THE USE OF SUPPLEMENTAL FEED IN PASTURE-BASED STOCKER CATTLE SYSTEMS FOR INCREASED NUTRIENT CYCLING

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Animal Sciences, Master of Science

Auburn, Alabama
December 14, 2024

Keywords: sustainability, byproducts, fertilizer, nutrient cycling

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ABSTRACT

In Alabama, pasture-based beef cattle operations are prevalent, but all-time high fertilizer costs present challenges to production. The objective of this research was to evaluate nutrient cycling through supplemental feeding or addition of legumes. Stocker steers (n = 60) were used in a put-and-take grazing and supplementation study, arranged as a generalized complete block design across two locations. Treatments included 0.5 or 1.0% BW supplemental feed (SUP0.5 or SUP1.0, respectively), interseeded red clover (CLOV), or a negative control (tall fescue pasture only; CON). There was an effect of treatment ($P \leq 0.01$) for ADG and gain per hectare, but not for forage mass ($P = 0.84$) or soil pH, OM, N, P, K, or microminerals ($P \geq 0.22$). Results are interpreted to mean that the one-year scale of stocker supplementation may not offset chemical fertilizer inputs, though partial budgets indicated increased revenue.

ACKNOWLEDGEMENTS

I would like to acknowledge the fact that without God in my life this thesis would not have been possible. Three bible verses helped me through my thesis they are as follows: Philippians 4:13 “I can do all things through him who strengthens me”, James 1:2-4 “Consider it pure joy, my brothers and sisters, whenever you face trials of many kinds, because you know that the testing of your faith produces perseverance. Let perseverance finish its work so you may be mature and complete, not lacking anything.” and Isaiah 40:31 “But those who hope in the Lord will renew their strength; they will soar on wings like eagles; they will run and not grow weary; they will walk and not be faint”.

I would like to give a special thank you to my committee members, Dr. Smith, Dr. Maples, Dr. Dillard, and Dr. Mullenix, for all their mentoring during her time at Auburn University. “You have given me more knowledge about nutrition, forage, and economics than I know what to do with. All four of you have played an important role in my future endeavors to be well rounded in the bovine industry.” -Macy L. Rockwell

“A HUGE thank you to the beef and forage team (Abbigail Hines, Abby Boggier, Ashlyn Hurst, Bekah Crews, Cecelia Sagastume, Cole Lincoln, Cynthia Siziba, Diva Rigney, Lauren St. Andrew, Peyton Zessin, Rushing Fuller) at Auburn University. Without you, this project would’ve been much more difficult (nearly impossible) to accomplish all the samplings in one day at each location. Mason Henson, thank you for being a mentor along the way and helping me with in-field methodology. You helped me adjust and put my foot down for the good of our project.”-Mace

Dr. Aghata Elins-Silva, Dr. Arturo Macias-Franco, Dr. Jose Pereira-Neto: “Thank you greatly for being by biggest role models and mentors in the research realm. You have shown me the true meaning of providing the research world and the general public with the true meaning behind why researchers are important. I will forever be grateful for your role as a researcher and friend.” -Macy

“To the friends and family back home. I thank the man upstairs every day for how close we all are. You have shown, guided, and allowed me to become an independent woman with her own agenda. I am forever grateful to have my village consisting of confident, wisdom-filled people.” -Mimers, Peach, Mamers, Job Boss

I dedicate my thesis to the following people who have tremendously helped me along the way and shaped me into the young lady I am now: Shane Rockwell (Father), Erica Rockwell (Mother), Ethan Rockwell (Brother), Frances Rockwell (Grandmother), Hortencia Chacon (Grandmother), Mary Branscomb (Friend and Coach), Aghata Silva (Friend and Mentor), Arturo Macias (Friend and Mentor). The following family members are no longer with us but helped guide me at a young age to pursue my love for agriculture all while upholding high moral standards: Geralidne Chislom (Great Grandmother), Rocky Rockwell (Grandfather), Floyd Chacon (Grandfather).

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LIST OF ABBREVIATIONS AND SYMBOLS

The author has made all efforts to observe the accepted abbreviations for *Journal of Animal Science* and *Applied Animal Science* as these are potential outlets for publication. The following list provides the abbreviations accepted by these journals as well as additional acronyms or abbreviations used throughout this document:

Abbreviation	**Definition**
ADF	acid detergent fiber, expressed inclusive of residual ash and assayed sequentially to neutral detergent fiber unless otherwise noted
ADG	average daily gain
ADL	acid detergent lignin
ANOVA	analys(es) of variance
AOAC	Association of Official Analytical Chemists
B	boron
BBREC	Black Belt Research and Extension Center, Marion Junction, AL
BUN	blood urea nitrogen
BW	body weight
BW^F	final body weight
BW^I	initial body weight
°C	degree(s) Celsius
c-	centi- (1×10^{-2}; prefix for physical units)
Ca	calcium

CEC	cation exchange capacity
CLOV	forage treatment in which steers were grazing tall fescue pastures interseeded with red clover
cmol_c	centimole of charge
CON	negative control forage treatment in which steers were grazing tall fescue without additional supplemental feed
CP	crude protein, calculated as nitrogen times 6.25
Cu	copper
d	day(s)
d-	deci- (1×10^{-1}; prefix for physical units)
df	degrees of freedom
DM	dry matter
doi	digital object identifier (used with citations)
F	F-distribution or ratio of variances (also identified as Snedecor's F statistic)
FA	forage allowance
Fe	iron
g	gram(s)
h	hour(s)
ha	hectare(s)
hd	head (count of animals)
K	potassium
k-	kilo- (1×10^{3}; prefix for physical units)

KY31	‘Kentucky 31’, a cultivar of tall fescue
L	liter(s)
M-	mega- (1×10^6; prefix for physical units)
m	meter(s)
m-	milli- (1×10^{-3}; prefix for physical units)
min	minute(s)
Mn	manganese
mo	month(s)
N	nitrogen
n	sample size
Na	sodium
NDF	neutral detergent fiber, assayed inclusive of α-amylase (unless otherwise stated), exclusive of sodium sulfite (unless otherwise stated), and expressed inclusive of residual ash
OM	organic matter
P	phosphorus
P	probability
SAS	SAS Institute, Inc. (formerly known as Statistical Analysis System)
SD	stocking density
SEM	standard error of the mean
SUP0.5	forage treatment in which steers were grazing tall fescue pastures and offered supplemental feed daily at 0.5% BW

SUP1.0	forage treatment in which steers were grazing tall fescue pastures and offered supplemental feed daily at 1.0% BW
t	t-distribution or Student distribution
TVREC	Tennessee Valley Research and Extension Center, Belle Mina, AL
vs.	versus
W	Shapiro-Wilk's W (a measure of normality)
wk	week(s)
wt	weight
yr	year(s)
Zn	zinc
α	probability of Type I error
μ-	micro- (1×10^{-6}; prefix for physical units)

CHAPTER I: INTRODUCTION

Background of the Study

Supplementation in the cattle industry consists of three main strategies: supply feeding, supplemental feeding, and enhancement feeding (Kellaway and Harrington, 2004). These strategies address five primary dietary deficiencies: protein, fiber, energy, minerals, and vitamins (Hammack et al., 2020). Byproduct feedstuffs are gaining popularity as an economical alternative to traditional commodity feedstuffs (Yang et al., 2021). Supplementation on pastures often reduces pasture dry matter (DM) intake (DMI) while increasing animal performance (Clark et al., 1987; Paterson et al., 1994; Machado et al., 2019). Tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) is a widely utilized forage grass in the southeastern United States, supporting over 8.5 million beef cattle (USDA, 2017). The presence of endophytes in tall fescue can alter its chemical composition and negatively impact animal performance (reduced body weights [BW] and average daily gains [ADG]; Bush and Burrus, 1988; Bauer, 2015). Proper supplementation strategies can positively impact soil health by increasing nutrient cycling within pasture systems, potentially enhancing soil fertility (Simpson et al., 2014). Byproduct supplementation could reduce labor, time, and processing costs compared to commodity feedstuffs, making it both sustainable and economical (Sun et al., 2024).

Statement of the Problem

The increasing costs of operational inputs, particularly inorganic fertilizers and supplemental feed, have presented significant challenges for cattle producers. Producers face uncertainties regarding the effects of supplementation on pasture utilization and animal performance, simultaneously. Byproduct supplementation has demonstrated positive impacts on animal productivity, including increased final BW, ADG, and gain per hectare (Clark et al., 1987). However, the optimal implementation in order to successfully increase economic revenue, pasture health, and soil fertility is lacking in the literature. Potential health risks associated with negative animal performance effects from forage and improper diet formulation necessitate careful consideration when optimizing nutritive value for ruminants (Owens and Basalan, 2016). These challenges facilitate the need for a comprehensive understanding of supplementation strategies that balance economic feasibility, animal performance, pasture health and soil fertility sustainability in stocker cattle production systems.

Research Objective

The objective of the study was to determine the effects of byproduct supplementation on stocker cattle performance, pasture health, soil health, and soil fertility. We hypothesized that byproduct supplementation feeding of stocker steers at increased levels would achieve substitution effects, becoming a source of feedthrough fertilization due to increased animal performance, pasture health, soil health and soil fertility.

Style and Form

This manuscript was prepared according to “Instructions to Authors (revised 2017)” from *Journal of Animal Science* (ASAS, 2017). All attempts were made to adhere to this style, except in cases where divergence was needed to adhere to the policies of the Auburn University or to increase clarity in the document.

CHAPTER II

REVIEW OF LITERATURE

Supplementation

Supplementation in the cattle industry aids producers through three main strategies: supply feeding, supplemental feeding, and enhancement feeding (Kellaway and Harrington, 2004; McLennan, 2004; Shastak and Pelletier, 2024). Supply feeding allows the producer to use feedstuffs to supply dietary nutrients when forage resources are limited (Kunkle et al., 2000). Supply feeding may also make use of supplemental feed to offset forage intake, allowing adequate forage regrowth (Kunkle et al., 2000; Mulliniks et al., 2015; Balehegn et al., 2022). Supplemental feeding is designed to address deficiencies in cattle diets that would otherwise limit animal performance (DelCurto et al., 2000; Kunkle et al., 2000; Hills et al., 2015; Empel et al., 2016). Enhancement feeding involves a base of supplemental feed that allows animals to increase the quality of intake and overall efficiency, meeting higher nutrient requirements during specific growth or production phases (Devendra and Lang, 2011; Makkar, 2016; Tona, 2018;). Substitution effects occur when feedstuffs are offered in addition to grazed forage, but the animal consumes the offered feed at the expense of grazing (Heinrichs, 1996; Rearte and Pieroni, 2001; Hazra, 2014).

Producers utilize the three main strategies of feed supplementation for five main dietary deficiencies: protein, fiber, energy, minerals, and vitamins (Hammack et al., 2020). These five dietary deficiencies of supplemental feeds can be and are more commonly corrected through supplementation commodity feedstuffs (Kunkle et al., 2000).

Commodity supplementation is a prevalent approach in beef cattle operations involving feeds produced from crops grown solely for animal feeding purposes (Hilimire, 2011; Gerber et al., 2015; Greenwood, 2021). Commodity supplementation includes oilseed meals (e.g., cottonseed meal, soybean meal), cereal grains (e.g., corn, grain sorghum), and whole seeds (e.g., barley, rolled oats; Hammack et al., 2020). Commodity feeds could be found bagged individually or have a mixture of the previously listed feeds, typically including a binder such as molasses (Kutish, 1950; Sarpong, 2020). This mixture is marketed to the producer to conveniently fulfill cattle dietary needs such as protein, fiber, carbohydrates, vitamins, minerals, and energy in a single, complete feed (Hall et al., 2001; Gashaw and Defar, 2017; Sauvant et al., 2023).However, commodity feeds are increasingly becoming less economically advantageous (Popp et al., 2016; Alqaisi et al., 2017). Thus, producers are evaluating alternate feed choices that may generate greater revenue for their operation (Madden, 1967; Wegner and Zwart, 2011; Torgerson, 2016).

