

Improving Eastern Grasslands Through Native Warm-Season Grasses

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DEDICATION

I dedicate this first to my Lord and Savior, Jesus Christ, for in Him, life has meaning. Second, to the best husband I could have ever asked for, Allen. Thank you for letting me chase my dreams and for your continued love and support. Thank you to our two amazing and wonderful children, Jacob and Hannah, who have been the most selfless and supportive teenagers. I love the three of you more than I could ever say. To my father and mother in love, Bill and Robbin, who are truly my own parents, thank you for treating me as your own and for all of your support and help through this journey. I never would have achieved this without you both. To my stepmother, Anna and my father, Jerry, thank you both for your love and encouragement. I love all four of you dearly.

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ABSTRACT

Summer cattle production for cow-calf pairs on tall fescue (TF) is impacted by fescue toxicosis and the semi dormancy of TF. Native warm-season grasses (NWSG) could be a viable forage option to fill the forage gap during the summer, lowering the amount of time that cow-calf pairs spend on toxic TF and improve soil health. However, little data is available on how NWSG affect the productivity of cow-calf operations on a farm scale. Therefore, we implemented an experiment at three sites, Booneville, AR, Linneus, MO and Louisville, TN, with cow-calf pairs (mature cows ≥ 3 years old, spring calving). We evaluated two forage systems that mix either a NWSG [big bluestem/indiangrass (BBIG) blend, eastern gamagrass (EG), or switchgrass (SG)] with TF, and compared them to a system that relies on TF only. Cattle ($n = 12$ pairs per experimental unit) were weighed yearly before initial grazing and again after final removal. Forage samples ($n = 15$) were collected at the beginning of grazing and once every twenty-eight days during the grazing season, and finally, at the conclusion of grazing. Harvested forages were tested for forage nutritive content (CP, NDF, ADF) using NIRS. Hay produced per system was documented. Input costs associated with each system were documented to compare the net returns to each system and per cow. At initiation and conclusion of the study, samples were taken for soil organic carbon (SOC) concentration, total nitrogen (N), bulk density (BD), wet aggregate stability (WAS), pH and Mehlich-3 nutrient concentrations. Mixed results indicate that incorporating NWSG in a program with TF may be of economic value to cow-calf production systems and could be a useful strategy to help lessen fescue toxicosis effects. In TN, there was indication that non-native, warm-season volunteer grasses within TF could be of help in lessening fescue toxicosis, while providing beneficial forage. Further research is needed to

determine what factors will increase carbon stocks, C:N ratios, WAS and BD within NWSG and non-native soils under grazing.

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INTRODUCTION

Overview of tall fescue

Tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.], hereinafter, ‘TF,’ is a non-native, cool-season, perennial grass that plays a role in several capacities, including livestock forage, hay production, erosion control, turf management, and as a lawn grass (Ball et al., 1991). Native to Europe and Northern Africa, it is likely that TF was a contaminant within meadow fescue seed (*Schedonorus pratensis*) introduced to North America from England prior to 1800 (Hoveland, 2009). Much of TF in North America today is Kentucky 31, a cultivar first taken from the William Suiter Farm in Manifee County, Kentucky in 1943 (Rogers and Locke, 2013). The high interest in Kentucky 31 during the 1940s resulted in the extensive planting throughout the lower Midwest and much of the South (Ball et al., 1991), as TF provided a cool-season perennial forage within these areas where few had ever persisted before (Ball et al., 1991). As a deep-rooting, sod-forming grass that spreads by rhizomes (Hall, 2023), Kentucky 31 was rapidly adopted and covers approximately 15 million ha today, in a region commonly called the “Fescue Belt” (Rogers and Locke, 2013).

Producers within the Fescue Belt continue to rely on this forage for numerous reasons. Tall fescue can tolerate an assortment of environmental conditions and stresses, while generating a substantial amount of forage (Aiken and Strickland, 2013). Tall fescue is typically more pest resistant than other forage species (Sleper and West, 1996). Additionally, TF has an advantage over other cool-season grasses with its capability to be utilized as a stockpile forage in late fall and winter from its fall growth. Stockpiled TF also retains greater forage digestibility and crude protein concentration than other cool-season stockpiled grasses (Sleper and West, 1996) as it has high leaf retention and produces broader leaves (Hall, 2023). For hay production, 4,000-9,000 kg ha⁻¹ dry matter are common (Lacefield et al., 2003).

However, TF does have limitations. In the 1950s-1970s, studies began to specify multiple problems with cattle grazing TF. In 1973, on a farm in north central Georgia, USDA researchers discovered a fungal endophyte within KY31 tissue that appeared to be linked with low gains in beef cattle (Bacon et al., 1977), a divergence from previous studies where rumen toxins or plant alkaloids were thought to be the culprit (Ferguson et al., 2021). The endophyte was later classified as *Acremonium coenophialum* (Morgan-Jones and Gams, 1982) and further reclassified as *Epichloe coenophiala* (Leuchtmann et al., 2017). Successive studies indicated a symbiotic relationship between TF and its endophyte, with the fungus obtaining nutrients from the grass, while TF receives several benefits, including increased resistance to pests and stress, improved seed viability and drought survival (Ferguson et al., 2021). A study on infected (TF⁺) and endophyte free TF demonstrated that stand loss was greater in pastures without the endophyte when subjected to a stressful environment (Arachevaleta et al., 1989). In another study in Georgia, four germplasms of TF (GA-5, GA-Jesup, GA-Jesup Improved, and GA-Ecotype KY31) were cultivated for three years to compare endophyte-infected and endophyte-free TF. The cultivars containing the endophyte had greater stand survival and yield than endophyte-free lines. This study further demonstrated that the loss of the endophyte within the plant decreased its fitness for summer drought tolerance (Bouton et al., 1993). Clearly, TF⁺ does not perform well when deprived of its symbiotic relationship with *Epichloe coenophiala*.

While the endophytic fungus may provide numerous benefits for growth rates and survival success, the association produces multiple difficulties for livestock. The ergot alkaloids produced by the endophyte induce fescue toxicosis, an illness that produces a vast array of symptoms in grazing livestock (Aiken and Strickland, 2013). Multiple studies with livestock including sheep, dairy and beef cattle grazing on infected TF⁺ have exhibited reduced weight

gains, decreased milk production, increased respiration rates, poor hair coat scores, increased body temperatures, decreased appetite and intake, lowered grazing intervals, increased salivation, lowered reproductive performance and increased time spent in the shade and water. Steers demonstrated an 82% increase for daily gain and a 42% increase in gain ha⁻¹ for steers on endophyte-free fescue compared with steers on TF⁺ throughout the grazing season (Hoveland et al., 1983). Another study utilizing steers on TF⁺ and endophyte free TF showed that steers on TF⁺ with a lower endophyte count (< 1%) grazed 40-60% longer during the warmer times of the day (12:00 -4:00 p.m.) than steers on TF⁺ with an elevated endophyte count (> 95%) (Stuedemann et al., 1985). Furthermore, steers that were relocated from the high to low endophyte infection did not return to their usual grazing habits for a month following their removal from the highly infected pastures. Additional studies reported elevated body temperatures of cattle consuming TF⁺, including research that demonstrated elevated core temperatures in heifers at nighttime with endophyte infected TF (Al-Haidary et al., 2001).

Fescue toxicosis appears to produce additional concerns for cattle during warmer periods. In episodes of heat stress, cattle demonstrated reduced ability to dispel body heat, and blood flow was found to decrease to rib skin, duodenum colon, and cerebellum tissues (Paterson et al., 1995). Moreover, fescue toxicosis creates problems in cattle reproduction as well, particularly with decreases in pregnancy, conception and calving rates (Ashley et al., 1987; Brown et al., 2000; McKenzie et. al., 1991; Poole et. al., 2019; Washburn and Green, 1991).

Undoubtedly, TF⁺ is a valuable forage, providing quality hay, high forage yields and adequate gains in cattle, but the presence of ergot alkaloids (produced by its symbiotic relationship with *Epichloe coenophiala*) is problematic for producers, as these alkaloids can manifest as fescue toxicosis in cattle, typically reducing animal performance and a revenue loss

for producers. As TF⁺ is the widespread forage within the Fescue Belt region (over 15 million ha), it would be advantageous for producers to have alternatives for grazing TF⁺ or strategies for lessening the effects of fescue toxicosis within cattle.

Native Warm Season Grasses – overview of big bluestem, eastern gamagrass, indiagrass and switchgrass

Native warm-season grasses (NWSG) are defined as grasses established in North America before European settlement and include species such as indiagrass [*Sorghastrum nutans* (L.) Nash], big and little bluestem [*Andropogon gerardii* Vitman, *Schizachyrium scoparium* (Michx.) Nash], switchgrass (*Panicum virgatum* L.) and eastern gamagrass [*Tripsacum dactyloides* (L.) L.]. Together, these species dominated grasslands of what is now the United States. These grasses can tolerate adverse ecological conditions, such as pests, diseases, heat, and drought (Keyser et al., 2011).

Big bluestem (BB) earns its name from its blue-green stems and dominates much of the Mid-western prairies, although its range extends to the southern US as well. Typically found in dry or sandy soils, BB is drought tolerant and requires little fertilizer. In a study in Pennsylvania, switchgrass and BB were grazed three times a year for three consecutive years without N fertilizer added to the pastures until the final year (Jung et al., 1985). Big bluestem is also effective for erosion control, due to its ability to establish a deep, fibrous root system and rhizome development.

Eastern gamagrass (EG) is a native perennial bunch grass found in the southern portions of the Mid-West and throughout the entire South, while even extending as far north as Massachusetts. Eastern gamagrass is typically found in moist areas but is also adapted to an extensive variety of soil conditions (Alderson et al., 2007). In a study in Maryland, EG was

established on six unlimed sites that were acidic with low moisture and compact soil, a soil condition that is typically not conducive for plant growth, yet EG still produced high biomass (Krizek et al., 2003). Research from Missouri demonstrated that EG roots were able to penetrate claypans, which typically limit rooting penetration, and moisture and nutrient accessibility to plants (Clark et al., 1998). As previously mentioned, EG grows well in wet soils and is categorized as a facultative wetland plant but has been observed to persist in drought conditions (Gitz et al., 2013).

Switchgrass is also a perennial bunch grass and, as a NWSG, is tolerant of poor ecological conditions, like BB and EG. The native range of SG is more widely spread than the other NWSG, even extending into Mexico and Canada (Hitchcock and Chase, 1950). Switchgrass roots typically extend the deepest of NWSG (Risser et al., 1981) and it thrives in flood lands and wetter soils (Weaver, 1954). Previously, SG played a major role in biofuel production (Wright and Turhollow, 2010), yet SG is an excellent forage for beef cattle as well. In a study in North Carolina, steers grazing switchgrass had a 66% greater average daily growth rate than steers grazing tall fescue and bermudagrass [*Cynodon dactylon* (L.) Pers.] (Burns et al., 1984). In a more recent analysis from 2013, steers on switchgrass gained 0.91 kg day^{-1} with a total beef yield of 340 kg ha^{-1} (Burns and Fisher, 2013).

Indiangrass (IG) is a tall, bunching perennial grass with a native range from the east coast to the Rocky Mountains and as far south as Arizona (Brakie, 2017). It is well adapted to a wide variety of soils, including heavy clays and sands (Brakie, 2017). While IG has been evaluated as a biofuel feed stock, it seems to be better suited for grazing (Hong et al., 2013; McIntosh, 2013). In a study in South Dakota, steers grazing pure IG stands had greater gain than those on BB and

SG (Krueger and Curtis, 1979). Indiangrass can be grown with BB as a mix and has shown promising results for cattle gains (Brazil et al., 2020; Mitchell and Anderson, 2008).

Using NWSG as a mitigation tool for reducing fescue toxicosis effects

Native grasses can be utilized for a variety of needs, such as biomass production, habitat restoration, soil erosion control and forage for multiple types of livestock. Additionally, these grasses may provide the quality forage needed during the “summer slump.” The summer slump refers to a period during the warmer months of the year, when cool-season grasses, such as TF⁺, are semi-dormant, alkaloid concentrations in fescue are increased and temperatures are high, resulting in an amplified effect of fescue toxicity in cattle. Adding warm-season grasses to a cool-season forage system allows for extended grazing days and reduced reliance on hay or other supplemental feed that are otherwise needed when cool-season grasses are not available (Hoveland et al., 1977). In an Illinois study, researchers utilized both annual and perennial NWSG grazing for cow-calf pairs grazing on cool-season grasses. The warm-season pastures produced 61% more herbage mass during July and August compared to the cool-season pastures (Tracy et al., 2010). Moreover, by including warm-season forages into a pasture rotation, the cool-seasonal grasses have resting time to recover, especially when environmental conditions are not favorable to their growth (Moore et al., 2004).

Numerous studies have been conducted on NWSG evaluating their forage quality capabilities for cattle weight gain and have demonstrated that NWSG can yield elevated rates of gain for beef cattle. These grasses have demonstrated excellent average daily gain (ADG) in steers, from 0.79 kg to 0.96 kg (Backus et al., 2017) and are capable of accommodating heifer development as well (Gadberry et al., 2024). In South Dakota, steers on BB produced 138 kg ha⁻¹ (Krueger & Curtis, 1979), while in North Carolina, steers grazing on BB had an increased ADG

of 1.08 kg day⁻¹ compared with 0.73 kg day⁻¹ by steers grazing a TF⁺ and bermudagrass system (Burns and Fisher, 2013). Incorporating EG in a forage production system appears to be favorable for cattle gains and generates high dry matter yields. In a three-year study, steers grazing EG produced high rates of gain (Aiken, 1997).

Further, each of these grasses can be successful and valuable forages for promoting ecosystem health (Lee et al., 1998). Environmentally, NWSG are well suited to drought, flooding and other unfavorable environments. Their large root systems and efficiency with photosynthesis allow them to flourish in higher temperatures than cool-season grasses. Further, since NWSG have high nitrogen (N) efficiency and tolerate nutrient poor soils, they do not require high fertility inputs, a considerable factor for producers that may wish to pursue more organic practices.

Native warm-season grasses can fill several roles in forage production for cow-calf operations in the US, particularly in the Fescue Belt region, where TF⁺ is the dominant, non-native, cool-season forage. These grasses possess several attributes that enable them to lessen the effects of the summer slump and fescue toxicosis, through their high yields and by producing strong animal performance. Additionally, they are already adapted to the native environments, enabling them to tolerate poor soil conditions and high temperatures, decreasing the amount of fertility input for producers and lowering risk during drought conditions. As they are non-invasive and are conservation friendly (improving soil health and having greater water use efficiency), they make excellent forage choices for producers interested in conservation practices.

REFERENCES

- Aiken, G. E. (1997). Temporal effects on steer performance and nutritive values for eastern gamagrass grazed continuously for different durations. *Journal of animal science*, 75(3), 803-808.
- Aiken, G.E. & Strickland, J.R. (2013). J.R. Forages and Pasture Symposium: Managing the tall fescue–fungal endophyte symbiosis for optimum forage-animal production, *Journal of Animal Science*: 91(5), 2369–2378.
- Alderson, J.S., J.K. Allison, M.R. Brakie, S.B. Bruckerhoff, J.A. Dickerson, J.L. Douglas, R.G. Esquivel, J.M. Grabowski, J.F. Henson, M.J. Houck, Jr., J.U. Kaiser, M.S. Kirkland, R.L. Noricks, S.L. Pfaff, J.M. Row, P.R. Salon, J. Stevens, L.M. Tharel, M. van der Grinten & R. Wynia. (2007). Eastern gamagrass. USDA-NRCS Plant Fact Sheet.
- Al-Haidary, A., Spiers, D.E., Rottinghaus, G.E., Garner, G.B., & Ellersieck, M.R. (2001). Thermoregulatory ability of beef heifers following intake of endophyte-infected tall fescue during controlled heat challenge, *Journal of Animal Science*: 79, (7), 1780–1788.
- Arachevaleta, M., Bacon, C.W., Hoveland, C.S. & Radcliffe, D.E. (1989). Effect of the tall fescue endophyte on plant response to environmental stress. *Agronomy Journal*: 81 (83-90).
- Ashley, T. L., Keltner, D. G., McLaren, J. B., Fribourg, H. A., & Onks, D. (1987). Performance of crossbred cows and calves grazing fescue pastures with varying levels of *Acremonium coenophialum* infection. *Journal of Animal Science*, 65, (49).
- Backus, W. M., Waller, J. C., Bates, G. E., Harper, C. A., Saxton, A., McIntosh, D. W., & Keyser, P. D. (2017). Management of native warm-season grasses for beef cattle and biomass production in the Mid-South USA. *Journal of animal science*, 95(7), 3143-3153.
- Bacon, C.W., Porter, J.K., Robbins, J.D., & Luttrell, E.S. (1977). *Epichloe typhina* from toxic

- tall fescue grasses. *Application of Environmental Microbiology*: 35: 576– 581.
- Ball, D., Lacefield, G.D., & Hoveland, C.S. (1991). The Tall Fescue Endophyte. University of Kentucky. Ext. AGR-149, Lexington, KY.
- Bouton, J.H., Gates, R.N., Belesky, D.P., & Owsley, M. (1993). Yield and Persistence of Tall Fescue in the Southeastern Coastal Plain after Removal of Its Endophyte. *Agronomy Journal*. 85:52-55.
- Brakie, M. (2017). Plant Guide for Indiangrass (*Sorghastrum nutans*). USDA-Natural Resources Conservation Service, East Texas Plant Materials Center. Nacogdoches, TX.
- Brazil, K. A., Keyser, P. D., Bates, G. E., Saxton, A. M., & Holcomb, E. D. (2020). Continuous grazing of mixed native warm-season grass in the fescue belt. *Agronomy Journal*, 112(6), 5067-5080.
- Brown, M.A., Brown, A.H. Jr, Jackson, W.G., & Miesner, J.R. (2000). Genotype x environment interactions in Angus, Brahman, and reciprocal cross cows and their calves grazing common bermudagrass and endophyte-infected tall fescue pastures, or both forages. *Journal of Animal Science*; 78:546-551.
- Burns, J. C., & Fisher, D. S. (2013). Steer performance and pasture productivity among five perennial warm-season grasses. *Agronomy Journal*, 105(1), 113-123.
- Burns, J. C., Mochrie, R. D., & Timothy, D. H. (1984). Steer Performance from Two Perennial Pennisetum Species, Switchgrass, and a Fescue—‘Coastal’ Bermudagrass System
1. *Agronomy Journal*, 76(5), 795-800.
- Clark, R., Alberts, E., Zobel, R.W., Sinclair, T.R., Miller, M.S., Kemper, W.D. & Foy, C.D. (1998). Eastern gamagrass (*Tripsacum dactyloides*) root penetration into and chemical properties of claypan soils. *Plant and Soil* , 33–45 (1998).

- Ferguson, T. D., Vanzant, E. S., & McLeod, K. R. (2021). Endophyte Infected Tall Fescue: Plant Symbiosis to Animal Toxicosis. *Frontiers in veterinary science*, 8, 774287.
- Gadberry, M. S., Moss, N., Tucker, C. A., & Wray, E. M. (2024). Performance of heifers grazing native or introduced mixed warm-season grasses during summer months in south-central United States. *Applied Animal Science*, 40(4), 456-465.
- Gitz, D. C., Baker, J. T., Stout, J. E., Brauer, D. K., Lascano, R. J., & Velten, J. P. (2013). Suitability of eastern gamagrass for *in situ* precipitation catchment forage production in playas. *Agronomy Journal*. 105, 907–914.
- Hall, M. (2023). Tall Fescue. Pennsylvania State University. Extension no. UC091. University Park, PA.
- Hitchcock, A.S. & Chase, A. (1950). Manual of the Grasses of the United States. United States Department of Agriculture. Publication No. 200. Washington, D.C.
- Hong, C. O., Owens, V. N., Lee, D., & Boe, A. (2013). Switchgrass, big bluestem, and indiangrass monocultures and their two-and three-way mixtures for bioenergy in the Northern Great Plains. *BioEnergy Research*, 6, 229-239.
- Hoveland, C. S. (2009). Origin and history. In H.A. Fribourg, D.B. Hannaway, and C.P. West (Ed.). *Tall fescue for the twenty-first century*, 1-10. American Society of Agronomy.
- Hoveland, C.S., Anthony, W.B., McGuire, J.A., & Starling, J.G. (1977). Overseeding winter annual forages on Coastal bermudagrass sod for beef cows and calves. University of Alabama, Ext. 496. Tuscaloosa, Alabama.
- Hoveland, C.S., Schmidt, S.P., King, C.C., Odom, J.W., Clark, E.M., McGuire, J.A., Smith, L.A., Grimes, H.W., & Holliman, J.L. (1983). Steer performance and association of

- Acremonium coenophialum Fungal Endophyte on Tall Fescue pasture. *Agronomy Journal*. 75, 821-824.
- Jung, G.A., J.L. Griffin, R.E. Kocher, J.A. Shaffer & C.F. Gross. (1985). Performance of switchgrass and bluestem cultivars mixed with cool-season species. *Agronomy Journal* 77:846-850.
- Keyser, P., Bates, G., Waller, J., Harper, C. & Doxon, E. (2011). Grazing native warm-season grasses in the Mid-South. University of Tennessee. Ext. SP731-C, Knoxville, TN.
- Krizek, D. T., Ritchie, J. C., Sadeghi, A. M., Foy, C. D., Rhoden, E. G., Davis, J. R., & Camp, M. J. (2003). A four-year study of biomass production of eastern gamagrass grown on an acid compact soil. *Communications in soil science and plant analysis*, 34(3-4), 457-480.
- Krueger, C. R., & Curtis, D. C. (1979). Evaluation of Big Bluestem, Indiangrass, Sideoats Grama, and Switchgrass Pastures with Yearling Steers 1. *Agronomy journal*, 71(3), 480-482.
- Lacefield, G.D., Hennings, J.C. & Phillips, T.D. (2003). Tall Fescue. University of Kentucky. Ext AGR-59. Lexington, KY.
- Lee, K.-H., Isenhardt, T. M., Schultz, R. C., & Mickelson, S. K. (1998). Nutrient and sediment removal by switchgrass and cool-season grass filter strips in Central Iowa, USA. *Agroforestry Systems*, 44(2), 121–132.
- Leuchtmann, A., Bacon, C. W., Schardl, C. L., White, J. F., & Tadych, M. (2014). Nomenclatural realignment of *Neotyphodium* species with genus *Epichloë*. *Mycologia*. 106:2, 202–215.
- McIntosh, D. W. (2013). Forage and Biomass Dual-purpose Harvest System Using Native Warm-season Grasses. Master's Thesis, University of Tennessee.

- McKenzie, P.P., & Erickson, B.H. (1991). Effects of fungal-infested fescue on gonadotrophin secretion and folliculogenesis in beef heifers. *Journal of Animal Science*, 69, 387.
- Mitchell, R. B., & Anderson, B. E. (2008). Switchgrass, big bluestem, and indiangrass for grazing and hay. *University of Nebraska-Lincoln Extension, IANR NebGuide G*, 1908.
- Moore, K.J., White, T.A., Hintz, R.L., Patrick, P.K., & Brummer, E.C. (2004). Sequential grazing of cool- and warm-season pastures. *Agronomy Journal*, 96, 1103-1111.
- Morgan-Jones, G. & Gams, W. (1982). Notes on Hyphomycetes. XLI. An endophyte of *Festuca arundinacea* and the anamorph of *Epichloe typhina*, a new taxa in one of two new sections of *Acremonium*.. *Mycotaxon*, 15: 311– 318.
- Paterson J., Forcherio C., Larson B., Samford M., & Kerley, M. (1995). The effects of fescue toxicosis on beef cattle productivity. *Journal of Animal Science*, 73(3):889-98.
- Poole, R.K., Devine, T.L., Mayberry, K.J., Eisemann, J.H., Poore, M.H., Long, N.M., & Poole, D.H. (2019). Impact of slick hair trait on physiological and reproductive performance in beef heifers consuming ergot alkaloids from endophyte-infected tall fescue. *Journal of Animal Science*, 97(4), 1456-1467.
- Risser, P.G., E.C. Birney, H.D. Blocker, S.W. May, W.J. Parton, & J.A. Wiens. (1981). The true prairie ecosystem. US/IBP Synthesis Series 16. Hutchinson Ross Pub
- Rogers, J. & Locke, J. (2013). Tall Fescue History, Application, Establishment and Management. Noble Foundation. Ext. NF-FO-13-03, Ardmore, Oklahoma.
- Sleper, D. & West, C. (1996). Tall fescue. In L. E. Moser, D. R. Buxton, & M. D. Casler (Eds.), Cool-season forage grasses (Vol. 34). American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

- Stuedemann, J.A., Wilkinson, S.R., Belesky, D.P., Devine, O.J., Breedlove, D.L., Thompson, F.N., Hoveland, C.S., Ciordia, H. & Townsend, W.E. (1985). Utilization and management of endophyte-infested tall fescue: Affects on steer performance and behavior. 17– 20. In J.D. Miller (ed.) Proc. 41st South. Pasture Forage Crop Imp. Conf., Raleigh, NC, 20–22 May. USDA/ARS U.S. Gov. Print. Office, Washington, DC.
- Tracy, B.F., Maughan, M., Post, N. & Faulkner, D.B. (2010). Integrating Annual and Perennial Warm-season Grasses in a Temperate Grazing System. *Forage and Grazing Lands*, 50 (5), 2171-2177.
- Washburn S.P. & Green J.T., Jr. (1991). Performance of replacement beef heifers on endophyte-infested fescue pastures. In: Proc 40 th Ann Conf of North Carolina Cattlemen's Assoc, NC State University, Raleigh, 1-4.
- Weaver, L.E. (1954). North American Prairie. Jensen Publ. Co., Lincoln, NE
- Wright, L., & Turhollow, A. (2010). Switchgrass selection as a “model” bioenergy crop: a history of the process. *Biomass and Bioenergy*, 34(6), 851-868.

CHAPTER I

A BIG BLUESTEM/INDIANGRASS COMPLEMENT ENHANCES CATTLE PRODUCTIVITY IN TALL FESCUE FORAGE SYSTEMS

ABSTRACT

As a cool-season (C_3) grass, tall fescue [TF: *Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.] provides limited forage during summer and fescue toxicosis can decrease weight gains and reproductive success in beef cattle. Native warm-season grasses (NWSG) have produced desirable weight gains and high-quality forage. Therefore, a complementary system using NWSG during summer could improve gains. Thus, an experiment was implemented with cow-calf pairs (mature cows ≥ 3 years old, spring calving), to evaluate two forage systems, one that relied on TF only and a complementary system that incorporated a NWSG with TF. Forage nutritive content (CP, NDF, ADF), body condition scores, cow and calf ($n = 12$ pairs per experimental unit) weights, and grazing days, hay produced, net hay balance, and water-use efficiency were documented. Input costs were also documented to compare net returns to each system and per cow. The complementary system had increased forage mass in June-August, greater weaning weights (289 vs 262 steers; 271 vs. 241, heifers), greater birth weights and increased kg weaned per ha. Grazing days, net hay balance and hay yield was greater in the TF-only system. Water use efficiency was greater in NWSG, particularly during the hotter months of summer. The net return to both system and per cow were not different between treatments but were likely impacted by the lack of open cows on TF100 due to low ergovaline levels within TF pastures.

INTRODUCTION

Beef production is an essential agricultural operation within the United States (US) and generated over US\$86 billion to the US economy in 2022 (USDA ERS, 2023). Over 82.6% of US cattle operations are cow-calf production systems (USDA NASS, 2024) and 40% of these operations are located within the “Fescue Belt” (Ren et al., 2021), an area comprised of almost 15 million ha, with tall fescue [TF: *Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.] as the dominant forage. However, cattle grazing endophyte infected tall fescue (TF⁺) frequently suffer from fescue toxicosis, a syndrome that costs the US beef industry more than US\$2 billion annually (Kallenbach, 2015) due to lower reproduction success (Ashley et al., 1987; Brown et al., 2000; McKenzie et al., 1991; Washburn and Green, 1991), decreased weight gain (Hoveland et al., 1983; McKenzie et al., 1991), and other symptoms (Hoveland et al., 1983; Poole et al., 2019) that lower overall cattle health. Further, as a cool-season (C₃) grass, TF⁺ is semi-dormant during summer, providing limited forage. Renovating existing TF⁺ pastures is not always a practical or financially viable solution, and producers are often limited from doing so (Poore and Horner, 2024).

Numerous studies have evaluated native warm-season grasses (NWSG) for forage quality and their ability to produce adequate weight gains for beef cattle. In South Dakota, steers on big bluestem (BB; *Andropogon gerardii* Vitman) produced 138 kg ha⁻¹ (Krueger and Curtis, 1979). In more recent studies, steers grazing BB had greater average daily gain (ADG) (1.08 kg day⁻¹,) than steers grazing a fescue and bermudagrass [BG; *Cynodon dactylon* (L.) Pers.] system (0.73 kg day⁻¹) (Burns and Fisher, 2013). Additionally, BB appears to have comparable or greater forage quality than TF⁺ (Griffin et al., 1980). Indiangrass [IG; *Sorghastrum nutans* (L.) Nash] also a NWSG, provides strong gains for beef cattle as well (Weaver, 1954). When grazed in a

mixed stand with BB, IG has produced greater or comparable gains in cattle than other warm-season grasses (Backus et al., 2017; Boyer et al., 2020).

Therefore, a complementary system using NWSG as the primary forage during summer when TF⁺ is semi-dormant and toxicity levels are elevated, could have a profound effect on cattle (McMurphy et al., 1975; Town and Ohlenbusch, 1992), and ecosystem health (Hendrickson et al., 2013; Kiniry et al., 2008), while increasing beef production (Backus et al., 2017; Brazil et al., 2020; Keyser et al., 2020) and lowering financial losses for producers (Doxon et al., 2012; Kallenbach, 2015). Thus, an experiment was implemented with spring calving, cow-calf pairs (mature cows ≥ 3 years old,) to evaluate two forage systems, one that relied on a C₃ grass only (TF⁺) and a complementary system that incorporated native, C₄ species [big bluestem/indiangrass mix [BBIG] with the same C₃ perennial, TF⁺].

The objectives of this study were to compare the productivity (grazing days per year, beef produced per ha), profitability (input costs, cost of gain, net return), sustainability (inputs), and water-use efficiency of these two systems. We hypothesized that the complementary system would be more profitable compared to the C₃-dominated system, with an increase in productivity (beef produced per ha and net hay balance) as a result of increased forage availability and nutritive content during summer (McMurphy et al., 1975; Town and Ohlenbusch, 1992), coupled with the reduction of fescue toxicosis from limited grazing time on TF⁺ (Drewnoski et al., 2009; Thompson et al., 1993). We also hypothesized that ecosystem health would be improved in the complementary system as a result of greater water use efficiency in native grasses (Hendrickson et al., 2013; Kiniry et al., 2008).

MATERIALS AND METHODS

Experimental Design: Two replicates of two treatments were used in this project. Treatment 1 (TF100), a cool-season forage system comprised predominately of toxic endophyte-infected TF⁺ and representative of the most common grazing system in the region, served as the control.

Treatment 2 (TF-BB) was a complementary cool-season/NWSG system, with the cool-season constituent also comprised of TF⁺ and with a BBIG mix representing 30% of the system as the NWSG. Each replicate of Treatment 1 was comprised of 12 ha of TF⁺, subdivided into 6, 2-ha paddocks. Treatment 2 had 4 ha of BBIG, subdivided into 5, 0.8-ha paddocks and 8 ha of TF⁺, subdivided into 4, 2-ha paddocks.

Site description: The research was conducted at the Missouri Forage Systems Research Center (38°51'27.7" N, 93°08'52.6" W) in Linneus, MO, from 2021-2023. The soil consisted of a rather poorly-drained, Armstrong clay (fine, smectitic, mesic Aquertic Hapludalfs), Purdin loam (fine, mixed, superactive, mesic Oxyaquic Hapludalfs), Lagonda silt loam (fine, smectitic, mesic Aquertic Argiudolls), Armstrong loam (fine, smectitic, mesic Aquertic Hapludalfs), Blackoat silt loam (fine-silty, mixed, superactive, mesic Fluvaquentic Endoaquolls) and Grundy silt loam (fine, smectitic, mesic Aquertic Argiudolls) (45%, 13%, 13%, 13%, 10% and 7%, respectively) (NRCS Web Soil Survey, 2023). Experimental units were similar in composition with respect to these soil series. Mean TF⁺ pasture soil pH was 6.67 with 46 kg ha⁻¹ P and 278 kg ha⁻¹ K. Mean BBIG pasture soil pH was 6.74 with 41 kg ha⁻¹ P and 245 kg ha⁻¹ K. Mehlich-3 nutrient concentrations were determined by the USDA-ARS Poultry Production and Product Safety Research lab (Fayetteville, AR).

Pasture Establishment: In 2016, 8 ha of TF⁺ pastures were renovated to NWSG stands, by spraying with glyphosate {N-[phosphonomethyl] glycine, isopropyl-amine salt} at the rate of 1.9

L product ha⁻¹ on 15 April, 2016 and then again on 15 May to eliminate the existing sod.

Pastures were then planted to a BBIG mix in June 2016 with cv “Kaw” and “Rumsey” in 20-cm rows with a no till, Truax FlexII model FLXII-816 drill (Truax Company, Inc., New Hope, MN) to a depth of 1 cm. Twenty-eight ha of existing TF⁺ pastures were used (established in 1977 as KY31, with 8 ha as an endophyte free “Missouri 96”) and were interseeded with 2.3kg ha⁻¹ red clover (*Trifolium pratense* L.) and .9kg ha⁻¹ white clover (*Trifolium repens*) in April 2021.

Pasture Management: Fertilization, liming, and weed control were handled similarly among all TF⁺ pastures for both treatments. All pastures received N in the form of urea [CO(NH₂)₂] at 62 kg ha⁻¹ annually in either April or May at greenup. Tall fescue pastures were hayed in June annually (additionally in August of 2021), with the exception of two TF⁺ paddocks per experimental unit, which were designated for fall stockpiling. Imazapic (2-[(RS)-4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl]-5-methylnicotinic acid) was applied to BBIG pastures in June of 2021 at a rate of .44 L ha⁻¹ product for broadleaf weed control. GrazonNext [aminopyralid +2,4-dichlorophenoxyacetic acid]) was applied in July of 2022 at a rate of 1.17 L ha⁻¹ product on TF⁺ paddocks to control encroachment of thistle. Big bluestem pastures were burned in April 2021 and 2023 prior to the commencement of the grazing season.

Cattle Management: Cows (mature Red Angus cows ≥3 years old, spring calving) were assigned (n = 12) in 2020 to one of four groups similar in parity, body condition, and weight. Groups were then randomly assigned to each treatment and remained on that treatment and group for the duration of the project. Cows determined to be open at the time of weaning were replaced in late April or early May (prior to breeding) or in November. Replacement animals were drawn from the same herd as the initial group and were comparable in size, body condition score (BCS), parity and pregnancy stage. Cows were fed supplements as needed to meet their National

Research Council requirements (2000) to maintain them at a minimum BCS of 5 at breeding time. Breeding was via artificial insemination (AI) under a Fixed-time, '7 & 7 Synch' protocol (Bonacker et al., 2020) with clean up bulls added approximately 2 weeks later. Bulls were removed approximately 45-50 days post-AI. Dates for AI were 10, 10, and 9 May in 2021, 2022, and 2023, respectively.

