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Article

Native Forbs Provide Pollinator Resources and Improve Forage Nutrient Composition, Animal Performance, and Pasture Productivity

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Abstract: Pollinator declines and expectations for more sustainable agriculture, including pasture-based enterprises, bring attention to strategies to enhance the habitat value of grazing lands. We evaluated native warm-season grass (NWSG) pastures with (FORB) and without (CONT) interseeded native forbs in 2021–2023. An analysis was conducted using R with the significance set at $p \leq 0.05$. The grass appeared to be weakened predominantly by grazing management practices. Forb density and mass had an inverse relationship in seasons two and three. Total forage mass declined in response to increased grazing days and weakened stands. The forage nutritive compositions differed, with more stable, season-long crude protein and lower fiber concentrations in late-season FORB, which supported higher bodyweight gains and season-long average daily gain. Black-eyed Susan (*Rudbeckia hirta*; BESU), lanceleaf coreopsis (*Coreopsis lanceolata*; LCOR), and showy ticktrefoil (*Desmodium canadensis*; STTF) were the most abundant forbs, and BESU, LCOR, and purple coneflower (*Echinacea purpurea*; PURC) produced long flowering windows. Cattle grazed STTF, cup plant (*Silphium perfoliatum*; CUPP), and oxeye sunflower (*Helopsis helianthoides*) the most. Under continuous stocking, a blend of BESU, LCOR, PURC, STTF, and CUPP produced acceptable cattle gains and provided pollinator resources, suggesting that this model may be a viable means to enhance the sustainability of pastures.

Keywords: native forages; forbs; pollinators; cattle; grazing

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1. Introduction

There is an increasing demand for sustainable agricultural practices worldwide [1], and beef production is no exception [2,3]. In the context of forage-based agriculture, the winter stockpiling of native grasses [4], utilization of cool- and warm-season pasture systems [5,6], and incorporation of diverse cover crops [7] have been explored to improve soil and environmental conditions while also supporting growing cattle. The use of introduced grass species in pastures has led to declining soil health [8–10], reduced plant diversity, and high inputs to sustain productivity. Non-native pastures also support fewer native pollinator species [11,12] and have been noted as a contributing factor to native insect declines [13]. Incorporating a diverse blend of native grasses and forbs can improve soil health [14–16], increase carbon sequestration [17], and offer floral resources [18–20], thus creating a habitat for a diversity of native animals and insects. In the case of insects, many can benefit other agricultural sectors, including row crop production, as a part of a broader integrated pest management strategy [21–23].

Native warm-season grasses (NWSGs) are productive grasses for summer grazing in the Mid-South USA [24,25] and include species like big bluestem (*Andropogon gerardii* Vitman; BB), indiangrass (*Sorghastrum nutans* (L.) Nash; IG), and little bluestem

(*Schizachyrium scoparium* (Michx.) Nash; LB). These grasses support growing cattle during summers [26–29], allow cool-season pastures to rest, and provide critical habitat for grassland birds like the northern bobwhite quail (*Colinus virginianus* L.) when grazed appropriately [30,31]. However, like other grasses, NWSGs provide minimal floral and nutritive resources for critical insect pollinator species like bumblebees (*Bombus* spp., e.g., *Bombus affinis* Cresson). Although conversion of grasslands for row crop production and urban development are the primary causes of habitat fragmentation, pastures dominated by introduced grass and clover species also contribute to this problem [12,32]. Compared to diverse native grasslands, pastures dominated by introduced species have fewer native floral resources that native pollinator species prefer [12,32–36]. Because of this habitat fragmentation and loss of floral resources, pollinator populations are at risk, including species like the rusty patch bumblebee that was listed as federally endangered in 2017 [37]. Therefore, it is critical to develop agricultural production strategies that provide habitat and floral resources for their survival.

Despite the limited benefit contemporary pasture systems provide for pollinators, they also present an opportunity to provide floral resources for critically impaired pollinator populations through incorporation of native plants, especially native forbs. Pastures make up over 178 ha in the U.S. [38], with more than 26 million ha across the eastern U.S. supporting over 12.8 million beef cattle (*Bos taurus* L.) on 306,000 farms that generate over USD 866 million in annual farm receipts [38]. This extensive pasture area, although often marginal habitat, provides connectivity among fragmented, higher quality pollinator habitats. Given this scale and their potential to connect existing habitats, Eastern U.S. pastures present a unique opportunity, where the incorporation of native plants could increase pollinator resources and ecosystem diversity while prospectively improving pasture productivity.

Although NWSGs have been incorporated into pasture systems to support cattle production and reduce the negative impacts of over-grazing tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.) during summer and/or severe drought [26–29], the inclusion of diverse native forbs and legumes, which provide floral resources for insect pollinators, has not been investigated. Therefore, the objectives of this research were to compare the relationship between NWSGs and forb density, forb flowering and grazing characteristics, forage mass, forage nutritive composition, and animal productivity for steers grazing NWSG pastures with and without interseeded native forbs. We hypothesized that the increased plant diversity provided by the interseeded forbs would maintain or improve pasture productivity and diversity, forage nutritive value, and animal growth while also providing floral resources.