Byproduct feedstuff supplementation has gained popularity as an economical alternative that meets or exceeds beef cattle dietary needs when compared with the use of commodity feedstuffs (Kellaway and Harrington, 2004; Yang et al., 2021). Byproducts are proven to be a viable source of supplementation to cattle (Clark et al., 1987; Shabtay et al., 2008; Alao et al., 2017). However, the protein, energy, and fibrous byproducts feedstuffs can vary widely in terms of processing techniques and modes of production (Zhang et al., 2021). Many researchers recommend nutritive value testing of byproduct feedstuffs prior to purchasing due to significant variation in feed value (Silva et al., 2019; Yang et al., 2021). Byproduct supplementation options vary depending on geography (Röös et al., 2016). The northeastern United States is focused more on corn byproducts such as distillers’ grains (Schenpf, 2011; Liu and Rosentrater, 2016). The western United States is focused on other products besides corn such as spent brewers grains (Westendorf and Wohlt, 2022). Florida has a rising usage of citrus pulp (Bakr, 2020; Arthington et al., 2002). The more common options in the southeastern United States include distiller grains, corn gluten feed, soybean hulls, and whole cottonseed (Linn et al., 1993; Poore, 2022).

Corn gluten feed and soybean hulls are currently the two most common byproducts used in the southeastern United States (Kunkle et al., 1999; St. Andrew, 2024). Corn gluten feed is derived from the wet milling of corn kernels (Deepak and Jayadeep, 2022). Initial processing includes the production of corn-based consumer products such as high fructose corn syrup, ethanol, or vegetable oils (Rausch et al., 2019). Wet milling removes components of the feed such as gluten or starches. The resulting product is typically viewed as economically sustainable (Schroeder, 1997), as other energy-demanding manufacturing methods are bypassed. Soyhulls is the more commonly used name for soybean hulls (Webb, 2003). After the soybean is removed from the hull, the hull is further processed by drying and grinding (Lucas, 2004). Though the resulting soybean hulls can be fed loose, it is becoming increasingly common for soybean hulls to be pelleted (Hancock and Behnke, 2000; Acedo-rico et al., 2010; Van der Pol et al., 2020).

Using byproduct feedstuffs, such as corn gluten feed and soybean hulls, can be a source of both economical and sustainable supplementation to improve performance in a grazing system (Salami et al., 2019; NRDC, 2021). Byproduct supplementation results in reduced labor, time, and processing compared to commodity feedstuffs (Sun et al., 2024), making it both sustainable and economical. This approach also mitigates the carbon footprint of feed production, uses fewer natural sources, and efficiently meets animals' nutritional needs (Ponnampalam and Holman, 2023).

Animal Response to Byproduct Supplementation

Byproduct supplementation has shown positive effects on animal performance such as increased final body weight, average daily gain (ADG), and gain per hectare (Clark et al., 1987). Distillers grains, both wet and dried forms, have generally increased final body weights by 10% and 5%, respectively, when compared with corn-based control diets (Liu, 2011). Corn gluten feed has demonstrated similar benefits, with wet corn gluten feed improving feed efficiency by 5.5% when fed at 60% of diet dry matter (Plascencia and Zinn, 1996). Soybean hull supplementation has shown mixed results, with moderate levels of 0.5% BW increasing ADG in grazing cattle (Hales et al., 2014; Smith et al., 2017). Supplementation at levels greater than 0.5% BW, however, may potentially decrease forage intake and digestibility (Smith et al., 2017). Whole cottonseed supplementation had benefited dairy cows when fed at 15% of dietary dry matter (DM), improving milk production and fat percentage (NRC, 2021). Supplementing distillers dried grains with solubles or corn gluten feed to grazing cattle increased production to 120 kg/ha or 90 kg/ha, respectively (Gunter, 2014). The high fat content of some byproducts may negatively impact rumen function if fed excessively (Salami et al., 2019; Correddu et al., 2020). Therefore, while byproduct supplementation can improve cattle growth performance and production efficiency, careful diet formulation is crucial to optimize nutritive value while avoiding potential health risks to the ruminant animal (Owens and Basalan, 2016).

Pasture and Soil Response to Supplementation

Cattle supplementation on pastures has been extensively studied, with research showing complex effects on forage utilization and pasture health (Mulliniks et al., 2015; Rao et al., 2015). Supplementation often reduces pasture DM intake (DMI) through substitution effects, with studies indicating a decrease of 0.6 kg of pasture intake for every 1 kg of supplement consumed (Paterson et al., 1994; Machado et al., 2019). Protein supplementation can improve intake and utilization of low-quality forages, especially when pasture crude protein falls below 7 to 8% (Leng, 1990; McCollum and Horn, 1990; Bohnert et al., 2002). Moderate supplementation may enhance pasture productivity by allowing for increased stocking rates without sacrificing animal performance. Stocking rates increased by 33% with corn-based supplementation (Kunkle et al., 2000; Gruber, 2024; Murray, 2024). However, excessive supplementation can negatively impact pasture growth by encouraging overgrazing and reducing plant vigor (Bohnert and Stephenson, 2016; Flack, 2016). Supplementation strategies can also influence pasture species composition over time by changing grazing patterns and plant selectivity (Augustine and McNaughton, 1998; Grace et al., 2018). Supplementation increases nutrient inputs into the animal system and cycling within pasture systems, potentially increasing soil fertility (Simpson et al., 2014). Supplementation also risks the potential of nutrient overloading in high traffic areas such as water troughs, feeding bunks, and shaded areas (Bickett-Weddle and Ramirez, 2005). Overall, while supplementation can enhance the utilization of available forage, considerable management is crucial to balance animal performance with long-term pasture sustainability and soil health goals (Rao et al., 2015; Guyader et al., 2016; Teague, 2018).

Forage

Tall Fescue

Origin

Tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) is a European forage utilized as a turf grass or as an agricultural forage for livestock (Craven et al., 2009). Tall fescue, a thriving perennial, flourishes in various environmental conditions such as drought, poor soil health, and different climates. In the 1800s, tall fescue was introduced to the United States as a forage and was commonly used among its settlers until the early 1930s (Hoveland, 2009). The forage was first pioneered in the Pacific Northwest of the United States, specifically in Oregon (Craven et al., 2009). Craven et al. (2009) stated that grazing management systems utilizing tall fescue was not as commonly used as other forages, such as orchard grass.

Dr. Fergus from the University of Kentucky discovered what would become ‘Kentucky 31’ (KY31) tall fescue growing wild on the William Suiter farm in Menifee, Kentucky, and decided to investigate the forage’s grazing qualities, such as vigor and disease/insect resistance, yield, and nutritive value (Craven et al., 2009; Hoveland, 2009). The cultivar was released to the public in 1943 and promoted for its vigor, disease resistance, and weather resilience (Hoveland, 2009). Kentucky 31 quickly gained popularity as the forage proved adaptable, persistent, and high yielding, particularly in the transition zone (the eastern side of the U.S., the divide between northeastern and southeastern states). Tall fescue has become a critical forage as almost 90% of beef cattle producers use grazing as a fundamental practice in their nutritional management systems (Dubeux Jr., 2017).

Characteristics and Defoliation Management

Tall fescue is a widely utilized forage grass in the southeastern and eastern central United States, supporting over 8.5 million beef cattle on approximately 10.12 million hectares (USDA, 2017). Tall fescue typically contains 11 – 15% crude protein, depending on seasonal factors and fertilization practices (Belesky et al., 1984). The presence of endophytes can slightly alter its chemical composition, with increased endophyte varieties showing increased crude protein levels compared to low endophyte varieties (Bush and Burrus, 1988). Tall fescue’s extensive root system allows for efficient nutrient absorption from the soil, significantly impacting the plant's nutritive value (Huang and Fry, 1998).

Defoliation, primarily through grazing, significantly impacts tall fescue growth and quality (Brink et al., 2010; Moot et al., 2021). Optimal growth for grazing scenarios is achieved with defoliation occurring every 14-d, ensuring that animals' nutritional needs are met while maintaining forage health (Kerrisk and Thomson, 1990). Uniform defoliation patterns are crucial to prevent overgrazing and maintain future grazing patterns (Flack, 2016). Grazing management strategies, such as rotational grazing and supplemental feeding, benefit the forage by allowing for resting periods and optimal growth (Paine et al., 1999; Undersander et al., 2002; Badger et al., 2017). Frequent spring defoliation is particularly beneficial, as the growing season typically extends from early April to the end of October, with decreased forage allowance from June to middle of August (Volenec and Nelson, 1983). By following these research-based fertilization and defoliation practices, producers can effectively improve tall fescue vigor, yield, and nutritive value while mitigating potential negative impacts on plant and animal health (Held and Potter, 2012).

Animal Response

Animal responses to tall fescue consumption have been extensively studied, revealing significant impacts on growth performance, productivity, and health (Porter et al., 1992; Sleper and West, 1996; Niedrecker et al., 2018). Tall fescue, particularly KY31, is known for its excellent environmental stress tolerance and higher dry matter yield under both optimal and drought conditions (Barnes, 2018). However, this grass is also considered toxic due to the endophytic fungus, *Epichloe coenophiala*, which produces ergot alkaloids, particularly ergovaline (Dinkins et al., 2023). The presence of these alkaloids leads to a notable disconnect between laboratory estimates of nutritive value and actual animal responses. Cattle grazing endophyte-infected tall fescue typically experience reduced BW gain and ADG compared to those on endophyte-free varieties (Bauer, 2015). Specifically, ADG reductions can range from 30-100% (Stuedemann and Hoveland, 1988). The severity of these performance reductions often increases with higher temperatures as both heat stress and alkaloid concentrations in the forage rise concurrently (Hemken et al., 1981). Consequently, beef cattle losses in the United States have been estimated at over $600 million annually due to reduced calf births and lower weaning weights (Hoveland, 1993). Research by Farney et al. (2018) investigated the impact of performance-enhancing strategies on steer performance in tall fescue pastures with varying levels of toxicity. This study found that an individual implementation or combination of implants, ionophores, and supplementation improved animal gains, particularly in pastures with higher ergovaline concentrations (Diaz et al., 2018; Farneyet al.,2018; Gomez, 2019). The proportion of endophyte-infected plants in a pasture can vary widely, affecting the severity of performance reduction (Agee and Hill, 1994). This variability contributes to the wide range of animal responses observed in production settings, which may not correlate with the measured nutritive value of tall fescue (Waghorn and Clark, 2004; Sollenberger et al., 2011). Effective management strategies are essential to optimize animal production on tall fescue pastures (Williamson et al., 2016; Barnes, 2018). Cattle grazing endophyte-infected tall fescue typically experience reductions in ADG of more than 50%, with weight gains dropping during warmer months due to increased heat stress and reduced feed intake (Hoveland et al., 1983; Ferguson et al., 2021). Careful management is crucial for optimizing animal responses and mitigating the negative effects of endophyte-infected tall fescue on cattle health and productivity (Ingram, 2019; Gomez, 2023).