Cattle stayed on their assigned pastures throughout the year except as needed for animal health or breeding purposes. Animals had ad libitum availability to water and mineral at all times. Animal care adhered to MU Institutional Animal Care and Use protocol #10117.

Grazing Management: Grazing commenced each spring when TF⁺ reached a 20-cm canopy height (11, 9 and 9 May in 2021, 2022, and 2023, respectively). The grazing season continued until TF⁺ could no longer support grazing (3, December 2021, 9 December 2022, and 25 January 2024, respectively) for TF-BB and (3, 12 and 25 January in 2022, 2023 and 2024, respectively) for TF100 replicates. TF⁺ paddocks were grazed on a rotational basis with grazing intervals of 14-16 days and rest periods of 45-50 days. Two TF⁺ paddocks within each replicate were allotted for fall stockpiling. Rest was given to those stockpiled paddocks during late summer and early fall. Surplus TF⁺ growth in all paddocks was harvested as hay. Big bluestem pastures were grazed beginning 17, 23 and 2 June in 2021, 2022, and 2023, respectively, when stands were able to sustain grazing (i.e., canopy height above 30 cm). They were grazed on a rotational basis with cattle moved among paddocks based on stand condition (canopy heights between 10-30 cm), with grazing intervals of 3-4 days per paddock and rest periods of 15-21 days. During summer, pairs were removed from BBIG pastures if pastures needed rest and were placed on their respective TF⁺ pastures, then returned to BBIG pastures as soon as they were able to support grazing again. Total days spent off BBIG pastures were 6 in 2021, 0 in 2022 and 41 in

2023. Grazing of BBIG pastures concluded when stand conditions could no longer support grazing (23 August, 1 and 7 September in 2021, 2022, and 2023, respectively). Pasture height was measured at each movement ($n = 15$) for both the paddock being left and for the next paddock in the rotation.

Hay produced was documented per treatment unit and paddock, by counting bales and weights of subsamples; one weight was taken per experimental unit and hay harvest date. Winter hay feeding was concentrated on the experimental unit paddocks. Excess harvested forage was fed back into the same system from which it was harvested with feeding days and kg of hay fed documented.

Data Collection:

Aerial cover of forage species (grass and, for fescue, clovers as well) was estimated twice annually (early May for cool-season in TF⁺ pastures and early July for warm-season in both TF⁺ and BBIG pastures) by using a Vogel frequency grid (0.75 m x 0.75 m) (100 cells in total) ($n=8$ per paddock).

Forage mass (FM) was sampled at the beginning of grazing, once every 28 days during the grazing season and at the conclusion of active grazing for each experimental unit. The samples were collected pre- and post-rotation from 15 randomly located, 0.09 m² quadrats within the actively grazed paddock in each replicate. Forage mass samples were clipped to a 2.5-cm residual height. Forage within this sample from the grazing horizon (above 30 cm for BBIG and 10 cm for TF⁺) was used to determine crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF). Forage samples were taken from 20% of all hay bales each year. Forage and hay samples were dried in a forced air oven at 55C for 72 hours and then ground using a Wiley Mill (Thomas-Wiley Laboratory Mill Model 4, Arthur H. Thomas Co.,

Philadelphia, PA) passing through a 2-mm screen; followed by a cyclone sample mill (UDY Corporation, Fort Collins, CO) ground to pass through a 1-mm screen (McIntosh et al., 2022). The samples were scanned on a Foss DS2500F using ISIScan Nova v. 8.0.6.2 (Foss North America, Eden Prairie, MN). Spectra were then applied to the 2021 Grass Hay calibration and samples containing legume species were predicted with the 2021 Mixed Hay calibration provided and licensed by the NIRS Forage and Feed Consortium (NIRSC, Berea, KY). The global and neighborhood statistical tests were monitored and evaluated for accuracy across all predictions with entire data set fitting the calibrations withing the ($H < 3.0$) limit of fit and reported accordingly (McIntosh et al., 2022; Murray and Cowe, 2004). Units of measurement for nutritive analyses and calculated parameters are presented at 100% dry matter (DM) across the data set.

Fescue toxicity was documented in May of 2022 for percent infection and ergovaline concentrations, and again in September of 2022 for ergovaline concentrations. Percent infection was assessed using a Phytoscreen *Epichloe* immunoblot assay (Agrinostics, Ltd., Watkinsville, Ga). In May, vegetative tillers (pre-anthesis) were cut at the soil surface from 25 randomly selected TF⁺ plants per experimental unit (Aiken et al., 2012). For ergovaline concentrations, 50 randomly selected tillers >0.32 cm in diameter (pre-anthesis) were taken per experimental unit (Vincelli et al., 2017) and stored at -20 C before freeze drying.

Samples were analyzed by ARS Forage-Animal Production Research Unit (Lexington, KY) using high performance liquid chromatography and fluorescence detection (Carter et al., 2010). Separation was accomplished using a Kinetex (Phenomenex Inc., Torrance, CA) 100 mm × 4.6 mm C18 column with 2.6-μm particle size (Klotz et al., 2018).

Water use efficiency (WUE) was documented by taking yield from three, randomly placed exclusion cages (1.5 m diameter) within three paddocks of each experimental unit ($n = 18$), based on species (TF⁺, BBIG) and soil wetness index values (wet, medium, dry) generated from the System for Automated Geoscientific Analyses (SAGA) (Conrad et al., 2015). Exclusions were moved to new random locations within the paddock once every 28 days, concurrent with forage sampling dates from May to September, annually. Forage mass was collected from each exclusion cage at the end of each 28-day period to capture ingrowth. Annual rainfall and average daily temperatures for the study were monitored based on data from thermometers and rain gauges located on site at headquarters (~3 km from pastures).

Four weights were taken per year per cow in both treatments: at breeding, when TF-BB cow-calf pairs entered BBIG pastures in the spring, again when pairs were removed in late summer, and at weaning. Weight was taken on two consecutive days and the mean calculated. Timing of weighing was such that animals had grazed each forage for 3-5 days preceding weighing to standardize gut fill due to differing passage rates for C₄ vs C₃ grasses (Reid et al., 1990; Sponheimer et al., 2003). Weights were taken on calves at birth, when entering BBIG pastures in spring, again when removed from BBIG pastures, and finally, at weaning. Body condition scores (BCS) (Whittier et al., 1993) were taken for cows at breeding and at weaning, with hair coat scores (HCS) taken in spring (Decker and Thomas, 2021).

Input costs associated with each experimental grazing system were documented in order to compare the net returns to each system (**Table 1.1**). Costs included pro-rated pasture establishment costs, annual pasture costs (e.g., fertilization, weed control), hay purchase cost if hay balance was negative and any other costs that varied across grazing systems. A positive hay balance was added as a source of revenue. A 10-year stand life was assumed for BBIG similar to

other NWSG (Boyer and Keyser, 2020) and for TF⁺. Establishment costs included seed, herbicide, custom drilling of seed, and custom herbicide application. The cost of these inputs was based on average local costs in 2018. Finally, a 10% cost of re-establishment was included to account for the risk of initial establishment failure and replanting.

Statistical Analysis

Weaning weight data, adjusted to 205-days of age, were used for the evaluation of calf weaning results (Hobbs and Smith, 1991) along with unadjusted calf weights at weaning. Total grazing days were calculated based on total days pairs grazed with an animal unit day (AUD) based on a 454 kg cow with a calf at her side (Meyer, 2010). Calculations for AUD were conducted per year by experimental unit and forage type (TF⁺ and BBIG).

Response variables (cattle performance and forage parameters) were analyzed using a mixed model analysis of variance (ANOVA) using PROC MIXED in SAS[®], version 9.4 (SAS Institute, Cary, NC, 2013) and considered significant at $\alpha = 0.05$. Response variables were tested for normality using PROC UNIVARIATE. For cattle metrics, fixed effects were treatment, year, and treatment $\times$ year with year as a repeated measure. The random effects in the model were year $\times$ individual cow/calf (treatment). Total grazing days were calculated by animal unit days (AUD) per year by experimental unit and forage type (TF⁺ and BBIG). Fixed effects in the vegetation models were treatment, month and treatment $\times$ month, with year $\times$ replicate (treatment), paddock $\times$ year $\times$ replicate (treatment) and month $\times$ paddock $\times$ year $\times$ replicate (treatment) as random effects. Sampling months were included as a repeated measure in models for forage mass and nutritive value parameters, with months April-November for the TF100 system and months May-September for the BBIG component. If variables failed diagnostic tests for equal variances (>5 -fold difference), then log, square root or rank transformations were made.

Net hay balance was the hay produced within each replicate less the amount pairs assigned to that replicate consumed annually. The fixed effect in hay yield and net hay balance was treatment, year and treatment $\times$ year. The random effects in the models were year $\times$ replicate (treatment), paddock $\times$ year $\times$ replicate (treatment) and month $\times$ paddock $\times$ year $\times$ replicate (treatment). If variables failed diagnostic tests for equal variances (> 5 -fold difference), then log, square root or rank transformations were made.

PROC MIXED was used to compare WUE (yield/precipitation) between species and not systems. Fixed effects in the model were species, month, SAGA values, species $\times$ month, species $\times$ SAGA, month $\times$ SAGA and species $\times$ month $\times$ SAGA. The random effects in the model were year, year $\times$ species, year $\times$ species $\times$ paddock, year $\times$ species $\times$ paddock $\times$ SAGA, year $\times$ species $\times$ paddock $\times$ SAGA $\times$ month. Sampling months were included as a repeated measure in the model. If variables failed diagnostic tests for equal variances (> 5 -fold difference), then the rank transformation was made.

The fixed effect in the economics models were treatment, year, and treatment $\times$ year with year as a repeated measure. The random effects in the model were year $\times$ replicate (treatment). If variables failed diagnostic tests for equal variances (> 5 -fold difference), then log, square root or rank transformations were made.

RESULTS AND DISCUSSION

Weather instruments operated by the center (~ 3 km from pastures) collected daily ambient temperatures and precipitation data throughout the experimental period (**Figure 1.1**). While monthly temperatures did not largely deviate over the 3-year period, precipitation levels fluctuated from the 30-year mean, particularly in the months of May-July in 2023 when Missouri experienced a statewide drought (Missouri Department of Natural Resources, 2024). Tall fescue

pastures in Missouri can generally support grazing into the winter (Dierking et al., 2008; Meyer et al., 2009) as typical fall precipitation in the state allows for stockpiling pastures (Hancock and Josey, 2017) and the cooler winter temperatures are conducive for TF⁺ vitality. Drought conditions in August and September of 2021 shortened the BBIG grazing season by two weeks; however, stockpiling occurred for all three years of the experiment.

Both BBIG and TF⁺ pastures had forage cover with little influence from other grasses and broad-leaf weeds (BLW) and thus, reasonably met the treatment objectives for this project (**Figure 1.2**). Percent TF⁺ cover in the TF⁺ paddocks for both treatments was between 77-83%. Broad-leaf weeds were 15% in TF100 and 10% in TF-BB. Big bluestem-indiangrass pastures had 75% BBIG cover, 7% BLW, and 4% of other cool-season grasses (principally timothy [*Phleum pratense*] and orchardgrass [*Dactylis glomerata*]) (**Figure 1.2**).

Canopy heights (**Figure 1.3**) remained within target range (10-30 cm for TF⁺, 33-66 cm for BBIG) during the duration of the experiment. In June, as daytime temperatures reached 17C and above, the BBIG pastures began a rapid growth period (Rothbart and Capel, 2006) and reached heights above 55 cm. Tall fescue canopy heights in the TF⁺ pastures in TF-BB decreased more in fall than TF100 due to the more limited area of TF in the complementary system. With appropriate grazing height management and BLW control, stands within both treatments remained relatively free of other warm- and cool-season grasses and BLW encroachment and were heavily dominated by TF⁺ and BBIG, respectively.

Forage mass interacted between treatment and month ($P < 0.01$; **Table 1.2**), being greater in BBIG during June-August (**Figure 1.4**) and nearly double that of TF⁺ in June and July ($P < 0.01$). Thus, these results support previous findings of increased FM in NWSG stands during the summer (Tracy et al., 2010; Vendramini and Moriel, 2020), even in drought conditions, such

as what was observed in 2023 during this study. This increase in yield in the complementary system, particularly during the warmer months when TF⁺ is typically less productive (Malinowski et al., 2005) can be of great economic benefit to a producer as it provides extended grazing days and lower feed costs in summer (Brazil et al., 2022; Lancaster and Larson, 2022). Although there was increased FM in BBIG in summer, FM remained adequate in all forage types throughout the experiment to where intake was not limited.

Within the grazing horizon, CP generally remained between 90 and 150 g kg⁻¹ for TF⁺ in both treatments and between 86-119 g kg⁻¹ for BBIG but did not differ between treatments ($P < 0.14$; Table 1.2, **Figure 1.5**). Although CP was lower in both forages during summer as fiber increased ($P < 0.01$), there were no month $\times$ treatment interaction ($P < 0.45$). While crude protein in BBIG was numerically lower than TF⁺, NWSG typically show reduced CP levels in lab results compared to cool-season grasses but are still capable of providing animal performance beyond what test levels would suggest (Mullahey, 1989). Both forages increased in NDF and ADF throughout the summer before decreasing in August ($P < 0.01$); there were no treatment $\times$ month interactions. Tall fescue generally remained between 560 and 620 g kg⁻¹ NDF (**Figure 1.5**) and between 290-350 g kg⁻¹ ADF. Big bluestem/indiangrass ranged between 620 and 670 g kg⁻¹ NDF (**Figure 1.5**) and between 350-380 g kg⁻¹ ADF. Neutral detergent fiber and ADF contents were greater in TF-BB ($P < 0.02$, $P < 0.02$, respectively), typical of warm-season grasses (Vendramini and Moriel, 2020) as they accrue structural fibers when maturing in warmer months of the year. However, previous studies have indicated that lab tests lagged digestibility by 100-200 g kg⁻¹ in NWSG (Griffin et al., 1980; Vona et al., 1984) and these grasses may have greater digestibility than reported. Both CP and fiber levels were well at an acceptable level for beef cows at all stages of production and would not limit performance (National Research Council,

2016) and were comparable to levels of CP, NDF and ADF values for these forages reported elsewhere when grazed (Boland et al., 2012; Gadberry et al., 2024; Keyser et al., 2022).

The TF⁺ pastures in the TF100 system had a mean infection rate of 77% while those in TF-BB had a mean infection rate of 81%. Ergovaline concentrations averaged 157 ppb in TF-BB across pastures (May sampling) and 163 ppb across pastures (September sampling). Fescue pastures in the TF100 system averaged 140 ppb across pastures (May sampling) and 158 ppb (September sampling). Ergovaline concentrations were consistent among replicates. The onset of fescue toxicosis symptoms generally appear between 200-800 ppb (Arnold et al., 2014). Toxicity levels were below the expected levels for fescue toxicosis. However, 17% of the TF100 pastures were endophyte free and thus, cows in TF100 replicate 2 only grazed 8 ha of TF⁺.

Treatments did not differ for cow weights at breeding or weaning, spring and fall BCS and hair coat scores (**Tables 1.3 and 1.4**). Cow weights at breeding decreased annually ($P < 0.01$), yet there was no year $\times$ treatment interaction ($P < 0.97$). Spring and fall BCS and hair coat scores did not differ with treatment ($P < 0.85$, $P < 0.61$, $P < 0.60$, respectively). The lack of differences within these cow metrics may be explained by the possible muted effect of a fescue toxicosis impact, as 8 ha of the TF were not infected and ergovaline levels in infected TF were all below the threshold where fescue toxicosis symptoms are expected. Cows do not generally gain weight during early lactation even on high quality forage (Sprinkle, 1996) and if cows were not at risk of daily exposure to toxic ergot alkaloids, differences in breeding and weaning weights and HCS would be less likely.

Differences were not noted between treatments in the mean total number of open cows ($P < 0.86$). As decreased conception rates in beef cattle are a common problem for cows grazing TF⁺ (Porter and Thompson, 1992; Roberts et al., 2004), the reduced ergovaline levels may again have

limited fescue toxicosis effects in the study. Further, the mean calving date was later in TF-BB (2 March vs. 24 February) than in TF100 ($P < 0.01$). Cows grazing TF⁺ are susceptible to prolonged gestation periods (Porter and Thompson, 1992), yet this effect was not observed in TF100 cows.

Unadjusted calf weights at weaning for both steers ($P < 0.03$) and heifers ($P < 0.02$), 205-day weaning weights for both steers ($P < 0.01$) and heifers ($P < 0.01$), and total kg weaned per ha ($P < 0.03$) were all greater in TF-BB than TF100 (**Table 1.4**). These results support previous studies that demonstrated that NWSG have produced greater or comparable gains than other forages in weaned steers and heifers (Brazil et al., 2022; Gadberry et al., 2024; Keyser et al., 2022); however, I am unaware of any research on comparisons of nursing calves on NWSG or TF⁺. Thus here, I present the first data on calves during this period on these forages. These results also further support the aforementioned idea that NWSG are still capable of providing quality animal performance despite CP levels based on conventional laboratory testing (Mullahey, 1989). Birthweights were also greater in TF-BB ($P < 0.05$) but treatment interacted with year ($P < 0.05$), with decreased weights in year 3 for TF100 (**Table 1.3**). In 2023, drought conditions persisted throughout most of the summer and likely contributed to the lower birth weights in TF100 during year 3. By contrast, the BB maintained stronger calf performance, a reflection of its ability to produce nutritious forage under substantial drought. Grazing days (**Table 1.4**) were greater in TF100 than TF-BB ($P < 0.02$), but the additional TF ha within the TF100 system (12 vs. 8) allowed for a longer grazing period and, therefore, more AUD. Grazing days decreased in year 3 ($P < 0.01$), but cattle were removed earlier from the study in this year for management reasons.

There were no differences between treatments in hay yield (**Table 1.5**, $P < 0.55$), nor were there differences in hay balance between treatments (**Table 1.5**, $P < 0.33$). There were more

opportunities in the TF100 system for hay production, which led to the numerically greater hay yield and contributed to the numerically lower hay balance for TF100. Furthermore, there were 12 ha of TF⁺ available in TF100 for grazing vs. only 8 ha for TF-BB, leading to a longer fall grazing season than TF-BB (31 in 2021 and 34 days longer in 2022); yet there were no differences in AUD ha⁻¹ between treatments for the fall period ($P < 0.83$). Therefore, while NWSG can lower hay requirements in the summer, producers would need to provide enough TF⁺ pasture for stockpiling and winter grazing to lower the need for winter hay feeding. Thus, consideration should be given when replacing TF⁺ with NWSG to the impact on fall and winter grazing seasons. Individual production systems may need to adjust the 33% NWSG complement to meet their conditions. Crude protein ($P < 0.15$) and ADF ($P < 0.09$) in hay did not differ between treatments (**Table 1.5**).

Across all months for the 3-year experimental period, including the drought in 2023, BBIG pastures had greater WUE (**Figure 1.6**) than TF⁺ pastures ($P < 0.01$). Differences were not noted among SAGA wetness index values ($P < 0.13$). Warm-season grasses have previously been documented to have high WUE, particularly in unfavorable environments or unfavorable conditions (Emmerich, 2007; Gelley et al., 2020; Hendrickson et al., 2013). This ability in both BB and IG may be a contributing factor for the increased forage mass that was noted in the complementary system during the hotter summer months. Greater WUE in forages allows producers to take full advantage of reduced moisture availability, a potential necessity as atmospheric temperatures rise (Polley et al., 2013) and drought occurrences become more frequent (US Drought Monitor, 2024).

The net return per cow and to system (**Tables 1.6 and 1.7**) was similar in both TF100 and TF-BB ($P < 0.46$, $P < 0.51$, respectively). However, replicate 2 in TF-BB had a highly unusual

loss of 7 cows and 1 calf in August 2023. Although there were elevated nitrates within this BBIG paddocks (6,539 ppm) (University of Missouri, Columbia, MO), the cause of death was undetermined (Personal communication, H. Naumann, University of Missouri). Extreme heat may have contributed with daytime temperatures during August 2023 remaining above 32 C with maximum humidity levels over 90% for a week, with overnight temperatures (23 C) remaining elevated as well. When the cow loss was removed from replicate 2 in 2023, the net return per cow was numerically greater in TF-BB (\$165) than TF100 (\$13) and in return to system (\$2,289) than TF100 (\$452), ($P < 0.11$, $P < 0.15$, respectively).

The lack of open cows within TF100 may have had an effect on net returns. While open cows were similar between treatments in this study due to the low ergovaline levels within TF⁺ pastures in TF100, pregnancy rates are often lower for cows on TF⁺ (Schmidt et al., 1986) and management decisions for open cows can be costly and complicated for producers (Baker, 2024; Ibendahl et al., 2004). Thus, a decrease in open cows could have a noticeable economic impact. The benefits of incorporating NWSG within a TF⁺ system to reduce the effects of fescue toxicosis, i.e., open cows, likely would have been noted in this study if the TF⁺ pastures had higher ergovaline levels or grazing had been initiated earlier.

CONCLUSIONS

The increased forage mass, greater birth and weaning weights (steers and heifers), and increased kg weaned per ha in the complementary system indicate that incorporating NWSG into a C₃-dominated production system may have the potential to mitigate the impacts of fescue toxicosis and reduced summer forage production. Further, NWSG are more tolerant of elevated temperatures and drought conditions, while still producing high yields, as noted with the increased WUE in BBIG pastures, particularly during the months of July and August 2023, when

there were consistent periods of high temperatures and drought. This could be of great importance, as global temperatures are projected to warm approximately 1.5 degrees Celsius by 2050 (World Meteorological Association, 2024). Net returns would likely be greater in a complementary system but were most likely impacted in this study by the lack of open cows from low ergovaline levels.

REFERENCES

- Aiken, G.E., Goff, B.M., Witt, W.W., Kagan, I.A., Sleugh, B.B., Burch, P.L., & Schrick, F.N. (2012). Steer and Plant Responses to Chemical Suppression of Seedhead Emergence in Toxic Endophyte-Infected Tall Fescue. *Crop Science*, 52, 960-969.
- Arnold, M., Gaskill, C., and Smith, R.S. (2014). Fescue Toxicosis. University of Kentucky Agriculture and Natural Resources Publications. Publication 169. Lexington, KY.
- Ashley, T.L., Keltner, D.G., McLaren, J.B., Fribourg, H.A., & Onks, D.(1987). Performance of crossbred cows and calves grazing rescue pastures with varying levels of Acremonium coenophialum infection. *Journal of Animal Science*; 65(Suppl 1):49
- Backus, W. M., Waller, J. C., Bates, G. E., Harper, C. A., Saxton, A., McIntosh, D. W., & Keyser, P. D. (2017). Management of native warm-season grasses for beef cattle and biomass production in the Mid-South USA. *Journal of animal science*, 95(7), 3143-3153.
- Baker, H. (2024). The Cost of Keeping an Open Cow. University of Florida Beef and Forage Economics. Gainesville, FL.
- Boland, H. T., Scaglia, G., Notter, D. R., Rook, A. J., Swecker Jr, W. S., & Abaye, A. O. (2012). Diet composition and dry matter intake of beef steers grazing tall fescue and alfalfa. *Crop Science*, 52(6), 2817-2825.
- Bonacker, R.C., Stoecklein, K.S., Locke, J.W.C., Ketchum, J.N., Knickmeyer, E.R., Spinka, C.M., Poock, S.E., & Thomas, J.M. (2020). Treatment with prostaglandin F_{2α} and an intravaginal progesterone insert promotes follicular maturity in advance of gonadotropin-releasing hormone among postpartum beef cows. *Theriogenology*, 157, 350.
- Boyer, C., & Keyser, P. (2020). Summary of the Economic and Production Performance of Native Grasses as Forage in the Fescue Belt. University of Tennessee. Knoxville, TN.

- Boyer, C. N., Zechiel, K., Keyser, P. D., Rhinehart, J., & Bates, G. E. (2020). Risk and returns from grazing beef cattle on warm-season grasses in Tennessee. *Agronomy Journal*, 112(1), 301-308.
- Brazil, K. A., Keyser, P. D., Bates, G. E., Saxton, A. M., & Holcomb, E. D. (2020). Continuous grazing of mixed native warm-season grass in the fescue belt. *Agronomy Journal*, 112(6), 5067-5080.
- Brazil, K. A., Keyser, P. D., Griffith, A. P., Boyer, C. N., & Mulliniks, J. T. (2022). Perennial warm-season grass forages impact on cow-calf profitability in the Fescue Belt. *Journal of Applied Farm Economics*, 5(1), 2.
- Brown, M.A., Brown, A.H. Jr, Jackson, W.G., & Miesner, J.R. (2000). Genotype x environment interactions in Angus, Brahman, and reciprocal cross cows and their calves grazing common bermudagrass and endophyte-infected tall fescue pastures, or both forages. *Journal of Animal Science*, 78:546-551.
- Burns, J.C., & Fisher, D.S. (2013). Steer performance and pasture productivity among five perennial warm-season grasses. *Agronomy Journal*, 105:113-123.
- Carter, J. M., Aiken, G.E., Dougherty, C.T. and Schrick, F.N. (2010). Steer responses to feeding soybean hulls and steroid hormone implantation on toxic tall fescue pasture. *Journal of Animal. Science*, 88, 3759–3766.
- Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlitz, L., Wehberg, J., Wichmann, V. & Böhner J. (2015). System for automated geoscientific analyses (SAGA) v. 2.1. 4. *Geoscientific model development*, 8 (7), 1991-2007.
- Decker, J., & Thomas, J. (2021). Hair shedding scores: A tool to select heat tolerant cattle. University of Missouri. Columbia, MO.

- Dierking, R. M., Kallenbach, R. L., Kerley, M. S., Roberts, C. A., & Lock, T. R. (2008). Yield and Nutritive Value of ‘Spring Green’ *Festulolium* and ‘Jesup’ Endophyte-Free Tall Fescue Stockpiled for Winter Pasture. *Crop science*, 48(6), 2463-2469.
- Doxon, E., Keyser, P., Bates, G., Harper, C., & Waller, J. (2012). Economic Implications for Growing Native Warm-Season Grasses for Forage in the Mid-South. Publication SP731-E. University of Tennessee. Knoxville, TN.
- Drewnoski, M. E., Oliphant, E. J., Poore, M. H., Green, J. T., & Hockett, M. E. (2009). Growth and reproductive performance of beef heifers grazing endophyte-free, endophyte-infected and novel endophyte-infected tall fescue. *Livestock Science*, 125(2-3), 254-260.
- Emmerich, W. E. (2007). Ecosystem water use efficiency in a semiarid shrubland and grassland community. *Rangeland Ecology & Management*, 60(5), 464-470.
- Gadberry, M. S., Moss, N., Tucker, C. A., & Wray, E. M. (2024). Performance of heifers grazing native or introduced mixed warm-season grasses during summer months in south-central United States. *Applied Animal Science*, 40(4), 456-465.
- Gelley, C. H., Ashworth, A. J., Keyser, P. D., Nave, R. L., & Rhinehart, J. D. (2020). Water-use efficiency of forage crops in the southeastern United States. *Agronomy*, 10(9), 1377.
- Griffin, J.L., P.J. Wangness, & G.A. Jung. (1980). Forage quality evaluation of two warm-season range grasses using laboratory and animal measurements. *Agronomy Journal*, 72: 951-956.
- Hancock, D.W. & Josey, R.W. (2017). Stockpiling Tall Fescue for Fall and Winter Grazing. Publication 920. University of Georgia. Athens, Ga.

- Hendrickson, J. R., Schmer, M. R., & Sanderson, M. A. (2013). Water use efficiency by switchgrass compared to a native grass or a native grass alfalfa mixture. *BioEnergy Research*, 6, 746-754.
- Hobbs, J. & Smith, S. (1991): Program to calculate 205-day adjusted weights (PBD205WT for purebred herds) (COM205WT for commercial herds) *OSU current report Oklahoma State University Cooperative Extension Service: 91 (312)*.
- Hoveland, C.S., Schmidt, S.P., King, C.C., Odom, J.W., Clark, E.M., McGuire, J.A., Smith, L.A., Grimes, H.W., & Holliman, J.L. (1983). Steer performance and association of *Acremonium coenophialum* Fungal Endophyte on Tall Fescue pasture. *Agronomy Journal*. 75, 821-824.
- Ibendahl, G. A., Anderson, J. D., & Anderson, L. H. (2004). Deciding when to replace an open beef cow. *Agricultural Finance Review*, 64(1), 61-74.
- Jung, G.A., J.L. Griffin, R.E. Kocher, J.A. Shaffer & C.F. Gross. (1985). Performance of switchgrass and bluestem cultivars mixed with cool-season species. *Agronomy Journal*, 77:846-850.
- Kallenbach, R. L. (2015). Bill E. Kunkle Interdisciplinary Beef Symposium: Coping with tall fescue toxicosis: Solutions and realities. *Journal of Animal Science*, 93(12), 5487-5495.
- Keyser, P. D., Lituma, C. M., Bates, G. E., Holcomb, E. D., Waller, J. C., & Griffith, A. P. (2020). Evaluation of eastern gamagrass and a sorghum× sudangrass for summer pasture. *Agronomy Journal*, 112(3), 1702-1712.
- Keyser, P., Zechiel, K. E., Bates, G., Ashworth, A. J., Nave, R., Rhinehart, J., & McIntosh, D. W. (2022). Evaluation of five C4 forage grasses in the tall Fescue Belt. *Agronomy Journal*, 114(6), 3347-3357.

- Kiniry, J. R., Lynd, L., Greene, N., Johnson, M. V. V., Casler, M., & Laser, M. S. (2008). Biofuels and water use: comparison of maize and switchgrass and general perspectives. *New Research on Biofuels (eds Wright JH, Evans DA)*, 17-30.
- Klotz, J.L., Aiken, G.E., Egert-McLean, A.M., Schrick, N., Chattopadhyay, N. & Harmon, D.L. (2018). Effects of grazing different ergovaline concentrations on vasoactivity of bovine lateral saphenous vein. *Journal of Animal Science*. 96, 3022–3030.
- Krueger, C.R. & D.C. Curtis. (1979). Evaluation of big bluestem, indiangrass, sideoats grama, and switchgrass pastures with yearling steers. *Agronomy Journal*, 71:480-482.
- Lancaster, P. A., & Larson, R. L. (2022). Evaluation of strategies to improve the environmental and economic sustainability of cow–calf production systems. *Animals*, 12(3), 385.
- Malinowski, D. P., Zuo, H., Kramp, B. A., Muir, J. P., & Pinchak, W. E. (2005). Obligatory summer-dormant cool-season perennial grasses for semiarid environments of the southern Great Plains. *Agronomy journal*, 97(1), 147-154.
- McIntosh, D. W., Kern-Lunbery, R., Goldblatt, P., Lemus, R., Griggs, T., Bauman, L., Boone, S., Shewmaker, G. & Teutsch, C. (2022). Guidelines for Optimal Use of NIRSC Forage and Feed Calibrations in Membership Laboratories (Second Edition). The University of Tennessee Press, Knoxville, TN.
- McKenzie, P.P., & Erickson, B.H. (1991). Effects of fungal-infested fescue on gonadotrophin secretion and folliculogenesis in beef heifers. *Journal of Animal Science*, 69, 387.
- McMurphy, W. E., Denman, C. E., & Tucker, B. B. (1975). Fertilization of Native Grass and Weeping Lovegrass 1. *Agronomy Journal*, 67(2), 233-236.
- Meyer, A. M., Kerley, M. S., Kallenbach, R. L., & Perkins, T. L. (2009). Comparison of grazing

- stockpiled tall fescue versus feeding hay with or without supplementation for gestating and lactating beef cows during winter. *The Professional Animal Scientist*, 25(4), 449-458.
- Meyer, T. L. (2010). Estimating livestock forage demand: Defining the animal unit. *Theses and Dissertations in Animal Science*, 11. University of Nebraska. Lincoln, NE.
- Mullahey, J. J. (1989). *Influence of management on production, development, and protein utilization of warm-season grasses*. The University of Nebraska. Lincoln, NE.
- Murray, I., & Cowe, I. (2004). Sample preparation. *Near-infrared spectroscopy in agriculture.*,44, 75-112.
- Polley, H. W., Briske, D. D., Morgan, J. A., Wolter, K., Bailey, D. W., & Brown, J. R. (2013). Climate change and North American rangelands: trends, projections, and implications. *Rangeland Ecology & Management*, 66(5), 493-511.
- Poole, R.K. & Poole, D.H. (2019). Impact of Ergot Alkaloids on Female Reproduction in Domestic Livestock Species. *Toxins (Basel)*. 11(6).
- Poore, M. H. & Horner, J., (2024). Economics and Other Factors Affecting the Adoption of Novel Endophyte Technology. *IGC Proceedings (1993-2023)*. 70.
- Porter, J. K., & Thompson Jr, F. N. (1992). Effects of fescue toxicosis on reproduction in livestock. *Journal of animal science*, 70(5), 1594-1603.
- Reid, R. L., Jung, G. A., Cox-Ganser, J. M., Rybeck, B. F., & Townsend, E. C. (1990). Comparative utilization of warm-and cool-season forages by cattle, sheep and goats. *Journal of Animal Science*, 68(9), 2986-2994.
- Ren, Y., Lambert, D. M., Clark, C. D., Boyer, C. N., & Griffith, A. P. (2021). Adoption of warm season grasses by beef cattle producers in the fescue belt. *Journal of Agricultural and Resource Economics*, 47(1), 190-208.

- Roberts, C., & Andrae, J. (2004). Tall fescue toxicosis and management. *Crop Management*, 3(1), 1-18.
- Rothbart, P., & Capel, S. (2006). Chapter 3. Maintaining and restoring grasslands. *Comparative and General Pharmacology*, 14-27.
- Schmidt, S.P., Danielson, D.A., Holliman, J.A., Grimes, H.W. & Webster, W.B. (1986). Fescue fungus suppresses growth and reproduction in replacement beef heifers. Highlights Agriculture. Res. 3315. Alabama Agriculture. Exp. Stn., Auburn University. Auburn, AL.
- Sponheimer, M., Robinson, T., Roeder, B., Hammer, J., Ayliffe, L., Passey, B., Cerling, T., Dearing, D. & Ehleringer, J. (2003). Digestion and passage rates of grass hays by llamas, alpacas, goats, rabbits, and horses. *Small Ruminant Research*, 48(2), 149-154.
- Sprinkle, J. E. (1996). Matching forage resources with cow herd supplementation. Publication AZ9523. University of Arizona. Tucson, AZ.
- Thompson, R. W., Fribourg, H. A., Waller, J. C., Sanders, W. L., Reynolds, J. H., Phillips, J. M., & Hunter, P. P. (1993). Combined analysis of tall fescue steer grazing studies in the Eastern United States. *Journal of animal science*, 71(7), 1940-1946.
- Towne, G., & Ohlenbusch, P. D. (1992). *Native hay meadow management*. Department of Agronomy. Kansas State University. Manhattan, KS.
- Tracy, B. F., Maughan, M., Post, N., & Faulkner, D. B. (2010). Integrating annual and perennial warm-season grasses in a temperate grazing system. *Crop Science*, 50(5), 2171-2177.
- Vendramini, J., & Moriel, P. (2020). Management of forages and pastures in Lower-South: I-10 Corridor. In *Management Strategies for Sustainable Cattle Production in Southern Pastures* (pp. 101-122). Academic Press.