2. Materials and Methods

2.1. Pasture Establishment

Research was conducted at the East Tennessee AgResearch and Education Center (ETREC), Holston Unit, in Knoxville, TN (35.96529°, −83.86307°). Ten ha of a previously established (2012), mixed NWSG (BB/IG/LB) pasture was divided into eight 1.1 ha paddocks in a complete randomized design with two treatments and four replicates. Four paddocks were the existing NWSG sward and served as the control (CONT). The remaining four paddocks were interseeded with an 18-species mixture of native forbs and legumes (FORB; Table 1; Ernst Conservation Seeds, Meadville, PA, USA). Species were selected based on adaptation to the Eastern U.S., plant physiology (i.e., forb or legume), life history (i.e., annual, biennial, and perennial), seed cost and availability (Ernst Conservation Seeds), value for pollinators or wildlife (Ernst Conservation Seed), previous research [39,40], and existing recommendations from various conservation sources. These species were interseeded 1 cm deep with a 1973 model Tye drill on 25 February 2021 and again on 2 April 2021 (9 kg pure live seed ha^{-1} total). The second planting date was a result of the initial planting's calibration being too low to achieve the desired target seeding rate. To assist in forb establishment and to control spring weeds in both treatments, all paddocks were sprayed with glyphosate (N-[phosphonomethyl]glycine; 2.3 L ha^{-1}) prior to forb emergence to control annual winter weeds on 8 March 2021. Pastures were not sprayed with herbicide following forb establishment because the herbicide tolerance was not well defined for the native forbs. The paddocks not interseeded with forbs were not sprayed during the study because of the limited encroachment of undesirable species for much of the study.

Table 1. Seeding rates of forbs interseeded in spring 2021 into an established NWSG † stand and grazed by weaned Angus calves, 2021–2023, at the East Tennessee AgResearch and Education Center, Holston Unit, Knoxville, TN, USA.

Common Name	**Scientific Name**	**Abbreviation**	**Seeding Rate (kg PLS ha^{-1})**	**Seeds m^{-2} ***
Black-eyed Susan	*Rudbeckia hirta* L.	BESU	0.56	194
Canada goldenrod	*Solidago canadensis* L.	CAGO	0.11	111
Cup plant	*Silphium perfoliatum* L.	CUPP	0.28	6
Illinois bundleflower §	*Desmanthus illinoensis* (Michx.) MacMill.	ILBF	0.56	1
Lanceleaf coreopsis	*Coreopsis lanceolata* L.	LCOR	0.56	27
Maximilian sunflower	*Helianthus maximiliani* Schrad.	MSUN	0.28	154
Oxeye sunflower	*Helopsis helianthoides* (L.) Sweet	OSUN	0.56	13
Prairie dock	*Silphium terebinthinaceum* Jacq.	PDOC	0.28	1
Plains coreopsis	*Coreopsis tinctoria* Nutt.	PLAC	0.01	7
Partridge pea §	*Chamaecrista fasciculata* (Michx.) Greene	PPEA	0.56	8
Panicledleaf ticktrefoil §	*Desmodium paniculatum* (L.) DC.	PTTF	0.56	25
Purple prairie clover §	*Dalea purpurea* (Vent.) Rydb.	PUPC	0.67	44
Eastern purple coneflower	*Echinacea purpurea* (L.) Moench	PURC	1.12	28
Roundhead bushclover §	*Lespedeza capitata* Michx.	RHBC	0.45	17
Slender bushclover §	*Lespedeza virginica* (L.) Britt.	SLBC	0.28	11
Showy ticktrefoil §	*Desmodium canadensis* (L.) DC.	STTF	0.56	9
Upright prairie coneflower	*Ratibida columnifera* (Nutt.) Woot & Standl.	UPPC	0.56	91
White prairie clover §	*Dalea candida* Michx.	WHPC	0.45	28

† Native warm-season grasses, NWSGs; pure live seed, PLS. * Approximate number of seeds planted m^{-2}. § Signifies a legume species.

The soil was a Shady–Whitwell complex (fine-loamy, mixed, subactive, thermic typic hapludults and fine-loamy, siliceous, semiactive, and thermic aquic hapludults) and Steadman silt loam (fine-silty, mixed, active, and thermic fluvaquentic eutrudepts) with a pH of 5.8 ± 0.21 and phosphorus and potassium contents of 47 ± 18.3 kg ha^{-1} and 176 ± 66.5 kg ha^{-1}, respectively. No nitrogen was applied to the paddocks during the study. Soil tests were conducted at the establishment (2021) and conclusion (2024) of the experiment. Three, 2.5 cm diameter cores were taken at 15 cm depths at three locations within each paddock stratified by slope position (ridge, side slope, and depression) for a total of 9 subsamples per paddock. The subsamples were combined by the stratification within each paddock for a total of 24 samples each sample year.

2.2. Temperature and Precipitation

Weather data were collected from the weather station at the East Tennessee AgResearch and Education Center (ETREC), Plant Science Unit, in Knoxville, TN, USA. Temperatures remained above the 30-year means in May, June, and July 2022 and below in May and June 2023 (Figure 1). Precipitation was below the 30-year means in May 2023, June 2022, July 2021, August 2022, and September 2022 and 2023. Above average rainfalls were observed in June 2023, July 2022 and 2023, and August 2021 and 2023.