Red Clover

Red clover (*Trifolium pratense* L.) is native to Europe, western Asia, and northwest Africa (Jones et al., 2020). It was introduced to North America by European colonists in the 17th century and has become an important forage legume (Stinner et al., 1992; Russelle, 2001). Red clover cell walls typically contains 20-30% cellulose, 10-20% hemicellulose, 5-10% lignin, and 10-20% pectin (Barwick, 1989; Heredia, 1995; Laine, 2005; Chen, 2014; Lin et al., 2024). This indicates that clover generally has lower lignin content than grasses, contributing to its higher digestibility (Buxton and Russell, 1988; Bakken et al., 2011). Red clover, being a legume, allows for common fertilization practices to only increase cell wall composition (Mckenna et al., 2018). Nitrogen fertilization, when used with a legume, is able to increase fixation of atmospheric N (LaRue and Patterson., 1981; Crews and Peoples, 2004). Additional excessive N fertilization to legumes is not recommended as the fertilization may increase the mineralization of N (Kessel et al., 2000). Potassium fertilization from legume usage increased winter survival and disease resistance as plant structure increased (Kresge, 1974). Optimal fertilization of red clover should be based on professional soil testing (Taylor and Smith, 1980; Gaudin et al., 2014). Phosphorus and potassium are carefully considered as the two main fertilization strategies, as N in excess can be a limiting factor (Delgado et al., 2024) Animal responses to red clover include increased palatability, digestibility, and protein intake (Weinert-Nelson et al., 2023).

Incorporating legumes like alfalfa or birdsfoot trefoil into tall fescue pastures improved forage yield and livestock performance (Cox, 2013; Bingham, 2014; Briscoe, 2018). Steers grazing tall fescue-legume mixtures showed higher average daily gains compared to those on tall fescue with or without nitrogen fertilization (Interrante et al., 2012, Bingham, 2014). Negative effects regarding animal responses are increased chances of bloat and phytoestrogens affecting the reproduction of the animal (Bingham, 2014). Overall, clover inclusion into the diet of cattle has a larger positive impact than a negative impact (Johansen et al., 2017; Dineen et al., 2018;).

Soil Health

Nitrogen Cycle and its Effects

The nitrogen cycle is crucial to plant, animal, and soil life environments. It consists of complex biological processes that reduce, add, and transfer nitrogen across various organisms within the soil ecosystem. The nitrogen cycle encompasses five key processes: denitrification, nitrification, fixation, leaching, and mineralization (Fenice, 2021). Denitrification is the process by which nitrate is reduced to gaseous forms of nitrogen via bacteria, typically resulting in nitrite and nitrogen gas (N_2) gases. Nitrification occurs when nitrifying bacteria and archaea oxidize ammonium into nitrate (Hayatsu et al., 2008). Fixation involves converting atmospheric N_2 into biologically available nitrogen through biological nitrogen fixation (Harrison, 2010). Leaching happens when available nitrate is leached from the soils due to heavy rainfall or human activities such as irrigation (Robertson and Goffman, 2024). Mineralization is a time-consuming process where microorganisms in the soil convert organic forms of N into inorganic forms through decomposition (Hayatsu et al., 2008).

Nitrogen is vital for fertilization as it allows plants to achieve leafy growth (Leghari et al., 2016). In grazed pastures, N availability directly influences the quantity and quality of forage produced. Research indicates that applying N at rates of 34-56 kg/ha can significantly enhance grass growth, particularly in grass-dominant pastures (USDA, 2017). Fertilization has been extensively studied for its effects on tall fescue vigor, yield, and nutritive value (Cowan, 1956; Sleper et al., 1996). Nitrogen application, particularly when applied in late fall at rates of 45-56 kg N/ha, increased tiller count and plant size (Molla and Tana, 2019; Mulugeta, 2019). Nitrogen further promoted the development of short rhizomes that produce new tillers and help plants spread on bare areas (Mulugeta, 2019). Fall fertilizer application also leads to faster spring green-up and improved root development in the following growing season, giving fertilized plants a competitive advantage over weeds and enhancing drought tolerance (Turner etal.,1992; Duble, 1996; O’Connor, 2009). Yield responses to N are substantial, with unfertilized tall fescue typically yielding about 1,270 kg of hay per acre (Laycock, 1982; Clark, 2006; Manevski et al., 2022). Crude protein levels in the forage increase at higher N rates, assuming timely harvest (Rotz and Muck, 1994; Nelson et al., 2012). Optimizing grazing while minimizing risks of extensive yield maturity, research suggests applying 101-135 kg N/ha for hay production, or about 15 g N/ kg of expected yield (Collins et al., 2020; Van Die, 2020).

The timing of N applications is critical; the first application should ideally occur in early spring to stimulate growth after winter dormancy (Smith and Kefford, 1964). A second application in mid spring or late summer can promote forage allowance and fall growth (Weisz et al., 2001).

Phosphorus Cycle and its Effects

The phosphorus cycle affects soils, water bodies, and living organisms through several processes: mineralization, immobilization, weathering, precipitation, adsorption, desorption, and dissolution (Tian et al., 2021). Mineralization involves converting organic phosphorus to inorganic phosphorus via soil microbes (Prasad and Chakraborty, 2019). Weathering occurs as soil minerals containing phosphorus are slowly released. Precipitation happens when insoluble phosphorus compounds with other minerals such as iron or calcium (Sims and Pierzynski, 2005). Adsorption refers to phosphorus binding with soil particles (Cornell University, 2005), while desorption involves releasing bound phosphorus back into the soil solution (Tian et al., 2021). Dissolution releases phosphorus from compound minerals into the soil solution (McConnell et al., 2020).

Phosphorus is essential for root development, energy transfer, and photosynthesis. It plays a critical role in establishing new pastures and maintaining existing ones. Deficiencies in phosphorus can lead to stunted growth and poor forage quality. Optimal soil test levels for phosphorus typically range from 45-56 kg/ha (USDA, 2017). Regular soil testing every four years is recommended to monitor phosphorus levels and ensure they remain within optimal ranges for pasture productivity. In intensively grazed pastures, over 80% of the phosphorus removed through grazing is recycled back into the soil via fecal matter and urine (Vendramini et al., 2007). Timing applications before planting or during early growth phases can maximize uptake by plants.

Potassium Cycle and its Effects

Potassium is essential for plant health as it regulates various physiological processes including water uptake and enzyme activation. The potassium cycle consists of five processes: weathering, absorption, fixation, leaching, and recycling from plant residue (Rawat et al., 2016). Weathering releases K from mineral compounds in the soil (Dotaniya et al., 2016), while absorption occurs as roots take up potassium (Drew et al., 1969). Fixation happens when K compounds bind within mineral structures; bound K can be released under certain conditions (Pandey, 2015). Leaching occurs when excess water causes K loss from the soil environment (Kayser and Isselstein, 2005). Recycling refers to the long-term process where plant residues after harvest are incorporated back into the soils to make K available again for plant uptake (Dotaniya et al., 2016). Soil properties such as density and organic matter impact K availability; dense soils lacking organic matter decrease available K for plants (Zorb et al., 2014). Soil moisture and temperature also influence K fixation; excessive water can leach away nutrients, while drier climates may render K unavailable (Bhattacharya et al., 2021).

Potassium is a fertilizer nutrient that can be used to observe the health of the plant from the plant’s growth and development (Etesami et al., 2017). Tall fescue, specifically KY31, is known for its persistence when adequate amounts of K are applied. Potassium commonly works in conjunction with nitrogen fertilization (Vough et al., 1994). Potassium fertilization rates are approximately 168 kg/ha, and the tall fescue stands allow for 25% more yield (Vough et al., 1994). Potassium used in small amounts dictates how healthy a forage is as it affects water management, root growth, plant vigor, disease resistance, and growth. Potassium affects water management as it allows for the efficiency of water to increase, therefore decreasing water loss, wilting, and drought susceptibility (Grzebisz et al., 2013). Potassium also increases the root development of plants, therefore increasing nutrient uptake (Shewmaker et al., 2008). Plant vigor is accomplished with K fertilization as the plant has established root stricture, ensuring above ground plant material is structurally sound and rapidly grows (Baidoo, 2022). Disease resistance is accomplished through K fertilization as the cell wall thickness is increased and infectious diseases are deterred (Ortel et al., 2024). Plant growth is accomplished from potassium fertilization as increased photosynthesis, enzymatic processes, and nutrient transportation come from adequate water, energy, nutrients and carbohydrates (Rawat et al., 2022).

Managing Soil Health

Microminerals heavily impact many aspects of soil health, such as pH, structure, organic matter, and nutrient availability (Shukla et al., 2018). The soil structure, manganese, and iron can heavily affect the pH in a soil system (Suda and Makino, 2016). These minerals impact how fluid the soil structure becomes as the minerals enable solubility to occur and how plant available all nutrients are to the plant (Bronick and Lal, 2005). Zinc is a micromineral that makes P readily available to the plant (Singh et al., 2010). In return, high amounts of P are an inhibitor of minerals such as iron and Zn (Mousavi, 2011).

Increasing soil organic matter (SOM) enhances soil structure while improving water retention capacity along with nutrient availability (Bashir et al., 2021). Higher SOM levels contribute to improved resilience against erosion and degradation (Bronick and Lal, 2005). Practices such as incorporating cover crops or using manure can improve SOM over time (Ding et al., 2006). Research has shown that integrating cover crops into pasture systems can increase SOM by enhancing root biomass along with promoting microbial diversity (Frasier et al., 2016).

Maintaining an optimal pH is crucial for nutrient availability in soils (Neina, 2019). Most forage crops thrive at a pH of around 5.5 to 7.5 (Fernandez and Hoeft, 2009). Thus, lime applications may be necessary to correct acidic soils (Goulding, 2016.). Soil pH affects nutrient solubility, particularly that of P and K, making it essential to monitor pH levels regularly (Penn and Camberato, 2019). Regular testing helps track changes over time; if tests indicate acidic conditions below pH 6.0, lime should be applied according to recommendations based on specific crop needs (Laekemariam and Kibret, 2021).

Cation exchange capacity (CEC) serves as an important indicator of overall fertility since it reflects how well soils hold onto essential nutrients like calcium (Ca), magnesium (Mg), K, and sodium, among others (Hodges, 2010; Osman, 2013). Soils exhibiting higher CEC values retain more nutrients available for plant uptake, directly influencing pasture productivity (Agegnehu et al., 2016). Understanding CEC informs fertilization strategies since low CEC soils may require more frequent applications or different management practices aimed at enhancing nutrient retention (Zou et al., 2019; Kalacsits et al., 2020).

In conclusion, managing soil health through targeted fertilization strategies focusing on N, P, K, microminerals, increasing organic matter, maintaining optimal pH levels, and understanding cation exchange capacity are critical elements sustaining productive grazed pastures. Regular testing combined with adaptive management practices will help optimize nutrient availability, improving overall pasture health (Coulding et al., 2008).

Economics

Cattle operations are a vital part of the agricultural economy. Cattle operations significantly contribute to rural livelihoods and global food (Upton, 2004). Understanding the economic factors such as cost implications of supplementation strategies, and fertilizer costs for producers seeking to enhance profitability and sustainability (Rotz et al., 2014; Gunter et al., 2020).

Several correlated factors, such as input costs and reduced revenue, influence the economic viability of cattle operations (Bowman and Ziberman, 2013). Forage and feed costs are typically the largest expense (60-70%) of total operational expenditures (Gunter et al., 2020). These feedstuff costs fluctuate due to grain market volatility, climate conditions, and shifts in geographical demand (Wilson and Ougrin, 2021). For example, drought can decrease hay and pasture availability, forcing producers to use increased supplemental feeds (Horn et al., 2003).

Stocker cattle operations face specific economic challenges, including price risk due to vulnerability to changes in feeder cattle prices between purchase and sale (Hill, 2015). Production efficiency is also crucial for operations. Managing fixed costs associated with land equipment and infrastructure are essential (Ochieng et al., 2020). Fixed costs remain constant regardless of production levels and could significantly impact net income if not meticulously managed (Marn and Rosiello, 1992). Producers must evaluate their operational scale and efficiency to minimize the negative effects of fixed costs on profitability (Cooper and Kaplan, 1988; Hansen, 2001). Reduced animal performance indicators include decreased ADG and feed efficiency, which influence overall profitability (Ramsbottom et al., 2015). Health management of stocker cattle is another inhibitor of production efficiency (Sweiger and Nichols, 2010). Health issues can increase veterinary costs or lead to potential mortality losses (Bennet, 2003). High morbidity rates among received cattle often arise from stress related to transportation and environmental changes (Bhattacharya et al., 2021). Effective health management strategies are essential to mitigate health-associated risks and ensure the animals reach target weights efficiently (Asem-Hiablie et al., 2016).