- Vincelli, P., Smith, S.R. & Tillery, T. (2017). Sampling for the Tall Fescue Endophyte in Pasture or Hay Stands. University of Kentucky, Ext. PPA-30. Lexington, Kentucky.
- Vona, L.C., Jung, G.A. Reid, R.L. & Sharp, W.C. (1984). Nutritive quality of warm-season grass hays for beef cattle and sheep; digestibility, intake and mineral utilization. *Journal of Animal Science*. 59:1582-1593.
- Washburn SP, & Green, J.T. Jr. (1991). Performance of replacement beef heifers on endophyte-infested fescue pastures. In: Proc 40 the annual conference of North Carolina Cattlemen's Association, NC State University, Raleigh; 1-4.
- Weaver, J. E. (1954). A seventeen-year study of plant succession in prairie. *American Journal of Botany*, 31-38.
- Whittier, J. C., Steevens, B. J., & Weaver, A. D. (1993). *Body condition scoring of beef and dairy animals*. University of Missouri. Columbia, MO.

APPENDIX I

Table 1.1: Total annualized pasture and hay costs (US\$ ha⁻¹) for establishing and maintaining two forage systems, TF100 [12 ha tall fescue (TF)], and TF-BB [4 ha of big bluestem/indiangrass (BB) mix and 8 ha of TF] during a 10-yr useful life. Pasture budget models are from the University of Tennessee Department of Agriculture and Resource Economics - <https://arec.tennessee.edu/extension/budgets/>.

Cost	TF100	TF-BB
	US\$	
ha ⁻¹		
Prorated establishment cost	35	36
Annualized hay cost	123	105
Annualized pasture cost	102	77
Total annual hay and pasture cost	260	218

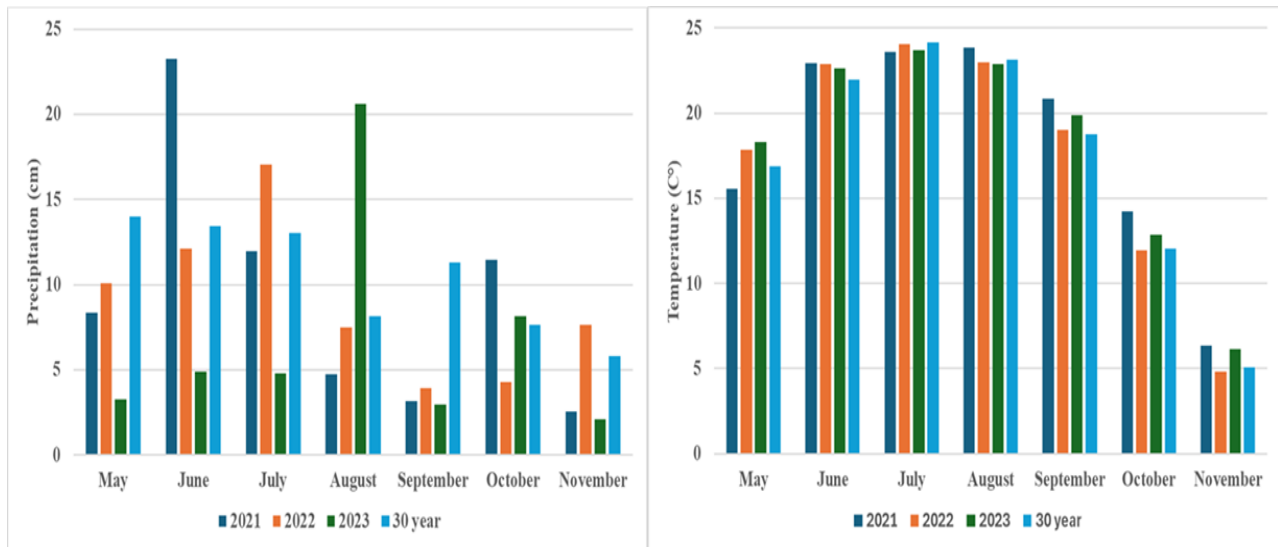


Figure 1.1: Mean monthly precipitation totals and average daily temperatures for 2021-2023 during grazing experiment at Missouri Forage Systems Research Center, Linneus, MO, with monthly precipitation totals and average daily temperatures for a 30-year period, Linneus, MO.

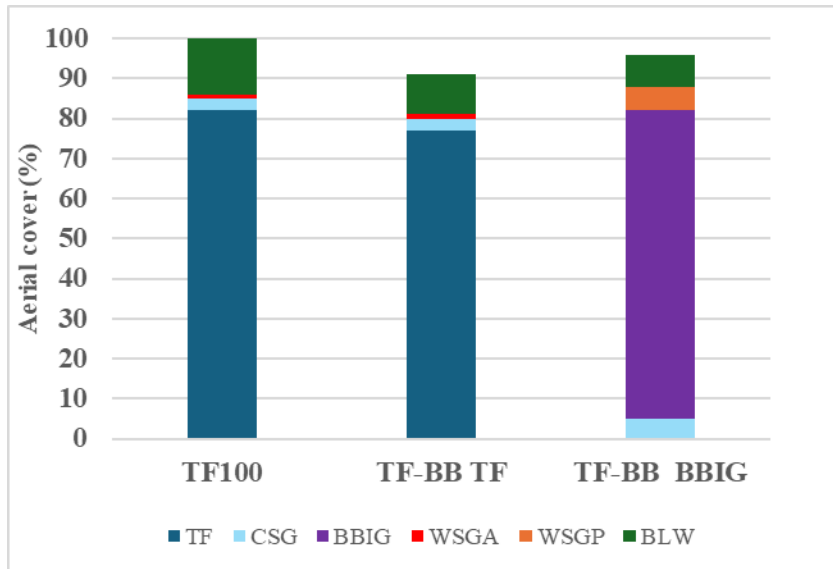


Figure 1.2. Aerial cover (%) of tall fescue (TF), other cool-season grasses (CSG), big bluestem/indiangrass (BBIG), warm-season annuals (WSGA), other warm-season perennials (WSGP), and broad-leaf weeds (BLW), in May and July for two forage systems, TF100 [12 ha tall fescue (TF)], and TF-BB [4 ha of big bluestem/indiangrass (BBIG) mix and 8 ha of TF], during grazing experiment at Missouri Forage Systems Research Center, Linneus, MO, 2021-2023. Cover values for TF-BB TF are for TF⁺ paddocks within the TF-BB treatment only, with cover values for TF-BB BBIG for BBIG paddocks within the TF-BB treatment only. In TF-BB TF, 9% of the cover was dead material or bare ground, with 5% dead material or bare ground in TF-BB BBIG.

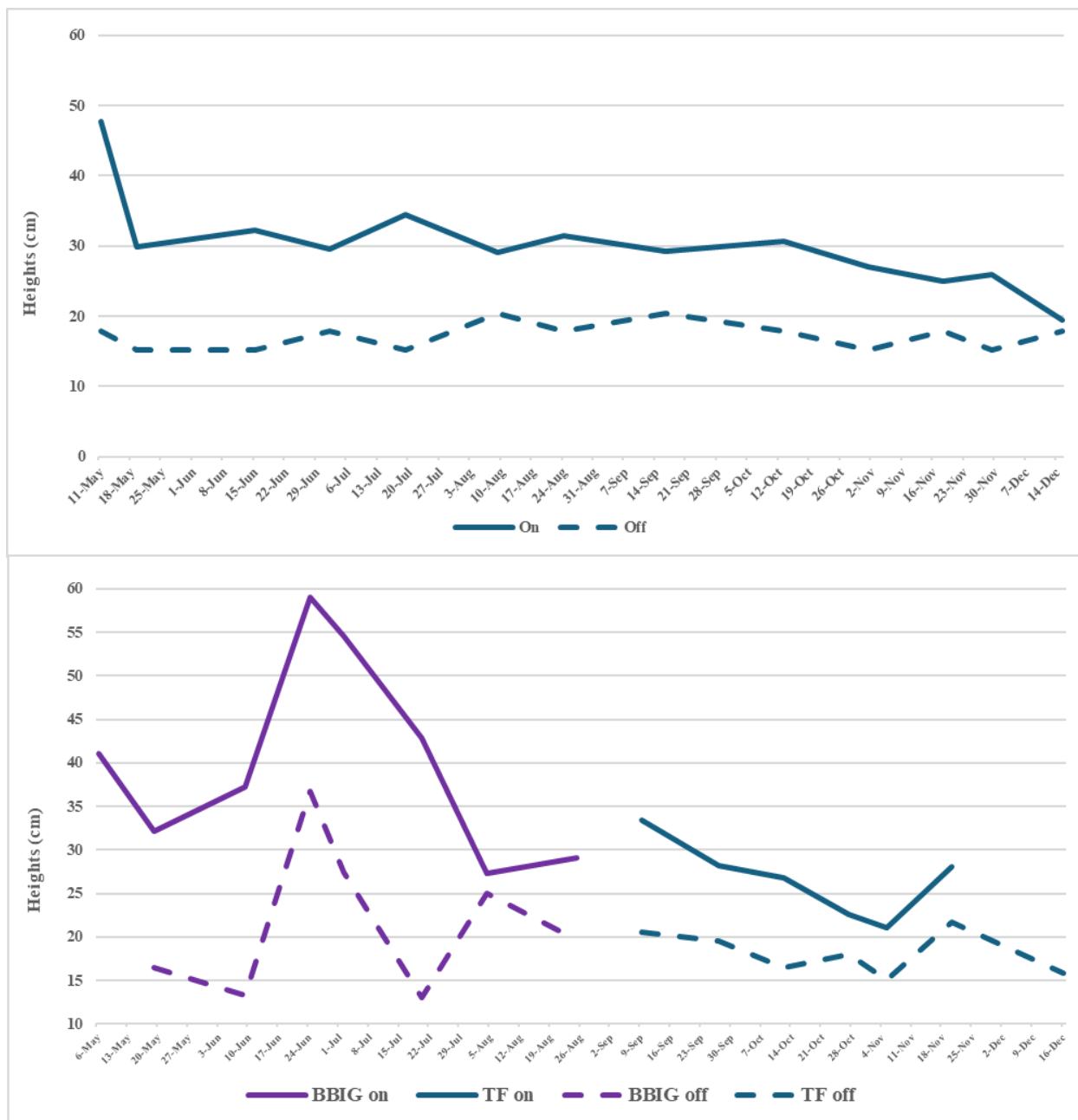


Figure 1.3. Mean grass canopy heights moving on and off paddocks for two forage systems, TF100 [12 ha tall fescue (TF)] (top), and TF-BB [4 ha of big bluestem/indiangrass (BBIG) mix and 8 ha of TF] (bottom) at Missouri Forage Systems Research Center, 2021-2023, Linneus, MO.

Table 1.2: Mixed model ANOVA results for forage mass and forage nutritive values for two forage systems (TF100 and TF-BB), TF100 [12 ha tall fescue (TF)], and TF-BB [4 ha of big bluestem/indiangrass (BBIG) mix and 8 ha of TF] at Missouri Forage Systems Research Center, 2021-2023, during grazing experiment at Missouri Forage Systems Research Center, Linneus, MO.

Variable	Effect	df (num, denom)	F-value	P > F
Forage mass	treatment	1, 12	4.27	0.06
	month	6, 284	38.73	0.01
	treatment × month	6, 284	10.01	0.01
Crude protein	treatment	1, 66	2.27	0.14
	month	6, 121	13.35	0.01
	treatment × month	6, 121	0.96	0.45
Neutral detergent fiber	treatment	1, 68	6.14	0.02
	month	6, 123	7.34	0.01
	treatment × month	6, 123	1.81	0.10
Acid detergent fiber	treatment	1, 70	5.43	0.02
	month	6, 113	12.14	0.01
	treatment × month	6, 113	1.91	0.08

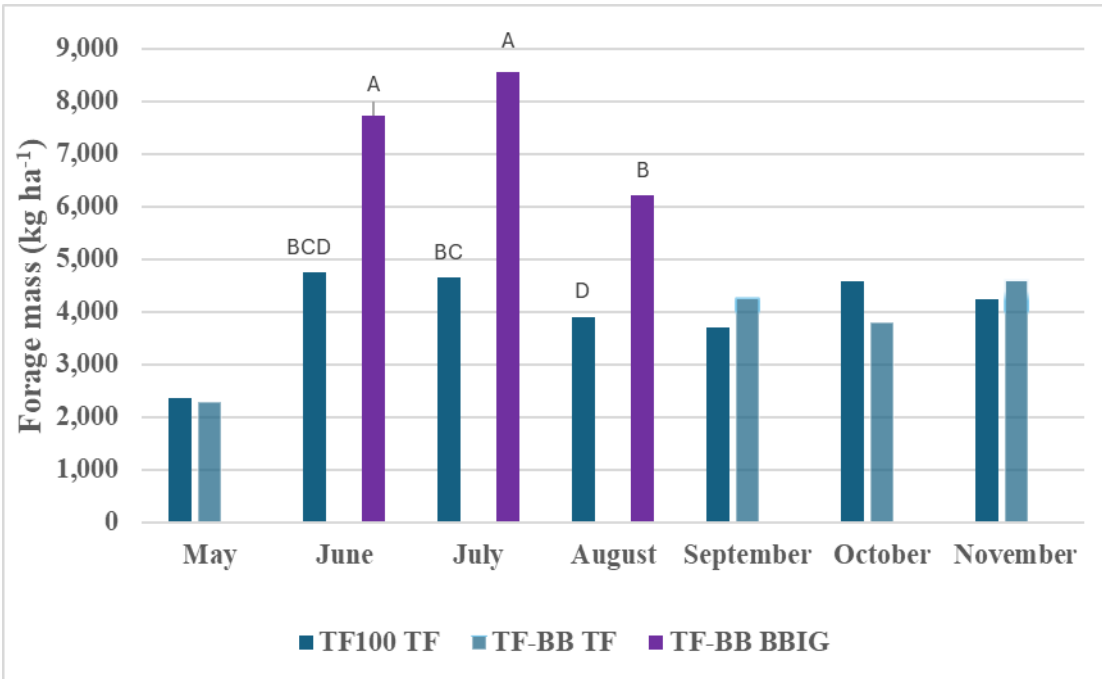


Figure 1.4. Mean monthly forage mass for two forage systems, TF100 [12 ha tall fescue (TF)], and TF-BB [4 ha of big bluestem/indiangrass (BBIG) mix and 8 ha of TF] at Missouri Forage Systems Research Center, Linneus, MO, 2021-2023. For TF-BB, mass is presented separately by each forage type, TF (TF-BB TF) and BBIG. Letters indicate differences ($P < 0.05$).

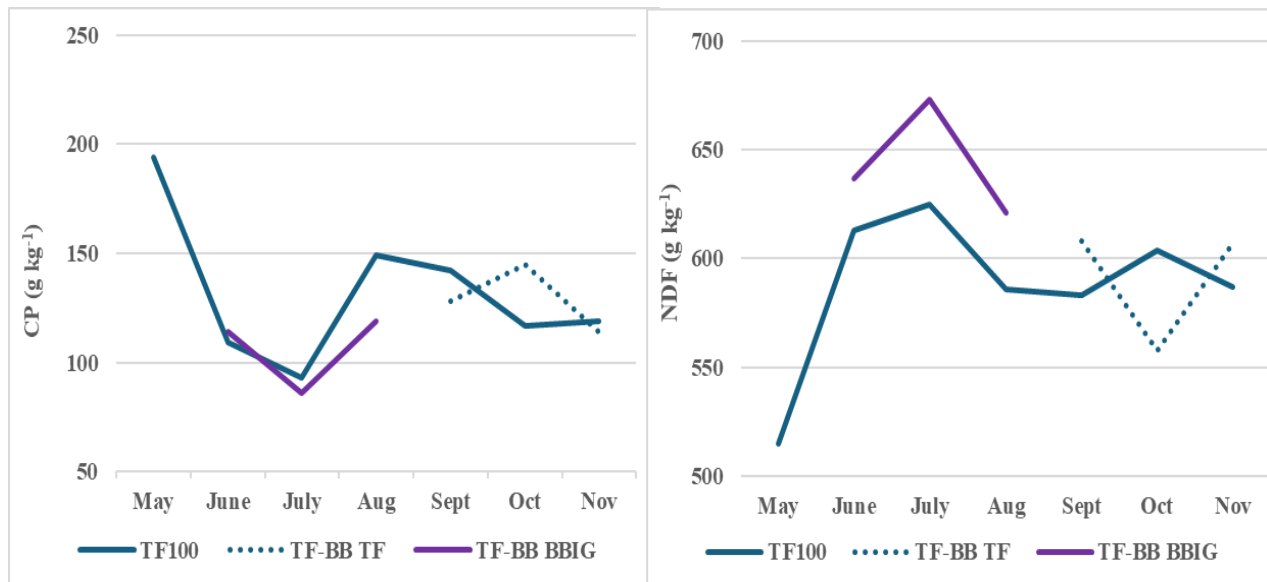


Figure 1.5. Crude protein (CP), and neutral detergent fiber (NDF) for two forage systems, TF100 [12 ha tall fescue (TF)], and TF-BB [4 ha of big bluestem/indiangrass (BBIG) mix and 8 ha of TF] during grazing experiment at Missouri Forage Systems Research Center, Linneus, MO, 2021-2023. Measures for CP and NDF are by grass types (TF and BBIG) by months.

Table 1.3: Mixed model ANOVA results for cattle response variables two forage systems (TF100 and TF-BB), TF100 [12 ha tall fescue (TF)], and TF-BB [4 ha of big bluestem/indiangrass (BBIG) mix and 8 ha of TF] during grazing experiment at Missouri Forage Systems Research Center, Linneus, MO, 2021-2023. Body condition score is denoted by BCS. Hair coat score is denoted by HCS. Adjusted weaning weight is denoted by AWW.

Variable	Effect	df (num, denom)	F-value	P > F
Cow weight at breeding	treatment	1, 138	0.03	0.86
	year	2, 138	26.04	0.01
	treatment × year	2, 138	0.03	0.97
Cow weight at weaning	treatment	1, 129	0.72	0.40
	year	2, 129	0.73	0.48
	treatment × year	2, 129	0.43	0.65
BCS (spring)	treatment	1, 136	0.13	0.72
	year	2, 136	13.62	0.01
	treatment × year	2, 136	0.16	0.85
BCS (fall)	treatment	1, 129	0.03	0.86
	year	2, 129	30.85	0.01
	treatment × year	2, 129	0.50	0.61
HCS	treatment	1, 136	0.20	0.65
	year	2, 136	45.26	0.01
	treatment × year	2, 136	0.52	0.60
Open cows	treatment	1,6	0.04	0.86
	year	2,6	3.88	0.08
	treatment × year	2,6	0.36	0.71
Birth date	treatment	1,121	6.15	0.01
	year	2,121	5.41	0.01
	treatment × year	2, 121	0.81	0.45
Calf weights at weaning, steers	treatment	1, 6	7.46	0.03
	year	2, 6	4.91	0.05
	treatment × year	2,6	0.03	0.97
Calf weights at weaning, heifer	treatment	1, 6	11.38	0.02
	year	2, 6	5.86	0.04
	treatment × year	2, 6	0.83	0.48
205-day AWW, steers	treatment	1, 63	12.01	0.01
	year	2, 63	77.70	0.01
	treatment × year	2, 63	0.01	0.10
205-day AWW, heifers	treatment	1,66	14.49	0.01
	year	2,66	49.22	0.01
	treatment × year	2,66	0.15	0.86
Total kg ha ⁻¹ weaned	treatment	1,6	8.64	0.03
	year	2,6	7.13	0.03
	treatment × year	2,6	0.87	0.46
Birth weight	treatment	1,117	3.88	0.05
	year	2,117	13.92	0.01

Table 1.3: Continued

	treatment × year	2,117	3.11	0.05
Grazing days	treatment	1,6	0.01	0.02
	year	2,6	15.42	0.01
	treatment × year	2,6	7.84	0.26

Table 1.4. Means for response variable for cattle for two forage systems, TF100 [12 ha tall fescue (TF)], and TF-BB [4 ha of big bluestem/indiangrass (BBIG) mix plus 8 ha of TF] during grazing experiment at Missouri Forage Systems Research Center, 2021-2023, Linneus, MO. Body condition score is denoted by BCS.¹ Hair condition score denoted by HCS². Means followed by different letters differ ($P < 0.05$). Adjusted weaning weight is denoted by AWW.

	TF100	TF-BB
Cow weights at breeding (kg)	582	580
Cow weights at weaning (kg)	620	630
BCS (spring)	5.5	5.5
BCS (fall)	5.5	5.5
HCS	2.5	2.5
Mean total open cows	2	2
Birth date	24-Feb a	2-Mar b
Calf weights at weaning (kg), steers	268b	294a
Calf weights at weaning (kg), heifers	241b	271a
205-day AWW (kg), steers	262b	289a
205-day AWW (kg), heifers	236b	264a
Total kg ha ⁻¹ weaned	247b	275a
Birth weights (kg)	38a	40a
2021	40a	39ab
2022	40ab	43a
2023	34c	38b
Grazing days (AUD ha ⁻¹)	311a	265b

¹ Body condition scores were estimated on a 9-point scale (Whittier et al., 1993).

² Hair scores were measured on a scale of 1 to 5 (Decker and Thomas, 2021).

Table 1.5. Mean annual hay yield, nutritive values (crude protein [CP] and acid detergent fiber [ADF]) and annual hay balance for two forage systems, TF100 [12 ha tall fescue (TF)], and TF-BB [4 ha of big bluestem/indiangrass (BBIG) mix plus 8 ha of TF], during grazing experiment at Missouri Forage Systems Research Center, Linneus, Mo, 2021-2023. Means followed by different letters differ ($P < 0.05$).

	TF100	TF-BB	F-value	P > F
Yield (kg ha ⁻¹)	5,657	5,178	0.41	0.55
CP (g kg ⁻¹)	90	100	3.82	0.15
ADF (g kg ⁻¹)	360	340	3.86	0.09
Net hay balance (kg)	-4,379	-6,490	1.13	0.33

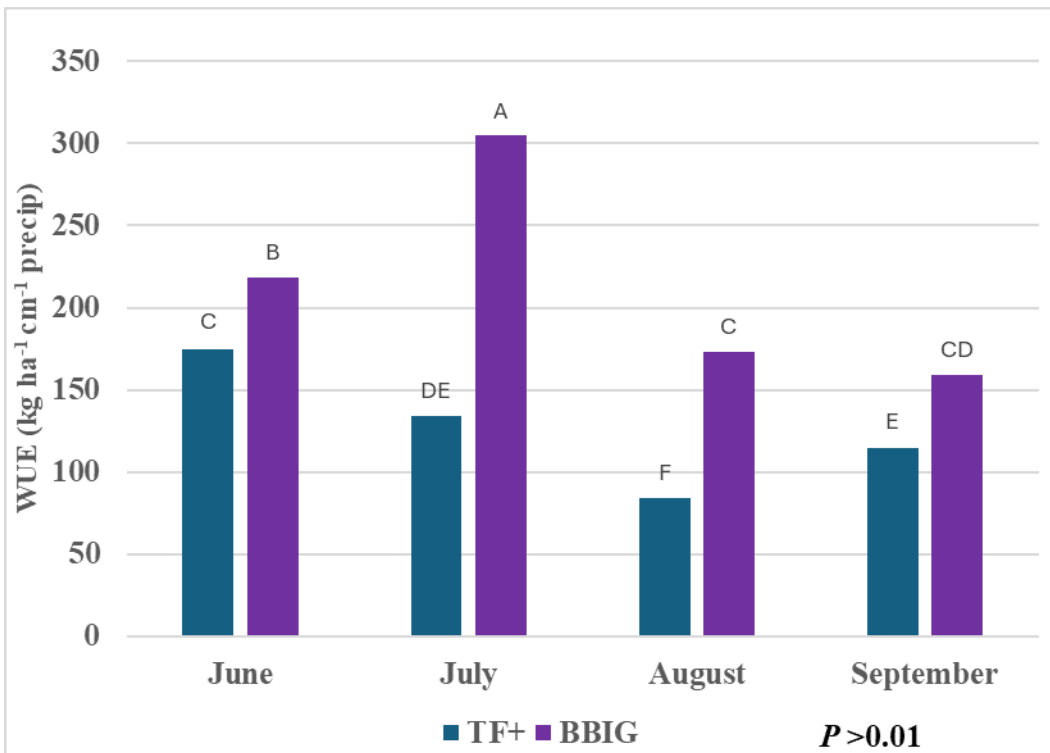


Figure 1.6. Mean water use efficiency (WUE) for grass types for two forage systems, TF100 [12 ha tall fescue (TF)], and TF-BB [4 ha of big bluestem/indiangrass (BBIG) mix and 8 ha of TF] during grazing experiment at Missouri Forage Systems Research Center, Linneus, MO, 2021-2023. Letters indicate differences ($P < 0.05$) between grass types.

Table 1.6: Mixed model ANOVA results for net return per cow and to system for two forage systems (TF100 and TF-BB), TF100 [12 ha tall fescue (TF)], and TF-BB [4 ha of big bluestem/indiangrass (BBIG) mix and 8 ha of TF], during grazing experiment at Missouri Forage Systems Research Center, Linneus, MO.

Variable	Effect	df (num, denom)	F-value	P > F
Net return per cow	treatment	1, 6	0.62	0.46
	year	2,6	29.54	0.01
	treatment × year	2,6	0.15	0.86
Net return to system	treatment	1,6	0.50	0.51
	year	2,6	22.59	0.01
	treatment × year	2,6	0.97	0.43

Table 1.7: Mean net return to cow and system for two forage systems (TF100 and TF-BB), TF100 [12 ha tall fescue (TF)], and TF-BB [4 ha of big bluestem/indiangrass (BBIG) mix plus 8 ha of TF], during grazing experiment at Missouri Forage Systems Research Center, 2021-2023, Linneus, MO. Means followed by letters differ.

Factor		Net Return	Standard error	F-value	P > F
TF100	Per cow (\$cow ⁻¹)	\$13	75.1	0.62	0.46
	To system (\$herd ⁻¹)	\$452	937.4	0.50	0.51
TF-BB	Per cow (\$cow ⁻¹)	\$64	75.1	0.62	0.46
	To system (\$herd ⁻¹)	\$1,079	937.4	0.50	0.51
2021	Per cow (\$cow ⁻¹)	436a	92.0	29.54	0.01
	To system (\$herd ⁻¹)	\$5,752a	1,148.1	22.59	0.01
2022	Per cow (\$cow ⁻¹)	\$78b	92.0	29.54	0.01
	To system (\$herd ⁻¹)	\$1,333b	1,148.1	22.59	0.01
2023	Per cow (\$cow ⁻¹)	-\$398c	92.0	29.54	0.01
	To system (\$herd ⁻¹)	-\$4,787c	1,148.1	22.59	0.01

CHAPTER II

**COMPARISON OF TALL FESCUE AND NATIVE WARM-SEASON GRASSES IN
COMPLEMENTARY FORAGE SYSTEMS IN THE SOUTHEASTERN UNITED
STATES**

ABSTRACT

Summer cattle production for cow-calf pairs on tall fescue [TF: *Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.] is impacted by this species' semi-dormancy and by fescue toxicosis. Native warm-season grasses (NWSG) could be a viable summer forage alternative. Thus, an experiment was implemented with cow-calf pairs (mature cows ≥ 3 years old, spring calving), to evaluate three forage systems, one that relied on TF only and two complementary systems that incorporated a NWSG with TF. Forage nutritive content (CP, NDF, ADF), body condition scores, cow and calf ($n = 12$ pairs per experimental unit) weights, and grazing days, hay produced, and water-use efficiency were documented. Input costs were documented to compare net returns to each system and per cow. Forage mass ($P < 0.54$) and nutritive values (CP, $P < 0.06$; NDF, $P < 0.12$; ADF, $P < 0.19$) did not differ among treatments, a result due in large part to severe drought in year 1 and large influence of bermudagrass in TF pastures. Greater calf gains in TF-BBIG than TF100 in 2023 (209 vs 180, steers), and increased kg weaned per ha in TF-BB in both years support the addition of NWSG during summer. Both BBIG and SG had high WUE during summer, with BBIG exceeding that for TF. Hay yield was greater in TF-BB in both years. Net returns did not differ among treatments but was impacted by the shortened grazing season from a severe drought in 2022 and a lack of hay production in TF100 from poorly drained pastures.

INTRODUCTION

Beef production is a principal agricultural operation in the United States (US), with 87.2% functioning as commercial cow-calf production (USDA-NASS, 2024). Over 40% of the US cow-calf productions operate in the eastern US (Livestock Marketing Information Center, 2018) and these production systems primarily rely on a cool-season grass, tall fescue [TF⁺; *Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.], for forage production. This is the most widespread forage on 15 million ha within the region which is commonly referred to as the ‘Fescue Belt’.

As a cool-season (C₃ photosynthetic pathway) grass, TF is not well adapted to excessive heat or prolonged summer drought and becomes semi-dormant during summer, a period often termed the ‘summer slump’. Therefore, adequate summer forage production is a concern and is essential to the profitability of livestock operations within the Fescue Belt (Lowe et al., 2015; Monroe et al., 2017). Cattle production within the Fescue Belt is further impacted by fescue toxicosis, a condition resulting from the ergot alkaloids produced by the fungal endophyte, *Epichloe coenophiala* (Leuchtman et al., 2017), within the TF⁺ plant. Ergot alkaloids are typically at elevated levels during the summer (Rottinghaus et al., 1991), putting beef cattle (*Bos Taurus*) at greater risk for fescue toxicosis symptoms, lowering cattle reproduction (Porter et al., 1992,) and growth performance (Thompson et al., 1993).

Native warm-season grasses (NWSG) could be a viable forage option to fill the forage gap during the summer slump and reduce the amount of time cow-calf pairs spend on TF⁺. Native warm-season grasses include species such as big bluestem (BB; *Andropogon gerardii* Vitman), indiangrass [IG; *Sorghastrum nutans* (L.) Nash], eastern gamagrass [EG; *Tripsacum dactyloides* (L.) L.] and switchgrass (SG; *Panicum virgatum* L.), three forages that have produced substantial

summer gains in growing classes of beef cattle within this region (Backus et al., 2017; Keyser et al., 2020; Lowe et al., 2015). As warm-season (C_4 photosynthetic pathway) grasses, BB and SG remain productive during summer (Hall et al., 1982), decreasing the need for hay or other supplemental feeds and may provide the nutritional demands of lactating beef cattle at this time (Rushing et al., 2019; Vendramini and Moriel, 2020).

Thus, a study was implemented in Arkansas to evaluate the potential of novel forage production systems to enhance yield, gains and profit and could be adopted across the Fescue Belt. The objectives of this study were to assess three forage systems for productivity (grazing days per year, beef produced per ha, hay produced), profitability (input costs, cost of gain, net return), and water-use efficiency (WUE). The three forage systems were two complementary systems that included a BB and IG blend (BBIG), SG and TF^+ , and a traditional forage system comprised of TF^+ -dominated pastures only, the typical forage in cow-calf production systems in the Fescue Belt. We hypothesized that the complementary systems would have greater animal performance, increased productivity and greater net returns. Although each of the NWSG share similar characteristics, we hypothesized that BBIG would have greater animal performance (Keyser et al., 2012) and SG would have greater WUE (Eichelmann et al., 2016; Hendrickson et al., 2013).

MATERIALS AND METHODS

Experimental Design: Two replicates of three treatments were used in this project. Treatment 1 (TF100) was a cool-season forage system consisting predominately of toxic endophyte infected TF^+ , representing the most widespread grazing system in the area and served as the control. Treatment 2 (TF-BB) was a complementary cool-season/NWSG system, with the cool-season element also comprised of TF^+ and with a BBIG mix representing 30% of the system land area

as the NWSG. Treatment 3 (TF-EG) was a complementary cool-season/NWSG system as well, with the cool-season forage comprised of TF⁺ and with EG as the 30% NWSG. Due to low stand density and associated productivity, EG was replaced with SG (TF-SG) in years 2 and 3 (2023-2024). Each replicate of Treatment 1 was comprised of 12 ha of TF⁺, subdivided into 6, 2-ha paddocks. Each complementary system included 4 ha of NWSG, subdivided into 4, 1-ha paddocks and 8 ha of TF⁺, subdivided into 4, 2-ha paddocks.

Site description: The research was conducted at the Dale Bumpers Small Farm Research Center (35°05'15.4" N, 93°59'38.6" W) in Booneville, AR, from 2022-2024. Data in this report consists of 2022-2023. The soils in the BB pastures consisted of a moderately well-drained, Leadvale silt loam (fine-silty, siliceous, semiactive, thermic Typic Fragiudults), while the soils in the SG pastures consisted of somewhat poorly drained Taft silt loam (fine-silty, siliceous, semiactive, thermic Glossaquic Fragiudults). The major soil type for 90% of the TF⁺ pastures were Taft silt loam, whereas 10% of the TF100 paddocks resided on Leadvale silt loam (NRCS Web Soil Survey, 2023). Mean TF⁺ pasture soil pH was 5.95 with 53 kg ha⁻¹ P and 372 kg ha⁻¹ K. Mean BBIG pasture soil pH was 5.76 with 88 kg ha⁻¹ P and 210 kg ha⁻¹ K. Mean EG pasture soil pH was 6.65 with 34 kg ha⁻¹ P and 150 kg ha⁻¹ K. Mean SG pasture soil pH was 5.76 with 6 kg ha⁻¹ P and 155 kg ha⁻¹ K. Mehlich-3 nutrient concentrations were determined by the USDA-ARS Poultry Production and Product Safety Research lab (Fayetteville, AR).

Pasture Establishment: Tall fescue pastures cv "KY-31" (56.7 ha) were established >20 years prior to the start of the study. To strengthen the stand prior to the study, all TF⁺ pastures were fertilized (600 kg ha⁻¹ of 13-13-27) in March 2017 and overseeded with KY-31 seed (no-till; JD1590; 34 kg ha⁻¹, 1.2 cm depth, 19-cm row spacing) in March 2018. In July 2018, Grazon P+D (2,4-Dichlorophenoxyacetic acid + picloram) was applied to all TF⁺ pastures at 3.5 L ha⁻¹

and in August 2018 at 2.3 L ha⁻¹. Prior to the start of the study, pastures were grazed September-December annually. On 23 Aug 2021, TF⁺ was mowed and on 15 Nov, and a mix of inoculated [Exceed Peat for Peanut, Cowpea (*Vigna unguiculata* (L.) Walp.), Lespedeza (*Lespedeza juncea* var. *sericea* (Thunb.) Lace & Hauech), Mung bean (*Vigna radiata* (L.) R. Wilczek), *Bradyrhizobium* sp. *Vigna*: 2x10⁸ CFU g⁻¹; 3.1g kg⁻¹ of seed]; (Visjon Biologics, Henrietta, TX), red clover (*Trifolium pratense* L.) (cv “Barduro”; 5.6 kg ha⁻¹) and white clover (*T. repens* L. Linnaeus) (cv “Durana”; 2.2 kg ha⁻¹) was no-till drilled (JD 1590) into fescue sod at 19-cm row spacing at a depth of 1.3 cm.

