blade</i>	--	BD†	--	BD†
<i>Sheath</i>	--	0.01*	--	BD†
<i>Stem</i>	--	0.17*	--	BD†
<i>Seedhead</i>	--	0.79	--	0.25

*Component contains replicate that was below detection limit of assay

†Below Detection Limit of Assay (i.e. $< 0.01 \mu\text{g g}^{-1}$)

concentrations of vegetative and reproductive tiller components collected during June (i.e. when ergovaline concentrations are highest; Bush and Fannin, 2009) from the Chaparral-treated and control pastures are shown in Table 4-6, and are presented for demonstrative purposes and were not statistically analyzed due to the alkaloid only occurring above the detection limit for a few samples. Ergovaline concentrations of each of the tiller components are considerably lower than those reported within the literature (Rottinghaus et al., 1991; Aiken et al., 2012; Goff et al., 2012), and were detected in all replicates only for the seedheads.

It is not known why ergovaline concentrations within the forage were low during both growing seasons. It is possible that the tall fescue tillers were not highly infected. The immunoblot assay used to determine infection rate is, at times subjective, and simply qualitatively measures the frequency in which *Neotyphodium* hyphae occurs within tiller (Hiatt et al., 1997; Hiatt et al., 1999), which does not always translate to the production of ergot alkaloids. Other researchers have also experienced similar levels of alkaloid production and infection rates (L.P. Bush, personal communication), and may be due to the relative immaturity of the stand. It is well documented that the presence of *Neotyphodium coenophialum* confers an ecological advantage to tall fescue within grazing systems (Read and Camp, 1986; Belesky and Fedders, 1996), and it is

reasonable to assume that these benefits may not always be received after establishment of the grass. Survival of the endophyte in tall fescue seed depends on many environmental conditions, including temperature and humidity (Welty et al., 1987). If variation among these climatic parameters slows endophyte growth beyond that of the grass, the resulting tillers may be weakly infected or endophyte-free as the hyphae of the fungus must initially colonize the apical meristems of the plant tissue (Christensen and Voisey, 2007; Christensen and Voisey, 2009). Multiple growing seasons may be needed for endophyte-infected tillers become the dominate form.

Steers did not exhibit any of the classical symptoms of tall fescue toxicosis because of the low concentrations of alkaloids. Rectal temperatures were higher in 2011 compared to 2012 (41.1 vs. 39.8°C) due to the higher ambient temperatures (Figure. 4-1), but did differ between herbicide treatment and GI ($P > 0.15$). Similarly, concentrations of serum prolactin for the steers were not different ($P > 0.30$) between growing season, herbicide treatment, or GI. At the end of grazing in 2011, steers from the control pastures were used within an additional study in which the post-graze recovery from tall fescue toxicosis was monitored (Bussard, 2012). Results of this study indicate that, despite the lower concentrations of ergovaline, steers experienced vasoconstriction of the caudal artery until approximately five weeks after the removal of tall fescue pastures (Bussard, 2012). This indicated that steers during 2011 were experiencing some degree of tall fescue toxicosis, and was likely due to the repeated exposure to low concentration of ergovaline leading to its bioaccumulation within the vasculature of the steer (Klotz et al., 2009). Steers grazing the Chaparral-treated pastures during 2011 were not used within the study, nor was the study replicated in 2012, so no conclusions may be drawn about potential for Chaparral to reduce the severity in the symptoms of tall fescue toxicosis.

CHAPTER V: Conclusions

Chaparral effectively inhibited the production of the seedheads within tall fescue pastures, but its efficiency varied slightly between growing seasons and is common among other chemical seedhead suppression studies. The herbicide was effective in controlling broadleaf weed species, as the majority of the non-tall fescue vegetation consisted of other cool-season grasses, such as orchardgrass and Kentucky bluegrass. Chaparral also reduced the percentage of tall fescue within treated pastures, although the magnitude of the decrease was lower than previous reports. Future studies will be needed to explicitly focus on the long term-effects of Chaparral use on grazed tall fescue pastures, as a potential risk for over-grazing of the species was documented within the first year of these studies under a light-moderate grazing intensity.