Forage allowance also poses a significant challenge for stocker operations that are heavily reliant on pasture-based grazing management systems (Rayburn, 2007; McNeil, 2020). Environmental factors, such as drought and excessive rainfall, can limit forage production (Niederecker et al., 2018). Insufficient forage may lead to producers purchasing chemical fertilizer or supplemental feeds, further constraining profit margins (Gunter et al., 2021). Chemical fertilizer costs are considered volatile due to global demand and energy price fluctuations (Skorupka and Nosalewicz, 2021). Chemical fertilizers are energy intensive, and prices often mirror oil prices due to manufacturing (Schnepf and Yacobucci, 2020). Chemical fertilizer prices create an economic challenge to producers as inflation has recently demonstrated a 66% increase year-over year (Good, 2022). Current costs for fertilization are $1.75/kg for N, $1.14/kg for P, and $1.16/kg for K (Quinn, 2024). These fertilizer prices exceed the $1.10/kg threshold for economical pasture fertilization, making fertilizer application less economically viable compared to hay production or feed purchase (Good, 2022; Johnson, 2022).

Supplemental feeding remains popular among cattle producers dealing with poor forage quality and mass as they are able to reduce grazing stress (Horn and McCollum, 1987; Smith, 2017). Producers weigh out the cost of using traditional commodities versus byproduct feeds for supplementation. Byproducts such as distillers grains, corn gluten feed, soyhulls, and beet pulp often provide an economical source of nutrients compared to commodity feedstuffs (NRDC, 2021). However, increased transportation and storage costs associated with certain byproducts have limited the producers to byproducts that geographically surround them in order for byproducts to remain a cost-effective alternative compared to commodity feedstuffs (NRC, 2021).

Beef Cattle Budgeting Strategies

Effective budgeting is essential for managing the financial aspects of cattle operations. Two types of budgets are commonly used: enterprise budgets and partial budgets. Enterprise budgets provide a comprehensive overview of all costs and returns associated with a specific enterprise within the operation such as cow-calf production or stocker operations, allowing producers to assess overall profitability (Boehlje and Eidman, 1984). Partial budgets focus specifically on evaluating the financial impact of changes within the operation without requiring a full enterprise budget analysis (Sim et al., 2011). Partial budgeting allows producers to quickly assess potential changes in an operation such as adopting new feeding strategies or investing in improved health management practices (Bewley et al., 2010). Partial budgeting can accomplish this by concentrating only on costs and returns that will potentially be changed (Boehlje and Eidman, 1984). Partial budgeting is particularly useful when comparing alternative practices or investments since it provides a streamlined method for analyzing potential outcomes without overwhelming complexity (Hanninen, 2013). By focusing on specific areas where changes may occur, producers can make informed decisions that enhance their operational efficiency and net income.

Understanding the economics of cattle operations involves analyzing various factors ranging from feed costs and market prices to health management challenges and budgeting practices (Amir and Knipscheer, 1989). Stocker operations face economic challenges that require meticulous management strategies to navigate efficiency (Allioui and Mourdi, 2024). Lastly, decisions regarding feed supplementation could have significant cost implications that influence overall profitability.

CHAPTER III

INCREASED SUPPLEMENTAL FEED OR INTERSEEDED LEGUMES AS A MEANS OF INCREASED NUTRIENT CYCLING IN TALL FESCUE PASTURE SYSTEMS

Synopsis

In Alabama, forage-based beef cattle operations are prevalent. However, with inflated input costs related to inorganic fertilizer, economic cattle production is challenging. One management decision under consideration in these circumstances is the choice of investment in inorganic fertilizer for pastures for supplemental feed for cattle. The objective of the study was to determine the effects of byproduct supplementation on stocker cattle performance, pasture health, soil health, and soil fertility. We hypothesized that byproduct supplementation of stocker steers at increased levels would achieve substitution effects, becoming a source of feedthrough fertilization for pasture nutrient cycling. Stocker steers (n = 60) were used in a put-and-take grazing and supplementation experiment, arranged in a generalized complete block design across two locations. Treatments included a 0.5 or 1.0% BW supplemental feed (SUP0.5 or SUP1.0, respectively), interseeded red clover (CLOV), or a negative control (tall fescue pasture only; CON). Forage allowance was targeted at 1.5 kg DM/kg BW, and steers grazed pastures for approximately 84 d. There was an effect of treatment ($P \leq 0.01$) for ADG, additional gain from supplementation, and gain per hectare. There was no effect of treatment ($P \geq 0.10$), however, on forage mass or nutritive value, nor was there an effect of treatment for ($P \geq 0.22$) for soil pH, OM, N, P, K, or microminerals. Results are

interpreted to mean that the one-year scale of stocker supplementation may not offset chemical fertilizer inputs, though partial budgets indicated increased revenue.

Introduction

In total, about 15.8 million hectares of land in the United States are dedicated to tall fescue production (USDA, 2017). The southeastern United States, which includes Texas, Arkansas, Louisiana, Mississippi, Alabama, Georgia, Tennessee, North Carolina, South Carolina, and Florida, encompasses approximately 130 million hectares of land (USDA, 2017). Among these states, approximately 5.67 million ha are utilized for grazing tall fescue, making it the predominant forage choice for about 70% of producers in the region (USDA, 2017; Dubeux Jr, 2017). Despite its resilience and adaptability to different environmental conditions, tall fescue requires intensive fertilizer inputs. This presents economic challenges for producers, especially in light of rising fertilizer costs. Recently, the input cost of inorganic fertilizer applications has seen a 66% year-over-year increase (Good, 2022). Current fertilizer costs are $1.75/kg for N, $1.14/kg for P, and $1.16/kg for K (Quinn, 2024). These prices exceed the $1.10/kg economic threshold, making fertilizer application less economically viable compared to hay production or purchase (Johnson, 2022).

Grazed feed constituting nearly a quarter (23%) of operational costs, producers are questioning the value of maintaining pasture and soil fertility for forage mass preservation (Johnson, 2022). This is due to the fact that input costs are increasing with stagnant or decreasing revenue (Barkema and Drabenstott, 1990; Veysset et al., 2019). Supplemental feeding remains popular among cattle producers dealing when faced with poor forage quality or mass (Horn and McCollum, 1987; Smith, 2017). Supplemental feeding at increased levels can potentially inhibit overall forage intake by substituting for daily requirements (Huston et al., 2002). Nevertheless, the general strategy aims to increase both forage intake and animal performance (Smith, 2017). This approach aligns with consumer concerns, as 95% of American consumers express interest in cattle access to adequate nutrition, including supplementation strategies, forage quality, and pasture size (USDA, 2017).

Recent studies have demonstrated the potential of feedthrough fertilization through supplementation strategies. Decreased forage intake due to supplementation could increase stocking density up to 21% (Smith et al., 2020). Hines (2021) found supplemented steers could excrete up to 0.5% N, 0.2% P, and 0.2% K through feces, potentially resulting in annual excretions of 14.6 kg N, 6.6 kg P, and 6.6 kg K per animal. Additionally, cattle fecal matter can provide adequate phosphorus levels to meet forage growth and development needs (Dillard et al., 2015). These research findings suggest that grazing cattle with increased supplementation levels could serve as a viable alternative or complement to traditional inorganic fertilizer input. However, the potential for intentionally utilizing supplemental feeding to support pasture productivity and soil health remains largely unexplored. Furthermore, there has been no comprehensive examination of the economic threshold for using supplemental feed to increase pasture fertility and soil health. Therefore, the objective of this study was to determine the effects of byproduct supplementation on stocker cattle performance, pasture health, soil health, and soil fertility.

Materials and Methods

All procedures for this experiment were approved by the Animal Care and Use Committee (IACUC) of Auburn University under Animal Use Protocol #2023-5325.

Experimental Design

This experiment was conducted as a generalized complete block design (randomized complete block design with replication within blocks; Cochran and Cox, 1957). The blocking factor was location and had two levels. The single treatment factor, supplementation, included four levels.

Pastures and Forages

Eight replicate pastures (1.0 ha) were used at the Black Belt Research and Extension Center (BBREC; 32.47° N, 87.23° W), and twelve replicate pastures (1.0 ha) were used at the Tennessee Valley Research and Extension Center (TVREC; 34.69° N, 86.88° W) in this 1-yr grazing and supplementation experiment. Soil types represented in the pastures at BBREC were Houston clay (Very-fine, smectitic, thermic Oxyaquic Hapluderts; 62.2% of land area), Leeper silty clay loam (Fine, smectitic, nonacid, thermic Vertic Epiaquepts; 20.4% land area) and Sumter silty clay (Fine-silty, carbonatic, thermic Rendollic Eutrudepts; 17.4% of land area). Soil types represented in the pastures at TVREC were Etowah silt loam (Fine-loamy, siliceous, semiactive, thermic Typic Paleudults; 84.1% of land area) and Ennis silt loam (Fine-loamy, siliceous, semiactive, thermic Fluventic Dystrudepts; 15.3% of land area). Pastures were fertilized with 22.68 kg N (granular) per ha prior to initiation of the experiment at BBREC (January 2024). Pastures were fertilized with 22.68 kg N (granular) at TVREC on 13 March 2024. No phosphorus or potassium fertilizer was applied at TVREC because soil tests indicated adequate P and K. Pastures in which supplemental feed was offered or clover was sown, no additional fertilizer occurred.

Two pastures at BBREC and three pastures at TVREC were sown with ‘AU Red Ace’ red clover (*Trifolium pratense* L. var. *sativum*). Clover was sown at 4.53 kg/ha on on 11 November 2024 at TVREC. This seeding rate was chosen to achieve a legume inclusion rate of 30% at BBREC and TVREC; actual inclusion throughout the season averaged 25%.

Animals

Backgrounded stocker steers were sourced from a private contractor and received on 2 February 2024 at BBREC (n = 42) and 9 February 2024 at TVREC (n = 63). Weaning occurred a minimum of 30 d prior to receiving. For pre-conditioning, steers received inoculation (and booster, as required) for blackleg (*Clostridium* spp.), bovine respiratory syndrome virus, *Hemophilus somnous*, infectious bovine rhinotracheitis, parainfluenza 3, and *Pasteurella*. Steers were also castrated and dehorned (as necessary) prior to receiving.

Upon receiving at the respective REC, steers were quarantined for 30-d. On arrival, steers were tested for common bovine infectious diseases (i.e., bovine viral diarrhea virus, Johne’s disease, anaplasmosis). During quarantine, steers were housed *en masse*, offered *ad libitum* access to grass hay and supplemental feed (50/50 blend of corn gluten feed and soybean hulls), and monitored for illness. Four steers were removed from BBREC and three from TVREC after testing positive for anaplasmosis.

Supplemental Feed

The supplemental feed was a pelleted blend of corn gluten feed feed/soybean hulls (1:1 ratio) sourced from each REC location co-op. A 230-g sample of supplemental feed was collected every 14 days for assessment of nutritive value (Table III-1).

Allocation and Management of Treatments

At each location, steers were stratified by initial body weight into groups, and groups were randomly assigned to each of the replicate pastures. Pastures were then randomly allocated to one of four supplementation treatments: 0.5% BW daily supplementation (SUP0.5), 1.0% BW daily supplementation (SUP1.0), interseeded red clover (CLOV), or negative control (tall fescue pasture only; CON). Water and trace mineralized salt (NaCl) were provided for *ad libitum* consumption.