On 15 May 2017, BBIG pastures were planted at 9.9 kg ha⁻¹ to 0.6 cm depth with a no-till drill (JD1590) in 9.1-cm rows. Big bluestem/indiangrass pastures were burned 16 March 2021 but received no other management prior to the start of the study in 2022. The BBIG stands were planted to cv “Kaw” and “Cheyenne”, respectively (3:2 BB to IG by seed mass).

All EG stands were established >20 years prior to the study. Eastern gamagrass stands consisted of cv “Pete” (4 ha) and “Bumpers” (4 ha). Prior to the study, EG pastures were managed with mowing once per year. Eastern gamagrass stands were burned on 16 March 2021 and GrazonNext [aminopyralid +2,4-dichlorophenoxyacetic acid]) applied at 2.45 L ha⁻¹ product in both July and August of 2021. Eastern gamagrass stands were clipped on 23 August 2021.

The 16-ha area chosen for SG establishment contained poorly drained soils (Taft silt loam [fine-silty, siliceous, semiactive, thermic Glossaquic Fragiudults]) and had no prior agricultural management. The area for SG establishment was disked (offset disc, JD6150M) and tilled (Mashio SE300) in May 2017, and tilled again just prior to planting to SG cv “Alamo” on 8 June 2017 (Suukuup drill) at 7.8 kg ha⁻¹ to 0.6 cm depth, in 9-cm rows. The stand was burned in March 2018 and replanted on 20 April 2018. Switchgrass stands were burned on 16 March 2021.

Pasture Management:

Grazing commenced each spring when NWSG canopies were ≥ 35 cm in height. Generally, this timing coincided with the end of calving each year, as IACUC protocol restricted the handling of calves until two weeks old. Cows did not graze TF⁺ prior to May due to poorly drained soils creating conditions not acceptable for calving. Tall fescue pastures became suitable for grazing in early May when NWSG pastures were also ready to graze. Forage mass that accumulated from March was harvested as hay in complementary systems, as cattle were placed on NWSG and would not graze TF⁺ until NWSG were exhausted. No hay was harvested in TF100. Fertilization, liming, and weed control were handled similarly among all TF⁺ pastures for all treatments. Stockpiling was not an option during the study, as precipitation was limited in summer and fall. All pastures received N in the form of urea [CO(NH₂)₂] at 78 kg ha⁻¹ in 2023 and 2024 March, except SG pastures which received 106 kg ha⁻¹ in 2023, due to a calibration error. Conditions were too wet for fertilizer application in 2022 and thus, none was applied. Controlled burns were conducted on 17 March 2022 and 2 March 2023 on all NWSG pastures. GrazonNext [aminopyralid +2,4-dichlorophenoxyacetic acid]) was applied to all BBIG pastures annually and to EG pastures in March of 2022 at a rate of 2.3 l product ha⁻¹.

Cattle Management: Cows (mature Angus cross cows ≥ 3 years old, spring calving) were randomly assigned (n = 12) in spring of 2020 to one of four groups similar in parity, body condition, and weight. Groups were then randomly assigned to each treatment and remained on that treatment and group for the duration of the project. Cows that lost their calf prior to weaning and cows determined to be open at the time of weaning were replaced in early May (prior to breeding). Replacement animals were drawn from the same herd as the initial group and met the criteria for selection and were comparable in size, body condition score (BCS), parity and

pregnancy stage to the removed cow. Cows were bred via natural service. Cattle stayed on their assigned pastures throughout the year except as needed for animal health or breeding purposes. At all times, cattle had ad libitum availability to water, mineral, and shade. Animal care adhered to the Agricultural Research Service (ARS) Institutional Animal Care and Use Committee Protocol # 22001.

Grazing Management: Due to the aforementioned calving restrictions, grazing on TF100 and complementary systems were initiated at the same time each year, with complementary systems starting with grazing on the NWSG component. Grazing commenced on 10 and 16 of May in 2022 and 2023, respectively. The grazing season continued until TF⁺ plant height was ≤ 10 cm (18 October and 1 November in 2022 and 2023). Tall fescue pastures were grazed on a rotational basis with cattle moved among their assigned paddocks based on stand condition, with grazing intervals of 12-14 days per paddock and rest periods of 70-80 days. Native warm-season grass pastures were grazed on a rotational basis with cattle moved among their assigned paddocks based on stand condition, with grazing intervals of 3-4 days per paddock and rest periods of 15 to 21 days. When the pre-grazing height for NWSG fell below 30 cm, pairs were removed from NWSG and placed on their respective TF⁺ pastures. Pairs returned to NWSG pastures once pre-grazing forage height exceeded 35 cm. Grazing continued on NWSG pastures until 15 September 2022 and 2023, when NWSG height fell below 30-cm. Total days spent off BBIG pastures was 34 in 2022 and 28 in 2023. Total days spent off EG pastures was 56 in 2022 and 0 days off SG in 2023. Post- and pre-grazed pasture height (n = 15 points per paddock) was measured at each rotation. Hay bales were counted and weighed (a sample of 15 bales) per replicate for each harvest to determine yield per system. A composite hay sample created from 4-core samples (Stary Quality Samplers, Alberta, Canada; 3.8-cm diameter, 60-cm length) from 20% of the

bales produced on each experimental unit was used to determine hay nutritional composition (University of Arkansas, Altheimer Lab). At the end of the study each fall, cattle were removed from experimental units, co-mingled, and housed on a common pasture and fed hay.

Data Collection:

Aerial cover of forage species (grass and, for fescue, clovers as well) was estimated twice annually (early May for cool-season in TF⁺ pastures and early July for warm-season in both TF⁺ and BBIG pastures) by using a Vogel frequency grid (0.75 m × 0.75 m) (100 cells in total) (n=8 per paddock). Forage mass was measured every 28-d from the initiation of grazing to the conclusion of active grazing for each experimental unit. The samples were collected prior to turnout on a fresh paddock and after rotation from 15, randomly placed 0.25-m² quadrats within an actively grazed paddock per experimental unit. Forage representing the grazing horizon was clipped at 30 cm for all NWSG species and 10 cm for TF⁺, for forage nutrient composition [crude protein, neutral detergent fiber (NDF) and acid detergent fiber (ADF)]. The remainder of the sample, ≤30-cm for NWSG and ≤10-cm for TF⁺, was clipped to 2.5 cm, collected, weighed, dried in a forced air oven at 55°C for 72 hours, and reweighed to determine dry matter. Post-grazing samples were taken following grazing in the same paddock as the pre-sample by clipping 15-randomly placed 0.25-m² quadrats to 2.5 cm, collected, and weighed before and after drying in a forced air oven at 55°C for 72 hours to determine residual forage mass.

Forage samples representing the grazing horizon were dried in a forced air oven at 55°C for 72 hours and then ground through a 2-mm screen (Wiley Mill, Thomas-Wiley Laboratory Mill Model 4, Arthur H. Thomas Co., Philadelphia, PA) passing through a 2-mm screen; followed by a cyclone sample mill (UDY Corporation, Fort Collins, CO) ground to pass through a 1-mm screen (McIntosh et al., 2022). The samples were scanned on a Foss DS2500F using

ISIScan Nova v. 8.0.6.2 (Foss North America, Eden Prairie, MN). Spectra were then applied to the 2021 Grass hay calibration and samples containing legume species were predicted with the 2021 Mixed Hay calibration provided and licensed by the NIRS Forage and Feed Consortium (NIRSC, Berea, KY). The global and neighborhood statistical tests were monitored and evaluated for accuracy across all predictions with entire data set fitting the calibrations withing the ($H < 3.0$) limit of fit and reported accordingly (McIntosh et al., 2022; Murray and Cowe, 2004). Units of measurement for nutritive analyses and calculated parameters are presented at 100% dry matter (DM) across the data set.

Fescue toxicity was documented by measuring percent endophyte infected tall fescue tillers on 1 May 2024 for percent endophyte infection and ergovaline concentrations on 17 April 2023 and 19 Sept 2023. Percent infection was assessed using a Phytoscreen *Epichloe* immunoblot assay (Agrinostics, Ltd., Watkinsville, Ga). In April, vegetative tillers (pre-anthesis) were cut at the soil surface from 25 randomly selected TF⁺ plants per experimental unit (Aiken et al., 2012). For ergovaline concentrations, 50 randomly selected tillers >0.32 cm in diameter (pre-anthesis) were taken per experimental unit (Vincelli et al., 2017). All samples were placed on ice and stored at -20 C before freeze drying. Samples were analyzed by ARS Forage-Animal Production Research Unit (Lexington, KY) using high performance liquid chromatography and fluorescence detection (Carter et al., 2010). Separation was accomplished using a Kinetex (Phenomenex Inc., Torrance, CA) 100 mm × 4.6 mm C18 column with 2.6-μm particle size (Klotz et al., 2018).

Four weights were taken per year per cow in both treatments: at breeding, when TF-BB cow-calf pairs entered BBIG pastures in the spring, again when pairs were removed in late summer, and at weaning. Weight was taken on two consecutive days and the mean calculated. Timing of weighing was such that animals had grazed each forage for 3-5 days preceding weighing to

standardize gut fill due to differing passage rates for C₄ vs C₃ grasses (Reid et al., 1990; Sponheimer et al., 2003). Weights were taken on calves at birth, at initiation of grazing and weaning (2 consecutive weights), if weaning occurred before the end of grazing, with 205-day adjusted weaning weights for calves calculated as well. Body condition scores (BCS) (Whittier et al., 1993) were taken for cows at breeding and at weaning, with hair coat scores (HCS) taken in spring (Decker and Thomas, 2021).

Water use efficiency (WUE) was documented by yield from 3, randomly placed exclusion cages (1.5-m diameter) within 3 paddocks of each experimental unit, based on forage species (TF⁺, BBIG, EG in 2022 and TF⁺, BBIG, and SG in 2023) (n =30). Exclusions were moved to new random locations within the paddock once every 28 days, concurrent with forage sampling dates from May to September, annually. Forage mass was collected from each exclusion cage at the end of each 28-day period to capture ingrowth. Annual rainfall and average daily temperatures for the study were monitored based on data from the National Weather Service's weather station at Booneville, Arkansas (~7.5 km from pastures).

Input costs associated with each experimental grazing system were documented in order to compare the net return in each system (**Table 2.1**). Costs included pro-rated pasture establishment costs, annual pasture costs (e.g., fertilization, weed control), annual hay costs and any other costs that varied across grazing systems. A 10-year stand life was assumed for EG pastures similar to other NWSG (Boyer and Keyser, 2020) and for TF⁺. Establishment costs included seed, herbicide, custom drilling of seed, and custom herbicide application. The cost of these inputs was based on average local costs in 2018. Finally, a 10% cost of re-establishment was included to account for the risk of initial establishment failure and replanting.

Statistical Analysis

Weaning weight data, adjusted to 205-days of age, were used for the evaluation of calf weaning results (Hobbs and Smith, 1991) along with unadjusted calf weights at weaning. Total grazing days were calculated based on total days pairs grazed with an animal unit day (AUD) based on a 454 kg cow with a calf at her side (Meyer, 2010). Calculations for AUD were conducted per year by experimental unit and forage type (TF⁺, BBIG, EG and SG).

Response variables (cattle performance and forage parameters) were analyzed using a mixed model analysis of variance (ANOVA) using PROC MIXED in SAS[®], version 9.4 (SAS Institute, Cary, NC, 2013) and considered significant at $\alpha = 0.05$. Response variables were tested for normality using PROC UNIVARIATE. For cattle metrics, fixed effects were year, and treatment (year). The random effects in the models were year $\times$ individual cow/calf (treatment). Fixed effects in the vegetation models were year, treatment (year) and month $\times$ treatment (year). The random effects in the model were replicate, replicate $\times$ treatment(year), paddock $\times$ replicate $\times$ treatment(year) and month $\times$ paddock $\times$ replicate $\times$ treatment(year). Sampling months were included as a repeated measure in models for forage mass and nutritive value parameters, with months May-October for the TF⁺ paddocks and months May-August for the NWSG component. If variables failed diagnostic tests for equal variances (>5 -fold difference), then log, square root or rank transformations were made.

The fixed effect in the hay models were year and treatment(year). The random effects in the models were replicate $\times$ rep(treatment). If variables failed diagnostic tests for equal variances (> 5 -fold difference), then log, square root or rank transformations were made.

PROC MIXED was used to compare WUE of forage species/combinations and not the systems themselves. Fixed effects in the model were species and month. The random effects in

the model were treatment $\times$ replicate (treatment), species $\times$ treatment $\times$ replicate (treatment), and paddock $\times$ species $\times$ treatment $\times$ replicate (treatment). Sampling months were included as a repeated measure in the model. If variables failed diagnostic tests for equal variances (> 5 -fold difference), then data were rank transformed.

The fixed effect in the economics models were year and treatment (year). The random effects in the model were year $\times$ replicate (treatment). If variables failed diagnostic tests for equal variances (>5 -fold difference), then log, square root or rank transformations were made.

RESULTS AND DISCUSSION

Weather instruments operated by the center (~ 7.5 km from pastures) collected daily average ambient temperatures and daily precipitation data throughout the experimental period (**Figure 2.1**). Monthly temperatures were higher than the 30-year mean in April-July in both years. Additionally, precipitation levels were much lower in May-October 2022, when a widespread drought affected the US (NOAA, 2023) and throughout the Arkansas River Valley (Alzurqani et al., 2023), with only 56.6 cm of precipitation during June-September at the study site. In 2023, with the exception of June, conditions were again drier than the 30-year mean.

In May, TF⁺ paddocks in all three systems had substantial cover of cool-season, broad-leaf weeds (BLW), predominantly buttercup (*Ranunculus repens*) (**Figure 2.2**). By July, warm-season grasses, particularly bermudagrass [BG; *Cynodon dactylon* (L.) Pers.] and yellow foxtail [*Setaria pumila* (Poir.) Roem. & Schult], dominated most of the TF⁺ paddocks, regardless of system (**Figure 2.3**). Tall fescue cover in TF100 decreased throughout the study across seasons, approaching significance ($P < 0.06$), with warm-season perennial (primarily BG) encroachment doubling from 2022 to 2023 ($P < 0.01$). Intensive grazing and hay harvests during summer months may have contributed to TF⁺ stand loss, particularly given the severe drought conditions

in 2022. In July, BBIG and SG paddocks had >70% NWSG cover, while EG paddocks were dominated by other warm-season grasses, principally yellow foxtail and barnyard grass [*Echinochloa crus-galli* (L.) P. Beauv] (**Figure 2.3**). Big bluestem/indiangrass cover increased (29%) from 2022 to 2023 ($P < 0.01$).

Canopy heights for grazing (**Figure 2.4**) remained within target range (33-66 for BBIG and SG, 10-30 cm for TF⁺) during the experiment. However, EG pastures had a target range of 36-61 cm and were frequently grazed below 8 cm due to the lack of available forage in the EG pastures. This exacerbated the problem of weaker EG stands prior to the start of the study. Appropriate grazing management with rest periods can increase NWSG cover, as noted with the increase in BBIG; however, the EG stands were more intensely grazed. Furthermore, EG stands typically have more space between plants than other NWSG, thus requiring more intensive management for BLW or other grasses and this may have been a contributing factor to the warm-season grass encroachment. Therefore, TF-EG pairs were swapped to SG in 2023.

Forage mass was greater in 2023 ($P < 0.02$; **Table 2.2**), as drought conditions persisted throughout the grazing season in 2022. Forage mass interacted between treatment (year) and month ($P < 0.04$) and was greater in TF-SG than TF100 in August ($P < 0.04$), but otherwise was comparable among treatments across all months (**Figure 2.5**). Native warm-season grasses generally produce more forage than introduced cool-season grasses, particularly during summer (Keyser et al., 2012; Pierce et al., 2017). However, the extended drought in year 1 led to a lower forage mass than typically expected of BBIG and EG (Henson, 2012), although forage mass continued to improve in BBIG stands throughout the summer of 2022. The BG in the TF⁺ stands also contributed to a higher than expected forage mass in TF100 during summer as well.

Crude protein was impacted by a treatment $\times$ month interaction ($P < 0.05$; **Figure 2.6**). In 2022 and 2023, there was an expected decline of CP for TF throughout the season. However, there was not a consistent pattern for CP for NWSG in 2023 ($P < 0.05$). Neutral detergent-fiber (**Figure 2.7**) and ADF contents did not differ among treatments ($P < 0.12$, $P < 0.19$, respectively) or years ($P < 0.68$, $P < 0.82$, respectively). Precipitation levels varied throughout the summer in 2023; previous research indicates that soil water availability is an important factor for influencing CP in grassland forages (Núñez et al., 2022) and this could explain the fluctuations in nutritive values for the NWSG. Both CP and fiber levels were well at an acceptable level for beef cows at all stages of production and would not limit performance (National Research Council, 2016).

The TF⁺ pastures in all systems had a mean infection rate of 100%. Ergovaline concentrations averaged 328 ppb in the TF-BB system across TF⁺ pastures (May sampling) and 393 ppb across pastures (September sampling). Fescue pastures in the TF-EG/TF-SG system averaged 315 ppb across pastures (May sampling) and 346 ppb (September sampling). Fescue pastures in the TF100 system averaged 243 ppb across pastures (May sampling) and 353 ppb (September sampling). The onset of fescue toxicosis symptoms will generally appear between levels of 200-800 ppb (Arnold et al., 2014). Therefore, cows in this study were exposed to ergovaline levels in all treatments likely to have induced fescue toxicosis.

Treatments did not differ for cow weights at breeding or at weaning (**Table 2.3**; $P < 0.72$, $P < 0.17$, respectively), although cow weights at breeding and weaning were numerically greater in the complementary systems in the second year (**Table 2.4**). However, cows do not generally gain weight during early lactation even on high quality forage (Sprinkle, 1996). Furthermore, all cows were fed BG hay throughout the winter season and differences in cow weights at breeding

would likely not be noted. Body condition scores in both spring and fall (**Table 2.3**) differed among treatments ($P < 0.05$, $P < 0.01$, respectively). Spring BCS were lower in TF-EG than TF100 and TF-BB in year 1, although these scores were at the start of the study and therefore, may not have been affected by treatment (**Table 2.4**). Fall BCS was lower in TF100 than TF-BB and TF-SG in year 2 ($P < 0.01$). Hair scores (**Table 2.4**) were not affected by treatment ($P < 0.51$) suggesting fescue toxicosis may not have been severe. On the other hand, pairs in TF100 had a greater number of open cows than TF-BB and TF-EG in 2022 and in 2023 had a greater number of open cows than TF-BB ($P < 0.04$). Cows in TF100 began the grazing season in May on TF⁺ when ergovaline levels were high, while cows in the complementary systems were turned out on NWSG pastures at that time. Cows in TF-BB typically did not return to TF⁺ pastures until pastures were hayed; thus, TF⁺ was less mature and BG was the more dominant forage available for grazing. As forage mass and nutritive values were consistent among treatments, it seems likely that the greater number of open cows was a result of fescue toxicosis, as decreased conception rates in beef cattle is a common problem from cows grazing on infected TF⁺ (Porter and Thompson, 1992; Roberts and Andrae, 2004). Further, the results seem to indicate that only a short amount of grazing time on NWSG may be enough to improve pregnancy rates (Coffey et al., 2015). The mean calving date was earlier in TF100 in year 1 (26 Feb) than TF-BB and TF-EG (12 March, 9 March, respectively, $P < 0.01$). However, this is likely due to the number of year 1 cows that were replaced the following spring, and calving dates in this year reflected a substantial influence from these replacement animals. In year 2, TF-SG had a later calving date (22 March) than TF100 (8 March) or TF-BB (7 February; $P < 0.01$). All bulls were replaced for temperament issues and 3 cows were replaced for lameness in TF-SG in 2023. These replacements may have contributed to the later calving date in TF-SG in 2023.

Calf weights at weaning for steers and heifers were not different among treatments ($P < 0.06$, $P > 0.61$, respectively) but were greater in 2022 ($P < 0.01$, **Table 2.4**). In 2022, the 205-day adjusted weaning weights for steers (**Table 2.4**) were not different among treatments but in 2023 they were greater in TF-BB than TF-SG and TF100 ($P < 0.01$). In 2022, the 205-day adjusted weaning weights for heifer were greater in TF-BB than TF-EG ($P < 0.03$). In addition, there was a greater total weight weaned per ha in TF-BB ($P < 0.02$) than TF100 in 2022 and, in 2023, TF-BB was greater than TF100 and TF-SG. This supports previous research that demonstrated NWSG have produced greater or comparable gains than other forages in weaned steers and heifers (Brazil et al., 2022; Gadberry et al., 2024; Keyser et al., 2022); however, I am unaware of any research on comparisons of nursing calves on NWSG or TF⁺. Thus here, I present the first data on calves during this period on these forages. Birthweights were not different among treatments ($P < 0.19$) and between years ($P < 0.97$) (**Table 2.5**). The large warm-season grass influence in the TF⁺ pastures may have muted the effect of fescue toxicosis with the dilution of ergovaline levels from other forages (i.e., BG). While efforts were ongoing to maintain stronger TF⁺ dominance within the TF⁺ stands, it remained a concern for the duration of the experiment and may explain the lack of variation within calf weights as pairs were grazing on warm-season grasses (BG) within TF⁺ pastures during the summer when ergovaline levels were high. Grazing days (**Table 2.4**) did not differ among treatments ($P < 0.09$) but increased in year 2 ($P < 0.01$). In year 1, severe drought conditions shortened the grazing season for all systems and likely contributed to the lack of a difference in grazing days between treatments in 2022.

Hay yield (**Table 2.5**) was greater in TF-BB than TF-EG during 2022 and TF-SG in 2023 ($P < 0.04$). Tall fescue pastures in TF-BB were grazed less during summer than TF⁺ pastures in TF-EG during 2022 (97 days in TF-EG vs. 63 days in TF-BB) due to the weakened EG stands

and this likely contributed to the lower hay yield. During 2023, the difference in yield was modest and may simply have been a result of slightly more productive pastures. Tall fescue pastures in the TF100 system were prone to flooding and were not accessible for harvesting during the study period. Crude protein ($P < 0.89$), NDF ($P < 0.74$) and ADF ($P < 0.11$) in hay did not differ among treatments (**Table 2.5**); however, all hay was produced from TF⁺ pastures only.

Water use efficiency (WUE) was not assessed in 2022 due to logistical constraints. In August 2023, big bluestem had greater WUE than TF⁺ ($P < 0.02$) (**Figure 2.8**). This supports previous studies in which NWSG had greater WUE than non-native grasses (Hendrickson et al., 2013; Kiniry et al., 2008).

Net returns to cow and to system did not differ among treatments in both years ($P < 0.15$, $P < 0.15$, respectively; **Table 2.7**). However, the greater number of open cows in TF100 and increased 205-day steer adjusted weaning weights in TF-BB in year 1 were impactful on the net returns. Additionally, the severe drought in 2022 shortened the grazing season and hay feeding days were extended for all treatments. As the poorly drained soils precluded hay production on the TF100 pastures, this necessitated purchasing hay and this impacted the net returns as purchasing hay was more cost-effective than hay production, thus giving an advantage to the TF100 system.

In a study in Tennessee, a simulated system with 30% SG and TF⁺ was more profitable than one comprised only of TF⁺ in both spring and fall calving seasons. In that study, the TF⁺-SG had a greater overall average net present value (\$37,197) than TF (\$14,324) (Brazil et al., 2022). In an additional study in Tennessee, stocker cattle grazing on SG had greater expected net returns (\$430) than non-native BG (\$110) and crabgrass [CG; (\$3)] (Boyer et al., 2020). Cattle grazing BBIG in the same study had a greater return (\$248) than CG and EG (\$285) had a

greater return than CG (Boyer et al., 2020). Thus, grazing NWSG grasses may have an economic benefit.

CONCLUSIONS

Forage mass and nutritive values did not differ among treatments as expected. However, the severe drought in 2022 and the large influence of BG in the TF⁺ pastures likely contributed to the lack of differences. The increased number of open cows in the TF100 system is a common issue in cow-calf operations in the Fescue Belt that rely on TF⁺ only and can be costly to producers. Thus, grazing NWSG pastures during breeding, May in this study, when ergovaline levels on TF⁺ are high, may mitigate decreased pregnancy rates for cows. The greater calf gains in TF-BB support previous research for greater gains in steers and heifers grazing BBIG and support the addition of these forages in a C₃-dominated forage base. Drought conditions began in 2022 and remained in place until 2023, yet both BBIG and SG continued to have high WUE during summer, with BBIG having a greater WUE than TF⁺. Higher temperatures and reduced precipitation are forecasted to increase in the Fescue Belt (Engström et al., 2020) and forages with increased WUE and drought tolerance may be of great importance to producers within this region. Incorporating a NWSG to form a complementary program with a cool-season forage may be of economic value to production systems but was not noted in this study due to the lack of hay production in TF100 pastures and the severe drought in 2022 that shortened the grazing season for all treatments.

REFERENCES

- Aiken, G.E., Goff, B.M., Witt, W.W., Kagan, I.A., Sleugh, B.B., Burch, P.L., & Schrick, F.N. (2012). Steer and Plant Responses to Chemical Suppression of Seedhead Emergence in Toxic Endophyte-Infected Tall Fescue. *Crop Science*: 52, 960-969.
- Alzurqani, S. A., Zurqani, H. A., White, D., Bridges, K., & Jackson, S. (2023). Mapping and Monitoring the Spatial and Temporal Variation of Drought and Its Impact on Vegetation Cover in Arkansas, USA. In *IGARSS 2023-2023 IEEE International Geoscience and Remote Sensing Symposium* (pp. 1664-1667).
- Arnold, M., Gaskill, C., and Smith, R.S. (2014). Fescue Toxicosis. University of Kentucky Agriculture and Natural Resources Publications. 169. Lexington, KY.
- Backus, W. M., Waller, J. C., Bates, G. E., Harper, C. A., Saxton, A., McIntosh, D. W., & Keyser, P. D. (2017). Management of native warm-season grasses for beef cattle and biomass production in the Mid-South USA. *Journal of animal science*, 95(7), 3143-3153.
- Boyer, C., & Keyser, P. (2020). Summary of the Economic and Production Performance of Native Grasses as Forage in the Fescue Belt. University of Tennessee. Knoxville, TN.
- Boyer, C. N., Zechiel, K., Keyser, P. D., Rhinehart, J., & Bates, G. E. (2020). Risk and returns from grazing beef cattle on warm-season grasses in Tennessee. *Agronomy Journal*, 112(1), 301-308.
- Brazil, K. A., Keyser, P. D., Griffith, A. P., Boyer, C. N., & Mulliniks, J. T. (2022). Perennial warm-season grass forages impact on cow-calf profitability in the Fescue Belt. *Journal of Applied Farm Economics*, 5(1), 2.
- Coffey, K. P., Coblenz, W. K., Caldwell, J. D., Ogden, R. K., Hess, T., Hubbell III, D. S., & Rosenkrans Jr, C. F. (2015). Pre-and postweaning performance by cows and calves that

- grazed toxic or nontoxic endophyte-infected tall fescue pastures. *The Professional Animal Scientist*, 31(6), 577-587.
- Decker, J., & Thomas, J. (2021). Hair shedding scores: A tool to select heat tolerant cattle. University of Missouri. Columbia, MO.
- Eichelmann, E., Wagner-Riddle, C., Warland, J., Deen, B., & Voroney, P. (2016). Evapotranspiration, water use efficiency, and energy partitioning of a mature switchgrass stand. *Agricultural and Forest Meteorology*, 217, 108-119.
- Hall, K. E., George, J. R., & Riedl, R. R. (1982). Herbage Dry Matter Yields of Switchgrass, Big Bluestem, and Indiangrass with N Fertilization 1. *Agronomy Journal*, 74(1), 47-51.
- Hendrickson, J. R., Schmer, M. R., & Sanderson, M. A. (2013). Water use efficiency by switchgrass compared to a native grass or a native grass alfalfa mixture. *BioEnergy Research*, 6, 746-754.
- Henson, J. F., (2012). Plant Guide for eastern gamagrass (*Tripsacum dactyloides*). USDA-Natural Resources Conservation Service, National Plant Data Center. Baton Rouge, LA.
- Hobbs, J. & Smith, S. (1991): Program to calculate 205-day adjusted weights (PBD205WT for purebred herds) (COM205WT for commercial herds) *OSU current report Oklahoma State University Cooperative Extension Service: 91 (312)*.
- Keyser, P. D., Bates, G. E., Waller, J. C., Harper, C. A., & Doxon, E. (2012). Grazing native warm-season grasses in the mid-South. *University of Tennessee Center for Native Grassland Management SP731-C. University of Tennessee, Knoxville, TN*.
- Keyser, P. D., Lituma, C. M., Bates, G. E., Holcomb, E. D., Waller, J. C., & Griffith, A. P. (2020). Evaluation of eastern gamagrass and a sorghum× sudangrass for summer pasture. *Agronomy Journal*, 112(3), 1702-1712.

- Kiniry, J. R., Lynd, L., Greene, N., Johnson, M. V. V., Casler, M., & Laser, M. S. (2008). Biofuels and water use: comparison of maize and switchgrass and general perspectives. *New Research on Biofuels* (eds Wright JH, Evans DA), 17-30.
- Klotz, J.L., Aiken, G.E., Egert-McLean, A.M., Schrick, N., Chattopadhyay, N. & Harmon, D.L. (2018). Effects of grazing different ergovaline concentrations on vasoactivity of bovine lateral saphenous vein. *Journal of Animal Science*, 96, 3022–3030.
- Leuchtmann, A., Bacon, C. W., Schardl, C. L., White, J. F., & Tadych, M. (2014). Nomenclatural realignment of *Neotyphodium* species with genus *Epichloë*. *Mycologia*. 106:2, 202–215
- Lowe II, J.K., Boyer, C.N., Griffith, A.P., Keyser, P., Bates, G.E., Waller, M. & Backus, W.M. (2015). Profitability of Beef and Biomass Production from Native Warm Season Grasses in Tennessee. *Agronomy Journal*, 107:1733-1740.
- McIntosh, D. W., Kern-Lunbery, R., Goldblatt, P., Lemus, R., Griggs, T., Bauman, L., Boone, S., Shewmaker, G. & Teutsch, C. (2022). Guidelines for Optimal Use of NIRSC Forage and Feed Calibrations in Membership Laboratories (Second Edition). The University of Tennessee Press, Knoxville, TN.
- Meyer, T. L. (2010). Estimating livestock forage demand: Defining the animal unit. *Theses and Dissertations in Animal Science*, University of Nebraska. Lincoln, NE.
- Monroe, A. P., Burger Jr, L. W., Boland, H. T., & Martin, J. A. (2017). Economic and conservation implications of converting exotic forages to native warm-season grass. *Global Ecology and Conservation*, 11, 23-32.
- Murray, I., & Cowe, I. (2004). Sample preparation. *Near-infrared spectroscopy in agriculture*, 44, 75-112.

- Núñez, L., Hirigoyen, A., Durante, M., Arroyo, J. M., Cazzuli, F., Bremm, C., & Jaurena, M. (2022). What factors control the crude protein content variation of a basaltic “Campos” native grassland of South America?. *Agronomy*, 12(8), 1756.
- Pierce, R. A., Kallenbach, R. L., Reinbott, T., Wright, R., & Udawatta, R. P. (2017). Mixtures of native warm-season grasses, forbs and legumes for biomass, forage and wildlife habitat. Publication g9423. University of Missouri. Columbia, MO.
- Porter, J. K., & Thompson Jr, F. N. (1992). Effects of fescue toxicosis on reproduction in livestock. *Journal of animal science*, 70(5), 1594-1603.
- Reid, R. L., Jung, G. A., Cox-Ganser, J. M., Rybeck, B. F., & Townsend, E. C. (1990). Comparative utilization of warm-and cool-season forages by cattle, sheep and goats. *Journal of Animal Science*, 68(9), 2986-2994.
- Roberts, C., & Andrae, J. (2004). Tall fescue toxicosis and management. *Crop Management*, 3(1), 1-18.
- Rushing, J. B., Maples, J. G., Rivera, J. D., & Lyles, J. C. (2020). Early-season grazing of native grasses offers potential profitable benefit. *Agronomy Journal*, 112(2), 1057-1067.
- Rottinghaus, G. E., Garner, G. B., Cornell, C. N., & Ellis, J. L. (1991). HPLC method for quantitating ergovaline in endophyte-infested tall fescue: seasonal variation of ergovaline levels in stems with leaf sheaths, leaf blades, and seed heads. *Journal of agricultural and food chemistry*, 39(1), 112-115.
- Sponheimer, M., Robinson, T., Roeder, B., Hammer, J., Ayliffe, L., Passey, B., Cerling, T., Dearing, D. & Ehleringer, J. (2003). Digestion and passage rates of grass hays by llamas, alpacas, goats, rabbits, and horses. *Small Ruminant Research*, 48(2), 149-154.

- Sprinkle, J. E. (1996). Matching forage resources with cow herd supplementation. Publication AZ9523. University of Arizona. Tucson, AZ.
- Thompson, R. W., Fribourg, H. A., Waller, J. C., Sanders, W. L., Reynolds, J. H., Phillips, J. M., & Hunter, P. P. (1993). Combined analysis of tall fescue steer grazing studies in the Eastern United States. *Journal of animal science*, 71(7), 1940-1946.
- Vendramini, J., & Moriel, P. (2020). Management of forages and pastures in Lower-South: I-10 Corridor. In *Management Strategies for Sustainable Cattle Production in Southern Pastures* (pp. 101-122). Academic Press.
- Vincelli, P., Smith, S.R. & Tillery, T. (2017). Sampling for the Tall Fescue Endophyte in Pasture or Hay Stands. University of Kentucky, Ext. PPA-30. Lexington, Kentucky.
- Whittier, J. C., Steevens, B. J., & Weaver, A. D. (1993). *Body condition scoring of beef and dairy animals*. University Extension, University of Missouri—Columbia.

APPENDIX II

Table 2.1: Total annualized pasture and hay costs (US\$ ha⁻¹) for establishing and maintaining four forage systems, TF100 [12 ha tall fescue (TF)], TF-BB [4 ha of big bluestem/indiangrass (BB) mix plus 8 ha of TF], TF-EG [4 ha of eastern gamagrass (EG) plus 8 ha of TF], and TF-SG [4 ha of switchgrass (SG) plus 8 ha of TF], during a 10-yr useful life. Pasture budget models are from the University of Tennessee Department of Agriculture and Resource Economics - <https://arec.tennessee.edu/extension/budgets/>.