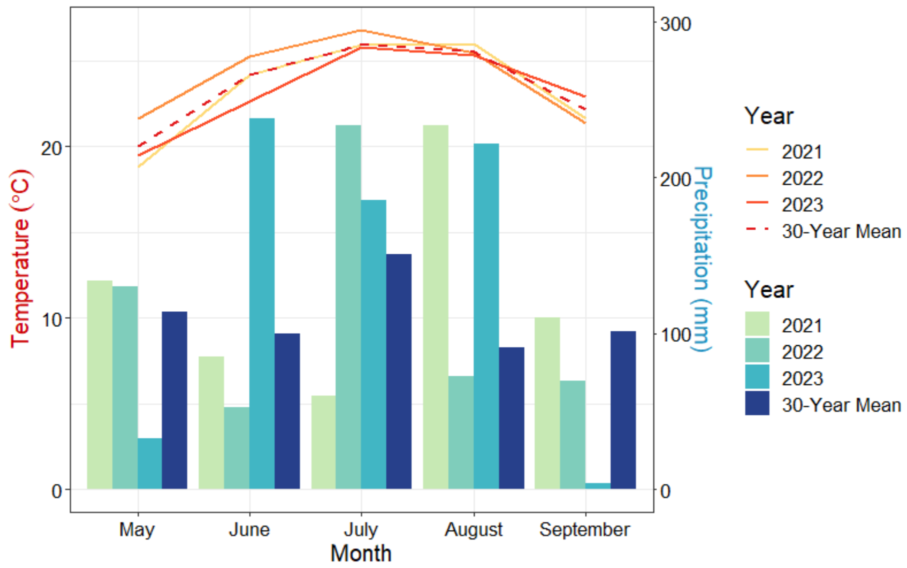

Figure 1. Monthly air temperature (°C) and precipitation (mm) for Knoxville, TN, USA, May–September, 2021–2023. Weather data were obtained from https://www.weather.gov/wrh/Climate?wfo=mrx (accessed on 22 February 2024).

2.3. NWSG and Forb Density

Plant densities were collected at the beginning and conclusion of each grazing season. Ten randomly placed 0.25 m^2 quadrats were sampled in each paddock. Native warm-season grasses were assessed by both plant and tiller counts within the quadrat. For interseeded paddocks, forbs were counted by species in ten 1 m^2 quadrats and NWSGs within a 0.25 m^2 quadrat nested within the 1 m^2 quadrats.

2.4. Forb Flowering and Grazing Characteristics

Each FORB paddock was binarily assessed for the presence of each forb species, whether present forbs were flowering, and whether the forbs were grazed. The samples were taken every 28 days in conjunction with forage mass samples. The length of flowering was noted based on the flower presence in each paddock by species.

2.5. Forage Mass and Forage Nutritive Composition

To determine forage mass, ten 0.25 m^2 quadrats were sampled in each paddock every 28 days by harvesting the available forage to a 5 cm stubble height. Forage was sorted into NWSGs, forbs, and weeds to determine botanical composition by dry mass. Weeds were defined as plants not intentionally introduced into the paddocks. Samples were dried in forced-air ovens (Wisconsin Oven Corporation, East Troy, WI, USA) at 55 °C until they maintained a constant mass (approximately 72 h) to determine the dry matter content.

Of the forage samples collected to determine forage mass, forage above a 30 cm stubble height was retained to determine nutrient composition. Forage below this stubble height was not within the grazing horizon of the NWSGs. After drying, samples were recombined by paddock and sampling date to include both NWSGs and forb components. The samples were then ground using a Wiley Mill (Thomas-Wiley Laboratory Mill Model 4, Arthur H. Thomas Co., Philadelphia, PA, USA) passing through a 2 mm screen; followed by a cyclone sample mill (UDY Corporation, Fort Collins, CO, USA) ground to pass through a 1 mm screen [41]. Additional drying of the prepared sample in a forced-air oven at 55 °C was conducted to ensure consistent moisture for scanning on a near-infrared spectrometer (NIRS) for less variability in the predicted results across all samples [42]. The samples were scanned on a Foss DS2500F using ISIScan Nova v. 8.0.6.2 (Foss North America, Eden Prairie, MN, USA). Spectra were then applied to the 2021 Grass Hay calibration in 2021 and 2022, and 2023 samples containing higher concentrations of forb species were predicted with the 2021 Mixed Hay calibration provided by the NIRS Forage and Feed Consortium (NIRSC, Berea, KY, USA). Global and neighborhood statistical tests were monitored for accuracy with the data set fitting the calibrations within the limit (H < 3.0) of fit [41,43]. Units of measurement for nutritive analyses and calculated parameters are presented on a 100% dry matter (DM) basis.

2.6. Pasture Productivity and Animal Performance

Weaned Angus calves (n = 32 annually; 250 ± 36 kg) from the ETREC herd were assigned to four per paddock based on similar weight ranges and total weight per paddock (888 ± 54 kg ha^{-1}) on 27 May 2021, 4 May 2022, and 25 April 2023. In 2022, to maintain the optimal forage canopy height early in the season, two weaned heifer calves from the ETREC herd were added with the steers to each of the 8 paddocks (n = 16) for two weeks. Heifer grazing days were accounted for in animal day (AD) calculations for 2022; no other measurements were taken from the heifers. In 2023, because of a limited number of steers available, each paddock was stocked with three steers and one heifer, also from the ETREC herd. Animals were weighed at stocking, at 28-day intervals, and when removed from paddocks. Weights were taken on two consecutive days prior to and following the stocking of paddocks. With the exception of the heifers in 2022, all animals grazed the paddocks continuously throughout each summer. All animals were removed from the paddocks on 26 August 2021 (91 days). However, animals were allowed to graze into late August and September in 2022 (120–135 days) and 2023 (123–134 days) based on individual paddock conditions (e.g., grass height and grazing uniformity) to determine differences in ADs by paddock. Animal days were the total number of grazing days ha^{-1}. Average daily gain (ADG) is the number of days spent grazing divided by the number of kg gained during that period. Total gain (GAIN; kg ha^{-1}) was the product of ADs and ADG. Animals had ad libitum access to minerals, water, and shade while grazing. All animal care and experimental procedures were approved by the University of Tennessee Institutional Animal Care and Use Committee (protocol: #2258).