Forage treatments were stocked at forage green up (3 March 2024 and 11 March 2024 for BBREC and TVREC, respectively). Pastures were managed in a variable stocking method (put-and-take) described by Mott and Lucas (1852). Forage treatments were continuously stocked with three tester steers (n = 60; n = 24 and 36 at BBREC and TVREC, respectively) beginning at forage green-up (3 March 2024 and 11 March 2024 for BBREC and TVREC, respectively). To manage excess forage growth above the target allowance (1.5 kg DM/kg BW), additional put-and-take steers were used as grazers to keep forage in a vegetative state (Mott and Lucas, 1952; Sollenberger and Burns, 2001).

Steers assigned to SUP0.5 or SUP1.0 were group-fed supplemental feed each morning. The amount of supplemental feed offered to each pasture was adjusted following each 28-d weigh period to represent a designated proportion of BW.

Grazing was terminated at each location when the forage allowance would no longer support the three continuously stocked tester steers. This occurred on the 22 May 2024 and 5 June 2024 at BBREC and TVREC, respectively, resulting in total grazing periods of 79 and 87 d, respectively.

Field Sampling

At the initiation of stocking and at 14-d intervals thereafter, forage mass was assessed by destructive harvest with battery-operated clippers (Makita, La Miranda, CA, USA) at six random locations within each pasture using a 0.25 m^2 quadrat. Six subsamples were collected in random locations from each paddock. Two of the subsamples were used for botanical separation to determine pasture species composition, and the remaining four were used to determine forage biomass and nutritive value.

At the initiation of stocking and at 28-d intervals thereafter, soil cores were taken to a depth of 15-cm at 10 random locations in each pasture to determine soil nutrient concentrations, including CEC, pH, and soil organic matter (SOM). Auburn University Department of Animal Sciences conducted ingrowth traps and root mass was determined according to the procedures of Cooley et al. (2019).

Forage and feed samples were dried at 55℃ in a gravity convection oven for at least 72-h. Once dry, samples were ground to pass through a 2-mm screen using a Eberbach E3500 Series Mill (Eberbach Corporation, Van Buren Charter Township, MI, USA), then a subsample ground to pass through a 1-mm screen. Ground samples were stored at ambient conditions until further analysis.

Animal Sampling

At the initiation of stocking, and at 28-d intervals thereafter, steers were weighed for determination of ADG and to inform decisions on stocking density and forage allowance. At each weigh date, a fecal sample was collected *per rectum* for the determination of nutrient excretion. At the initial weigh date, the weigh date on d 56, and the weigh date at the termination of the experiment, blood was collected by jugular venipuncture for assessment of nitrogen metabolism, mineral status, and plasma concentrations of lysergic acid (a metabolite of ergovaline found in tall fescue).

Fecal and blood samples were transported on ice from the respective REC to the laboratory in Auburn, AL. Fecal samples were stored at -20°C until further analysis. Serum was separated by centrifugation at 15,000 × g for 10 min and stored at -20°C until further analysis.

Analytical Procedures

Blood urea nitrogen was determined using the ThermoFisher Urea Nitrogen (BUN) colorimetric detection kit (Pub. No MAN0025406). Briefly, 96-well plates were prepared as the serum samples were thawing at room temperature to ensure a lack of nitrogen dissipating from the sample. Serial dilutions were conducted for 8 standards, from 10 mg/dL to 0.3135 mg/dL. Serum samples, after thawed, were diluted in a 1:10 using deionized water. Each well received 50 µL of diluted serum or standard. Lastly, 75 µL of two color reagents A (acidic solution for color) and B (acidic solution for color) were pipetted into each well and were incubated at room temperature for 30 min. The microLiter plate was read at 450 nm for absorbance analysis. Absorbance was recorded utilizing the standard samples linear regression curve.

Feed and forage samples were assayed for dry matter (DM) and organic matter (OM) according to the procedures of AOAC (2000). Neutral and acid detergent fibers (NDF and ADF, respectively) were determined according to the procedures of Vogel et al. (1999) using the ANKOM^{DELTA} (Ankom Technologies, Macedon, NY, USA). Acid detergent lignin (ADL) was determined according to the procedures of AOAC (2000) using the ANKOM Daisy^{II} incubator. Minerals (N, P, and K) was determined by the University of Georgia's Agricultural and Environmental Laboratory according to the procedures of Saha et al. (2020).

Soil was assayed for, pH, CEC, N, and Mehlich-3 extractable minerals by the Soil, Water, and Forage Testing Laboratory at Auburn University according to the procedures of Sikora et al. (2014). Soil organic matter was determined by the University of Georgia's Soil Testing Laboratory according to the procedures of Nelson and Sommers (1996).

Economic analysis was conducted using a partial budgeting approach (Gittinger, 1982; Kay, Edwards and Duffey, 2019). The partial budget was calculated using the following equation:

$$\text{Net change in profit} = (\text{additional revenue} + \text{reduced cost}) - (\text{reduced revenue} + \text{additional costs})$$

Reduced cost was quantified based on the expense of chemical fertilizer (N, P, and K) applied. Additional revenue was calculated using the producer provided sale prices. The sum of reduced cost and additional revenue constituted a positive economic impact. Additional costs encompassed expenses associated with supplementary preventative measures (e.g., deworming), cattle treatments (e.g., pink eye management), and any extra inorganic fertilizer applications. Reduced revenue, typically accounting for culled cattle, was not applicable in this study. The sum of additional cost and reduced revenue represented a positive economic impact.

Statistical Analyses

Data were analyzed using SAS 9.4 (SAS Institute Inc.). Prior analysis, raw data were tested using the PROC UNIVARIATE and the NORMAL option to ensure the data were normally distributed.

All response variables were analyzed using the generalized linear mixed models procedure (PROC GLIMMIX) in SAS. 9.4. Animal-level responses (initial and final BW, ADG, additional gain from supplementation, and feed offered) were analyzed using the fixed effect of treatment and random effects of location, paddock within location, and animal within paddock by location. Blood urea N was treated as repeated measurement on the subject of paddock within location which included fixed effect of treatment and random effect of location, paddock within location, and animal within paddock by location. Pasture-level responses (gain per hectare, forage allowance, and stocking rate) were analyzed using the fixed effect of treatment and random effects of location and paddock within location. Forage and soil responses were treated as repeated measures on the subject of paddock within location with the fixed effect of treatment, and random effect of location and paddock within location. For all analyses, denominator degrees of freedom were adjusted using the second order Kenward-Roger approximation method (Kenward and Roger, 2009).

The α-level for the mean differences was set at 0.05. Means separations were conducted using *F*-protected *t*-tests with the Tukey-Kramer adjustment (Kramer, 1956). Differences were declared when $P < \alpha$.

Results and Discussion

There was no interaction of treatment and day of study ($P > 0.08$) for any response variable measures. Thus, for the remainder of this section, main effects will be discussed.

Animal Performance

By design, there were no differences among treatments ($P = 0.17$) for initial BW of steers (Table III-2). There were differences, however, among treatments ($P \leq 0.01$) for final BW, ADG, and additional gain from supplementation. Steers from SUP1.0 had the greatest ($P < 0.05$) final BW, ADG, and additional gain from supplementation. By contrast, steers from CON had the least ($P < 0.05$) final BW and ADG. Steers from SUP0.5 and CLOV were intermediate to the two. Steers from SUP1.0 had a 10% increase in final BW and a 62% increase in ADG compared with CON. These differences between SUP1.0 and CON are supported by previous studies (Hill et al., 2015; Smith et al., 2020). The lack of difference, however, between CON and SUP0.5 are in contrast to the findings of Smith et al. (2020) but align with the findings of Smith et al. (2021). These discrepancies in response to supplementation are likely indicative of nuances related to supplemental feeding (the provision of a limiting nutrient) and enhancement feeding (the synergistic effect of feeding that can result in positive or negative associative effects).

There were differences among study days ($P < 0.01$; Figure III-1), but not among treatments or the interaction of treatment and day ($P \geq 0.17$; Table III-2) for BUN. Data on nitrogen consumption (Vendramini, 2024) and absorption into the blood (Lavery, 2021) suggest that this pattern should coincide with the overall nitrogen cycling in the forage's seasonal availability and quality. While the CP concentration of supplemental feed was consistent throughout the experiment, forage CP concentrations decreased with time, potentially creating an imbalance of protein derived from supplementation and energy derived from forages (Vanderhoff et al., 2024).

Stocking Responses

There were no differences among treatments ($P = 0.84$) or interactions of treatment and day ($P = 0.83$) for forage mass (Table III-3). However, forage mass increased ($P < 0.05$) from the beginning of the season through the mid-point, then declined toward the conclusion of grazing (Figure III-2). At trial initiation, the forage height was approximately 25.4 cm, which is considered above the optimal grazing height (Castillo, 2022). This could indicate increased forage maturity. Fescue palatability is inversely correlated to its maturity (Van Santen, 1992). Additionally, senesced material could explain why there was an increase on d 28 compared to d 14 as the forage mass was able to recover from grazing of dead material on the pastures (Nelson et al.,1994; Rotz et al., 1994).

By design, there were no differences among treatments for forage allowance ($P = 0.29$). However, there were also no differences among treatments for stocking rate ($P =$

0.79; Table III-3). The average forage allowance of 1.9 kg DM/kg BW exceeded the initial target forage allowance of 1.5 kg DM/kg BW. While an excessive forage allowance becomes non-limiting in assessing ADG potential of the grazing animal, this abundance of forage potentially masked the effects of supplementation strategies on pasture utilization (Carmo et al., 2013; Ford, 2014; Clark, 2016; Hersom, 2020). Smith et al. (2020; 2021) found stocking rate differences with titrated supplementation; however, in those studies, forage allowance was much lower (approx. 1 kg DM/kg BW) and, thus, grazing pressure allowed for observations about pasture utilization potential. Others have found, though, that supplementation may not alter pasture stocking rates (Silva et al., 2013; Aaron et al., 2015).

In spite of the lack of treatment effects for stocking rate, however, there was an effect of treatment for gain per hectare ($P = 0.01$; Table III-3). Pastures assigned to SUP1.0 had the greatest ($P < 0.05$) gain (276 kg/ha), and those from CON had the least (169 kg/ha), with SUP0.5 and CLOV intermediate. This increase in gain per unit area is consistent with previous observations about the effect of supplemental feeding in the grazing environment (Vendramini et al., 2007; Smith et al., 2020; Smith et al., 2021)

Forage Nutritive Value

There was no effect of treatment ($P \geq 0.10$) nor interaction of treatment by day ($P \geq 0.07$) for forage concentrations of ADF, ADL, N, P, or K (Table III-3). There were, however, differences among treatments ($P = 0.02$) for forage concentrations of NDF. Forage concentrations of NDF were greatest ($P < 0.05$) from CON and least from CLOV, with both supplemental treatments intermediate. Neutral detergent fiber is related to the potential voluntary intake of the grazing animal (Tekce and Gul, 2014). The lower the NDF concentration, the higher the potential intake (ACES, 2019). Nutrient-dense feedstuffs (legumes and supplemental feed) typically result in lower NDF values (Lardy and Waterman, 2020). The observations in this experiment could have been a response to minor differences in grazing patterns within the pastures in which supplemental nutrition (feedstuffs or legumes) was offered.

There was an effect of day ($P < 0.01$) for forage concentrations of NDF and ADF, but not ADL ($P = 0.17$; Figure III-3). While forages tend to increase in fiber concentrations across a season, even when supplemental feed is offered (Smith et al., 2020; Smith et al., 2021), the consistent grazing pressure observed in our experiment may have suppressed any potential effect of forage maturity. No differences in ADL were expected as Kanapeckas et al. (2011) found that tall fescue growing in the spring season has consistent ADL fractions.