Cost	TF100	TF-BB	TF-EG	TF-SG
	US\$ ha ⁻¹			
Prorated establishment cost	35	36	41	33
Annualized hay cost	123	105	123	106
Annualized pasture cost	102	77	77	78
Total annual hay and pasture cost	260	218	241	217

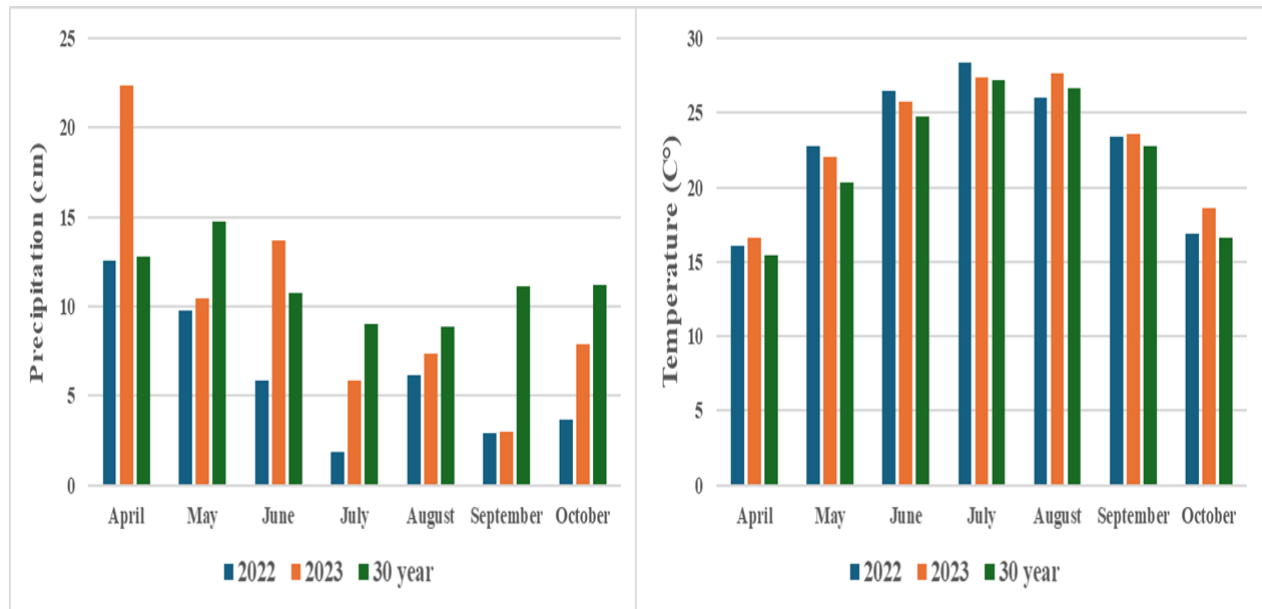


Figure 2.1. Mean monthly precipitation totals and average daily temperatures for 2022-2023 during grazing experiment at Dale Bumpers Small Farms Research Center, Booneville, AR, with monthly precipitation totals and average daily temperatures for a 30-year period.

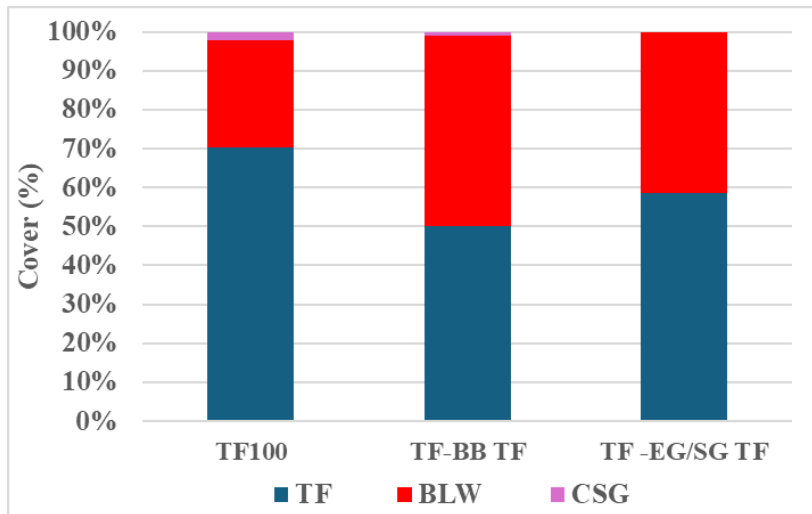


Figure 2.2: Cool-season aerial cover (%) of tall fescue (TF⁺), broad-leaf weeds (BLW) and other cool-season grasses (CSG) in May for three forage systems, TF100 [12 ha tall fescue (TF)], TF-BB [4 ha of big bluestem/indiangrass (BB) mix and 8 ha of TF] and TF-EG/SG, a system with 4 ha of eastern gamagrass (EG) in 2022 and switchgrass (SG) in 2023, with 8 ha of TF, during grazing experiment at Dale Bumpers Small Farms Research Center, Booneville, AR, 2022-2023. Cover values in the TF-BB TF and TF-EG/SG TF are for TF paddocks only.

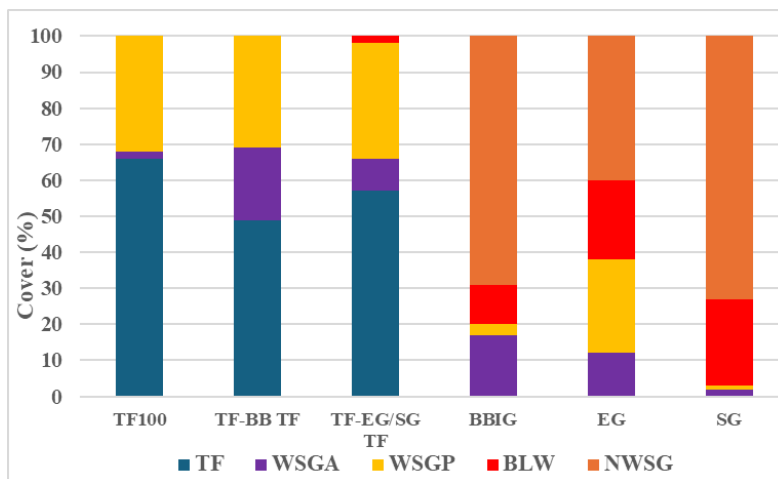


Figure 2.3: Warm-season aerial cover (%) of tall fescue (TF), warm-season grass annuals (WSGA), warm-season grass perennials (WSGP), broad-leaf weeds (BLW) and native warm-season grasses (NWSG) in July for three forage systems, TF100 [12 ha tall fescue (TF)], TF-BB [4 ha of big bluestem/indiangrass (BB) mix plus 8 ha of TF], and TF-EG/SG, a system with 4 ha of eastern gamagrass (EG) in 2022 and switchgrass (SG) in 2023, plus 8 ha of TF, during grazing experiment at Dale Bumpers Small Farms Research Center, Booneville, AR, 2022-2023. Cover values in the TF-BB TF and TF-EG/SG TF are for TF paddocks only.

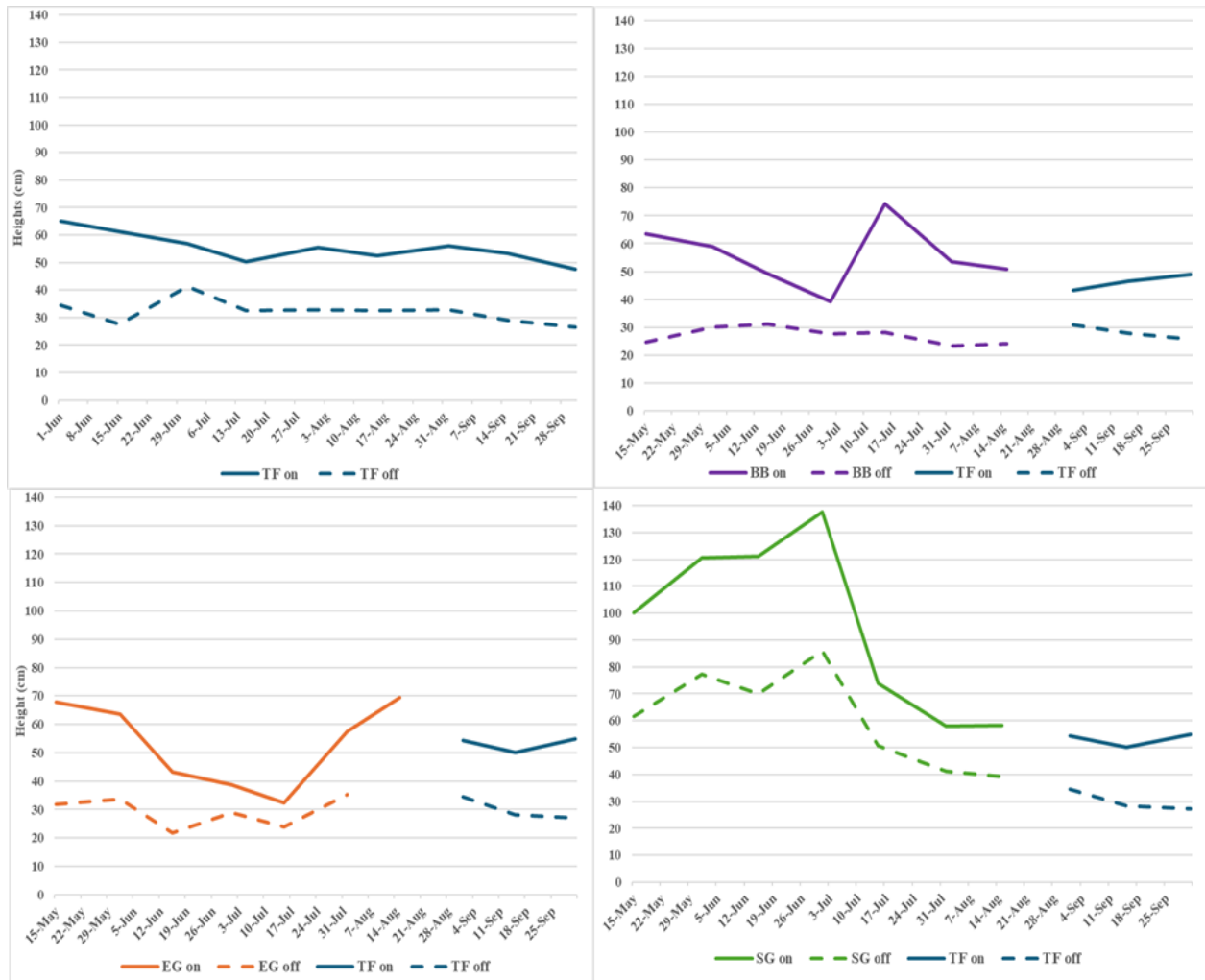


Figure 2.4. Mean grass canopy heights moving on and off paddocks for four forage systems, TF100 [12 ha tall fescue (TF)] (top left), TF-BB [4 ha of big bluestem/indiangrass (BB) mix and 8 ha of TF] (top right) TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF] (bottom left), and TF-SG [4 ha of switchgrass (SG) and 8 ha of TF] (bottom right), at Dale Bumpers Small Farms Research Center, Booneville, AR, 2022-2023.

Table 2.2. Mixed model ANOVA results for forage mass and forage nutritive values for four forage systems (TF100, TF-BB, TF-EG and TF-SG), TF100 [12 ha tall fescue (TF)], TF-BB [4 ha of big bluestem/indiangrass (BB) mix and 8 ha of TF], TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF], and TF-SG [4 ha of switchgrass (SG) and 8 ha of TF], 2022-2023, during grazing experiment at Dale Bumpers Small Farms Research Center, Booneville, AR.

Variable	Effect	df (num, denom)	F-value	P > F
Forage mass	year	1, 9	8.89	0.02
	treatment(year)	4, 9	0.84	0.54
	month × treatment(year)	24, 22	2.12	0.04
Crude protein	year	1, 7	5.79	0.05
	treatment(year)	4, 6	4.07	0.06
	month × treatment(year)	24, 23	2.03	0.05
Neutral detergent fiber	year	1, 7	0.18	0.68
	treatment(year)	4, 7	2.68	0.12
	month × treatment(year)	24, 22	0.96	0.54
Acid detergent fiber	year	1, 7	0.06	0.82
	treatment(year)	4, 7	2.07	0.19
	month × treatment(year)	24, 20	1.32	0.27

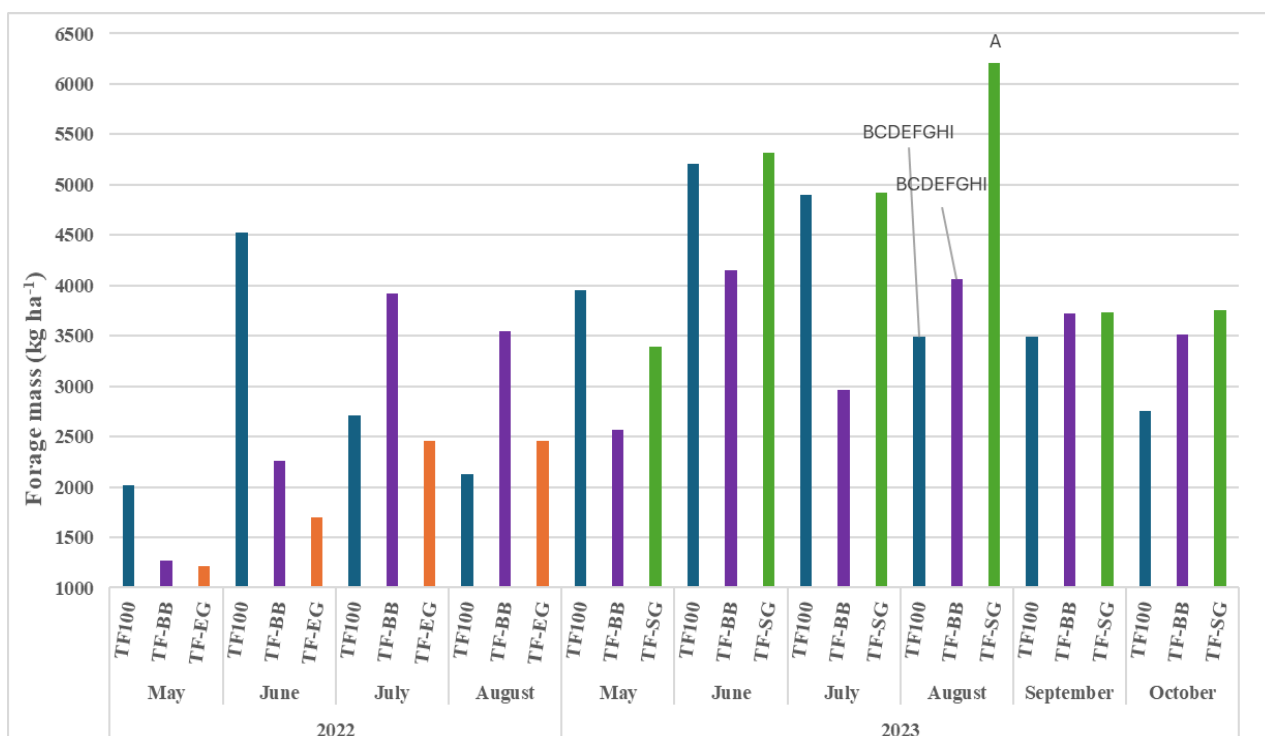


Figure 2.5: Mean monthly forage mass for four forage systems, TF100 [12 ha tall fescue (TF)], TF-BB [4 ha of big bluestem/indiangrass (BB) mix and 8 ha of TF], TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF], and TF-SG [4 ha of switchgrass (SG) and 8 ha of TF], during grazing experiment at Dale Bumpers Small Farms Research Center, Booneville, AR, 2022-2023. For TF-BB, TF-EG and TF-SG, mass is presented separately by each forage type, TF (TF-BB TF, TF-EG TF, and TF-SG TF) and BB, EG and SG. Letters indicate differences ($P < 0.05$) between treatments.

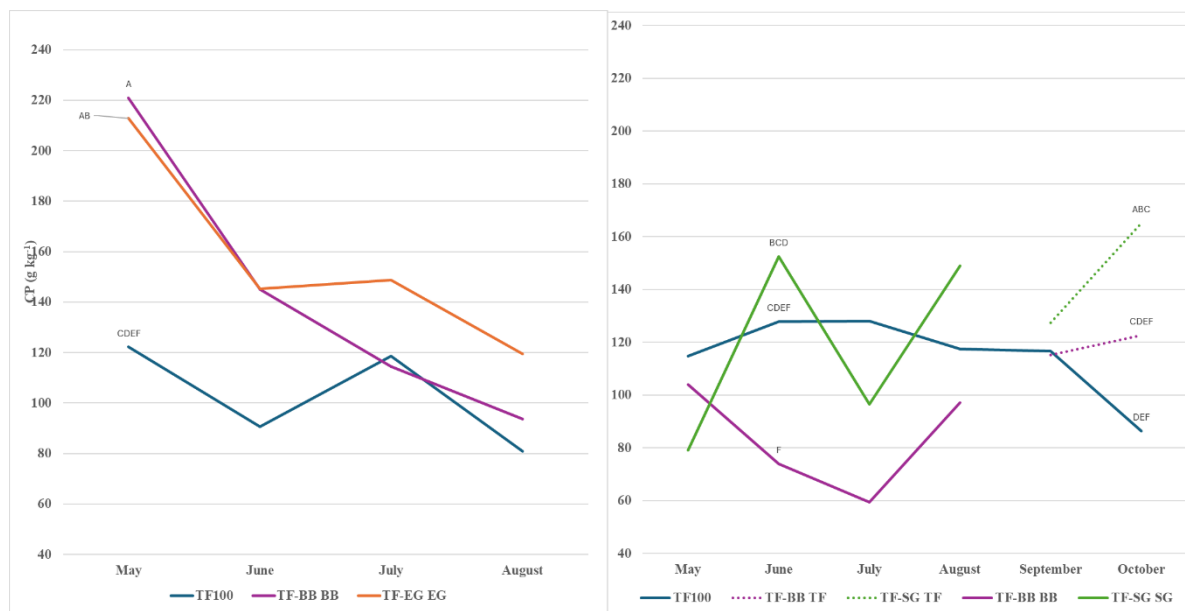


Figure 2.6: Crude protein (CP) by grass species for four forage systems, TF100 [12 ha tall fescue (TF)], TF-BB [4 ha of big bluestem/indiangrass (BB) mix and 8 ha of TF], TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF], and TF-SG [4 ha of switchgrass (SG) and 8 ha of TF], during grazing experiment at Dale Bumpers Small Farms Research Center, Booneville, AR, in 2022 (left) and 2023 (right). Values in TF-BB and TF-EG are for BB and EG paddocks only and those in TF-BB and TF-SG are for BB and SG paddocks only. Letters indicate differences ($P < 0.05$).

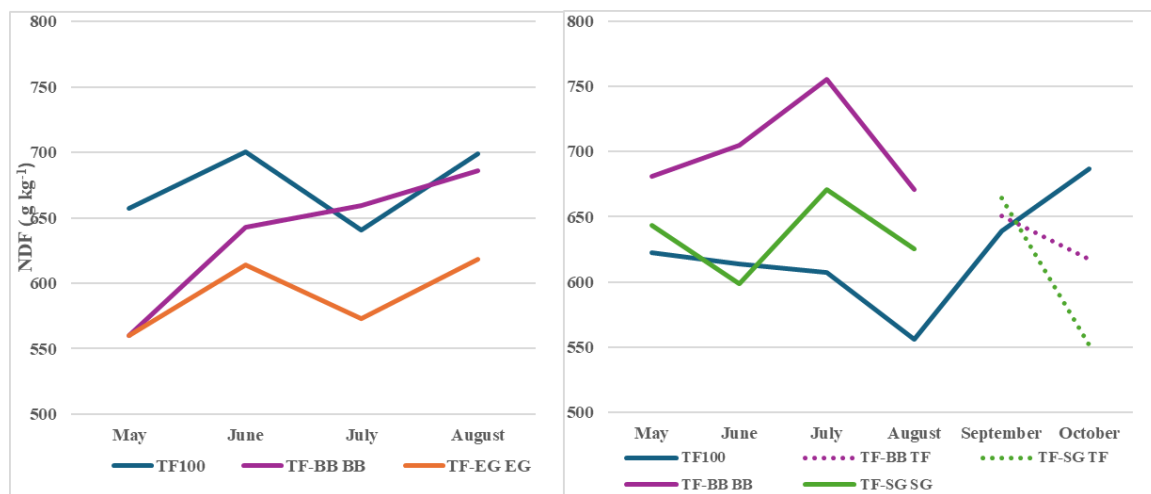


Figure 2.7: Neutral detergent fiber (NDF) by grass species for four forage systems, TF100 [12 ha tall fescue (TF)], TF-BB [4 ha of big bluestem/indiangrass (BB) mix and 8 ha of TF], TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF], and TF-SG [4 ha of switchgrass (SG) and 8 ha of TF], during grazing experiment at Dale Bumpers Small Farms Research Center, Booneville, AR, in 2022 (left) and 2023 (right). Values in TF-BB and TF-EG are for BBIG and EG paddocks only and those in TF-BB and TF-SG are for BBIG and SG paddocks only.

Table 2.3: Mixed model ANOVA results for response variable to cattle for four forage systems (TF100, TF-BB, TF-EG and TF-SG), TF100 [12 ha tall fescue (TF)], TF-BB [4 ha of big bluestem/indiangrass (BB) mix and 8 ha of TF], TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF], and TF-SG [4 ha of switchgrass (SG) and 8 ha of TF], 2022-2023, during grazing experiment at Dale Bumpers Small Farms Research Center, Booneville, AR. Body condition score is denoted by BCS. Hair condition score is denoted by HCS. Adjusted weaning weight is denoted by AWW.

Variable	Effect	df (num, denom)	F-value	P > F
Cow weight at breeding	year	1, 138	1.28	0.26
	treatment(year)	4, 138	0.52	0.72
Cow weight at weaning	year	1, 138	2.34	0.13
	treatment(year)	4, 138	1.61	0.17
BCS (spring)	year	1, 138	409.48	0.01
	treatment(year)	4, 138	2.50	0.05
BCS (fall)	year	1, 136	181.47	0.01
	treatment(year)	4, 136	17.87	0.01
HCS	year	1, 138	0.11	0.74
	treatment(year)	4, 138	0.82	0.51
Open cows	year	1, 6	34.95	0.01
	treatment(year)	4, 6	4.98	0.04
Birth date	year	1, 140	3.89	0.05
	treatment(year)	4, 140	4.55	0.01
Calf weight at weaning, steers	year	1, 6	51.97	0.01
	treatment(year)	4, 6	4.05	0.06
Calf weights at weaning, heifers	year	1, 6	79.20	0.01
	treatment (year)	4, 6	0.71	0.61
205-day AWW, steers	year	1, 74	154.64	0.01
	treatment(year)	4, 74	4.50	0.01
205-day AWW, heifers	year	1, 54	134.70	0.01
	treatment(year)	4, 54	2.85	0.03
Total kg ha ⁻¹ weaned	year	1, 6	108.00	0.01
	treatment(year)	4, 6	7.25	0.02
Birth weight	year	1, 140	0.01	0.97
	treatment(year)	4, 140	1.57	0.19
Grazing days	year	1, 6	58.91	0.01
	treatment (year)	4, 6	3.27	0.09

Table 2.4. Means for response variables for cattle for four forage systems (TF100, TF-BB, TF-EG and TF-SG), TF100 (12 ha tall fescue), TF-BB (4 ha of big bluestem/indiangrass mix and 8 ha of TF), TF-EG (4 ha of eastern gamagrass and 8 ha of TF), and TF-SG (4 ha of switchgrass and 8 ha of TF), during grazing experiment at Dale Bumpers Small Farms Research Center, 2022-2023, Booneville, AR. Body condition score is denoted by BCS³. Hair condition score is denoted by HCS⁴. Adjusted weaning weight is denoted by AWW. Means followed by lowercase letters within rows differ ($P < 0.05$). Means followed by uppercase letters indicate differences within years ($P < 0.05$).

2022		TF100	TF-BB	TF-EG	TF-SG
	Cow weights at breeding (kg)	528	516	525	N/A
	Cow weights at weaning (kg)	556	573	561	N/A
	BCS (spring)	6.7a	6.7a	6.4b	N/A
	BCS (fall)	5.2d	5.4d	4.9e	N/A
	HCS	2.6	2.3	2.8	N/A
	Mean total open cows	6b	2a	5a	N/A
	Birth date (mean)	26-Feb c	12-Mar ab	9-Mar b	N/A
	Calf weights at weaning (kg), steers	250	279	272	N/A
	Calf weights at weaning (kg), heifers	253	265	249	N/A
	205-day AWW (kg), steers	260a	263a	244a	N/A
	205-day AWW (kg), heifers	255ab	283a	244b	N/A
	Total kg ha ⁻¹ weaned	248bc	268a	254ab	N/A
	Birth weights (kg)	34	35	34	N/A
	Grazing days (AUD ha ⁻¹)	73B	76B	75B	N/A
2023	Cow weights at breeding (kg)	525	531	N/A	545
	Cow weights at weaning (kg)	535	570	N/A	544
	BCS (spring)	4.9c	4.9c	N/A	5.0c
	BCS (fall)	5.7c	7.3a	N/A	6.7b
	HCS	2.5	2.8	N/A	2.4
	Mean total open cows	2b	0c	N/A	1bc
	Birth date (mean)	8-Mar b	7-Feb bc	N/A	22-Mar a
	Calf weights at weaning (kg), steers	208	238	N/A	207
	Calf weights at weaning (kg), heifers	199	193	N/A	191
	205-day AWW (kg), steers	180c	209b	N/A	187c
	205-day AWW (kg), heifers	170	180	N/A	171
	Total kg ha ⁻¹ weaned	202d	216c	N/A	198d
	Birth weights (kg)	34	36	N/A	33
	Grazing days (AUD ha ⁻¹)	82A	82A	N/A	80A

³ Body condition scores were estimated on a 9-point scale (Whittier et al., 1993).

⁴ Hair scores were measured on a scale of 1 to 5 (Decker and Thomas, 2021).

Table 2.5. Mean hay yield and nutritive values (crude protein [CP], neutral detergent fiber[NDF] and acid detergent fiber [ADF]) for four forage systems, TF100 [12 ha tall fescue (TF)], TF-BB [4 ha of big bluestem/indiangrass (BB) mix and 8 ha of TF], TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF], and TF-SG [4 ha of switchgrass (SG) and 8 ha of TF], during grazing experiment at Dale Bumpers Small Farms Research Center, Booneville, AR, 2022-2023.

Year	Treatment		Mean	F-value	P > F
2022	TF-BB	Yield (kg ha ⁻¹)	4,682a	8.00	0.04
		CP (g kg ⁻¹)	97	0.12	0.89
		NDF (g kg ⁻¹)	541	0.33	0.74
		ADF (g kg ⁻¹)	349	8.00	0.11
	TF-EG	Yield (kg ha ⁻¹)	3,780b	8.00	0.04
		CP (g kg ⁻¹)	99	0.12	0.89
		NDF (g kg ⁻¹)	543	0.33	0.74
		ADF (g kg ⁻¹)	359	8.00	0.11
2023	TF-BB	Yield (kg ha ⁻¹)	2,857c	8.00	0.04
		CP (g kg ⁻¹)	63	0.12	0.89
		NDF (g kg ⁻¹)	545	0.33	0.74
		ADF (g kg ⁻¹)	402	8.00	0.11
	TF-SG	Yield (kg ha ⁻¹)	2,446d	8.00	0.04
		CP (g kg ⁻¹)	63	0.12	0.89
		NDF (g kg ⁻¹)	545	0.33	0.74
		ADF (g kg ⁻¹)	402	8.00	0.11

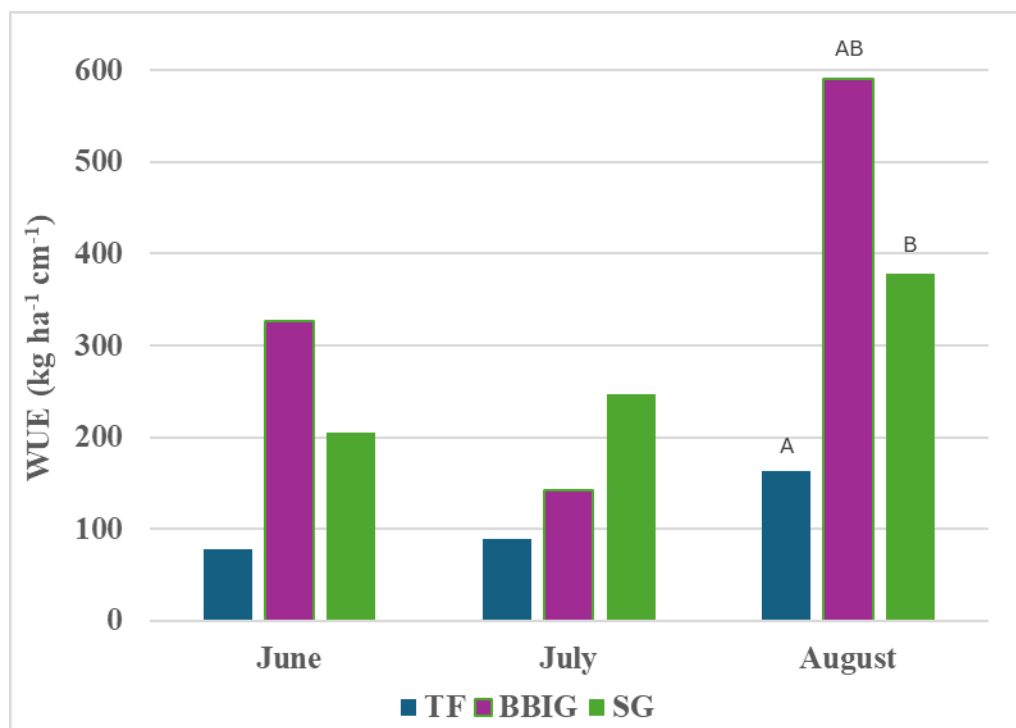


Figure 2.8. Mean water use efficiency (WUE) for grass types for three forage systems, TF100 [12 ha tall fescue (TF)], TF-BB [4 ha of big bluestem/indiangrass (BBIG) mix and 8 ha of TF] and TF-SG [4 ha of switchgrass (SG) and 8 ha of TF], during grazing experiment at Dale Bumpers Small Farms Research Center, Booneville, AR, 2023. Letters indicate differences ($P < 0.05$) between grass types.

Table 2.6: Mixed model ANOVA results for net return per cow and to system for four forage systems (TF100, TF-BB, TF-EG, and TF-SG), TF100 [12 ha tall fescue (TF)], TF-BB [4 ha of big bluestem/indiangrass (BB) mix and 8 ha of TF], TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF], and TF-SG [4 ha of switchgrass (SG) and 8 ha of TF], 2022-2023, during grazing experiment in Dale Bumpers Small Farms Research Center, Booneville, AR.

Variable	Effect	df (num, denom)	F-value	P > F
Net return per cow	Year	1,6	0.63	0.46
	treatment (year)	4,6	2.52	0.15
Net return to system	Year	1,6	0.63	0.46
	treatment(year)	4,6	2.52	0.15

Table 2.7: Net return to cow and system for four forage systems, TF100 [12 ha tall fescue (TF)], TF-BB [4 ha of big bluestem/indiangrass (BB) mix and 8 ha of TF], TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF], and TF-SG [4 ha of switchgrass (SG) and 8 ha of TF], during grazing experiment at Dale Bumpers Small Farms Research Center, 2022-2023,Booneville, AR.

Year	Treatment	Net Returns	Return	F-value	P > F
2022	TF100	Per cow (\$cow ⁻¹)	\$35	2.52	0.15
		To system (\$herd ⁻¹)	\$418	2.52	0.15
2022	TF-BB	Per cow (\$cow ⁻¹)	\$202	2.52	0.15
		To system (\$herd ⁻¹)	\$2,420	2.52	0.15
2022	TF-EG	Per cow (\$cow ⁻¹)	-\$177	2.52	0.15
		To system (\$herd ⁻¹)	-\$2,126	2.52	0.15
2023	TF100	Per cow (\$cow ⁻¹)	\$143	2.52	0.15
		To system (\$herd ⁻¹)	\$1,717	2.52	0.15
2023	TF-BB	Per cow (\$cow ⁻¹)	\$91	2.52	0.15
		To system (\$herd ⁻¹)	\$1,097	2.52	0.15
2023	TF-SG	Per cow (\$cow ⁻¹)	\$5	2.52	0.15
		To system (\$herd ⁻¹)	\$55	2.52	0.15

CHAPTER III

A COMPARISON OF TWO COMPLEMENTARY FORAGE SYSTEMS IN THE TALL FESCUE BELT

ABSTRACT

Incorporating non-toxic, warm-season forages into a tall fescue [TF: *Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.] dominated system could lessen impacts of fescue toxicosis and low summer yield. Therefore, an experiment was implemented with cow-calf pairs (mature cows ≥ 3 years old, spring calving), to evaluate two forage systems, one that relied on TF only and a complementary system that incorporated a native warm-season grass (NWSG) with TF. Forage nutritive content, body condition scores, cow and calf (n = 12 pairs per experimental unit) weights, grazing days, hay produced, and water-use efficiency were documented. Input costs were also documented to compare net returns to each system and per cow. Differences were not noted between treatments in forage mass, nutritive content, cattle parameters, hay yield or net returns to both cow and to system, but this is potentially due to mixed TF pastures with other non-native, warm-season grasses. The lack of differences suggests warm-season volunteer grasses within TF⁺ stands could potentially alleviate fescue toxicosis symptoms, while providing beneficial forage. Water-use efficiency was greater in the NWSG stands, indicating that NWSG are more tolerant of adverse environmental conditions. The greater returns to cow and to per system in the TF-EG system indicate that incorporating a NWSG into a cool-season forage program can be of economic value to a producer, even if there are only moderate cattle gains.

INTRODUCTION

Approximately 40% of the nation's cow-calf operations are located in the eastern United States (Livestock Marketing Information Center, 2018). A large segment of these operations depend upon cool-season grasses in their forage production systems, with tall fescue [TF⁺; *Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.] as the principal grass. Tall fescue grows on over 14 million ha within a section commonly denoted as the 'Fescue Belt' (US Department of Agriculture, 2019). Cow-calf producers typically use TF⁺ because of its simple management, productivity, and lack of pests (Sleper and West, 1996). As a C₃ grass, TF⁺ provides a considerable amount of forage in the spring, with additional yield in the fall. In the warmer months of June, July and August however, TF⁺ is semi-dormant, particularly during periods of drought or intense heat, producing lower quality forage (Hall, 2023). Furthermore, pastures comprised of only TF⁺ produce limited forage during these months (a period referred to as the 'summer slump') and often require producers to feed hay to maintain cattle nutritional needs.

Additionally, ergot alkaloids produced by *Epichloe coenophiala*, an endophytic fungus found within TF⁺, can decrease birth and weaning weights in beef cattle (*Bos taurus*), symptoms of a syndrome known as fescue toxicosis. Low birth weights can increase the incidence of calf deaths at birth and lower energy reserves within the calf itself (Ferrell, 1993). Low weaning weights can potentially carry over to lower slaughter weights (Duwalage et al., 2023). A study on cow-calf pairs from birth in March to September weaning showed that calves grazing on infected TF⁺ pastures had lower birth weight, lower gain, and lower weaning weights than calves on novel-endophyte infected pastures (Watson et al., 2004). A study in South Carolina reported similar results with reduced cow weights and milk production associated with grazing infected

TF⁺ (Wilbanks et al., 2021). In 2020, the estimated cost of fescue toxicosis for producers was over one billion annually for the United States (Pent and Fike, 2020).

Incorporating warm-season forages, such as native warm-season grasses (NWSG) or non-natives such as johnsongrass [JG; *Sorghum halepense* (L.) Pers], dallisgrass (DG; *Paspalum dilatatum* Poir) and crabgrass [CG; *Digitaria sanguinalis* (L.)], into cool-season forage systems could help lessen the impact of fescue toxicosis and the summer slump, by providing the necessary forage during the summer, eliminating the need for hay or other supplements during this period, while lowering cattle exposure to ergot alkaloids, as alkaloids levels in TF⁺ are elevated during summer (Rottinghaus et al., 1991).