2.7. Statistical Analysis

The analysis was conducted using R software (version 4.3.2, R Foundation for Statistical Computing, Vienna, Austria) running RStudio (version 2023.12.1.402, Posit Software, Boston, MA, USA), and the statistical significance was set at $p \leq 0.05$. Treatment differences in plant and tiller densities were compared using mixed-effects general linear models under a Poisson distribution, and the remaining response variables were analyzed using mixed-effects ANOVA running a Type III Wald F test with Kenward–Roger df. To address non-normality and unequal variances, transformations were applied to NWSG forage mass (squared) and nutritive composition (NDF and ADF to the third and second power, respectively). Native grass plant and tiller densities were analyzed with forage treatment (CONT or FORB), year, and season (spring or fall) as fixed effects and replicate as a random effect. Forb plant density was analyzed with year and season as fixed effects and replicate as a random effect. The correlation between NWSG tillers and forb density was analyzed using a Kendall correlation test. Chi-squared tests were performed to compare the frequency of forb presence (not present, present but not flowering, present and flowering) among species and for all forb species by month. Forb abundance and ranking based on plant abundance, persistence, flowering window, and grazing observations were numerically assessed for each species similar to Richwine et al. [39]. Ranks were assigned ordinally and compared to other present species as opposed to a set scale. A rank of 1 corresponded to the greatest abundance, most persistent, longest flowering window, and most frequently grazed compared to the other forbs. Grass, forb, and weed mass, nutritive composition (CP, NDF, and ADF), and ADG were each analyzed with forage treatment, month (grazing interval for ADG), and year as fixed effects and replicate as a random effect. Season-long ADG, AD, and GAIN were analyzed with forage treatment and year as fixed effects and replicate as a random effect. Two- and three-way interactions of the main effects were assessed as fixed effects in all models and are presented when significant. Month and year were treated as repeated measures. Response variables transformed for analysis were back-transformed for presentation of the results. Mean separations were compared using Tukey's honest significant difference test.

3. Results

3.1. NWSG and Forb Density

Grass density was not different ($p > 0.05$) among treatments (Figure 2) and was similar ($p > 0.05$) across the seasons and years in FORB. However, CONT decreased ($p < 0.05$) in plant density from spring to fall each year. The grass tiller density was the greatest ($p < 0.05$) in spring 2021 compared to 2022 and 2023 for both treatments and differed ($p < 0.05$) among the treatments in fall 2021 and 2023 and spring 2023. The forb density was the greatest ($p < 0.01$) in spring 2021. Afterward, forb density declined and remained similar ($p > 0.05$) in the following seasons and years, except for an increase in forb density in spring 2023.

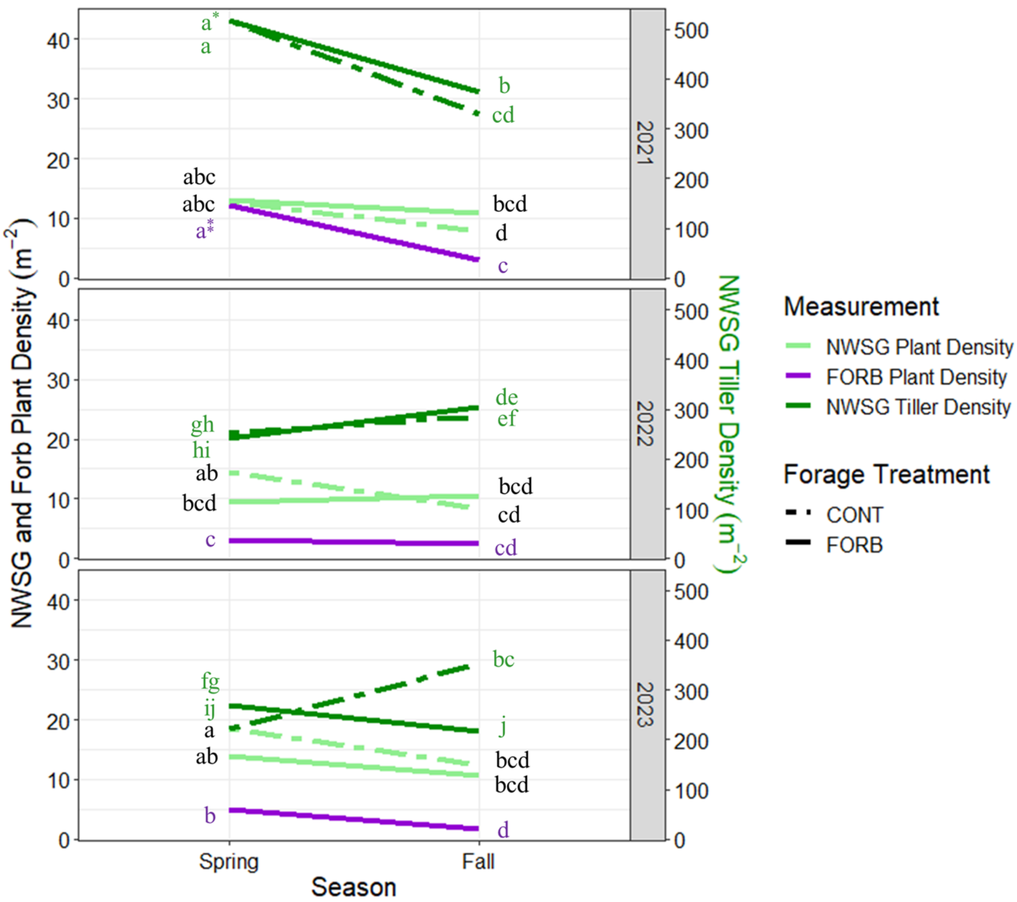

Figure 2. Native warm-season grass plant (light green) and tiller (dark green) and forb plant (purple) densities for CONT † and FORB pastures, 2021–2023, at the East Tennessee AgResearch and Education Center, Holston Unit, Knoxville, TN, USA. † Native warm-season grass, NWSG; control NWSG mixture, CONT; forb and NWSG mixture, FORB. * Mean NWSG plant (black letters) and tiller (green letters) densities with different letters varied ($p < 0.05$) among forage treatments, seasons, and years. ‡ Mean forb density (purple letters) compared across season and year differed ($p < 0.05$).