There was an effect of day ($P < 0.01$) for forage concentrations of N, P, and K (Figure III-4). Nitrogen concentrations decreased over time, while P and K concentrations increased with time. These responses were of interest because they could serve as indicators of plant uptake of nutrients deposited through the supplemental feeding. Phosphorus increasing over the duration of the study suggests a translocation later in the growing season (Grant et al., 2001). Early-season potassium concentrations are consistent with cool season grasses exhibiting luxury consumption of K (Brejda, 2000), while increased values in the remainder of the study could be attributed to forage mass accumulation (Drewnoski et al., 2009).

Soil Responses

Soil minerals

There was no effect of treatment ($P \geq 0.22$) or interaction of treatment and day ($P \geq 0.08$) for any soil mineral (Table III-4). This was surprising given the findings of Hines (2021) that manure from steers receiving supplemented feed resulted in increased forage growth potential, at least at the greenhouse scale. By extension, these changes should have resulted in an alteration of the soil nutrient profile. However, we posit that the length of the experiment (one yr) was not sufficient to see an incorporation of organic nutrients that would be derived from fecal material into the soil mineral profile.

There was an effect of day ($P < 0.05$) on soil N, P, and K (Figure III-5). Soil N decreased ($P < 0.05$) with time, while soil P and K increased ($P < 0.05$) with time, with the breakpoint occurring around d 56. A decrease in soil N could occur for many reasons, such as lack of microbial activity, uneven grazing, leaching, and plant uptake (Russelle, 1992; McGovern et al., 2014). Consistent forage allowance would likely rule out uneven and overgrazed paddocks decreasing the nitrogen (Gao et al., 2004; Yan et al., 2015). The increase in soil P and K across the trial could lend credence to the notion that time was not sufficient to see treatment differences from the deposition of organic nutrients.

There was an effect of day on soil Ca ($P < 0.01$; Figure III-6), Mn ($P < 0.01$), Mg ($P < 0.01$), Fe ($P = 0.01$), and Cu ($P < 0.01$; Figure III-7). Calcium and magnesium accumulated in a similar pattern to that observed in soil P and K (Figure III-5). Manganese decreased ($P < 0.05$) across the season. There was no discernable pattern, though, for Fe or Cu. Microminerals are indicators of overall soil health, affecting forage quality (Li et al., 2022). Improved soil structure, root development, and animal bone health result from higher calcium and magnesium values (McDowell and Valle, 2000). Sodium, boron, iron, and aluminum can alter rumen fermentation, nutrient digestibility, and disease/disorder susceptibility (White et al., 2019; Sprinkle et al., 2020; Lopez et al., 2021).

Soil health

There were no differences among treatments ($P \geq 0.26$; Table III-4), days ($P \geq 0.35$), or their interaction ($P \geq 0.47$) for SOM or pH. The average organic matter value in the soil was approximately 6%, while the average pH was approximately 7.0. While we would have anticipated that supplementation and its expected concomitant increase stocking rate would have resulted in increased SOM through manure deposition, we nevertheless did not observe a negative impact of cattle management on soil health.

There was no effect of treatment ($P = 0.70$) or interaction of treatment and day ($P = 0.59$) for soil CEC (Table III-4). There was, however, an effect of day ($P < 0.01$) on soil CEC (Figure III-8). The CEC of pasture soil decreased ($P < 0.05$) with time. A decrease in cations from leaching could be an explanation for this change (Wu et al., 2023).

Root dynamics

There was no effect of treatment ($P = 0.77$) on root growth as measured via the ingrowth technique (Table III-4). Differences in soil fertility over time ($P \leq 0.01$), despite the absence of differences ($P > 0.08$) among treatments, suggest that the slow release of mineral deposits may have led to uniform soil conditions across treatments (Fageria et al., 2011; Houde et al., 2020; Table 2). This gradual nutrient accumulation could have resulted in similar root growth patterns consistent with soil and forage N (Fransen et al., 1998;

Dubeux Jr. et al., 2007; Table 2; Table 3). Lastly, the limited sample size due to the successful retrieval of only 17 out of 36 ingrowth traps may have introduced variability, potentially masking any subtle differences in root growth (Goldsmith et al., 2022). The 87-d incubation period, while sufficient for observing above-ground growth, may not have been sufficient to detect significant differences in root development under supplementation for fertilization conditions.

Economics

Partial budgeting analysis revealed that supplementation strategies for stocker cattle had increased profitability compared to control or red clover-supplemented paddocks (Table III-5). This finding was driven by the additional weight gain and pounds sold of supplemented cattle. Net profit changes of $2,126.75, $2,540.99, and $455.00 were observed from SUP0.5, SUP1.0, and CLOV, respectively, compared to CON. Supplementation of steers at 1% BW was the most economical option for producers, considering a shift from additional inorganic fertilization to byproduct supplementation. However, the choice between supplementation strategies may depend on the producer's financial situation and pasture goals, with CLOV inclusion potentially serving as a viable alternative. It is crucial to note that this trial did not observe soil fertilization differences between treatments, and future studies could provide a more comprehensive economic analysis by considering long-term effects and the potential for complete replacement of chemical fertilizers.

The selling times for different treatments varied across locations, with supplemented steers sold shortly after the trial, legume-treated steers sold in mid-July due to animal performance effects, and control steers sold in mid-September. While this selling approach may not be ideal for research purposes, it realistically demonstrates the impacts of management strategies on cattle performance and market timing (Hampel and Schroeder, 1998; Coffey, 2001).

Byproduct supplementation demonstrated several benefits, including mitigation of negative animal responses to tall fescue, provisions of a cost-effective alternative to additional inorganic fertilizers, improvement of stocker steer animal performance, pasture, and soil health through natural fertilization (Rochon et al., 2004; Nkoa, 2014; Tichenor, 2016; Teague and Kreuter, 2020; Murray, 2024).

The initial year of this two-year trial focused on establishing uniform paddock soil conditions through consistent inorganic fertilization, creating a standardized nutrient baseline across all experimental paddocks. This preparatory phase is crucial for subsequent years' data, which will accurately reflect the economic implications of substituting inorganic fertilizer with byproduct supplementation.

Conclusion

Supplementation of steers grazing tall fescue pasture resulted in enhanced animal performance. Among the four treatments, SUP1.0 resulted in the greatest final BW and ADG, and steers receiving SUP0.5 and CLOV performed similarly. The lack of differences in stocking rate in this experiment means that animals likely did not substitute supplemental feed for forage intake as the management strategy would have dictated. In the one-yr scope of this experiment, contrary to our original hypothesis, there were also no changes observed in soil nutrient status. Partial budgets indicated that SUP1.0 could increase producer profits compared to CON and CLOV due primarily to increased cattle gain. However, this profit is subject to year-to-year fluctuations due to volatile inorganic fertilizer and byproduct feed prices. We concluded that byproduct supplementation remains a viable management strategy for stocker cattle, though these effects may not translate to systemic nutrient cycling benefits. A second year of this experiment is planned to observe longer-term effects of these management strategies on the animal-plant-soil interface.

Table III-1 Nutritive value and cost of supplemental feed used in the evaluation of supplemental feeding or interseeded legumes for increased nutrient cycling in tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) forage systems

	Nutrient[2], % DM						
Location	**OM**	**NDF**	**ADF**	**CP**	**P**	**K**	**Cost[3]**
BBREC	89.5	51.2	31.4	14.92	0.55	1.53	$2.00
TVREC	89.3	50.9	29.2	14.23	0.49	1.42	$1.46

[1] BBREC = Black Belt Research and Extension Center, Marion Junction, AL; TVREC = Tennessee Valley Research and Extension Center, Belle Mina, AL

[2] NDF = neutral detergent fiber, assayed inclusive of α-amylase, exclusive of sodium sulfite, and expressed inclusive of residual ash; ADF = acid detergent fiber, expressed inclusive of residual ash and assayed sequentially to neutral detergent fiber; CP = crude protein; P = phosphorus; K = potassium

[3] Cost is based on the price paid per kg by the respective research and extension center at the time of feed purchase.

Table III-2 Animal performance from steers that received supplemental feed or grazed interseeded legumes in tall fescue forage (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) systems

Item	**Treatment[1]**				**SEM[2]**	***P*-value**
	CON	**SUP0.5**	**SUP1.0**	**CLOV**		
Initial BW, kg	266	266	269	268	22.8	0.96
Final BW, kg	309^{b}	329^{ab}	340^{a}	321^{ab}	23.9	< 0.01
ADG, kg/d	0.5^{b}	0.8^{ab}	0.9^{a}	0.6^{ab}	0.07	0.01
Additional gain, kg/d	0.0	0.2^{ab}	0.3^{a}	0.1^{ab}	0.08	< 0.01
Feed offered, kg	0.0	0.5^{b}	1.1^{a}	0.0	0.01	< 0.01
Feed-to-gain ratio, kg/kg BW	-	2.4	3.8	-	2.19	-
Blood urea N, mg/dL	1.1	1.1	1.0	1.2	0.07	0.17

[1] CON = negative control forage treatment in which steers were grazing tall fescue without additional supplemental feed; SUP0.5 = forage treatment in which steers were grazing tall fescue pastures and offered supplemental feed (1:1 ratio of corn gluten feed and soybean hulls) daily at 0.5% BW; SUP1.0 = forage treatment in which steers were grazing tall fescue pastures and offered supplemental feed (1:1 ratio of corn gluten feed and soybean hulls) daily at 1.0% BW; CLOV = forage treatment in which steers were grazing tall fescue pastures interseeded with red clover (*Trifolium pratense* L.)

[2] SEM = standard error or the mean

[a, b] Means within a row without common superscripts letters are different ($P \leq 0.05$).

Table III-3 Pasture-level responses and forage nutritive value from pastures in which steers either received supplemental feed or grazed interseeded legumes in tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) forage systems

	Treatment[2]					
Item[1]	**CON**	**SUP0.5**	**SUP1.0**	**CLOV**	**SEM**[3]	***P*-value**
Forage mass, kg DM/ha	1,901	1,960	2,053	1,933	218.2	0.84
Forage allowance, kg DM/kg BW	1.8	1.9	2.0	1.8	0.09	0.70
Stocking rate, kg BW/ha	1,060	1,125	1,106	1,187	181.1	0.78
Gain per hectare, kg/ha	169^{b}	243^{ab}	276^{a}	193^{ab}	34.3	0.01
NDF, % DM	62.7^{a}	61.4^{ab}	60.3^{ab}	57.9^{b}	0.02	0.02
ADF, % DM	32.4	32.5	31.9	31.2	0.02	0.11
ADL, % DM	4.0	4.0	3.8	4.1	0.002	0.85
N, % DM	1.9	1.9	1.9	2.1	0.34	0.12
P, % DM	0.2	0.2	0.2	0.3	0.03	0.10
K, % DM	1.6	1.7	1.7	1.8	0.25	0.71

[1] NDF = neutral detergent fiber, assayed inclusive of α-amylase, exclusive of sodium sulfite, and expressed inclusive of residual ash; ADF = acid detergent fiber, expressed inclusive of residual ash and assayed sequentially to neutral detergent fiber; ADL = acid detergent lignin; N = nitrogen; P = phosphorus; K= potassium

[2] CON = negative control forage treatment in which steers were grazing tall fescue without additional supplemental feed; SUP0.5 = forage treatment in which steers were grazing tall fescue pastures and offered supplemental feed (1:1 ratio of corn gluten feed and soybean hulls) daily at 0.5% BW; SUP1.0 = forage treatment in which steers were grazing tall fescue pastures and offered supplemental feed (1:1 ratio of corn gluten feed and soybean hulls) daily at 1.0% BW; CLOV = forage treatment in which steers were grazing tall fescue pastures interseeded with red clover (*Trifolium pratense* L.)

[3] SEM = standard error or the mean.