As a NWSG, eastern gamagrass [EG; *Tripsacum dactyloides* (L.) L.] could be used as a complement to TF⁺. Eastern gamagrass is a perennial bunch grass and is indigenous to the southeastern United States (Springer and Dewald, 2004), produces high animal gain (280-450 kg ha⁻¹) (Dewald et al., 2006) in cattle (Keyser et al., 2020). Yet, research on the outcomes of beef cattle grazing EG in a forage program (Tracy et al., 2010) and how NWSG affects the productivity of cow-calf operations is still limited, especially in comparison to the considerable emphasis that has been placed on other NWSG, such as big (BG; *Andropogon gerardii* Vitman) and little bluestem [LB; *Schizachyrium scoparium* (Michx) Nash], indianguass [IG; *Sorghastrum nutans* (L.) Nash] and switchgrass (SG; *Panicum virgatum* L.) (Boyer et al., 2020; Gadberry et al., 2024; Keyser et al., 2022; Marks, 2020; Rushing et al., 2020).

Therefore, an experiment was implemented with cow-calf pairs (mature cows ≥ 3 years old, spring calving), to evaluate two forage systems, one that relied on a cool-season (C₃) grass, TF⁺ and a mix of volunteer, warm-season, non-native grasses (a typical system found within the

Fescue Belt region) and a complementary system that incorporated a native, warm-season (C₄) species [eastern gamagrass (EG)] with the same C₃ perennial, TF⁺.

The objective was to assess the effects of these two forage production systems on productivity (beef and hay produced per ha), profitability (input costs, net return), and sustainability as measured by water balances (water-use efficiency and soil moisture). We hypothesized that the complementary system would be more profitable (Lowe et al., 2015; Monroe et al., 2017; Rushing et al., 2020), compared to the C₃-dominated system, with an increase in productivity (beef produced per ha and net hay balance) in the complementary system as a result of increased forage availability and nutritive value during summer (McMurphy et al., 1975; Towne and Ohlenbusch, 1992), coupled with the reduction of fescue toxicosis by limiting grazing time on TF⁺ (Drewnoski et al., 2009; Thompson et al., 1993). Additionally, the complementary system would have greater animal performance (Backus et al., 2017; Brazil et al., 2020; Keyser et al., 2020), net returns and a more favorable cost of production than with the C₃-dominated system (Doxon et al., 2012; Phillips and Coleman, 1995). Ecosystem health would be improved across the complementary system as a result of greater overall pasture vigor based on greater water-use efficiency (WUE) (Hendrickson et al., 2013; Kiniry et al., 2008).

MATERIALS AND METHODS

Experimental Design: Two replicates of two treatments were used in this project. Treatment 1 (TF100) was a cool-season forage system comprised predominately of toxic-endophyte infected TF⁺, the most common grazing system in the region, and served as the control. Treatment 2 (TF-EG) was a complementary cool-season/NWSG system, with the cool-season constituent also comprised of TF⁺ and with EG representing 30% of the system as the NWSG. Each replicate of Treatment 1 was comprised of 12 ha of TF⁺, subdivided into 6, 2-ha paddocks. Treatment 2 had

8 ha of TF⁺, also subdivided into 4, 2-ha paddocks and 4 ha of EG, subdivided into 6, 0.67-ha paddocks.

Site description: The research was conducted at the East Tennessee AgResearch and Education Center, Blount Unit (ETREC, 35°50'36.96" N, 83°57'16.78" W) in Louisville, TN, from 2021-2023. The soils consisted of a well-drained, Alcoa loam (fine, parasesquic, thermic Rhodic Paleudults), Cumberland silty clay (fine, mixed, semiactive, thermic Rhodic Paleudalfs), Decatur silty clay (fine, kaolinitic, thermic Rhodic Paleudults), Dewey silty clay (fine, kaolinitic, thermic Typic Paleudults), Farragut silty clay (clayey, mixed, semiactive, thermic Humic Hapludults) and Tellico loam (fine, parasesquic, thermic Typic Rhodudults) (20%, 30%, 15%, 10%, 10% and 10%, respectively, of experimental pasture area) (NRCS Web Soil Survey, 2023). Experimental units were similar in representation of these soil series. Mehlich-3 nutrient concentrations were determined by the University of Tennessee Soil Plant and Pest Center (Nashville, TN). Mean TF⁺ pasture soil pH was 6.54 with 115 kg ha⁻¹ P and 551 kg ha⁻¹ K. Mean EG pasture soil pH was 6.48 with 99 kg ha⁻¹ P and 449 kg ha⁻¹ K.

Pasture Establishment: Eastern gamagrass pastures were established in 2010 – 2013 with either cv 'Highlander' or 'Pete' in 76-cm rows with a John Deere model 1750 vacuum planter (John Deere, Inc., Moline, IL) to depth of 4 cm. In February 2021, 3.6 ha of EG were sprayed with a non-selective herbicide, glyphosate {N-[phosphonomethyl] glycine, isopropyl-amine salt} at 2 L product ha⁻¹) to control cool-season annual weeds. Twenty-eight ha of existing TF⁺ pastures were used, along with 12 ha that were reseeded to KY31 TF⁺ at 17 kg ha⁻¹ along with 11 kg ha⁻¹ red ('FSG401') (*Trifolium pratense* L.) and 2 kg ha⁻¹ white ('Will' ladino) (*T. repens* L.) clover in November 2020 with a Haybuster model 107 drill (Haybuster, Jamestown, North Dakota) in 19-cm rows to a depth of 1.3 cm. Prior to reseeding, pastures were sprayed with glyphosate at 2 L

product ha⁻¹. The 20 ha of existing TF⁺ pastures were interseeded with 11 kg ha⁻¹ red ('FSG401') and 2 kg ha⁻¹ white ('Will' ladino cultivar) clovers, in November 2020 and with the same Haybuster drill.

Pasture Management: Fertilization, interseeding of clovers, and weed control were handled similarly among all TF⁺ pastures for both treatments. Tall fescue pastures in both systems received N in the form of urea [CO(NH₂)₂] at 68 kg ha⁻¹ annually in March at greenup. Pastures were hayed in May and June annually, with the exception of two paddocks per experimental unit, which were designated for fall stockpiling in 2021. In 2022 and 2023, stockpiling was not an option, as drought conditions precluded N fertilization. Eastern gamagrass pastures were sprayed with CimarronPlus ((methyl 2-[[[(4-methoxy-6-methyl-1, 3, 5-triazin-2-yl) amino] carbonyl] amino] sulfonyl] benzoate)) at 28 g ha⁻¹ product and 2,4-D (2,4-dichlorophenoxyacetic acid) at 1.17 L ha⁻¹ in April 2022. Tall fescue and EG pastures received DuraCor (aminopyralid Potassium florypyrauxifen-benzyl) at 1.31 L product ha⁻¹ (TF⁺) and 1.46 L product ha⁻¹ (EG) in March of 2023. Additionally, 8 ha of TF⁺ paddocks requiring weed control were sprayed with 2, 4-D at 2.34 L product ha⁻¹. Based on soil samples, 60 kg ha⁻¹ P were applied to 12 ha of the TF⁺ pastures April of 2023.

Cattle Management: Cows (mature Angus cows ≥ 3 years old, spring calving) were assigned (n = 12) in 2020 to one of four groups similar in parity, body condition, and weight. Groups were then randomly assigned to each treatment and remained on that treatment and group for the duration of the project. Cows determined to be open at the time of weaning were replaced in October. Replacement animals were drawn from the same herd as the initial group and were comparable in size, body condition score (BCS), parity and pregnancy stage. Cows were fed supplements as needed to meet their National Research Council requirements (2000) to maintain

them at a minimum BCS of 6 at breeding time. Breeding was via artificial insemination (AI) under a Fixed-time, 'Co-Synch + CIDR' protocol (Johnson et al., 2018) with clean up bulls added approximately 2 weeks later. Bulls were removed approximately 60 days post-AI. Dates for AI were 10, 22, and 20 April in 2021, 2022, and 2023, respectively.

During calving (approximately December 10-February 20 each year), cattle from both treatment systems were held within a common paddock. Otherwise, cattle stayed on their assigned pastures throughout the year except as needed for animal health or breeding purposes. Animals had ad libitum access to water, mineral, and shade. Animal care adhered to UT-Institutional Animal Care and Use protocols #2258-0320 and #2258-0323.

Grazing Management: Grazing commenced each spring when TF⁺ had reached a 20-cm canopy height (3 May, 22 and 20 April in 2021, 2022, and 2023, respectively). The grazing season continued until fall when TF⁺ could no longer support grazing (7, 15 December and 1 November in 2021, 2022, and 2023, respectively). Surplus TF⁺ growth was harvested as hay. Hay produced was documented per treatment unit and paddock, by counting bales and obtaining weights of subsamples (one bale per experimental unit and hay cutting). Animals on TF⁺ paddocks were rotated based on stand condition with each entry concluded at a canopy height of approximately 10 cm with grazing intervals of 10-14 days per paddock and rest periods of 6-8 weeks. Two TF⁺ paddocks within each replicate of both systems were allotted for hay during spring and for fall stockpiling. Rest was given to those stockpiled paddocks during late summer and early fall.

Eastern gamagrass was grazed beginning when stands were able to sustain grazing pressure (a canopy height above 36 cm) each spring (26, 17 and 8 May in 2021, 2022, and 2023, respectively). Eastern gamagrass pastures were also grazed on a rotational basis with cattle moved within assigned paddocks based on stand condition, with grazing intervals of 3-4 days per

paddock and rest periods of 15-21 days. If at any point during summer, EG was not able to sustain grazing, pairs were removed from EG and placed on their respective TF⁺ pastures and then returned to EG pastures as soon as the pastures were able to support grazing again. Days spent off EG pastures were 60 in 2021, with 0 days in 2022 and 2023. Grazing of EG pastures concluded late summer annually (13, 30 August and 12 September in 2021, 2022, and 2023, respectively), when the stand conditions could no longer support grazing. Pasture height was measured (n = 10) at each movement for both the paddock being vacated and for the upcoming paddock to be grazed. Winter hay feeding was concentrated on a common, designated calving lot for all groups.

Data Collection:

Aerial cover of forage species (grass and, for fescue, clovers as well) was estimated twice annually (early May for cool-season and early July for warm-season) by using a Vogel frequency grid (0.75 m × 0.75 m) (100 cells in total) (n = 8 grids per paddock).

Forage mass was sampled at the beginning of grazing, once every 28 days during the grazing season, and at the conclusion of active grazing for each experimental unit. The samples were collected pre- and post-rotation from 15, randomly-located, 0.25 m² quadrats within an actively grazed paddock per treatment unit. Forage mass samples were clipped to a 2.5-cm residual height. Forage within this sample from the grazing horizon (above 35 cm for EG and 10 cm for TF⁺) was used to determine forage nutritive values (crude protein [CP], neutral detergent fiber [NDF] and acid detergent fiber [ADF]). Forage samples were taken from 20% of all hay bales each year by taking a 5-cm core, 20 cm into the bale perpendicular to the circumference. Forage and hay samples were dried in a forced air oven at 55C for 72 hours and then ground using a Wiley Mill (Thomas-Wiley Laboratory Mill Model 4, Arthur H. Thomas Co.,

Philadelphia, PA) passing through a 2-mm screen; followed by a cyclone sample mill (UDY Corporation, Fort Collins, CO) ground to pass through a 1-mm screen (McIntosh et al., 2022). The samples were scanned on a Foss DS2500F using ISIScan Nova v. 8.0.6.2 (Foss North America, Eden Prairie, MN). Spectra were then applied to the 2021 Grass Hay calibration and samples containing legume species were predicted with the 2021 Mixed Hay calibration provided and licensed by the NIRS Forage and Feed Consortium (NIRSC, Berea, KY). The global and neighborhood statistical tests were monitored and evaluated for accuracy across all predictions with entire data set fitting the calibrations withing the ($H < 3.0$) limit of fit and reported accordingly (McIntosh et al., 2022; Murray and Cowe, 2004). Units of measurement for nutritive analyses and calculated parameters are presented at 100% dry matter (DM) across the data set.

Fescue toxicity was documented in May 2022 for percent infection and ergovaline concentrations and again in August for ergovaline concentrations. Percent infection was assessed using a Phytoscreen *Epichloe* immunoblot assay (Agrinostics, Ltd., Watkinsville, Ga). In May, vegetative tillers (pre-anthesis) were cut at the soil surface from 25, randomly-selected TF⁺ plants per experimental unit (Aiken et al., 2012). For ergovaline concentrations, 50, randomly-selected tillers >0.32-cm in diameter (pre-anthesis) were taken per experimental unit (Vincelli et al., 2017). All samples were placed on ice and stored at -20 C before freeze drying. Samples were analyzed by ARS Forage-Animal Production Research Unit (Lexington, KY) using high performance liquid chromatography and fluorescence detection (Carter et al., 2010). Separation was accomplished using a Kinetex (Phenomenex Inc., Torrance, CA) 100 mm × 4.6 mm C18 column with 2.6-μm particle size (Klotz et al., 2018).

Four weights were taken per year per cow in both treatments: at breeding, when TF-BB cow-calf pairs entered BBIG pastures in the spring, again when pairs were removed in late summer, and at weaning. Weight was taken on two consecutive days and the mean calculated. Timing of weighing was such that animals had grazed each forage for 3-5 days preceding weighing to standardize gut fill due to differing passage rates for C₄ vs C₃ grasses (Reid et al., 1990; Sponheimer et al., 2003). Weights were taken on calves at birth, when entering EG pastures in spring, again when removed from EG pastures, and finally, at weaning. Body condition scores (BCS) (Whittier et al., 1993) were taken for cows at breeding and at weaning, with hair coat scores (HCS) taken in spring (Decker and Thomas, 2021).

Water use efficiency (WUE) was documented by taking yield from 3, randomly placed exclusion cages (1.5-m diameter) within three paddocks of each experimental unit (n = 18), based on species (TF⁺, EG) and soil wetness index values (wet, medium, dry) generated from the System for Automated Geoscientific Analyses (SAGA) (Conrad et al., 2015). Exclusion cages were moved to new random locations within the same paddock and SAGA wetness category once every 28 days, concurrent with forage sampling dates from May to September, annually. Forage mass was collected from each exclusion cage at the end of each 28-day period to capture ingrowth and were clipped to a 10-cm residual height for TF⁺ pastures and 35 cm for EG pastures, to represent the grazing horizon. Annual rainfall totals and average daily temperatures for the study area were based on data from the National Weather Service's weather station at McGhee Tyson Airport (~3.2 km). Two soil moisture sensors (HOBO data loggers, Onset Computer Co., Bourne, MA) were placed at 16-cm depths, both in the medium SAGA category, per experimental unit (n = 4). Readings of soil water tension (ranging from 0-239 kPa, with zero being fully saturated) were collected from each sensor concurrent with WUE yield sampling.

Input costs associated with each experimental grazing system were documented in order to compare the net return to each system (**Table 3.1**). Costs included pro-rated pasture establishment costs, annual pasture costs (e.g., fertilization, weed control), annual hay costs and any other costs that varied across grazing systems. A 10-year stand life was assumed for EG pasture similar to other NWSG (Lowe et al., 2015) and for TF⁺. Establishment costs included seed, herbicide, custom drilling of seed, and custom herbicide application. The cost of these inputs was based on average local costs in 2018. Finally, a 10% cost of re-establishment was included to account for the risk of initial establishment failure and replanting.

Statistical Analysis

Weaning weight data, adjusted to 205-days of age, were used for the evaluation of calf weaning results (Hobbs and Smith, 1991) along with unadjusted calf weights at weaning. Total grazing days were calculated based on total days pairs grazed with an animal unit day (AUD) based on a 454 kg cow with a calf at her side (Meyer, 2010). Calculations for AUD were conducted per year by experimental unit and forage type (TF⁺ and EG).

Response variables (cattle performance and forage parameters) were analyzed using a mixed model analysis of variance (ANOVA) using PROC MIXED in SAS[®], version 9.4 (SAS Institute, Cary, NC, 2013) and considered significant at $\alpha = 0.05$. Response variables were tested for normality using PROC UNIVARIATE. For cattle metrics, the repeated measure was year and fixed effects were treatment, year, and treatment $\times$ year. The random effects in the model were year $\times$ individual cow/calf (treatment). Fixed effects in the forage mass model were treatment, month, and treatment $\times$ month. The random effects in the model were year $\times$ rep(treatment), paddock $\times$ year $\times$ replicate (treatment) and month $\times$ paddock $\times$ year $\times$ replicate (treatment). The fixed effects in the nutritive analysis models were treatment, month, and treatment $\times$ month. The

random effects in the model were year $\times$ rep(treatment), paddock $\times$ year $\times$ replicate (treatment) and month $\times$ paddock $\times$ year $\times$ replicate (treatment). Sampling months were included as a repeated measure in models for forage mass and nutritive value parameters, with months April-November for the TF100 system and months May-September for the EG component. If variables failed diagnostic tests for equal variances (>5 -fold difference), then log, square root or rank transformations were made.

The fixed effect in the hay models were year, and treatment (year), with treatments nested in year. The random effects in the models were replicate $\times$ rep(treatment). If variables failed diagnostic tests for equal variances (>5 -fold difference), then log, square root or rank transformations were made.

PROC MIXED was used to compare WUE and to adjust for soil moisture as a covariate. Water use efficiency was compared by species and not by systems. Fixed effects in the model were species, month, SAGA values, species $\times$ month, species $\times$ SAGA, month $\times$ SAGA and species $\times$ month $\times$ SAGA. The random effects in the model were year, year $\times$ species, year $\times$ species $\times$ paddock, year $\times$ species $\times$ paddock $\times$ SAGA, year $\times$ species $\times$ paddock $\times$ SAGA $\times$ month. Sampling months were included as a repeated measure in the model. If variables failed diagnostic tests for equal variances (>5 -fold difference), then the rank transformation was made.

The fixed effect in the economics models were treatment, year, and treatment $\times$ year with year as a repeated measure. The random effects in the model were year $\times$ replicate (treatment). If variables failed diagnostic tests for equal variances (>5 -fold difference), then log, square root or rank transformations were made.

RESULTS AND DISCUSSION

Weather instruments operated by the National Oceanic and Atmospheric Association (NOAA) at the McGhee Tyson Airport (~4.8 km) collected daily average ambient temperatures and daily precipitation data throughout the experimental period. In 2022, monthly temperatures were warmer in May-July and cooler in Sept-October than 30-year means (**Figure 3.1**). Precipitation levels deviated from the 30-year mean throughout the duration of the experiment and were particularly lower in April, June, July, and September 2021, June, August, and September 2022, and in May and September-November 2023. During June and August 2023, precipitation was above long-term means (**Figure 3.1**).

In May, TF⁺ paddocks in both treatments were dominated by cool-season grasses and a modest component of clovers (**Figure 3.2**) that was below the recommended amount of 20-40% for alleviation of fescue toxicosis in TF⁺ spring pastures (Aiken et al., 2016; Harlow et al., 2022; McMurphy, et al. 1990; Thompson, 1993). By July, however, TF⁺ cover dropped considerably and TF⁺ paddocks in both systems had a substantial component of warm-season perennials and annuals (30%, 10%, respectively, in TF100 and 20%, 10%, respectively, in TF-EG in early July) growing within gaps in the fescue pastures, such as foxtail (*Setaria* species), JG and DG (**Figure 3.3**). Broad-leaf weed (BLW) cover was 15% in TF100 and 12% in TF-EG. Eastern gamagrass pastures had a considerable amount (35-40%) of warm-season perennials (e.g., foxtail, JG and DG) during early July as well, with 10% BLW. Tall fescue cover in TF-EG improved from 2021 (23%) to 42% in 2023, while cover stayed consistent among years in TF100 ($P < 0.14$). Although warm-season grass encroachment in TF⁺ was a concern for both systems, the rest given to TF⁺ pastures in TF-EG during summer appeared to have enhanced stand cover. Eastern gamagrass cover did not vary among years ($P < 0.25$).

Canopy heights for grazing (**Figure 3.4**) remained within target ranges (36-61 cm for EG and 10-30 cm for TF⁺) with two notable exceptions. By early May, EG pastures, which begin growth earlier (April) than other NWSG (Roberts and Kallenbach, 1999), had already reached heights above 80 cm. The TF-EG pairs did not move onto EG pastures until mid to late May; thus, the stocking density was too low to keep EG within optimum range in early summer. Similarly, the stocking density was too low for TF⁺ pastures in April-May, as TF⁺ reached heights above 40 cm before decreasing in late-May. Heights were above target range again in TF100 pastures in early-July through mid-September (55-70 cm). However, this increase of TF⁺ in July-September was due to the presence of other warm-season grasses within these pastures. By October, the influence of warm-season grasses in TF⁺ pastures in both treatments were muted and heights remained within target range.

Forage mass was similar between treatments ($P < 0.54$) but was highest in May ($P < 0.01$). There were no treatment $\times$ month interactions. Warm-season grasses and BLW influenced FM in both treatments through the majority of the grazing season ($P < 0.01$; **Figure 3.3**). That the TF⁺ pastures were influenced by other warm-season grasses and BLW, likely explains the lack of differences in forage mass between treatments in summer. Previous studies have demonstrated greater forage mass in NWSG pastures (Burns and Fisher, 2013; Keyser et al., 2016; Rushing et al., 2020), an advantage that may have been noticeable in TF-EG if TF⁺ stands had minimal amounts of other warm-season grasses. Yet, the comparable forage mass indicates that producers may be able to alleviate summer slump through the presence of volunteer warm-season grasses within cool-season pastures. However, producers would need to determine the amount of volunteer grasses that would be acceptable within individual paddocks, in order to protect TF⁺ stand quality and prevent a complete stand type change.

Crude protein differed by month ($P < 0.01$; **Table 3.2**), decreasing later in the grazing season as forages became more fibrous ($P < 0.01$) and, in the case of TF^+ , as early as May (**Figure 3.6**). Crude protein ranged from 140-200 g kg⁻¹ for TF^+ in both treatments and between 120-190 g kg⁻¹ for EG, but did not differ between treatments ($P < 0.76$, **Figure 3.6**). However, TF100 samples in this study maintained a CP of 140-160 g kg⁻¹ from June-August, a time when CP for a cool-season species would normally be expected to decline. By comparison, CP of TF^+ during summer typically remains below these levels, falling between 90-140 g kg⁻¹ (Sleper and West, 1996). The warm-season species in the TF^+ pastures likely contributed to the elevated CP in TF100 during the summer. While crude protein in EG was numerically lower than TF^+ , NWSG typically show reduced CP levels in lab results compared to cool-season grasses but are still capable of providing animal performance beyond what test levels would suggest (Mullahey, 1989). Neutral detergent-fiber (**Figure 3.6**) and ADF contents differed by month but not between treatments ($P < 0.49$, $P < 0.89$, respectively) and there were no month $\times$ treatment interactions. Both NDF and ADF were lowest in April and highest in August ($P < 0.01$, $P < 0.01$, respectively). Fiber concentrations increased in TF^+ and remained consistent at approximately 650 g kg⁻¹ (NDF) and 350 g kg⁻¹ (ADF) for the remainder of the season. Eastern gamagrass fiber concentrations fluctuated throughout the season [between 620-705 g kg⁻¹ (NDF) and 310-380 g kg⁻¹ (ADF)] in response to grazing cycles and associated plant maturation. Both CP and fiber levels were at a level acceptable for beef cows at all stages of production and would not limit performance (National Research Council, 2016).

The TF^+ pastures in the TF100 system had a mean infection rate of 80% while those in the TF-EG system had a mean infection rate of 42%. Ergovaline concentrations averaged 257 ppb (May sampling) and 117 ppb (September sampling) in the TF-EG system. Fescue pastures in

the TF100 system averaged 643 ppb (May sampling) and 288 ppb (September sampling). The onset of fescue toxicosis symptoms will generally appear between levels of 200-800 ppb (Arnold et al., 2014). However, approximately 30% of the TF⁺ pastures in TF-EG and 40% of the TF⁺ pastures in TF100 were comprised of other warm-season grasses and BLW during summer, providing a diluting effect on the toxicity levels (Roberts and Andrae, 2004). Anecdotally, cows in the TF100 system were observed to exhibit signs of heat stress (e.g., lingering near water sources and shade), while cows in the TF-EG system often continued to graze during the same time periods.

Treatments did not differ for cow weights at breeding or weaning ($P < 0.06$, $P < 0.77$, respectively; **Table 3.3**). Cow weights at weaning fluctuated among years ($P < 0.03$) but there was no year $\times$ treatment interaction. Neither spring or fall BCS nor HCS (**Table 3.3**) were affected by treatment ($P < 0.25$, $P < 0.94$, $P < 0.52$, respectively). Likewise, number of open cows (**Table 3.3**) was similar between treatments ($P < 0.29$). Differences in treatments were not noted for calving dates ($P < 0.48$) (**Table 3.4**). Calving occurred later ($P < 0.01$) in 2023 and 2024 (4 February) than 2022 (22 January); however, AI dates were 10-12 days later in years 2 and 3 than year 1. Delays were not treatment related, but due to management decisions. Cows do not generally gain weight during early lactation (Sprinkle, 1996) and if cows were not exposed to toxic levels of ergot alkaloids, differences may not occur in cow weights at breeding and weaning or for BCS and HCS. Furthermore, the influence of warm-season grasses and BLW within the EG stands indicate that cows may have been grazing lower quality forage rather than typically provided by pure EG stands, which may explain the lack of greater cattle performance in TF-EG that was expected. While the volunteer warm-season grasses did not undergo separate nutritive analysis in this experiment, previous studies show that DG has a lower nutritive value

than other grasses (Venuto et al., 2003). Foxtail has adequate nutritive value for ruminants (Martin and Anderson, 1975), but when grazed by sheep in a study in Minnesota, foxtail was not palatable (Martin and Anderson, 1975) and cattle will generally select for other grasses (Abaye et al., 2009). Casual observation in the current study suggested cattle avoided foxtail as well.

Calf weights at weaning for both steers and heifers were not different between treatments ($P < 0.26$, $P < 0.17$, respectively; **Table 3.3**) or years ($P < 0.20$, $P < 0.81$, respectively). The 205-day adjusted weaning weights were not different between treatments for both steers ($P < 0.06$) and heifers ($P < 0.77$) (**Table 3.3**) but were numerically greater (15 kg) in steers in the TF-EG system, approaching significance ($P < 0.06$; **Table 3.4**). Differences were noted among years as kg weaned ha⁻¹ fluctuated ($P < 0.01$), but there was no year $\times$ treatment interaction ($P < 0.89$). In 2021, kg weaned ha⁻¹ was lowest (237 kg). Differences in treatments were not noted for birthweights ($P < 0.74$). I am unaware of any research on comparisons of nursing calves on NWSG or TF⁺. Thus here, I present the first data on calves during this period on these forages. Previous studies have demonstrated that NWSG have produced greater or comparable gains than other forages in weaned steers and heifers (Brazil et al., 2022; Gadberry et al., 2024; Keyser et al., 2022). The influence of warm-season grasses within the stands may explain the lack of differences in calf weights, yet the numerically greater 205-day adjusted weaning weight for steers in TF-EG suggests that a vigorous stand of EG may support greater rates of gains for nursing calves as has been previously documented for weaned steers and heifers.

Grazing days (**Tables 3.3** and **3.4**) did not differ ($P < 0.41$) between treatments. In a previous study on the same EG pastures at this site, bred heifers averaged 400 AUD ha⁻¹ (May-August) (Keyser et al., 2020) and in another study in Tennessee, EG stands provided 423 AUD ha⁻¹ (Backus et al., 2017), more than the EG stands in this study (231 AUD ha⁻¹). Pairs in this

study that could have taken advantage of the forage in EG pastures during summer had less opportunity to do so because of the aforementioned pasture conditions, and therefore, spent more time on TF⁺ pastures (60 days during 2021). While pairs were not on TF⁺ pastures during the summers of 2022 and 2023, they spent a shorter period grazing EG stands in 2022 (107 days) and 2023 (128 days) than expected .

In a study in Arkansas, cows grazing TF⁺ pastures (492 µg kg⁻¹ ergovaline) throughout the fall, spring and during a 60-day breeding season beginning May 10, had reduced cow weights at weaning, HCS, and calving rates (Coffey et al., 2015) compared to cows on non-toxic TF (57 µg ka⁻¹ ergovaline). Conversely, in a similar study in Georgia, calving rates did not differ between cows on TF⁺ (448 ppb ergovaline) and those on non-toxic TF (0 ppb ergovaline) (Watson et al., 2004). However, cattle in that study were not placed on TF⁺ pastures until March. Therefore, the number of days grazing TF⁺ with exposure to ergot alkaloids may be of greater importance to the onset of fescue toxicosis symptoms than ergovaline levels. Additionally, the decreased grazing time in EG pastures during the summer likely limited the expected benefit of reduced exposure to toxic fescue (the ergovaline levels in TF⁺ pastures in TF-EG in May were above the threshold for the expected onset of fescue toxicosis).

Hay yield (**Table 3.5**) did not differ between treatments ($P < 0.88$). Crude protein ($P < 0.63$), NDF ($P < 0.31$) and ADF ($P < 0.30$) (Table 3.5) likewise were similar among treatments. In 2021, TF⁺ paddocks were utilized for stockpiling but not in 2022 and 2023 due to drought conditions, limiting fertilization opportunities.

Eastern gamagrass had a greater WUE than TF⁺ in July ($P < 0.01$) (**Figure 3.7**), even during summer drought conditions in 2021 and 2022. In June, TF⁺ had unexpectedly elevated WUE. However, enclosures were placed in early June when warm-season grasses were not as

easily detected. By July and August, other non-target species were more easily noticeable and could be avoided when placing enclosures. Thus, the elevated WUE observed in TF in June was strongly influenced by the presence of other warm-season grasses. In previous studies, native grasses have demonstrated high WUE, even in adverse environmental conditions (Eichelmann et al., 2016; Hendrickson et al., 2013). There were no differences noted in SAGA wetness index values (wet, mid and dry) ($P > 0.26$) but the covariate slope indicated WUE in both species decreased by $1.19 \text{ kg ha}^{-1} \text{ cm}^{-1}$ precipitation ($P < 0.01$) as soil moisture ($\text{m}^3 \text{ m}^{-3}$) increased. This relationship has also been observed in maize (Niu et al., 2022) and range grasses (Koech et al., 2015) and WUE has been shown to increase in drought conditions, i.e., lower soil moisture (Zou et al., 2020). Water use efficiency levels declined in July and August in both species, but precipitation levels were often higher than in June leading to increased soil moisture levels. Thus, increases in WUE may be more dependent on soil moisture and drought levels than topography, i.e., SAGA values. As drought becomes more frequent (US Drought Monitor, 2024), greater WUE in NWSG may be of particular importance in forage production systems.

The net return per cow and to system was greater in TF-EG ($P < 0.01$, $P < 0.01$, respectively) (**Table 3.6**). There were no differences in returns across years ($P < 0.53$), but returns were greater in TF-EG in 2021 and 2023 ($P < 0.04$, **Table 3.7**). Although the number of open cows, the 205-day adjusted weaning weights for steers and heifers and the hay yield in TF100 were not significant, these variables contributed to the lower returns in that system. The numerically lower hay yield in TF100 demonstrated an additional problem with the summer slump, as harvesting pastures (particularly cool-season forages in semi-dormancy) in drought conditions can stress and damage stands. Furthermore, the lack of rest for TF⁺ stands in TF100

during hotter summer months led to weakened stands and potentially contributed to the lower hay yield in this system.

CONCLUSIONS

While FM, CP, NDF and ADF were not greater in the TF-EG system as expected, the large presence of volunteer warm-season grasses in the TF⁺ pastures may have provided a benefit for forage production, as results indicated that TF⁺ was comparable to NWSG in FM and nutritive values. Differences were not noted between treatments in cattle parameters in this study, but this was potentially due to the limited grazing time on the EG stands and to the effect of mixed TF⁺ pastures. Cattle were likely grazing on warm-season grasses within TF⁺ pastures for much of the grazing season, particularly during the ‘summer slump.’ Therefore, warm-season volunteer grasses within TF⁺ stands could alleviate fescue toxicosis symptoms, while providing beneficial forage. Still, cow weights at breeding and 205-day adjusted weights for both steers and heifers were numerically greater in TF-EG. Additionally, the greater returns to cow and to per system in TF-EG demonstrate that incorporating a NWSG into a cool-season forage program may be of economic value to a producer, even if there are only moderate cattle gains. These results reiterate the importance of taking full advantage of grazing NWSG during summer (as opposed to the limited time on EG stands in year 1 of this study). Regardless, producers need to properly manage NWSG pastures to ensure they capture their full potential during their productive season.

The increased WUE in EG during mid-summer, when drought conditions and higher temperatures are more frequent, indicated that NWSG are more tolerant of adverse environmental conditions. These particular conditions have high potential to become more commonplace based on climate trends (Apurv and Cai, 2021; Strzepek et al., 2010), with several

states within the Fescue Belt falling into the medium category of drought vulnerability (Engström et al., 2020). Therefore, incorporating NWSG into a TF⁺ dominated system as a complementary forage, may be of economic value to producers by providing high-quality forage during the summer grazing season when TF⁺ is semi-dormant, improving cattle performance and lowering the risks of negative impacts during drought seasons.

REFERENCES

- Abaye, A. O., Scaglia Alonso, G., Teutsch, C. D., & Raines, P. M. (2009). The nutritive value of common pasture weeds and their relation to livestock nutrient requirements. Publication 418-150. Virginia Tech. Blacksburg, VA.
- Aiken, G.E., Goff, B.M., Witt, W.W., Kagan, I.A., Sleugh, B.B., Burch, P.L., & Schrick, F.N. (2012). Steer and Plant Responses to Chemical Suppression of Seedhead Emergence in Toxic Endophyte-Infected Tall Fescue. *Crop Science*, 52, 960-969.
- Alderson, J.S., Allison, J.K., Brakie, M.R., Bruckerhoff, S.B., Dickerson, J.A., Douglas, J.L., Esquivel, R.G., Grabowski, J.M., Henson, J.F., Houck Jr., M.J., Kaiser, J.U., Kirkland, M.S., Noricks, R.L., Pfaff, S.L., Row, J.M., Salon, P.R., Stevens, J., Tharel, L.M., Van der Grinten, M., & Wynia, R. (2007). Eastern Gamagrass. United States Department of Agriculture Natural Resources Conservation Service, 2-4.
- Apurv, T., & Cai, X. (2021). Regional drought risk in the contiguous United States. *Geophysical Research Letters*, Vol. 48:5.
- Arnold, M., Gaskill, C. & Smith, S. R.. (2014). Fescue Toxicosis. Agriculture and Natural Resources Publications. 169.
- Backus, W. M., Waller, J. C., Bates, G. E., Harper, C. A., Saxton, A., McIntosh, D. W., & Keyser, P. D. (2017). Management of native warm-season grasses for beef cattle and biomass production in the Mid-South USA. *Journal of animal science*, 95(7), 3143-3153.
- Boyer, C. N., Zechiel, K., Keyser, P. D., Rhinehart, J., & Bates, G. E. (2020). Risk and returns from grazing beef cattle on warm-season grasses in Tennessee. *Agronomy Journal*, 112(1), 301-308.