3.2. Forb Flowering and Grazing Characteristics

The 18 forb species demonstrated varying establishment and flowering frequencies ($\chi^2 = 710.7$, df = 34, $p < 0.01$; Figure 3). Black-eyed Susan (BESU), lanceleaf coreopsis (LCOR; Table 1), upright prairie coneflower (UPPC), and purple coneflower (PURC) flowered the most frequently ($p < 0.02$). Cup plant (CUPP), Maximilian sunflower (MSUN), oxeye sunflower (OSUN), panicledleaf ticktrefoil (PTTF), and showy ticktrefoil (STTF) were present but displayed fewer flowers ($p < 0.01$). Illinois bundleflower (ILBF), prairie dock (PDOC), plains coreopsis (PLAC), purple prairie clover (PUPC), roundhead bushclover (RHBC), slender bushclover (SLBC), and white prairie clover (WHPC) were the least frequently observed ($p < 0.01$) species. Forb maturity differed by month ($\chi^2 = 63.51$, df = 10, $p < 0.01$; Figure 4). The blooming percent was fairly consistent across the season ($p > 0.05$), and only differed from expected values in May and August ($p < 0.05$).

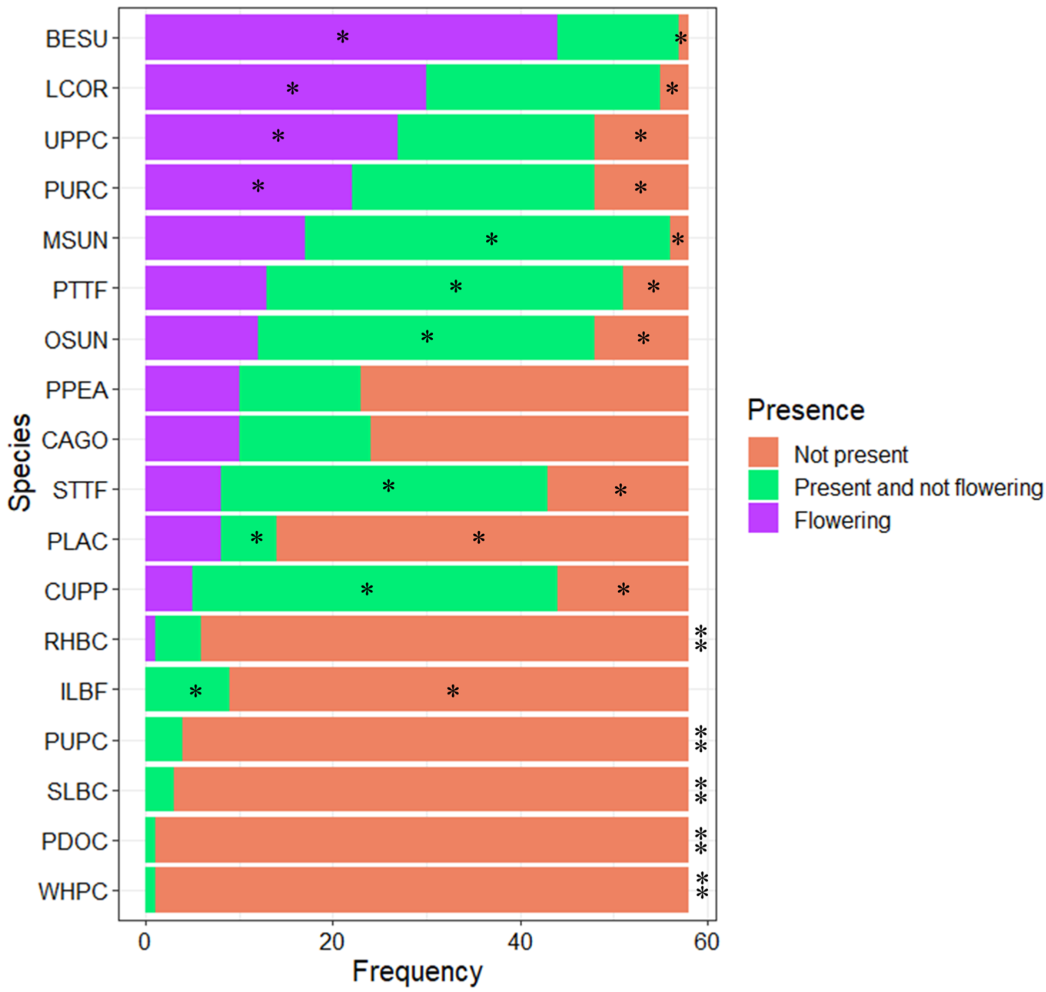

Figure 3. Observed presence of forb species [†], 2021–2023, at the East Tennessee AgResearch and Education Center, Holston Unit, Knoxville, TN, USA. Frequencies [§] are the total number of each observed conditions per species across all surveys (n = 58 per species). [†] Black-eyed Susan, BESU; lanceleaf coreopsis, LCOR; upright prairie coneflower, UPPC; purple coneflower, PURC; Maximilian sunflower, MSUN; panicledleaf ticktrefoil, PTTF; oxeye sunflower, OSUN; partridge pea, PPEA; Canada goldenrod, CAGO; showy ticktrefoil, STTF; plains coreopsis, PLAC; cup plant, CUPP; roundhead bushclover, RHBC; Illinois bundleflower, ILBF; purple prairie clover, PUPC; slender bushclover, SLBC; prairie dock, PDOC; white prairie clover, WHPC. * Frequencies differed from expected values within a presence category ($\chi^2 = 710.73$, df = 34, $p < 0.01$). [‡] Frequencies differed from expected values in all three presence categories ($p < 0.05$). [§] $n_{total} = 1044$.