Chaparral-treated pastures were lower in forage availability during both growing season due to the loss in reproductive growth, but maintained similar steer grazing days (i.e. carrying capacity) as within the control pastures at a low grazing intensity. Thus, in terms of animal production, similar levels of forage production may be obtained between Chaparral-treated and control pastures. Forage within the Chaparral-treated pastures was also consistently higher in concentrations of crude protein and *in vitro* digestible dry matter. The trends in water soluble carbohydrate concentrations varied between the herbicide treatments with growing seasons, and were believed to be the result of environmental effects. In addition to inhibition of reproductive growth, there may be additional nutritive value benefits received from Chaparral as the vegetative tiller components from these pastures were observed to have higher crude protein and *in vitro* digestible dry matter concentrations compared to those from the control pastures. Grazing intensity affected forage availabilities and crude protein concentrations in 2012 and was the directed response to better forage utilization under the moderate grazing intensity. There was not a grazing intensity effect in 2011 due to concern of over-grazing within the Chaparral-moderate grazing intensity treatments, which led to conservative stocking of these pastures.

The improvement in forage nutritive value led to higher average daily gain and measures of carcass quality traits for steers grazing within the Chaparral-treated pastures. In 2011, higher average daily gain were able to compensate for the lower carrying capacities on the Chaparral-treated pastures and resulted in similar estimates of gain per hectare between the herbicide treatments. However during 2012, the improvements in steer average daily gain were not as large within Chaparral-treated pastures, and resulted in higher gain per hectare within the control pastures due to higher carrying capacities. Gain per hectare was similar during 2011 for both grazing intensity treatments but were higher for the moderate grazing intensity treatments in 2012. The effects of Chaparral and grazing intensity treatments on reducing the severity in the symptoms of tall fescue toxicosis were not adequately examined within the current study due to the limited production of ergot alkaloids in tall fescue. It may be rationalized that Chaparral may reduce the symptoms of toxicosis because of the herbicides ability to inhibit the production of seedheads that contain high concentrations of alkaloids, but future research will be needed to confirm this conclusion.

Overall it may be concluded that Chaparral improved forage nutritive value and increased steer average daily gain, and is consistent with previous reports of the agronomic value of the herbicide. This suggests that that the herbicide is of value to beef operations, but more research is needed on how to practically incorporate its use into producer operations. Because similar levels of carrying capacities were obtained between the Chaparral-moderate grazing intensity and control-low grazing intensity treatments, it is possible that gain per hectare may be increased within the Chaparral-treated pastures by increasing the stocking densities. However, there were legitimate concerns of stand deterioration with Chaparral-moderate grazing intensity treatment during the first year, which implies that grazing management systems will need to be examined before Chaparral may be sustainably incorporated by producers.

CHAPTER VI: Implications

Chaparral has some potential for use within beef operations in Kentucky. Aminopyralid, one of the active ingredients of the herbicide is effective in controlling common pastures weeds of the state, such as tall ironweed or various types of thistles (Green et al., 2006). In addition, metsulfuron suppresses reproductive growth of tall fescue pastures leading to higher forage nutritive value throughout the growing season. Incorporation of the herbicide into stocker operations will depend upon the production goals of Kentucky farmers. Chaparral resulted in higher steer ADG as a result of the maintenance of higher forage quality, which may be of value in certain situations, such as in small “freezer” beef or niche-market operations. However, total beef produced per unit of area (i.e. GPH) is often of greater importance within stocker operations, and was lower in Chaparral-treated pastures because of lower forage availabilities. Increasing stocking densities did produce a similar number of grazing days between Chaparral-treated and control pastures, but also raises the risk of overgrazing of the pastures and stand deterioration. The need to sustainably increase stocking densities in Chaparral-treated pastures needs to be further addressed if Chaparral is to provide any practical non-weed related benefits. This may be by examining the grazing management system (i.e. rotational grazing) aspects of beef production.

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VITA

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Education:

- **Ph.D. Crop Science, University of Kentucky** (In Progress)
 - Dissertation: Effects of grazing intensity and chemical seedhead suppression on tall fescue pasture and steer productivity.
 - Minor: Plant Physiology
 - Co-Major Professor: Glen E. Aiken
 - Co-Major Professor: William W. Witt
 - Cumulative GPA: 4.0
- **M.S. Agronomy, Iowa State University** (2010)
 - Thesis: Double-cropping sorghum for biomass production.
 - Minor: Biochemistry
 - Co-Major Professor: Kenneth J. Moore
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 - Cumulative GPA: 3.9
- **B.S. Agronomy, West Virginia University** (2007)
 - Manga cum laude
 - Co-Advisor: John A. Balasko
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 - Cumulative GPA: 3.65

Professional Experience:

- Graduate research assistant, University of Kentucky, 2010-present.
- Graduate research assistant, Iowa State University, 2007-2010.
- Cartographic technician, NRCS Geospatial Research Unit, 2007.
- Undergraduate research assistant, West Virginia University, 2005-2006.