- Brazil, K. A., Keyser, P. D., Bates, G. E., Saxton, A. M., & Holcomb, E. D. (2020). Continuous grazing of mixed native warm-season grass in the fescue belt. *Agronomy Journal*, 112(6), 5067-5080.
- Brazil, K. A., Keyser, P. D., Griffith, A. P., Boyer, C. N., & Mulliniks, J. T. (2022). Perennial warm-season grass forages impact on cow-calf profitability in the Fescue Belt. *Journal of Applied Farm Economics*, 5(1), 2.
- Burns, J.C., & Fisher, D.S. (2013). Steer performance and pasture productivity among five perennial warm-season grasses. *Agronomy Journal*, 105:113-123.
- Carter, J. M., Aiken, G.E., Dougherty, C.T. & Schrick, F.N. (2010). Steer responses to feeding soybean hulls and steroid hormone implantation on toxic tall fescue pasture. *Journal of Animal. Science*, 88, 3759–3766.
- Coffey, K. P., Coblenz, W. K., Caldwell, J. D., Ogden, R. K., Hess, T., Hubbell III, D. S., & Rosenkrans Jr, C. F. (2015). Pre-and postweaning performance by cows and calves that grazed toxic or nontoxic endophyte-infected tall fescue pastures. *The Professional Animal Scientist*, 31(6), 577-587.
- Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlitz, L., Wehberg, J., Wichmann, V. & Böhner J. (2015). System for automated geoscientific analyses (SAGA) v. 2.1. 4. *Geoscientific model development*, 8 (7), 1991-2007.
- Decker, J., & Thomas, J. (2021). Hair shedding scores: A tool to select heat tolerant cattle. University of Missouri. Columbia, MO.
- Dewald, C. L., Berg, W. A., Sims, P. L. & Gillen, R. L. (2006). Eastern gamagrass. USDA, Agriculture Research Service.

- Doxon, E., Keyser, P., Bates, G., Harper, C., & Waller, J. (2012). SP731-E Economic Implications for Growing Native Warm-Season Grasses for Forage in the Mid-South. University of Tennessee. Knoxville, TN.
- Drewnoski, M. E., Oliphant, E. J., Poore, M. H., Green, J. T., & Hockett, M. E. (2009). Growth and reproductive performance of beef heifers grazing endophyte-free, endophyte-infected and novel endophyte-infected tall fescue. *Livestock Science*, 125(2-3), 254-260.
- Duwalage, K. I., Wynn, M. T., Mengersen, K., Nyholt, D., Perrin, D., & Robert, P. F. (2023). Predicting Carcass Weight of Grass-Fed Beef Cattle before Slaughter Using Statistical Modelling. *Animals*, 13(12), 1968.
- Eichelmann, E., Wagner-Riddle, C., Warland, J., Deen, B., & Voroney, P. (2016). Evapotranspiration, water use efficiency, and energy partitioning of a mature switchgrass stand. *Agricultural and Forest Meteorology*, 217, 108-119.
- Engström, J., Jafarzadegan, K., & Moradkhani, H. (2020). Drought vulnerability in the United States: An integrated assessment. *Water*, 12:7, 2033.
- Ferrell, C. L. (1993). Factors influencing fetal growth and birth weight in cattle. *Beef Research Program Progress Report*, No. 4 (Part 1): 104-107
- Gadberry, M. S., Moss, N., Tucker, C. A., & Wray, E. M. (2024). Performance of heifers grazing native or introduced mixed warm-season grasses during summer months in south-central United States. *Applied Animal Science*, 40(4), 456-465.
- Hall, M. (2023). Tall Fescue. Pennsylvania State University. Extension no. UC091. University Park, PA.
- Harlow, B. E., Flythe, M. D., Hamilton, T. A., Ji, H., Schrick, F. N., & Aiken, G. E. (2021).

- Effects of overseeding red clover in endophyte-infected tall fescue pastures on steer physiology and performance. *Applied Animal Science*, 37(6), 748-757.
- Hendrickson, J. R., Schmer, M. R., & Sanderson, M. A. (2013). Water use efficiency by switchgrass compared to a native grass or a native grass alfalfa mixture. *BioEnergy Research*, 6, 746-754.
- Hobbs, J. & Smith, S. (1991): Program to calculate 205-day adjusted weights (PBD205WT for purebred herds) (COM205WT for commercial herds) *OSU current report Oklahoma State University Cooperative Extension Service: 91 (312)*.
- Johnson, S.K., Cooke, R.F., Dahlke, G.R., Funston, R.N., Hall, J.B. Lamb, G.C., Lauderdale, J.W., Patterson, D.J., Perry, G.A., Van Eenennaam. (2018). 2018 Protocols for Synchronization of Estrus and Ovulation in Beef Cows and Heifers. Kansas State University. Ext. MF2573 J. Manhattan, Kansas.
- Keyser, P. D., Holcomb, E. D., Lituma, C. M., Bates, G. E., Waller, J. C., Boyer, C. N., & Mulliniks, J. T. (2016). Forage attributes and animal performance from native grass interseeded with red clover. *Agronomy Journal*, 108:1, 373-383.
- Keyser, P. D., Lituma, C. M., Bates, G. E., Holcomb, E. D., Waller, J. C., & Griffith, A. P. (2020). Evaluation of eastern gamagrass and a sorghum× sudangrass for summer pasture. *Agronomy Journal*, 112(3), 1702-1712.
- Keyser, P., Zechiel, K. E., Bates, G., Ashworth, A. J., Nave, R., Rhinehart, J., & McIntosh, D. W. (2022). Evaluation of five C4 forage grasses in the tall Fescue Belt. *Agronomy Journal*, 114(6), 3347-3357.

- Kiniry, J. R., Lynd, L., Greene, N., Johnson, M. V. V., Casler, M., & Laser, M. S. (2008). Biofuels and water use: comparison of maize and switchgrass and general perspectives. *New Research on Biofuels (eds Wright JH, Evans DA)*, 17-30.
- Klotz, J.L., Aiken, G.E., Egert-McLean, A.M., Schrick, N., Chattopadhyay, N. & Harmon, D.L. (2018). Effects of grazing different ergovaline concentrations on vasoactivity of bovine lateral saphenous vein. *Journal of Animal Science*, 96, 3022–3030.
- Koech, O. K., Kinuthia, R. N., Karuku, G. N., Mureithi, S. M., & Wanjogu, R. (2015). Water use efficiency of six rangeland grasses under varied soil moisture content levels in the arid Tana River County, Kenya. *African Journal of Environmental Science and Technology*, 9:7, 632-640.
- Lowe II, J.K., Boyer, C.N., Griffith, A.P., Keyser, P., Bates, G.E., Waller, M. & Backus, W.M. (2015). “Profitability of Beef and Biomass Production from Native Warm Season Grasses in Tennessee.” *Agronomy Journal* , 107:1733-1740.
- Marks, M. L. (2020). *Alternative Forage Systems for Developing Replacement Heifers*. Doctoral dissertation, Auburn University. Auburn, AL.
- Marten, G. C., & Andersen, R. N. (1975). Forage Nutritive Value and Palatability of 12 Common Annual Weeds 1. *Crop Science*, 15(6), 821-827.
- McIntosh, D. W., Kern-Lunbery, R., Goldblatt, P., Lemus, R., Griggs, T., Bauman, L., Boone, S., Shewmaker, G. & Teutsch, C. (2022). Guidelines for Optimal Use of NIRSC Forage and Feed Calibrations in Membership Laboratories (Second Edition). The University of Tennessee Press, Knoxville, TN.
- McMurphy, W. E., Denman, C. E., & Tucker, B. B. (1975). Fertilization of Native Grass and Weeping Lovegrass 1. *Agronomy Journal*, 67(2), 233-236.

- McMurphy, W. E., Lusby, K. S., Smith, S. C., Muntz, S. H., & Strasia, C. A. (1990). Steer performance on tall fescue pasture. *Journal of Production Agriculture*, 3(1), 100-102.
- Meyer, T. L. (2010). Estimating livestock forage demand: Defining the animal unit. *Theses and Dissertations in Animal Science*, 11. University of Nebraska. Lincoln, NE.
- Monroe, A. P., Burger Jr, L. W., Boland, H. T., & Martin, J. A. (2017). Economic and conservation implications of converting exotic forages to native warm-season grass. *Global Ecology and Conservation*, 11, 23-32.
- Mullahey, J. J. (1989). *Influence of management on production, development, and protein utilization of warm-season grasses*. The University of Nebraska. Lincoln, NE.
- Murray, I., & Cowe, I. (2004). Sample preparation. *Near-infrared spectroscopy in agriculture*, 44, 75-112.
- Niu, L., Wang, Z., Zhu, G., Yu, K., Li, G., & Long, H. (2022). Stable soil moisture improves the water use efficiency of maize by alleviating short-term soil water stress. *Frontiers in Plant Science*, 13, 833041.
- Pent, G. & Fike, J. (2020). Fescue Toxicosis – What It is and How It Costs You. United States Department of Agriculture. Ext. CIG # 69-33A7-16-1243.
- Phillips, W. A., & Coleman, S. W. (1995). Productivity and economic return of three warm season grass stocker systems for the Southern Great Plains. *Journal of Production Agriculture*, 8(3), 334-339.
- Reid, R. L., Jung, G. A., Cox-Ganser, J. M., Rybeck, B. F., & Townsend, E. C. (1990). Comparative utilization of warm-and cool-season forages by cattle, sheep and goats. *Journal of Animal Science*, 68(9), 2986-2994.
- Roberts, C., & Andrae, J. (2004). Tall fescue toxicosis and management. *Crop*

- Management*, 3(1), 1-18.
- Roberts, C. A., & Kallenbach, R. L. (1999). *Eastern gamagrass*. MU Extension, University of Missouri. Columbia, MO.
- Rottinghaus, G. E., Garner, G. B., Cornell, C. N., & Ellis, J. L. (1991). HPLC method for quantitating ergovaline in endophyte-infested tall fescue: seasonal variation of ergovaline levels in stems with leaf sheaths, leaf blades, and seed heads. *Journal of agricultural and food chemistry*, 39(1), 112-115.
- Rushing, J. B., Maples, J. G., Rivera, J. D., & Lyles, J. C. (2020). Early-season grazing of native grasses offers potential profitable benefit. *Agronomy Journal*, 112:2, 1057-1067.
- Sleper, D. & West, C. (1996). Tall fescue. In L. E. Moser, D. R. Buxton, & M. D. Casler (Eds.), *Cool-season forage grasses* (Vol. 34). American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.
- Sponheimer, M., Robinson, T., Roeder, B., Hammer, J., Ayliffe, L., Passey, B., Cerling, T., Dearing, D. & Ehleringer, J. (2003). Digestion and passage rates of grass hays by llamas, alpacas, goats, rabbits, and horses. *Small Ruminant Research*, 48(2), 149-154.
- Springer, T. L., & Dewald, C. L. (2004). Eastern gamagrass and other *Tripsacum* species. *Warm-season (C4) grasses*, 45, 955-973.
- Sprinkle, J. E. (1996). Matching forage resources with cow herd supplementation. Publication AZ9523. University of Arizona. Tucson, AZ.
- Strzepek, K., Yohe, G., Neumann, J., & Boehlert, B. (2010). Characterizing changes in drought risk for the United States from climate change. *Environmental Research Letters*. Vol. 5:4, 044012.

- Thompson, R. W., Fribourg, H. A., Waller, J. C., Sanders, W. L., Reynolds, J. H., Phillips, J. M., & Hunter, P. P. (1993). Combined analysis of tall fescue steer grazing studies in the Eastern United States. *Journal of animal science*, 71(7), 1940-1946.
- Towne, G., & Ohlenbusch, P. D. (1992). *Native hay meadow management*. Department of Agronomy. Kansas State University. Manhattan, KS.
- Tracy, B. F., Maughan, M., Post, N., & Faulkner, D. B. (2010). Integrating annual and perennial warm-season grasses in a temperate grazing system. *Crop Science*, 50(5), 2171-2177.
- Venuto, B. C., Burson, B. L., Hussey, M. A., Redfearn, D. D., Wyatt, W. E., & Brown, L. P. (2003). Forage yield, nutritive value, and grazing tolerance of dallisgrass biotypes. *Crop Science*, 43(1), 295-301.
- Vincelli, P., Smith, S.R. & Tillery, T. (2017). Sampling for the Tall Fescue Endophyte in Pasture or Hay Stands. University of Kentucky, Ext. PPA-30. Lexington, Kentucky.
- Watson, R.H., McCann, M.A., Parish, J.A., Hoveland, C.S., Thompson, F.N., & Bouton, J.H. (2004). Productivity of cow–calf pairs grazing tall fescue pastures infected with either the wild-type endophyte or a nonergot alkaloid-producing endophyte strain, AR542. *Journal of Animal Science*, 82 (11), 3388–3393.
- Whittier, J. C., Steevens, B. J., & Weaver, A. D. (1993). *Body condition scoring of beef and dairy animals*. University Extension, University of Missouri. Columbia, MO.
- Wilbanks, S.A., Justice, S.M., West T., Klotz J.L., Andrae J.G., & Duckett, S.K. (2021). Effects of Tall Fescue Endophyte Type and Dopamine Receptor D2 Genotype on Cow-Calf Performance during Late Gestation and Early Lactation. *Toxins.*, 13(3):195.
- Zou, J., Ding, J., Welp, M., Huang, S., & Liu, B. (2020). Assessing the response of ecosystem

water use efficiency to drought during and after drought events across Central Asia. *Sensors*, 20(3), 581.

APPENDIX III

Table 3.1: Total annualized pasture and hay costs (US\$ ha⁻¹) Total annualized pasture and hay costs (US\$ ha⁻¹) for establishing and maintaining two forage systems, TF100 [12 ha tall fescue (TF)], and TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF], during a 10-yr useful life. Pasture budget models are from the University of Tennessee Department of Agriculture and Resource Economics - <https://arec.tennessee.edu/extension/budgets/>.

Cost	TF100	TF-EG
	US\$ ha ⁻¹	
Prorated establishment cost	35	41
Annualized hay cost	123	123
Annualized pasture cost	102	77
Total annual hay and pasture cost	260	241

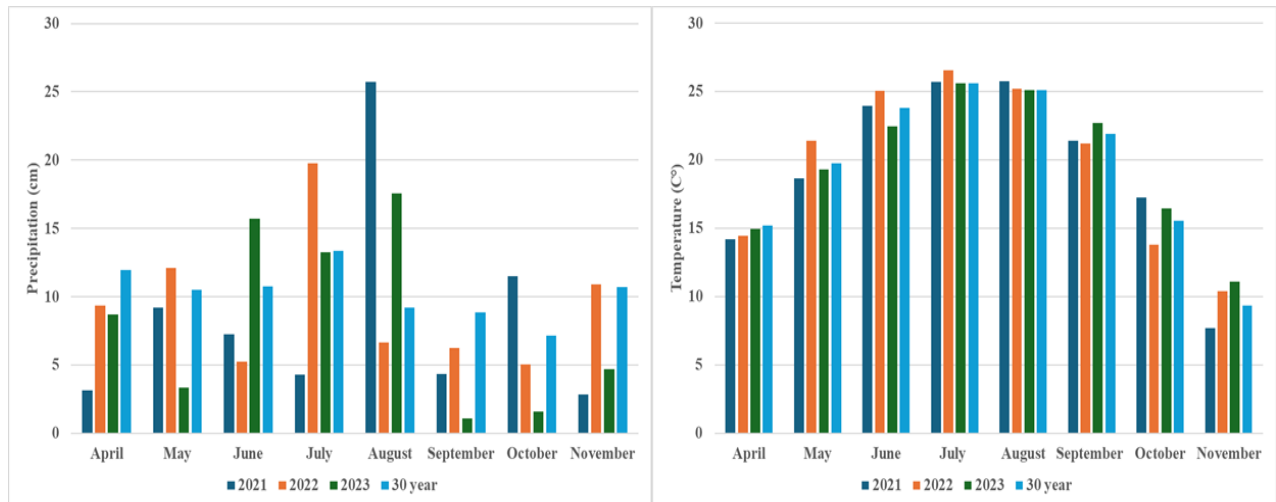


Figure 3.1: Mean monthly precipitation totals and average daily temperatures for 2021-2023 during grazing experiment at East Tennessee Research Education Center, Blount Unit, Louisville, TN, with monthly precipitation totals and average daily temperatures for a 30-year period in Louisville, TN.

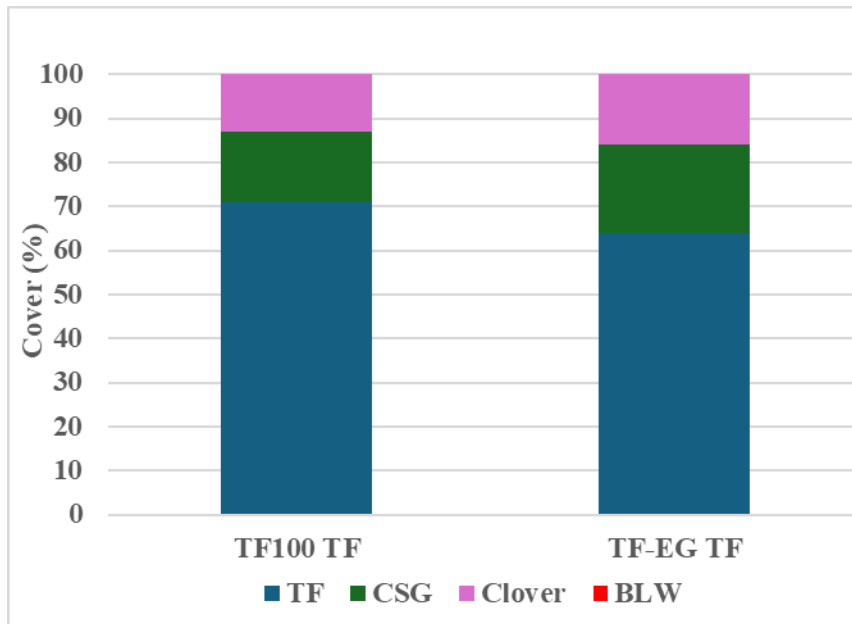


Figure 3.2. Aerial cover (%) of tall fescue (TF), other cool-season grasses (CSG), clover and broad-leaf weeds (BLW), in May for two forage systems, TF100 [12 ha tall fescue (TF)], and TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF, during grazing experiment at East Tennessee Research Education Center, Blount Unit, Louisville, TN, 2021-2023. Cover values for TF-EG TF are for TF⁺ paddocks within the TF-EG treatment only.

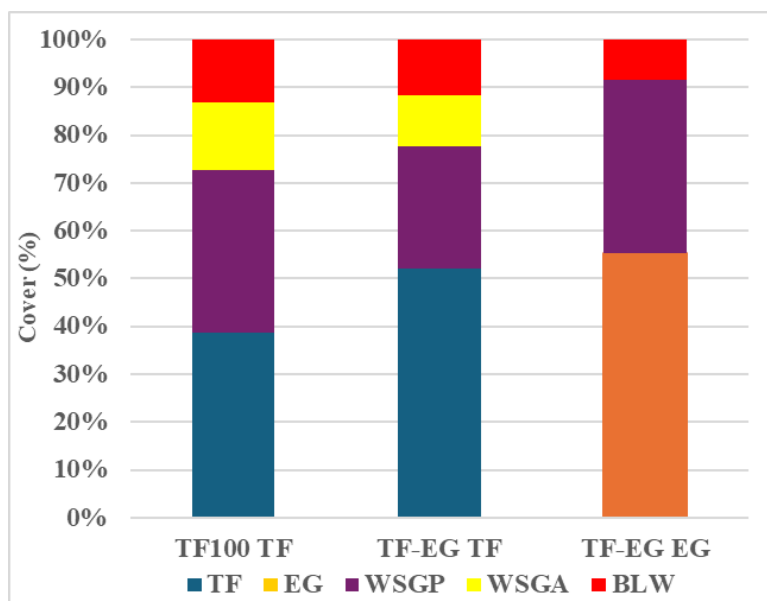


Figure 3.3. Aerial cover (%) of tall fescue (TF), eastern gamagrass (EG), warm-season grass perennials (WSGP), warm-season grass annuals (WSGA) and broad-leaf weeds (BLW) for two forage systems, TF100 [12 ha (TF)], and TF-EG [4 ha of (EG) and 8 ha of TF], during grazing experiment at East Tennessee Research Education Center, Blount Unit, Louisville, TN, 2021-2023. Cover values for TF-EG TF are for TF paddocks within the TF-EG treatment only.

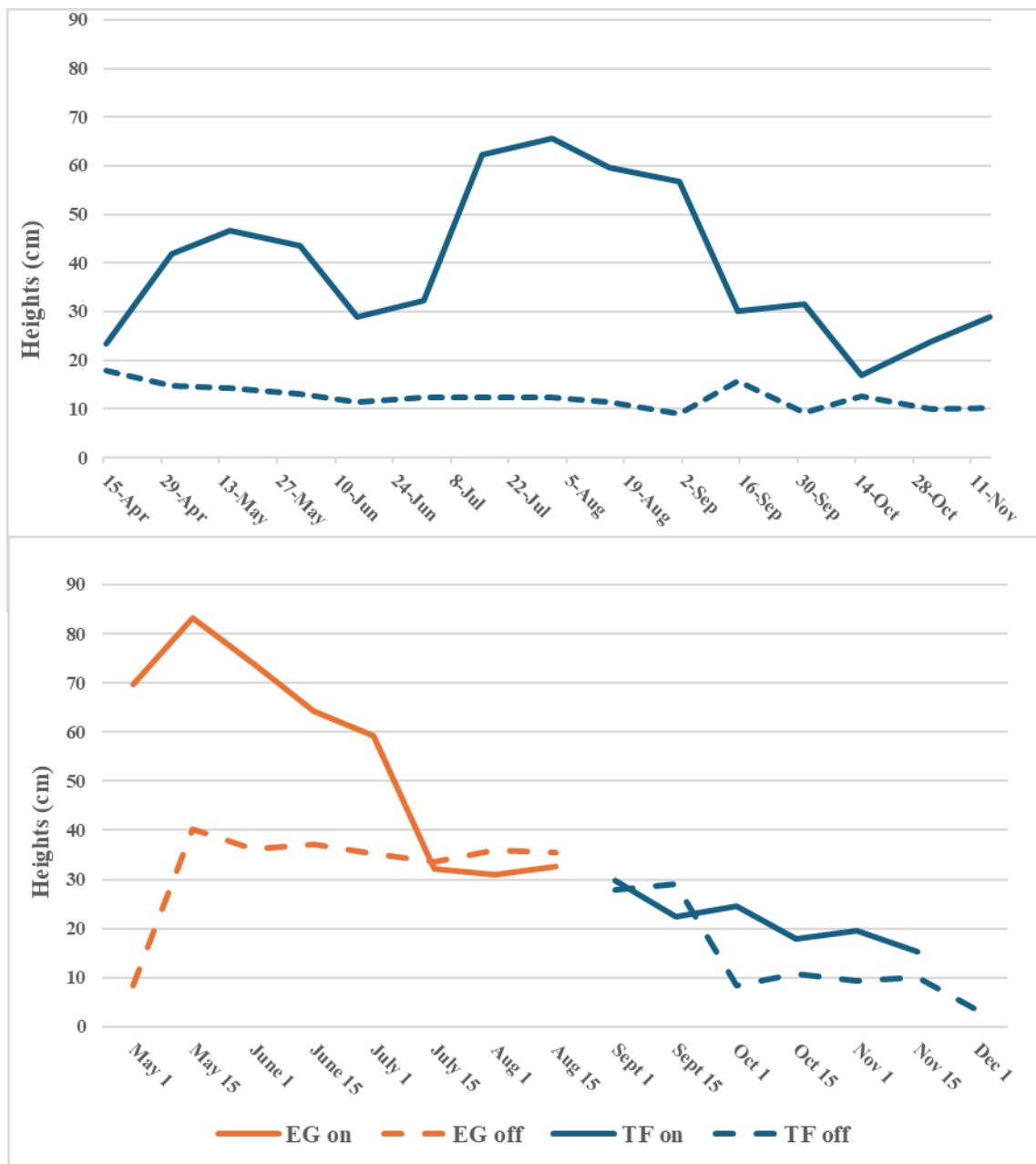


Figure 3.4. Mean grass canopy heights moving on and off paddocks for two forage systems, TF100 [12 ha tall fescue (TF)] (top), and TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF] (bottom) at East Tennessee Research Education Center, Blount Unit, 2021-2023, Louisville, TN.

Table 3.2: Mixed model ANOVA results for forage mass and forage nutritive values for two forage systems (TF100 and TF-EG), TF100 [12 ha tall fescue (TF)], and TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF, 2021-2023, during grazing experiment at East Tennessee Research Education Center, Blount Unit, Louisville, TN.

Variable	Effect	df (num, denom)	F-value	P > F
Forage mass	Treatment	1, 11	0.19	0.67
	Month	7, 198	4.06	0.01
	treatment × month	7, 198	3.31	0.01
Crude protein	Treatment	1, 76	0.10	0.76
	Month	7, 76	2.73	0.01
	treatment × month	7, 76	1.97	0.07
Neutral detergent fiber	Treatment	1, 76	0.48	0.49
	Month	7, 76	4.49	0.01
	treatment × month	7, 76	1.18	0.32
Acid detergent fiber	Treatment	1, 76	0.02	0.89
	Month	7, 76	4.99	0.01
	treatment × month	7, 76	1.38	0.23

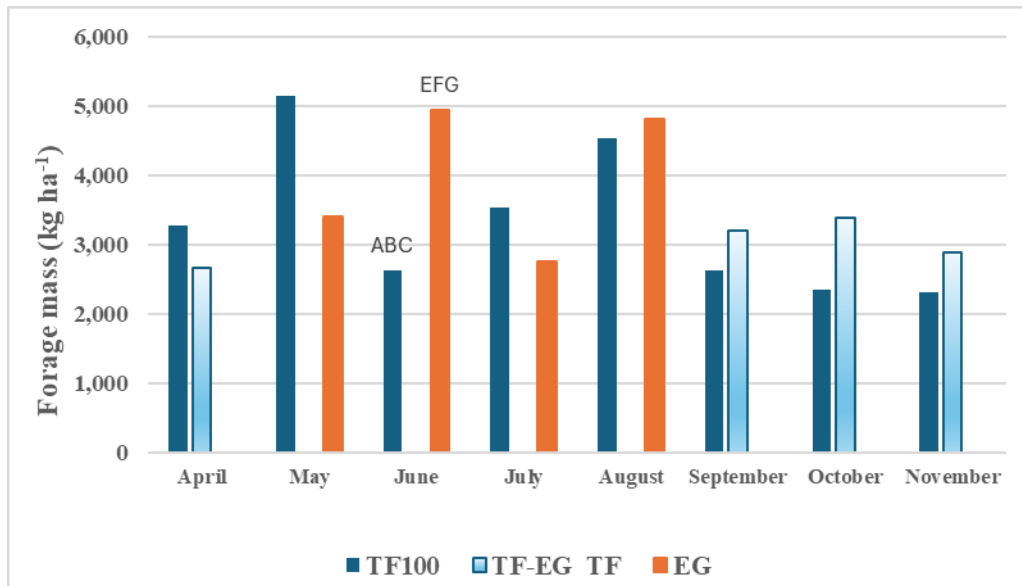


Figure 3.5. Mean monthly forage mass for two forage systems, TF100 [12 ha tall fescue (TF)], and TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF] at East Tennessee Research Education Center, Blount Unit, 2021-2023, Louisville, TN. For TF-EG, mass is presented separately by each forage type, TF (TF-EG TF) and EG.

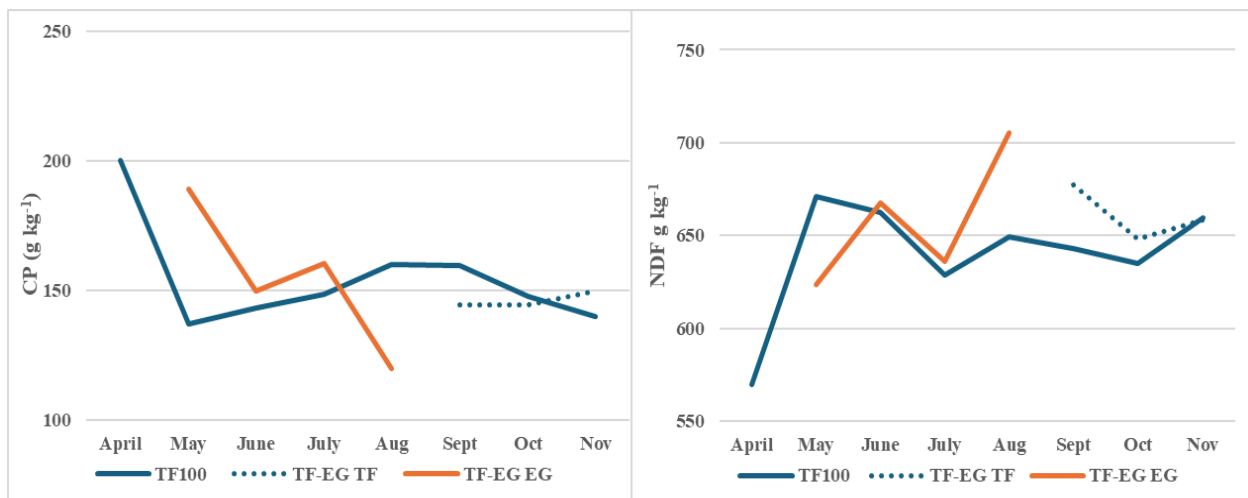


Figure 3.6. Crude protein (CP, left), and neutral detergent fiber (NDF, right) for two forage systems, TF100 [12 ha tall fescue (TF)], and TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF], during grazing experiment at East Tennessee Research Education Center, Blount Unit, Louisville, TN. CP and NDF are by grass types (TF and EG) by month for 2021-2023.

Table 3.3: Mixed model ANOVA results for response variable to cattle for two forage systems (TF100 and TF-EG), TF100 [12 ha tall fescue (TF)], and TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF] 2021-2023, during grazing experiment at East Tennessee Research Education Center, Blount Unit, Louisville, TN. Body condition score is denoted by BCS. Hair coat score is denoted by HCS. Adjusted weaning weight is denoted by AWW.

Variable	Effect	df (num, denom)	F-value	P > F
Cow weight at breeding	treatment	1, 137	3.66	0.06
	year	2, 137	0.51	0.60
	treatment × year	2, 137	0.13	0.88
Cow weight at weaning	treatment	1, 138	0.09	0.77
	year	2, 138	3.46	0.03
	treatment × year	2, 138	0.54	0.58
BCS (spring)	treatment	1, 137	1.33	0.25
	year	2, 137	1.73	0.18
	treatment × year	2, 137	0.74	0.48
BCS (fall)	treatment	1, 138	0.01	0.94
	year	2, 138	1.19	0.31
	treatment × year	2, 138	0.03	0.97
HCS	treatment	1, 137	0.42	0.52
	year	2, 137	32.68	0.01
	treatment × year	2, 137	0.74	0.48
Open cows	treatment	1, 6	1.33	0.29
	year	2, 6	0.25	0.79
	treatment × year	2, 6	3.58	0.09
Birth date	treatment	1, 118	0.50	0.48
	year	2, 118	14.06	0.01
	treatment × year	2, 118	0.26	0.77
Calf weights at weaning, steers	treatment	1, 6	0.26	0.63
	year	2, 6	2.12	0.20
	treatment × year	2, 6	0.03	0.97
Calf weights at weaning, heifers	treatment	1, 6	0.17	0.70
	year	2, 6	0.22	0.81
	treatment × year	2, 6	0.40	0.69
205-day AWW, steers	treatment	1, 70	3.62	0.06
	year	2, 70	2.37	0.10
	treatment × year	2, 70	0.08	0.93
205-day AWW, heifers	treatment	1, 58	0.09	0.77
	year	2, 58	0.02	0.98
	treatment × year	2, 58	1.59	0.21
Total kg ha ⁻¹ weaned	treatment	1, 6	0.16	0.71
	year	2, 6	6.80	0.03
	treatment × year	2, 6	0.03	0.97
Birth weight	treatment	1, 87	0.11	0.74

Table 3.3: Continued

	year	1, 87	0.11	0.74
	treatment × year	1, 87	0.01	0.93
Grazing days	treatment	1, 6	0.77	0.41
	year	2, 6	3.48	0.10
	treatment × year	2, 6	0.09	0.91

Table 3.4. Means for response variable for cattle for two forage systems, TF100 [12 ha tall fescue (TF)], and TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF during grazing experiment at East Tennessee Research Education Center, Blount Unit, 2021-2023, Louisville, TN. Body condition score is denoted by BCS⁵. Hair coat score is denoted by HCS⁶. Adjusted weaning weight is denoted by AWW. Means followed by letters differ within years.

	TF100	TF-EG
Cow weights at breeding (kg)	694	717
Cow weights at weaning (kg)	675	679
BCS (spring)	6.1	6.2
BCS (fall)	6.1	6.1
HCS	2.8	2.7
Mean open cows	2	1
Birth date	29-Jan	1-Feb
Calf weights at weaning (kg), steers	285	292
Calf weights at weaning (kg), heifers	268	272
205-day AWW (kg), steers	274	289
205-day AWW (kg), heifers	259	262
Total kg ha ⁻¹ weaned	281 ⁷	279
Birth weights (kg)	36	36
Grazing days (AUD ha ⁻¹)	256	251

⁵ Body condition scores were estimated on a 9-point scale (Whittier et al., 1993).

⁶ Hair scores were measured on a scale of 1 to 5 (Decker and Thomas, 2021).

⁷ One TF100 replicate had 13 calves due to twins.

Table 3.5. Mean hay yield, nutritive values (crude protein [CP], neutral detergent fiber [NDF] and acid detergent fiber [ADF]) for two forage systems, TF100 [12 ha tall fescue (TF)], and TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF], during grazing experiment at East Tennessee Research Education Center, Blount Unit, Louisville, TN, 2021-2023.