Species ranking indicated the biennial BESU and short-lived perennial LCOR had high ranks due to high abundance, best persistence after three years, and long flowering windows (Table 2). Panicledleaf and showy ticktrefoils were the highest-ranking legumes but had poor persistence. Prairie dock, PUPC, RHBC, SLBC, and WHPC established poorly, ranking lowest of the 18 species.

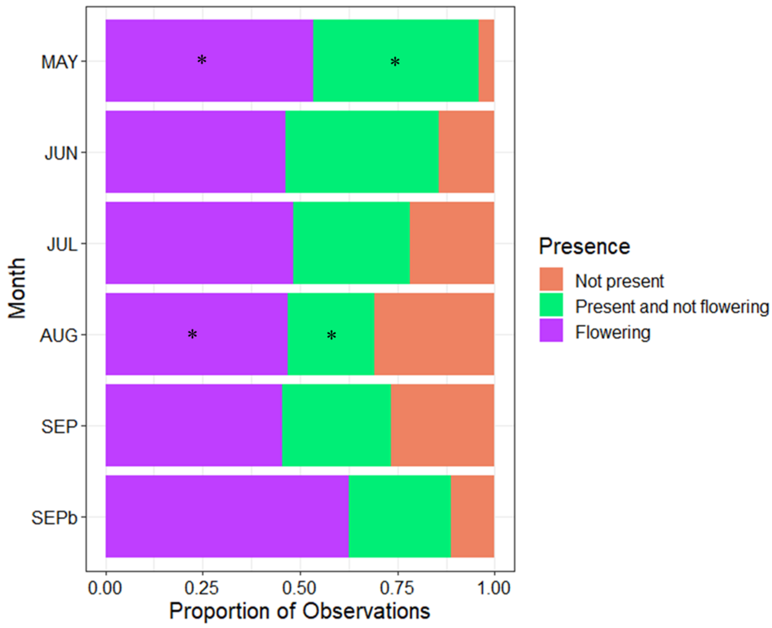

Figure 4. Observed forb presence by month †, 2021–2023, at the East Tennessee AgResearch and Education Center, Holston Unit, Knoxville, TN, USA. Frequency § proportions are the percent of each observed condition per month across all surveys (n = 72–216 monthly †). † May, MAY (n = 144); June, JUN (n = 216); July, JUL (n = 216); August, AUG (n = 216); early September, SEP (n = 180); late September, SEPb (n = 72). * Frequencies differed from expected values within a presence category (χ^2 = 63.51, df = 10, p < 0.01). § n_{total} = 1044.

Table 2. Overall abundance, persistence, flowering, and grazing ranks of forbs grazed in 2021–2023, at the East Tennessee AgResearch and Education Center, Holston Unit, Knoxville, TN, USA.

Species †	Abundance (Total Plants) *	2023 Plants m^{-2} §	Abundance Rank	2023 Plants Rank (Persistence)	Flowering Window Rank ‡	Grazing Rank ⁑	Rank Average	Overall Rank ⁂
BESU	526	1.6	1	1	2	7	2.8	1
LCOR	140	0.3	3	3	1	6	3.3	2
PTTF	64	0.5	4	2	7	1	3.5	3
STTF	156	0	2	6	7	1	4	4
MSUN	42	0.2	5	4	4	4	4.3	5
PURC	39	0.1	7	5	1	5	4.5	6
OSUN	38	0.1	8	5	3	2	4.5	7
CUPP	27	0.3	10	3	5	3	5.3	8
UPPC	34	0.2	9	4	3	8	6	9
PPEA	41	0	6	6	7	8	6.8	10
CAGO	23	0.2	11	4	5	8	7	11
PLAC	7	0	12	6	6	8	8	12
ILBF	5	0	13	6	8	8	8.8	13
PDOC	1	0	14	6	8	8	9	14
RHBC	1	0	14	6	8	8	9	14
PUPC	0	0	15	6	8	8	9.3	15
SLBC	0	0	15	6	8	8	9.3	15
WHPC	0	0	15	6	8	8	9.3	15

† Black-eyed Susan, BESU; Canada goldenrod, CAGO; cup plant, CUPP; Illinois bundleflower, ILBF; lanceleaf coreopsis, LCOR; Maximilian sunflower, MSUN; oxeye sunflower, OSUN; prairie dock, PDOC; plains coreopsis, PLAC; partridge pea, PPEA; panicledleaf ticktrefoil, PTTF; purple prairie clover, PUPC; purple coneflower, PURC; roundhead bushclover; RHBC; slender bushclover, SLBC; showy ticktrefoil, STTF; upright prairie coneflower, UPPC; white prairie clover, WHPC. * Total abundance is the sum of all plants counted in spring and fall, 2021–2023. § The mean number of plants counted in spring and fall, 2023, m^{-2} was used to rank persistence. ‡ Flowering window rank (1–8; 1 = longest flowering window, 8 = shortest flowering window or not observed flowering) based on the length of flowering observed; ranks with the same number bloomed for similar durations but were not necessarily blooming at the same time in a season. ⁑ Grazing rank (1–8; 1 = most grazed, 8 = least grazed or not grazed) based on plant grazing occurrence. ⁂ Overall rank (1–15; 1 = most recommended forb, 15 = least recommended forb) based on average rank; abundance separated ties in average rank; those exhibiting the same abundance and ranks had the same overall rank.