Table III-4 Soil health and nutrient status from pastures in which steers either received supplemental feed or grazed interseeded legumes in tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) forage systems

	Treatment[2]					
Item[1]	**CON**	**SUP0.5**	**SUP1.0**	**CLOV**	**SEM[3]**	***P*-value**
N, %	0.2	0.2	0.2	0.2	0.04	0.70
P, ppm	15	17	22	22	27	0.22
K, ppm	163	178	192	196	49.0	0.69
Ca, ppm	5,199	5,258	5,174	5,266	2,959.9	0.96
Na, ppm	49	49	47	48	4.3	0.74
Mn, ppm	44	41	40	45	41.9	0.81
B, ppm	0.4	0.4	0.4	0.4	0.10	0.42
Mg, ppm	149	158	159	166	42.3	0.90
Fe, ppm	4.3	4.1	4.8	4.8	4.42	0.54
Al, ppm	141	142	135	138	138.4	0.71
Cu, ppm	1.4	1.50	1.5	1.7	1.2	0.77
Zn, ppm	0.3	0.3	0.3	0.3	0.27	0.98
SOM, %	6.1	6.2	5.8	6.0	1.94	0.63
CEC, cmol_c/kg	21.1	21.4	21.0	21.1	10.97	0.70
pH	6.9	7.0	7.0	7.0	0.63	0.26
Root growth[4], mg/cm^3·d	0.23	0.18	0.17	0.08	0.105	0.77

[1] N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Na = sodium; Mn = manganese; B = boron; Mg = magnesium; Fe = iron; Al: aluminum; Cu = copper; Zn = zinc; SOM = soil organic matter; CEC = cation exchange capacity

[2] CON = negative control forage treatment in which steers were grazing tall fescue without additional supplemental feed; SUP0.5 = forage treatment in which steers were grazing tall fescue pastures and offered supplemental feed (1:1 ratio of corn gluten feed and soybean hulls) daily at 0.5% BW; SUP1.0 = forage treatment in which steers were grazing tall fescue pastures and offered supplemental feed (1:1 ratio of corn gluten feed and soybean hulls) daily at 1.0% BW; CLOV = forage treatment in which steers were grazing tall fescue pastures interseeded with red clover (*Trifolium pratense* L.)

[3] SEM = standard error or the mean

[4] Root growth was measured via the ingrowth technique across the 87-d grazing period only at the Tennessee Valley Research and Extension Center location.

Table III-5 Partial budget analysis from pastures in which steers either received supplemental feed or grazed interseeded legumes in tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) forage systems

	Treatment[1]			
Item	**CON**	**SUP0.5**	**SUP1.0**	**CLOV**
Additional revenue[2]	$18,500.00	$21,175.00	$22,137.50	$19,250.00
Reduced cost[3]	$0.00	$0.00	$0.00	$0.00
Reduced revenue[4]	$0.00	$0.00	$0.00	$0.00
Additional cost[5]	$26.50	$574.76	$1,123.02	$321.50
Net change in profit[6]	$18,473.50	$20,600.25	$21,014.49	$18,928.50

[1] CON = negative control forage treatment in which steers were grazing tall fescue without additional supplemental feed; SUP0.5 = forage treatment in which steers were grazing tall fescue pastures and offered supplemental feed (1:1 ratio of corn gluten feed and soybean hulls) daily at 0.5% BW; SUP1.0 = forage treatment in which steers were grazing tall fescue pastures and offered supplemental feed (1:1 ratio of corn gluten feed and soybean hulls) daily at 1.0% BW; CLOV = forage treatment in which steers were grazing tall fescue pastures interseeded with red clover (*Trifolium pratense* L.)

[2] Additional revenue was calculated as $\text{No. of steers} \times (\text{sales price} \times \text{steer BW})$.

[3] Reduced cost represents the savings in cost of additional inorganic fertilizer for treatments that did not receive additional fertilization.

[4] There was no reduced revenue because no morbidity or mortality was observed in the experiment.

[5] Additional costs represent the cost of additional deworming treatments for CON, the cost of supplemental feed for SUP0.5 and SUP1.0, and the cost of clover seed for CLOV.

[6] $\text{Net change in profit} = (\text{additional revenue} + \text{reduced cost}) - (\text{reduced revenue} + \text{additional costs})$

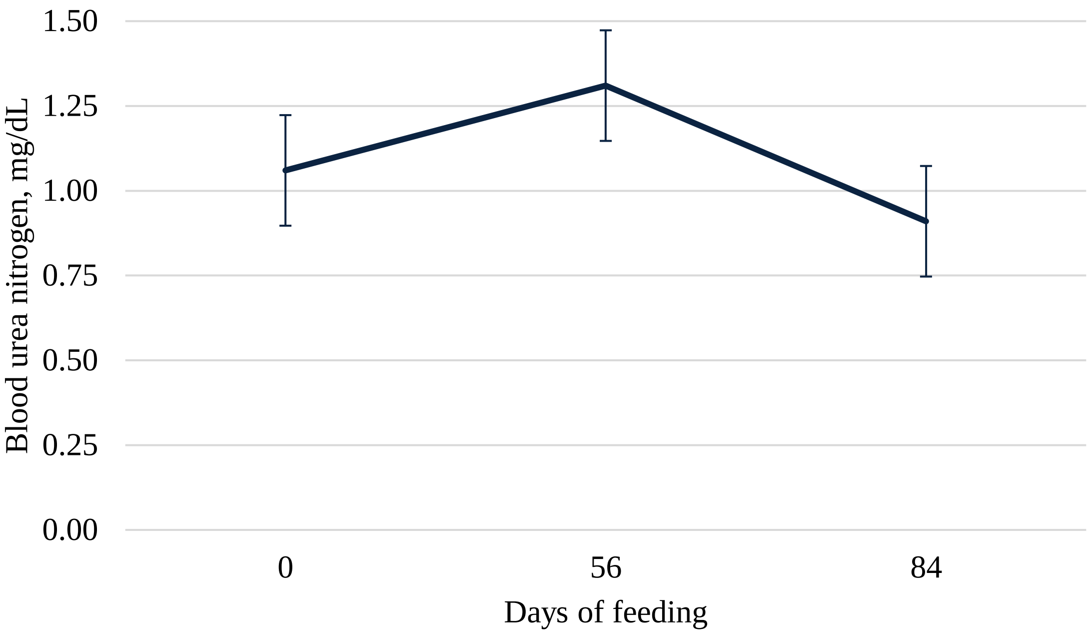

Figure III-1 Blood urea nitrogen ($P < 0.01$) from steers that received supplemental feed or grazed interseeded legumes in tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) forage systems

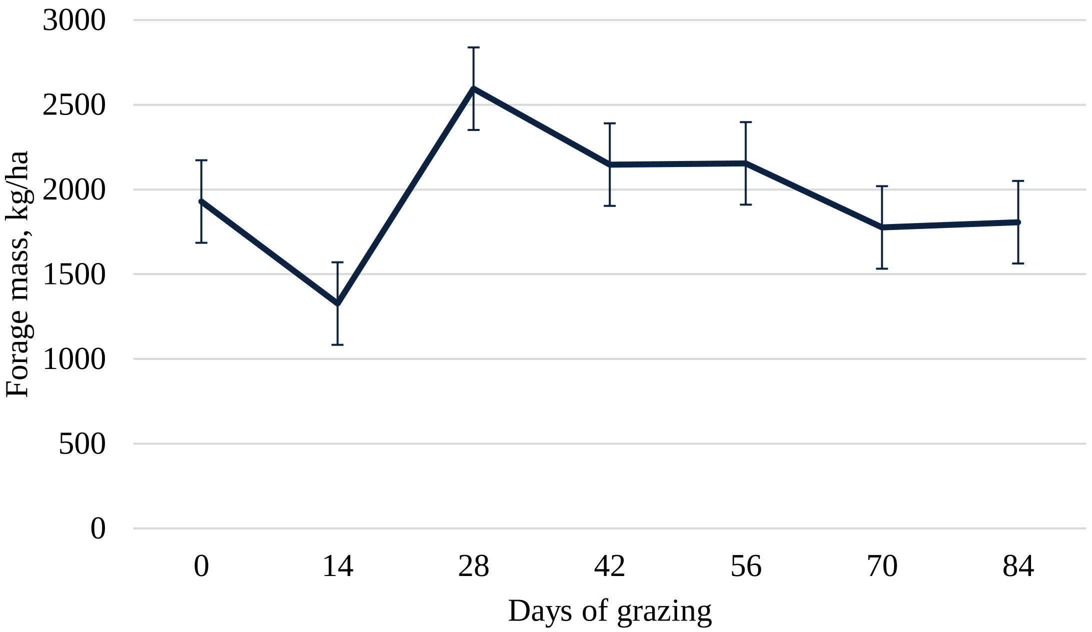

Figure III-2 Forage mass ($P < 0.01$) from pastures in which steers either received supplemental feed or grazed interseeded legumes in tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) forage systems

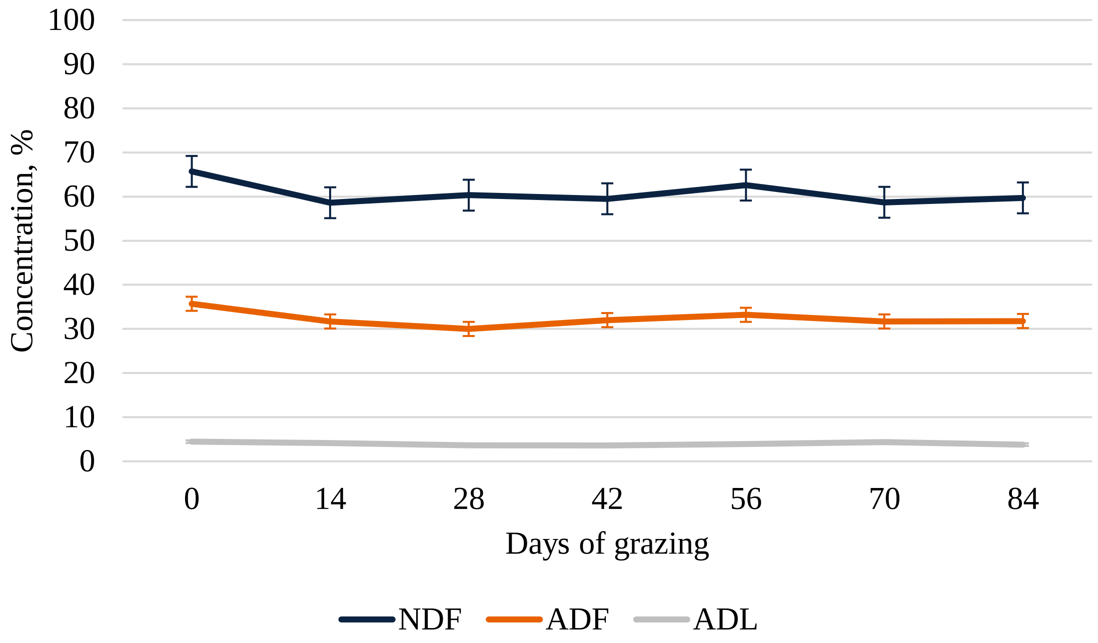

Figure III-3 Neutral detergent fiber (NDF; $P < 0.01$), acid detergent fiber (ADF; $P < 0.01$), and acid detergent lignin (ADL; $P = 0.17$) concentrations of forages from pastures in which steers either received supplemental feed or grazed interseeded legumes in tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) forage systems