Professional Activities:

- Graduate student subcommittee (ACS 237.1), American Society of Agronomy, 2011-present
- Peer reviewer for *Crop Science*.
- Peer reviewer for *Forage and Grazinglands*.
- Peer reviewer for *Journal of Agriculture and Food Chemistry*.
- Peer reviewer for *African Journal of Biotechnology*.

Awards and Honors:

- Gerald O. Mott Meritorious Graduate Student Award, American Society of America, 2012.
- 3rd Place, Emerging Scientist Competition, American Forage and Grasslands Council, 2012.
- Research Excellence Award, Iowa State University, 2010.
- Gustav-Gertrude-Peter C. Seeck Fellowship, Iowa State University, 2007-2009.
- Pest Control Operators Association of West Virginia Scholarship, West Virginia University, 2005-2006.
- Promise Scholar, West Virginia University, 2003-2007.

Teaching Experience:*Teaching Assistant:*

- AGRON 526, Field Plot Technique, Iowa State University, 2010.
- AGRON 154, Fundamentals of Soil Science, Iowa State University, 2007-2009.
- AGRN 452, Grain and Special Crops, West Virginia University, 2006.

Guest Lecturer:

- ASC 382, Animal Production Principles, University of Kentucky, 2012.
- PLS 404, Integrated Weed Management, University of Kentucky, 2012.
- PLS 510, Forage Management and Utilization, University of Kentucky, 2012.

Professional Organizations:

- American Society of Agronomy
- Crop Science Society of America
- American Forage and Grassland Council
- Kentucky Forage and Grassland Council
- Gamma Sigma Delta

Publications:*Refereed Journal:*

- Flythe, M.D., I.A. Kagan, J.L. Klotz, **B.M. Goff**, and G.E. Aiken. Antimicrobial activity of red clover (*Trifolium pratense* L.) extract on ammonia-producing caprine rumen bacteria. *Small Rumin. Res. In Press*.
- **Goff, B.M.**, G.E. Aiken, W.W. Witt, B.B. Sleugh, and P. L. Burch. Steer consumption and ergovaline recovery from in vitro digested residues of tall fescue seedheads. *Crop Sci.* 52: 1437-1440.
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- **Goff, B.M.**, P.T. Murphy, and K.J. Moore. 2012. Comparison of common lignin methods and modifications on forage and lignocelulosic materials. *J. Sci. Food. Agr.* 92: 751-758.
- **Goff, B. M.**, Moore, K. J., Waramit, N., and Fales, S. L. 2011. Morphological development affects the prussic acid potential of 'Rumsey' indiagrass. Online. *Forage and Grazinglands* doi:10.1094/FG-2011-1004-01-BR.

- **Goff, B.M.**, K.J. Moore, S.L. Fales, and J.F. Pedersen. 2011. Comparison of the use of gas chromatography, spectrophotometry, and near infrared spectroscopy to quantify prussic acid potential in forages. *J. Sci. Food Agric.* 91: 1523-1526.
- **Goff, B.M.**, K.J. Moore, S.L. Fales, and E.A. Heaton. 2010. Double-cropping sorghum for biomass production. *Agron. J.* 102: 1586-1592.

Non-refereed:

- **Goff, B.M.**, G.E. Aiken, W.W. Witt, P.L. Burch, and B.B. Sleugh. 2012. Effects of grazing intensity and chemical seedhead suppression on steers grazing tall fescue pastures. In Proc. American Forage and Grassland Conference, Louisville, KY. 9-11 Jan.
- **Goff, B.M.**, G.E. Aiken, and W.W. Witt. 2011. Ergovaline recovery from digested residues of grazed tall fescue seedheads. In Proc. American Forage and Grassland Conference, French Lick, IN. 12-15 June.
- Aiken, G.E., W.W. Witt, **B.M. Goff**, and I.A. Kagan. 2011. Chemical suppression of seedhead emergence in toxic endophyte-infected tall fescue for improving cattle weight gain and physiology. In Proc. American Forage and Grassland Conference, French Lick, IN. 12-15 June.