3.3. Forage Mass and Forage Nutritive Composition

The native grass forage mass reflected a three-way interaction among forage treatment, month, and year ($p = 0.04$; Table 3). The mean NWSG masses were similar ($p > 0.05$) among the treatments over the three years, except in June 2021, when FORB produced less NWSG (Figure 5). Over the three years, the NWSG forage mass generally declined each year. The Forb mass was dependent on a two-way interaction with month and year ($p < 0.01$). Forbs contributed minimally to the total forage mass in 2021 (<1%) but increased in 2022 and 2023. The weed mass differed by treatment and was dependent on a two-way interaction between month and year ($p < 0.01$). Weeds contributed minimally to total available forage mass in 2021 (<1%) and was greatest ($p < 0.05$) in 2023. Weed masses decreased ($p < 0.05$) over the 2022 season for both treatments and were similar ($p > 0.05$) among months for both CONT and FORB in 2021 and 2023.

Crude protein reflected two-way interactions between forage treatment and month ($p = 0.01$), as well as month and year ($p < 0.01$). Crude protein decreased ($p < 0.05$) throughout each grazing season within CONT but was similar throughout the season in FORB ($p > 0.05$; Figure 6). May 2022 and 2023 and June 2023 produced the greatest ($p < 0.05$) CP concentrations across both treatments. The models for NDF and ADF reflected three-way interactions among forage treatment, month, and year ($p < 0.01$). Both fiber concentrations increased over each grazing season but were generally similar among treatments most of the grazing season.

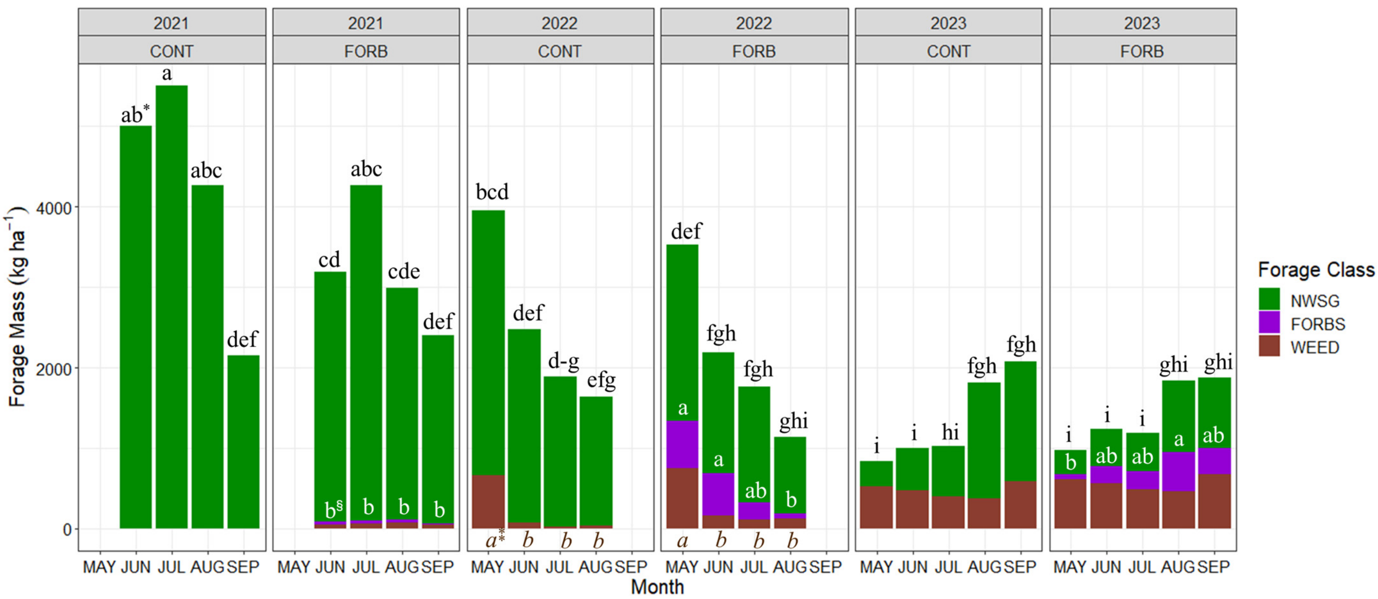

Figure 5. Mean forage mass by forage class within CONT † and FORB pastures, 2021–2023, at the East Tennessee AgResearch and Education Center, Holston Unit, Knoxville, TN, USA. † Control NWSG mixture, CONT; native warm-season grass, NWSG; forb and NWSG mixture, FORB; forb forage class, FORBS; mixed native warm-season grass forage class, NWSG; weeds forage class, WEED. * Mean forage mass of NWSG (black letters) with different letters varied ($p < 0.05$) among forage treatments, months, and years. § Mean forage mass of FORB (white letters) with different letters varied ($p < 0.05$) among months and years. ‡ Mean forage mass of WEED (italic brown letters) with different letters varied ($p < 0.05$) among forage treatments and months within year.

Table 3. Model results for the ANOVAs on the NWSG † and forb characteristics, forage mass, nutrient composition, animal performance, and pasture productivity during the experiment of the grazing CONT and FORB pastures, 2021–2023, at the East Tennessee AgResearch and Education Center, Holston Unit, Knoxville, TN, USA.