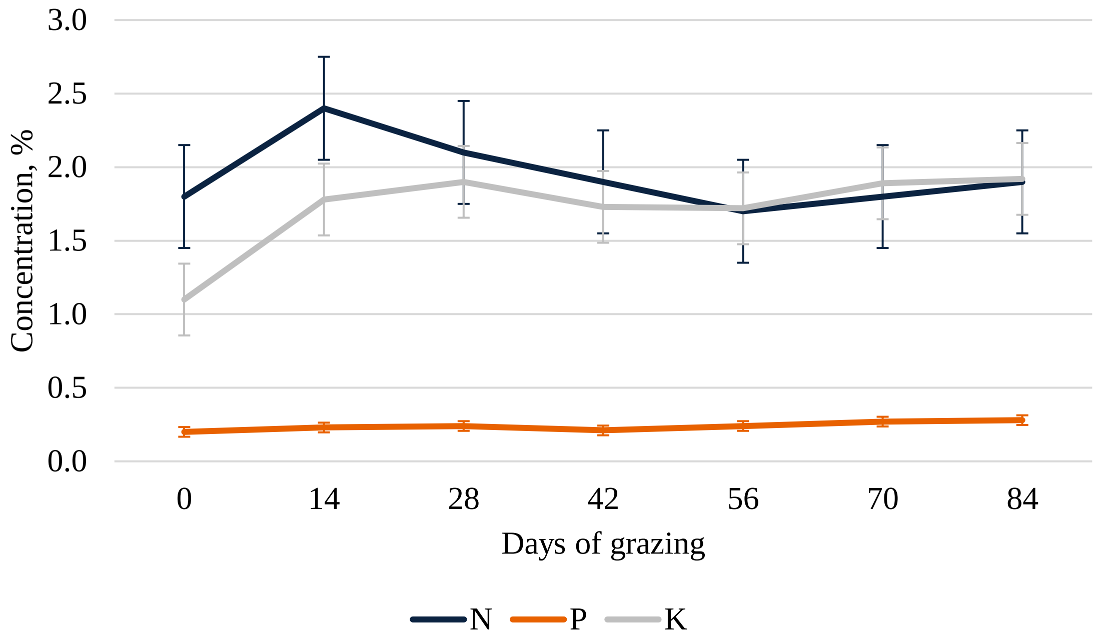

Figure III-4 Nitrogen (N; $P < 0.01$), phosphorus (P; $P < 0.01$), and potassium (K; $P < 0.01$) concentrations of forages from pastures in which steers either received supplemental feed or grazed interseeded legumes in tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) forage systems

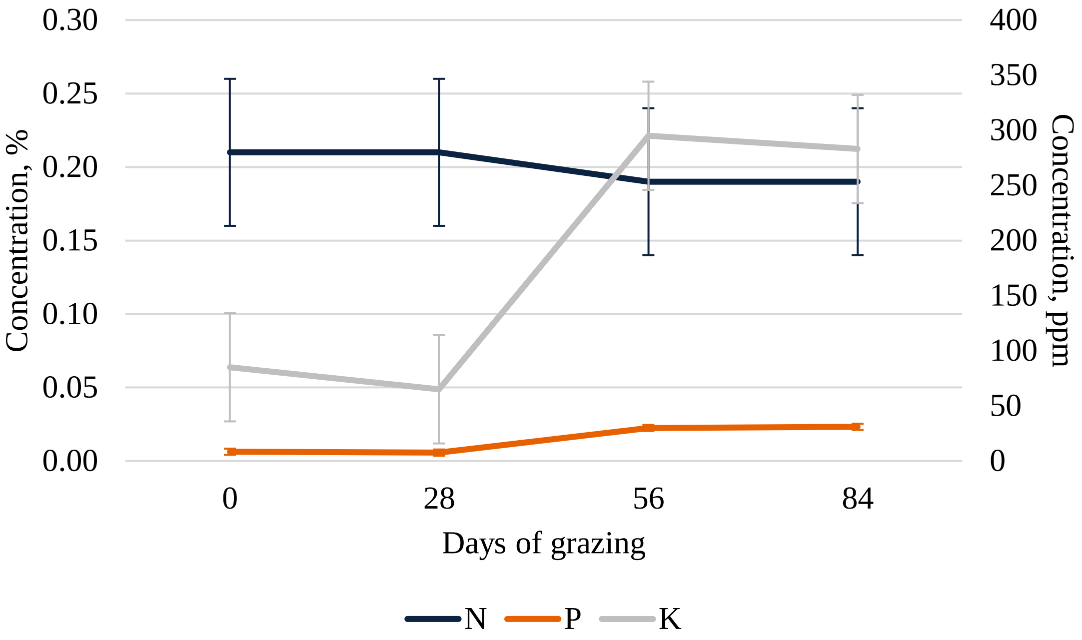

Figure III-5 Nitrogen (N; *P* < 0.01), phosphorus (P; *P* < 0.01), and potassium (K; *P* < 0.01) concentrations of soil from pastures in which steers either received supplemental feed or grazed interseeded legumes in tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) forage systems

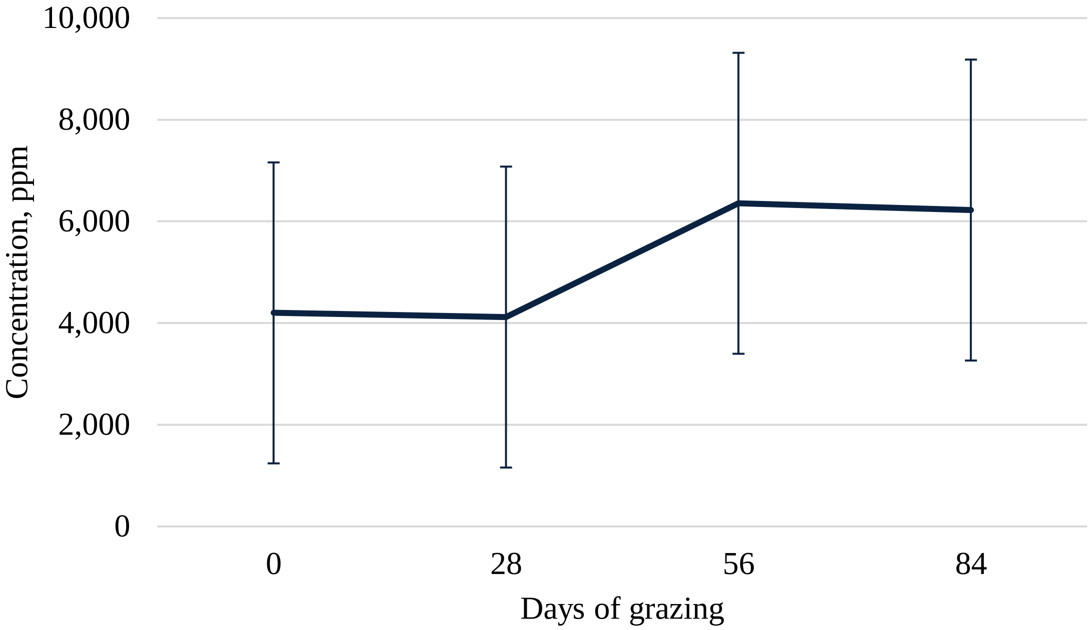

Figure III-6 Calcium (Ca; *P* < 0.01) concentrations of soil from pastures in which steers either received supplemental feed or grazed interseeded legumes in tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) forage systems

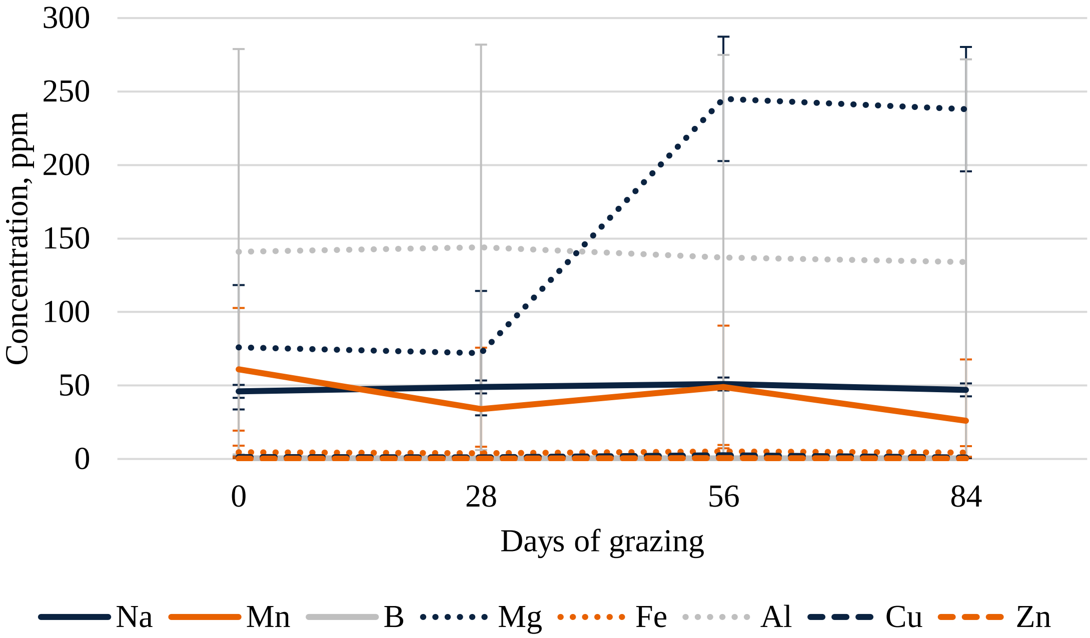

Figure III-7 Sodium (Na; *P* =0.16), manganese (Mn; *P* < 0.01), boron (B; *P* = 0.09), magnesium (Mg; *P* < 0.01), iron (Fe; *P* = 0.03), aluminum (Al; *P* = 0.13), copper (Cu; *P* < 0.01), and zinc (Zn; *P* = 0.38) concentrations of soil from pastures in which steers either received supplemental feed or grazed interseeded legumes in tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) forage systems

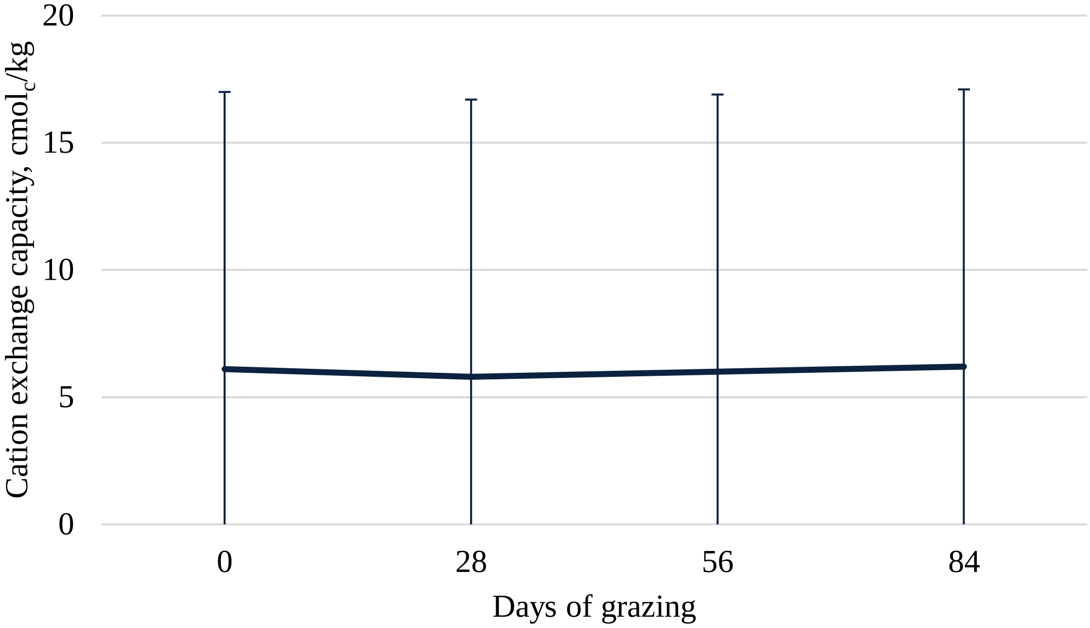

Figure III-8 Cation exchange capacity ($P < 0.01$) of soil from pastures in which steers either received supplemental feed or grazed interseeded legumes in tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) forage systems

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