Miscellaneous:

- **Goff, B.**, K. Moore, S. Fales, and E. Heaton. 2009. Potential for sorghum genotypes in a double-cropping system. In Annual Progress Reports - Northwest Research Farm and Allee Demonstration Farm, ISRF09-29, Iowa State University, Cooperative Extension Service, Ames, IA.

Abstracts:

- Bussard, J.R., G.E. Aiken, J.R. Strickland, K.R. Brown, **B.M. Goff**, A.P. Foote, and J.L. Klotz. 2012. Changes in vasculature contraction and constriction in cattle relative to time-off endophyte-infected tall fescue. ASAS/ADSA Annual Meetings, Phoenix, AZ. July 15-19.
- Klotz, J.L., J.R. Bussard, G.E. Aiken, A.P. Foote, D.L. Harmon, K.R. Brown, **B.M. Goff**, and J.R. Strickland. 2012. Lateral saphenous vein response to serotonergic and α -adrenergic receptor agonists changes relative to time off endophyte-infected tall fescue. ASAS/ADSA Annual Meetings, Phoenix, AZ. July 15-19.
- Bussard, J.R., G.E. Aiken, J.R. Strickland, K.R. Brown, **B.M. Goff**, A.P. Foote, and J.L. Klotz. 2012. Changes in vasculature contraction and constriction in cattle relative to time-off endophyte-infected tall fescue. In Proc. American Forage and Grassland Conference, Louisville, KY. 9-11 Jan.
- Aiken, G.E., **B.M. Goff**, W.W. Witt, and I.A. Kagan. 2011. Chemical suppression of reproductive development in endophyte-infected tall fescue for improving cattle weight gain and physiology. ASA-CSSA-SSSA Annual Meetings. San Antonio, TX. Oct. 16-19.
- **Goff, B.M.**, G.E. Aiken, and W.W. Witt. 2011. Ergovaline recovery from digested residues of grazed tall fescue seedheads. ASA-CSSA-SSSA Annual Meetings. San Antonio, TX. Oct. 16-19.
- Flythe, M.D., I.E. Kagan, G.L. Gellin, **B.M. Goff**, G.E. Aiken, and P.R. Cheeke. 2011. Plant phenolic compounds that modulate amino acid- and peptide- catabolism by caprine rumen microbes. ASM Annual Meetings. New Orleans, LA. May 21-24.

- Klotz, J.L., G.E. Aiken, A.P. Foote, L.P. Bush, K.R. Brown, **B.M. Goff**, and J.R. Strickland. 2011. Contractile response to ergovaline, 5-hydroxytryptamine_{2A}, α _{2A}-, and α _{2C}-adrenergic receptor agonists relative to time off of endophyte-infected tall fescue. ASAS/ADSA Annual Meetings, New Orleans, LA. July 10-14.
- **Goff, B.M.**, K.J. Moore, S.L. Fales, and E.A. Heaton. 2009. The potential of a double cropping system for biomass production. ASA-CSSA-SSSA Annual Meetings. Pittsburgh, PA. Nov. 1-5.
- **Goff, B.M.**, K.J. Moore, and S.L. Fales. 2008. The potential of a double cropping system for biomass production. Biobased Industry Outlook Conference. Ames, IA. Sept. 7-10.
- **Goff, B.M.**, L.M. McDonald, and E.M. Pena-Yewtukhiw. 2006. The explicit effects of water content and bulk density on TDR response. ASA-CSSA-SSSA Annual Meetings. Indianapolis, IN. Nov. 12-16.

Invited Presentations:

- **Goff, B.** and G. Aiken. 2011. Chaparral herbicide stocking rate study. DowAgrosciences Pasture Summit. Oct. 11.
- **Goff, B.** and G. Aiken. 2011. Seedhead suppression of tall fescue. Kentucky Forage and Grasslands Council Field Day, Versailles, KY. Sept. 8.
- **Goff, B.M.**, G.E. Aiken, and W.W. Witt. 2011. Suppression of reproductive growth of tall fescue with Chaparral. University of Kentucky/DowAgrosciences/USDA-ARS Field Day. Versailles, KY. June 23.
- **Goff, B.M.** and E.A. Heaton. 2008. Sugar crops for ethanol production. Muscatine Sugar Beet Field Day, Muscatine, IA. Sept. 25.