Year	Treatment		Mean	F-value	P > F
2021	TF	Yield (kg ha ⁻¹)	5,096	0.13	0.88
		CP (g kg ⁻¹)	147	0.59	0.63
		NDF (g kg ⁻¹)	595	2.24	0.31
		ADF (g kg ⁻¹)	313	2.29	0.30
2022	TF	Yield (kg ha ⁻¹)	5,772	0.13	0.88
		CP (g kg ⁻¹)	120	0.59	0.63
		NDF (g kg ⁻¹)	731	2.24	0.31
		ADF (g kg ⁻¹)	405	2.29	0.30
	TF-EG	Yield (kg ha ⁻¹)	6,272	0.13	0.88
		CP (g kg ⁻¹)	142	0.59	0.63
		NDF (g kg ⁻¹)	653	2.24	0.31
		ADF (g kg ⁻¹)	346	2.29	0.30
2023	TF	Yield (kg ha ⁻¹)	3,570	0.13	0.88
		CP (g kg ⁻¹)	114	0.59	0.63
		NDF (g kg ⁻¹)	716	2.24	0.31
		ADF (g kg ⁻¹)	403	2.29	0.30
	TF-EG	Yield (kg ha ⁻¹)	4,200	0.13	0.88
		CP (g kg ⁻¹)	120	0.59	0.63
		NDF (g kg ⁻¹)	645	2.24	0.31
		ADF (g kg ⁻¹)	369	2.29	0.30

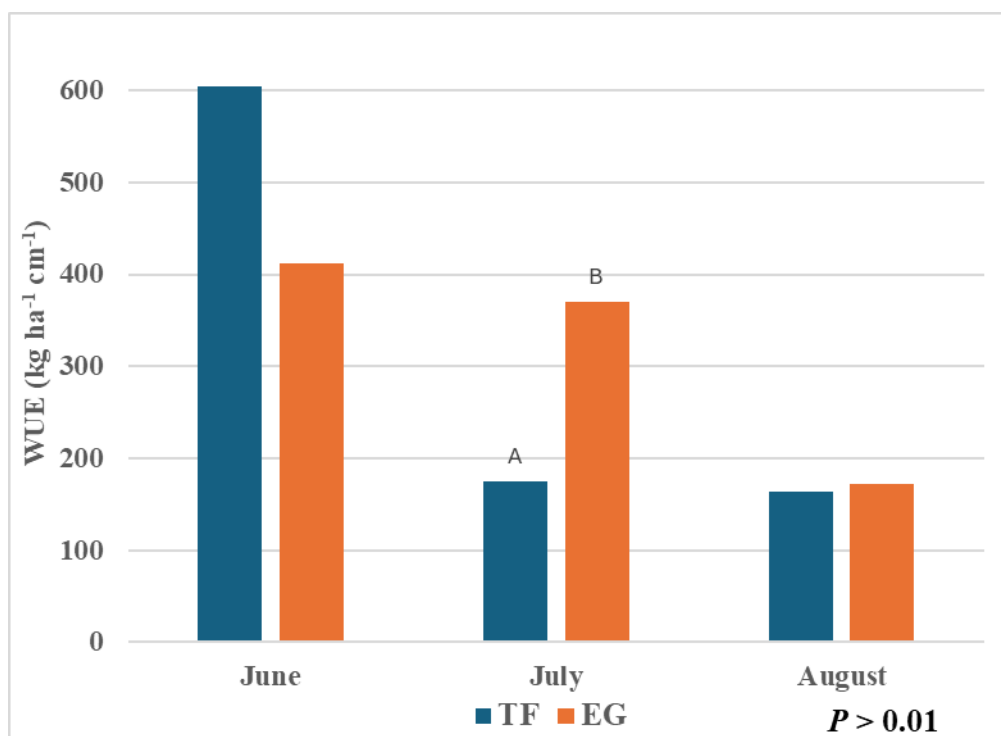


Figure 3.7. Mean water use efficiency (WUE) for TF and EG grass types for two forage systems, TF100 [12 ha tall fescue (TF)], and TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF], during grazing experiment at East Tennessee Research Education Center, Blount Unit, Louisville, TN, 2021-2023. Letters indicate differences ($P < 0.05$) between grass types.

Table 3.6. Mixed model ANOVA results for net returns to system and per cow for two forage systems(TF100 and TF-EG), TF100 [12 ha tall fescue (TF)], and TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF], 2021-2023, during grazing experiment at East Tennessee Research Education Center, Blount Unit, Louisville, TN.

Variable	Effect	df (num, denom)	F-value	P > F
Net return per cow	treatment	1, 6	38.53	0.01
	year	2, 6	0.70	0.53
	treatment × year	2, 6	5.63	0.04
Net return to system	treatment	1, 6	38.53	0.01
	year	2, 6	0.70	0.53
	treatment × year	2, 6	5.63	0.04

Table 3.7. Net return to cow and system for two forage systems, TF100 [12 ha tall fescue (TF)], and TF-EG [4 ha of eastern gamagrass (EG) and 8 ha of TF], during grazing experiment at East Tennessee Research Education Center, Blount Unit, 2021-2023, Louisville, TN. Means followed by letters differ within returns ($P < 0.05$).

Treatment	Year		Net Return	F-value	P > F
TF100	2021	Per cow (\$cow ⁻¹)	-\$20d	5.63	0.04
		To system (\$herd ⁻¹)	-\$238d	5.63	0.04
	2022	Per cow (\$cow ⁻¹)	\$134bc	5.63	0.04
		To system (\$herd ⁻¹)	\$1,605bc	5.63	0.04
	2023	Per cow (\$cow ⁻¹)	\$12cd	5.63	0.04
		To system (\$herd ⁻¹)	\$144cd	5.63	0.04
TF-EG	2021	Per cow (\$cow ⁻¹)	\$411a	5.63	0.04
		To system (\$herd ⁻¹)	\$4,937a	5.63	0.04
	2022	Per cow (\$cow ⁻¹)	\$236ab	5.63	0.04
		To system (\$herd ⁻¹)	\$2,828ab	5.63	0.04
	2023	Per cow (\$cow ⁻¹)	\$219ab	5.63	0.04
		To system (\$herd ⁻¹)	\$2,622ab	5.63	0.04

CHAPTER IV

CARBON SEQUESTRATION POTENTIAL AND IMPROVED SOIL HEALTH

PASTURES WITH NATIVE WARM-SEASON GRASSES IN SOUTHERN US

ABSTRACT

Tall fescue [TF⁺; *Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.] and other cool-season species are not well adapted to excessive heat and extended summer drought conditions. Native warm-season grasses (NWSG) are very tolerant of drought and could have increased soil carbon stocks and soil health than the more poorly adapted TF. Therefore, a study was implemented on two sites (one each in Missouri and Tennessee) with cow-calf production systems to evaluate two forage systems, one that relied on a cool-season (C₃) grass only, TF and a complementary system that incorporated a NWSG (C₄) species with TF. At initiation (2021) and conclusion (2023) of the study, samples were taken for soil organic carbon (SOC) concentration, total nitrogen (N), bulk density (BD), wet aggregate stability (WAS), pH and Mehlich-3 extractable nutrient concentrations. All sampling was assigned based on soil wetness index values (wet, medium, dry) generated from the System for Automated Geoscientific Analyses (SAGA). The C:N ratio and SOC stocks were greater in TF at Tennessee. Wet aggregate stability, BD and pH were greater in eastern gamagrass (EG). The influence of other non-native grasses and the relatively short time interval between sampling may explain the unexpected greater SOC stocks and C:N ratio in TF at Tennessee. Grazing did increase the C:N ratio in Missouri in both TF and big bluestem/indiangrass (BBIG) over the experiment's duration. Further research is needed to determine what factors will increase SOC stocks, C:N ratios, WAS and BD in soils within NWSG and non-native grasslands under grazing.

INTRODUCTION

Grasslands contain over one-third of above and belowground soil organic carbon (SOC) stocks (Bai and Cotrufo, 2022) and could possibly sequester approximately 3 Gt carbon (C) per year globally (Janowiak et al., 2017). Consequently, grasslands are of high importance for their C capture and storage and have been proposed as a possible climate mitigation strategy through soil C sequestration (Tessema et al., 2020). In 2017, nearly 2.83 million ha of land in the US was used for grassland pasture and range (USDA Economic Research Service, 2024). However, a large percentage of these grasslands lie in a 15 million ha region known as the ‘Fescue Belt’ dominated by a non-native perennial grass, tall fescue [TF; *Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.]. Tall fescue and other cool-season species (C_3 photosynthetic pathway), are not well adapted to severe climate fluctuations, such as excessive heat, extended summer drought conditions or severe flooding.

An interest in soil health and sustainable agriculture has increased recently, with an upsurge in research for best management practices in production systems (American Farm Bureau, 2020; Kalaitzandonakes et al., 2023). In North America, native warm-season grasses (NWSG) may be a leading forage in this movement, due to the grasses’ inherent high N-use efficiency, tolerance of acidic soils, and low fertility inputs (Keyser et al., 2012). Additionally, these perennial grasses develop extensive root systems that enhance soil microbial activity and support increased C sequestration through abundant aboveground growth (Wepking, 2017). Therefore, native grasses are more effective at improving soil quality than cool-season grasses with shallow roots or sod-forming non-native grasses (Keyser et al., 2022). In an Arkansas study, a comparison of a non-native, cool-season perennial, orchardgrass (*Dactylis glomerata*), with a warm-season, native grass mix [big bluestem (*Andropogon gerardii* Vitman)] and little bluestem

[(*Schizachyrium scoparium* (Michx.) Nash)] revealed an increase in soil microbial diversity in the native grass system (Gurmessa et al., 2021). A recent study in Nebraska demonstrated that native grasslands had greater SOC and microbial biomass (7.39 kg SOC m⁻² and 65.6 mmol MB m⁻², respectively) than a cedar (6.80 kg SOC m⁻² and 38.4 mmol MB m⁻²) or pine forest (5.87 kg SOC m⁻² and 39.9 mmol MB m⁻²) (Li et al., 2023). Native warm-season grasses are very tolerant of drought and flooding (Keyser et al., 2012; Pent and Daniel, 2020) and could improve soil health because of their ability to tolerate climatic extremes, leading to better soil health and elevated carbon levels than the more poorly adapted, non-native grasses.

Therefore, a study was implemented on two sites with cow-calf grazing systems in the Fescue Belt to evaluate two forage systems, one that relied on a cool-season (C₃) grass only, TF (the typical system found within the Fescue Belt) and a complementary system that incorporated a native, warm-season (C₄) species, with TF. The objectives were to assess the influence of these grass species (TF and NWSG) on SOC accumulation, soil aggregation, bulk density, and nutrient availability. We hypothesized that measures of soil health would be greater in the NWSG than the TF with greater SOC, lower bulk density, greater soil aggregation, and greater nutrient availability.

MATERIALS AND METHODS

Experimental Design: Two replicates of three treatments were used in this project. Treatment 1 (TF100) was a cool-season forage system dominated by toxic endophyte infected TF, representing the most widespread grazing system in the area, and served as the control. Treatment 2 (TF-BB) was a complementary cool-season/NWSG system, with the cool-season element also comprised of TF and with a big bluestem (BB) and indiagrass [IG; *Sorghastrum nutans* (L.) Nash] mix (BBIG) representing 30% of the system as the NWSG. Treatment 3 (TF-

EG) was a complementary cool-season/NWSG system as well, with the cool-season forage comprised of TF⁺ and with eastern gamagrass [EG; *Tripsacum dactyloides* (L.) L.] as the 30% NWSG.

Site Description: The TF100 treatment and the TF-EG treatment were implemented at the East Tennessee AgResearch and Education Center, Blount Unit (ETREC, 35°50'36.96" N, 83°57'16.78" W) in Louisville, TN, from 2021-2023. The soil consisted of a well-drained, Alcoa loam (fine, parasesquic, thermic Rhodic Paleudults), Cumberland silty clay (fine, mixed, semiactive, thermic Rhodic Paleudalfs), Decatur silty clay (fine, kaolinitic, thermic Rhodic Paleudults), Dewey silty clay (fine, kaolinitic, thermic Typic Paleudults, Farragut silty clay (clayey, mixed, semiactive, thermic Humic Hapludults) and Tellico loam (fine, parasesquic, thermic Typic Rhodudults) (20%, 30%, 15%, 10%, 10% and 10%, respectively, of experimental pasture area) (NRCS Web Soil Survey, 2023). Experimental units were similar in representation of these soil series. Mean TF pasture soil pH was 6.54 with 115 kg ha⁻¹ P and 551 kg ha⁻¹ K. Mean EG pasture soil pH was 6.48 with 99 kg ha⁻¹ P and 449 kg ha⁻¹ K.

The TF100 treatment and the TF-BB treatment were implemented at the Missouri Forage Systems Research Center (38°51'27.7" N, 93°08'52.6" W) in Linneus, MO, from 2021-2023. The soil consisted of a rather poorly-drained, Armstrong clay (fine, smectitic, mesic Aquertic Hapludalfs), Purdin loam (fine, mixed, superactive, mesic Oxyaquic Hapludalfs), Lagonda silt loam (fine, smectitic, mesic Aquertic Argiudolls), Armstrong loam (fine, smectitic, mesic Aquertic Hapludalfs), Blackoar silt loam (fine-silty, mixed, superactive, mesic Fluvaquentic Endoaquolls) and Grundy silt loam (fine, smectitic, mesic Aquertic Argiudolls) (45%, 13%, 13%, 13%, 10% and 7%, respectively) (NRCS Web Soil Survey, 2023). Experimental units were similar in composition. Mean TF pasture soil pH was 6.71 with 56 kg ha⁻¹ P and 246 kg ha⁻¹ K.

Mean BBIG pasture soil pH was 6.69 with 46.60 kg ha⁻¹ P and 239.96 kg ha⁻¹ K. Mehlich-3 nutrient concentrations were determined by the USDA-ARS Poultry Production and Product Safety Research lab (Fayetteville, AR).

Pasture Establishment and Management: At the site in Tennessee, EG pastures were established in 2010 – 2013 with either cv ‘Highlander’ or ‘Pete’ eastern gamagrass. Twenty-eight ha of existing TF pastures were used, along with 12 ha that were reseeded to KY31 TF at 17 kg ha⁻¹ along with 11 kg ha⁻¹ red clover [*Trifolium pratense* L. (‘FSG401’)] and 2 kg ha⁻¹ white (‘Will’ ladino) clover (*T. repens* L.) in November 2020. The 20 ha of existing TF pastures were interseeded with 11 kg ha⁻¹ red (‘FSG401’) and 2 kg ha⁻¹ white (‘Will’ ladino cultivar) clovers, also in November 2020. Fertilization was handled similarly among all TF⁺ pastures for both treatments. Tall fescue pastures in both systems received N in the form of urea [CO(NH₂)₂] at 68 kg ha⁻¹ annually in March at greenup. Based on soil samples, 60 kg ha⁻¹ P were applied to 12 ha of the TF⁺ pastures in spring of 2023.

At the Missouri site, 8 ha of TF pastures were renovated to NWSG stands in 2016. Pastures were then planted to a BBIG mix in June of 2016 with cv “Kaw” and “Rumsey.” Twenty-eight ha of existing TF pastures were utilized (established in 1977 as KY31, with 8 ha as “Missouri 96”) and were interseeded with 2.3kg ha⁻¹ red clover and .9kg ha⁻¹ white clover in April of 2021. Fertilization was handled similarly among all TF pastures for both treatments. All pastures received N in the form of urea [CO(NH₂)₂] at 62 kg ha⁻¹ annually in April and May at greenup. Big bluestem pastures were burned in April 2021 and 2023 prior to the commencement of the grazing season.

Grazing Management: In Tennessee, grazing commenced each spring (3 May, 22 and 20 April in 2021, 2022, and 2023, respectively) and continued until fall (7, 15 December and 1 November

in 2021, 2022, and 2023, respectively). Tall fescue pastures were grazed on a rotational basis with cattle moved within assigned paddocks based on stand condition, with grazing intervals of ten to fourteen days per paddock and rest periods of 6-8 weeks. Eastern gamagrass pastures were grazed on a rotational basis, beginning each spring (26, 17 and 8 May in 2021, 2022, and 2023, respectively), with grazing intervals of three to four days per paddock and rest periods of 15 to 21 days. Pairs were removed from EG stands during the summer if EG stands were not able to support grazing and placed on their respective TF pastures and returned to EG pastures as soon as the pastures were able to support grazing again. Days spent off EG pastures was 60 in 2021, with 0 days in 2022 and 2023. Grazing of EG pastures concluded late summer annually (13, 30 August and 12 September in 2021, 2022, and 2023, respectively).

In Missouri, grazing commenced each spring (11, 9 and 9 May in 2021, 2022, and 2023, respectively) and concluded in early winter (3, December 2021, 9 December 2022, and 25 January 2024, respectively) for TF-BB and (3, 12 and 25 January in 2022, 2023 and 2024, respectively) for TF100 pairs. TF pastures were divided into 6, 2.0-ha paddocks and rotated based on stand condition. Big bluestem pastures were divided into 5, 0.80-ha paddocks and were grazed on a rotational basis, beginning each spring (17, 23 and 2 June in 2021, 2022, and 2023, respectively), with grazing intervals of 3-4 days per paddock and rest periods of 15-21 days. During summer, pairs were removed from BBIG pastures if pastures needed rest and were placed on their respective TF pastures, then returned to BBIG pastures as soon as the pastures were able to support grazing again. Total days spent off BBIG pastures were 6 in 2021, 0 in 2022 and 41 in 2023. Grazing of BBIG pastures concluded 23 August, 1 and 7 September in 2021, 2022, and 2023, respectively.

Data Collection: At the initiation of the study (March 2021), prior to grazing, and at the conclusion of the study (when cow-calf pairs were removed from pastures, January 2024), samples were taken for SOC concentration, total N, bulk density, wet aggregate stability, pH and Mehlich-3 nutrient concentrations. All sampling was allocated based on soil wetness index values (wet, medium, dry) generated from the System for Automated Geoscientific Analyses (SAGA) (Conrad et al., 2015) (n=96, Tennessee, n=36, Missouri). Each sample consisted of approximately 10 composited cores collected to 15 cm within a 2-m² area, using a 1.9-cm diameter stainless-steel probe. Samples were air dried and sieved using a 2-mm sieve, then through a 1-mm sieve. For C and N analysis, samples were placed in capped vials with a metal tumbling bar and placed on a mechanical rotator overnight. Concentrations of SOC and total N were determined by dry-combustion method on a C:N analyzer (Elementar vario MAX cube , Langensfeld, Germany). Aggregate stability was determined using 1-mm sized aggregates by an Eijkelkamp wet sieving apparatus (Tiemann & Grandy, 2015). Soil pH was determined from the composited samples extracted with the probe. These samples were air-dried and ground to pass through a 2-mm screen. Mehlich-3 nutrient concentrations were determined using a 1:10 soil mass:extractant solution volume ratio (Mehlich, 1984) and analyzed by inductively coupled plasma spectrometry (ICP, Agilent Technologies, Santa Clara, CA).

In conjunction with the above sampling, bulk density (BD) samples were taken at the same location and within the same SAGA classification. Bulk density samples were taken by the core method (Grossman and Reinsch, 2002). Sampling was performed when the soil surface was uniformly dry across all soil types and all grazing treatments. The soil bulk density samples were obtained using a traditional slide hammer (5-cm diameter) containing a plastic sleeve (309 cm³) using the core method (Blake, 1965). Undisturbed cores were extracted to a depth of 15 cm. In

the lab, non-decomposed plant materials and rocks were removed from BD cores. Cores were dried at 105 C° for 24 hours. Bulk density was then determined using the oven-dry mass of the cores and the core volume (Food and Agriculture Organization, 2019).

Statistical Analysis

The carbon stock (Mg ha^{-1}) was calculated by multiplying the SOC concentration with the corresponding BD and sampling depth. Carbon stock, C:N ratio, wet aggregate stability, bulk density, pH and Mehlich-3 nutrients were analyzed using a mixed model analysis of variance (ANOVA) using PROC MIXED in SAS®, version 9.4 (SAS Institute, Cary, NC, 2013) and considered significant at $\alpha = 0.05$. Response variables were tested for normality using PROC UNIVARIATE. Fixed effects in the models were grass species and sampling interval. Random effects were grass species $\times$ pasture. If variables failed diagnostic tests for equal variances (>5 -fold difference), then log, square root or rank transformations were made.

RESULTS AND DISCUSSION

Carbon stock was greater in TF in Tennessee ($P < 0.01$) and but did not differ between TF and BBIG in Missouri ($P < 0.85$; **Table 4.1**). The soil C:N ratio was greater in TF in Tennessee ($P < 0.01$). In Missouri, the C:N ratio did not differ between treatments ($P < 0.88$) but was greater in the final year than at the initiation of the project ($P < 0.01$) (**Figure 4.1**). There were no treatment $\times$ year interactions ($P < 0.62$). The C:N ratio increased throughout the study in EG in Tennessee, but decreased in TF ($P < 0.01$).

In both locations, there was encroachment of volunteer warm-season grasses, cool-season grasses and broad-leaf weeds (30% in Missouri, 40% in Tennessee) in the NWSG pastures. The influence of these species within the NWSG pastures may have contributed to the lack of differences in carbon stocks in Missouri and the lower carbon stocks in EG in Tennessee. Native

warm-season grasses have a lower N content than other grass species because of their higher N efficiency, and therefore, typically have a greater soil C:N ratio after decomposition (Kaitlin, 2008). However, the aforementioned warm-season and cool-season grass influence in the NWSG pastures may have lowered the C:N ratio to a similar one in a non-native pasture. Further, current research suggests that NWSG generally have a greater microbial diversity compared to cool-season grasses due to their larger root systems and their ability to tolerate adverse ecological conditions (Kaitlin, 2018; Keyer, 2012) and thereby, lowering the C:N ratio. While microbial activity was not measured in this study, it is possible that the NWSG pastures had higher activity than TF⁺ pastures, thus reducing their C:N ratio as well.

Forage mass increased in Missouri from year 1 to year 2 during the duration of the experiment. Increased plant mass will result in more C inputs to the soil through plant litter and extended root systems (Zhang and Xi, 2021). Higher precipitation amounts can also increase the potential for soil N leaching (Chen et al., 2016) and Missouri received more rainfall in year 2. These two factors may have contributed to the increase in the C:N ratio at Missouri from initiation to the final year in the study.

Wet aggregate stability was greater in EG in Tennessee ($P < 0.03$, **Table 4.1**) and increased throughout the course of the study ($P < 0.01$). Extensive and deep root networks, such as found in NWSG (Ryan and Marks, 2005) will increase WAS (Hetrick et al., 2016; Li et al., 2020). Therefore, the root systems within the EG pastures likely contributed to the greater WAS in EG. In Missouri, WAS was greater in TF ($P < 0.03$, **Table 4.1**). The aforementioned warm-season grass influence within the BBIG pastures may have contributed to the lower WAS.

Bulk density samples were not collected at the initiation of the study in Missouri due to logistical constraints. Samples were collected in the final year of the study, at the conclusion of

grazing. Differences were not noted between species in BD in Missouri ($P < 0.44$, **Table 4.1**). Bulk density was greater in EG ($P < 0.01$, **Table 4.1**) at the Tennessee site. Generally, NWSG have a lower bulk density, as NWSG have larger root networks and more open spaces between plants, leading to less compaction and increased aeration, but the warm-season grass influence in the EG pastures likely filled in these open spaces between EG plants. The nutrient availability (P, K) remained consistent between treatments and years at both locations (**Table 4.2**); however, pH was greater in EG in Tennessee (**Table 4.2**).

CONCLUSIONS

Although carbon stocks and the C:N ratio were greater in TF in Tennessee, the influence of other non-native C_4 grasses may have contributed to the increase. Further, the relatively short time interval between initial and final sampling of pastures may have contributed to the lack of differences in Missouri and the unexpected increase in TF in Tennessee, as differences would more likely require a longer interval to develop. The grass species did increase the C:N ratio in Missouri over the duration of the experiment and may be an example of how light to moderate grazing can improve C:N ratio with appropriate stocking densities. The greater WAS in EG in Tennessee may be an example of NWSG successfully exploiting their native environment, potentially through their fibrous root systems that enhance aggregate stability (Kibet et al., 2016; Li et al., 2020).

Managing forage systems for increased carbon stocks is crucial to recover important ecosystem services, such as soil nutrient cycling (Chapin et al., 2022; Liu et al., 2023), C sequestration (Derner and Schuman, 2007), microbial diversity (Xiang et al., 2023; Zhou et al., 2023), and water availability (Fiebel et al., 2024). Research with a longer duration will be needed

to determine what factors are most important for increasing carbon stocks, C:N ratios, aggregate stability and bulk density within NWSG and non-native soils under grazing.

REFERENCES

- Bai, Y., & Cotrufo, M. F. (2022). Grassland soil carbon sequestration: Current understanding,] challenges, and solutions. *Science*, 377(6606), 603-608.
- Blake, G. R. (1965). Bulk density. *Methods of soil analysis: Part 1 physical and mineralogical properties, including statistics of measurement and sampling*, 9, 374-390.
- Chapin, F. S., Matson, P. A., Mooney, H. A., & Vitousek, P. M. (2002). Principles of terrestrial ecosystem ecology. Springer: New York, NY.
- Chen, Z., Ding, W., Xu, Y., Müller, C., Yu, H., & Fan, J. (2016). Increased N₂O emissions during soil drying after waterlogging and spring thaw in a record wet year. *Soil Biology and Biochemistry*, 101, 152-164.
- Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlitz, L., Wehberg, J., Wichmann, V. & Böhner J. (2015). System for automated geoscientific analyses (SAGA) v. 2.1. 4. *Geoscientific model development*, 8 (7), 1991-2007.
- Derner, J. D., & Schuman, G. E. (2007). Carbon sequestration and rangelands: a synthesis of land management and precipitation effects. *Journal of soil and water conservation*, 62(2), 77-85.
- Feifel, M., Durner, W., Hohenbrink, T. L., & Peters, A. (2024). Effects of improved water retention by increased soil organic matter on the water balance of arable soils: A numerical analysis. *Vadose Zone Journal*, 23(1), e20302.
- Grossman, R. B., & Reinsch, T. G. (2002). 2.1 Bulk density and linear extensibility. *Methods of soil analysis: Part 4 physical methods*, 5, 201-228.
- Gurmessa, B., Ashworth, A. J., Yang, Y., Adhikari, K., Savin, M., Owens, P., & Corti, G.

- (2021). Soil bacterial diversity based on management and topography in a silvopastoral system. *Applied Soil Ecology*, 163, 103918.
- Hetrick, S., Ketterings, Q., Czymmek, K., Sadeghpour, A., Langner, A., O'Neill, K., & Gabriel, A. (2016). Improving Aggregate Stability. Cornell University Cooperative Extension. Ithaca, NY.
- Janowiak, M., Connelly, W. J., Dante-Wood, K., Domke, G. M., Giardina, C., Kayler, Z., & Buford, M. (2017). Considering forest and grassland carbon in land management. *General Technical Report, Washington Office*, 95.
- Kaitlin, G. A. (2018). Using Native Warm-Season Grasses in Forage Systems for Improvements in Ecosystem Services. Thesis. Virginia Tech. Blacksburg, VA.
- Kalaitzandonakes, M., Ellison, B., & Coppess, J. (2023). Promoting Sustainable Agricultural Production in the Next Farm Bill: Is There Any Common Ground? *farmdoc daily*, 13(44).
- Keyser, P., Zechiel, K. E., Bates, G., Ashworth, A. J., Nave, R., Rhinehart, J., & McIntosh, D. W. (2022). Evaluation of five C4 forage grasses in the tall Fescue Belt. *Agronomy Journal*, 114(6), 3347-3357.
- Keyser, P. D., Bates, G. E., Waller, J. C., Harper, C. A., & Doxon, E. (2012). Grazing native warm-season grasses in the mid-South. *University of Tennessee Center for Native Grassland Management SP731-C. University of Tennessee, Knoxville, TN*.
- Kibet, L. C., Blanco-Canqui, H., & Jasa, P. (2016). Long-term tillage impacts on soil organic matter components and related properties on a Typic Argiudoll. *Soil and Tillage Research*, 155, 78-84.
- Li, J., Yuan, X., Ge, L., Li, Q., Li, Z., Wang, L., & Liu, Y. (2020). Rhizosphere effects promote

- soil aggregate stability and associated organic carbon sequestration in rocky areas of desertification. *Agriculture, Ecosystems & Environment*, 304, 107126.
- Li, L., Hosseiniaghdam, E., Drijber, R., Jeske, E., Awada, T., Hiller, J., & Kaiser, M. (2023). Conversion of native grassland to coniferous forests decreased stocks of soil organic carbon and microbial biomass. *Plant and Soil*, 491(1), 591-604.
- Liu, L., Sayer, E. J., Deng, M., Li, P., Liu, W., Wang, X., & Piao, S. (2023). The grassland carbon cycle: Mechanisms, responses to global changes, and potential contribution to carbon neutrality. *Fundamental Research*, 3(2), 209-218.
- Mehlich, A. (1984). Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. *Communications in soil science and plant analysis*, 15(12), 1409-1416.
- Pent, G. J., & Daniel, J. B. (2020). Converting pastures to native warm season grasses: forage for drought in Bedford county.
- Ryan, M. B., & Marks, R. (2005). *Native warm-season grasses and wildlife*. Natural Resources Conservation Service, Wildlife Habitat Management Institute.
- Tessema, Y. M., Jasińska, J., Yadeta, L. T., Świtoniak, M., Puchalka, R., & Gebregeorgis, E. G. (2020). Soil loss estimation for conservation planning in the welmel watershed of the Genale Dawa Basin, Ethiopia. *Agronomy*, 10(6), 777.
- Tiemann, L. K., & Grandy, A. S. (2015). Mechanisms of soil carbon accrual and storage in bioenergy cropping systems. *Gcb Bioenergy*, 7(2), 161-174.
- Wepking, N. R. (2017). An Assessment of Traits Impacting Native Warm-Season Grass Adoption by Pasture Managers in the Mid-South. Thesis. University of Tennessee. Knoxville, TN.
- Xiang, Y., Chang, S. X., Shen, Y., Chen, G., Liu, Y., Yao, B., & Li, Y. (2023). Grass cover

increases soil microbial abundance and diversity and extracellular enzyme activities in orchards: A synthesis across China. *Applied Soil Ecology*, 182, 104720.

Zhang, C., & Xi, N. (2021). Precipitation changes regulate plant and soil microbial biomass via plasticity in plant biomass allocation in grasslands: a meta-analysis. *Frontiers in plant science*, 12, 614968.

Zhou, R., Liu, Y., Dungait, J. A., Kumar, A., Wang, J., Tiemann, L. K., ... & Tian, J. (2023). Microbial necromass in cropland soils: A global meta-analysis of management effects. *Global Change Biology*, 29(7), 1998-2014.

APPENDIX IV

Table 4.1. Carbon stock, C:N ratio, bulk density (BD) and wet aggregate stability (WAS) for three grass species, tall fescue (TF), big bluestem/indiangrass (BBIG) mix and eastern gamagrass (EG) during grazing experiment at Missouri Forage Systems Research Center, Linneus MO and at East Tennessee Research Education Center, Blount Unit, Louisville, TN, 2021-2023. Means followed by letters differ within locations.

Location	Species		Mean	F-value	<i>P</i> > F
MO	BBIG	Carbon stock (Mg ha ⁻¹)	33	0.04	0.85
		C:N ratio	13.5	0.02	0.88
		WAS (%)	72.1b	4.64	0.03
		BD (g cm ³)	1.18	0.61	0.44
	TF	Carbon stock (Mg ha ⁻¹)	36	0.04	0.85
		C:N ratio	13.5	0.02	0.88
		WAS (%)	78.6a	4.64	0.03
		BD (g cm ³)	1.19	0.61	0.44
TN	EG	Carbon stock (Mg ha ⁻¹)	35b	18.00	0.01
		C:N ratio	12.4b	7.54	0.01
		WAS (%)	85.9a	4.90	0.03
		BD (g cm ³)	1.23a	19.49	0.01
	TF	Carbon stock (Mg ha ⁻¹)	62a	18.00	0.01
		C:N ratio	15.4a	7.54	0.01
		WAS (%)	83.5b	4.90	0.03
		BD (g cm ³)	1.15b	19.49	0.01

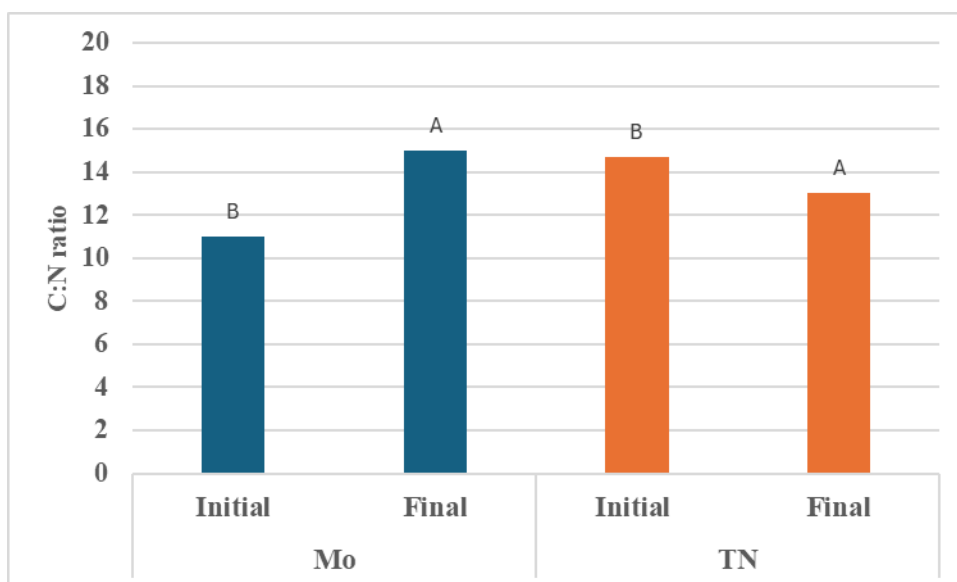


Figure 4.1: The C:N ratio in the initial and final sampling seasons during a three-year grazing experiment at Missouri Forage Systems Research Center, Linnues MO and at East Tennessee Research Education Center, Blount Unit, Louisville, TN, 2021-2023. Letters indicate significant ($P > 0.05$) differences within sampling seasons per location.

Table 4.2. Mehlich-3 concentrations and pH for P and K for three grass species, tall fescue (TF), big bluestem/indiangrass (BBIG) mix and eastern gamagrass (EG) during grazing experiment at Missouri Forage Systems Research Center, Linnues MO and at East Tennessee Research Education Center, Blount Unit, Louisville, TN, 2021-2023. Means followed by letters differ within locations.

Location	Species		Mean	F-value	$P > F$
MO	BBIG	pH	6.74	0.79	0.38
		Mehlich-3 P (kg ha ⁻¹)	39	3.32	0.07
		Mehlich-3 K (kg ha ⁻¹)	267	0.03	0.86
	TF	pH	6.68	0.79	0.38
		Mehlich-3 P (kg ha ⁻¹)	48	3.32	0.07
		Mehlich-3 K (kg ha ⁻¹)	275	0.03	0.86
TN	EG	pH	6.73a	14.14	0.01
		Mehlich-3 P (kg ha ⁻¹)	95	1.23	0.27
		Mehlich-3 K (kg ha ⁻¹)	536	0.08	0.78
	TF	pH	6.43b	14.14	0.01
		Mehlich-3 P (kg ha ⁻¹)	120	1.23	0.27
		Mehlich-3 K (kg ha ⁻¹)	539	0.08	0.78

VITA

Megan Elizabeth Berry is a South Carolina native, where she attended the University of South Carolina Aiken, and received a Bachelor of Science in Biology, with a concentration in Environmental Restoration and Remediation. Her research there was on plant interactions within the rhizosphere. She then received her Master of Science in Biology at Clemson University in 2020, while teaching secondary education science. She desired to learn more about the agriculture sector and thus began her Doctor of Philosophy in Natural Resources at the University of Tennessee -Knoxville in 2021. Her research is centered on the incorporation of native grasses into forage programs and using a “working lands” approach, which seeks to enhance agricultural productivity while simultaneously providing quality environmental habitat for grassland wildlife and improving soil health. She is excited to use this approach after graduation within the field of conservation.