Predictor	F-Value	df	*p*-Value
	NWSG forage mass		
Forage treatment	9.77	1	<0.01
Month	1.52	4	0.20
Year	62.95	2	<0.01
Forage treatment × Month	0.61	4	0.65
Forage treatment × Year	0.81	2	0.45
Month × Year	22.05	6	<0.01
Forage treatment × Month × Year	2.28	6	0.04
	Forb forage mass		
Month	1.89	4	0.13
Year	3.44	2	0.04
Month × Year	7.82	6	<0.01
	Weed mass		
Forage treatment	5.16	1	0.03
Month	3.96	4	<0.01
Year	14.71	2	<0.01
Month × Year	4.61	6	<0.01
	CP		
Forage treatment	0.18	1	0.67
Month	14.08	4	<0.01
Year	11.94	2	<0.01
Forage treatment × Month	3.35	4	0.01
Forage treatment × Year	1.50	2	0.23
Month × Year	2.98	7	<0.01
Forage treatment × Month × Year	1.98	7	0.07
	NDF		
Forage treatment	4.51	1	0.04
Month	11.29	4	<0.01
Year	3.17	2	0.05
Forage treatment × Month	0.74	4	0.56
Forage treatment × Year	0.71	2	0.49
Month × Year	1.19	7	0.32
Forage treatment × Month × Year	3.73	7	<0.01
	ADF		
Forage treatment	0.51	1	0.48
Month	19.46	4	<0.01
Year	1.96	2	0.15
Forage treatment × Month	5.24	4	<0.01
Forage treatment × Year	2.51	2	0.09
Month × Year	0.90	7	0.51
Forage treatment × Month × Year	3.51	7	<0.01
	ADG		
Forage treatment	4.86	1	0.03
Month	107.23	3	<0.01
Year	13.98	2	<0.01
Forage treatment × Month	1.66	3	0.18
Forage treatment × Year	0.26	2	0.77
Month × Year	11.71	5	<0.01
Forage treatment × Month × Year	3.59	5	<0.01

Table 3. *Cont.*

Predictor	F-Value	df	*p*-Value
	Season-long ADG		
Forage treatment	10.32	1	<0.01
Year	4.25	2	0.02
	Animal days		
Forage treatment	9.68	1	<0.01
Year	1546.39	2	<0.01
Forage treatment × Year	10.64	2	<0.01
	Gain		
Forage treatment	7.02	1	<0.01
Year	109.67	2	<0.01

† Native warm-season grass, NWSG; control NWSG mixture, CONT; forb and NWSG mixture, FORB; crude protein, CP; neutral detergent fiber, NDF; acid detergent fiber, ADF; average daily gain, ADG.

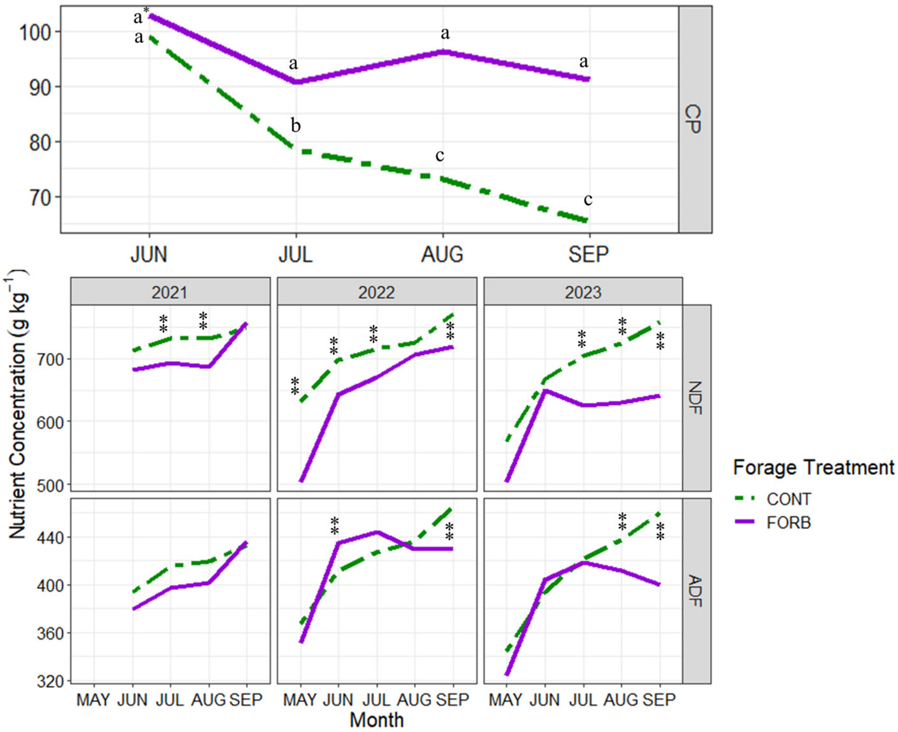

Figure 6. Mean forage nutritive composition (g kg^{-1} DM †) of grazed CONT and FORB pastures, 2021–2023, at the East Tennessee AgResearch and Education Center, Holston Unit, Knoxville, TN, USA. † Dry matter, DM; control NWSG mixture, CONT; native warm-season grass, NWSG; forb and NWSG mixture, FORB; crude protein, CP; neutral detergent fiber, NDF; acid detergent fiber, ADF. * Mean CP content among forage treatments and months without the same letter differed ($p < 0.05$). ‡ NDF and ADF contents between forage treatments within a month and year differed ($p < 0.05$).

3.4. Pasture Productivity and Animal Performance

Monthly ADG was dependent on a three-way interaction among forage treatment, month, and year ($p < 0.01$; Figure 7). Average daily gain decreased ($p < 0.05$) through the grazing season each year but remained similar among the treatments during each 28-day period, except during ADG112 in 2022 and ADG28 in 2023. Season-long ADGs and GAINs did not have significant interaction ($p = 0.76$ and $p = 0.40$, respectively) between forage treatment and year. Both season-long ADGs and GAINs were greater ($p < 0.01$ and $p < 0.01$, respectively; Table 4) for FORB each year compared to CONT. Across years, 2023 produced greater ($p < 0.05$) season-long ADGs for both treatments compared to 2021, and 2022 and

2023 demonstrated greater ($p < 0.05$) GAINs than 2021. Animal days reflected a two-way interaction between forage treatment and year ($p < 0.001$). Animal days were least during 2021 and treatments only differed in 2022 with more days in CONT than FORB ($p < 0.05$).

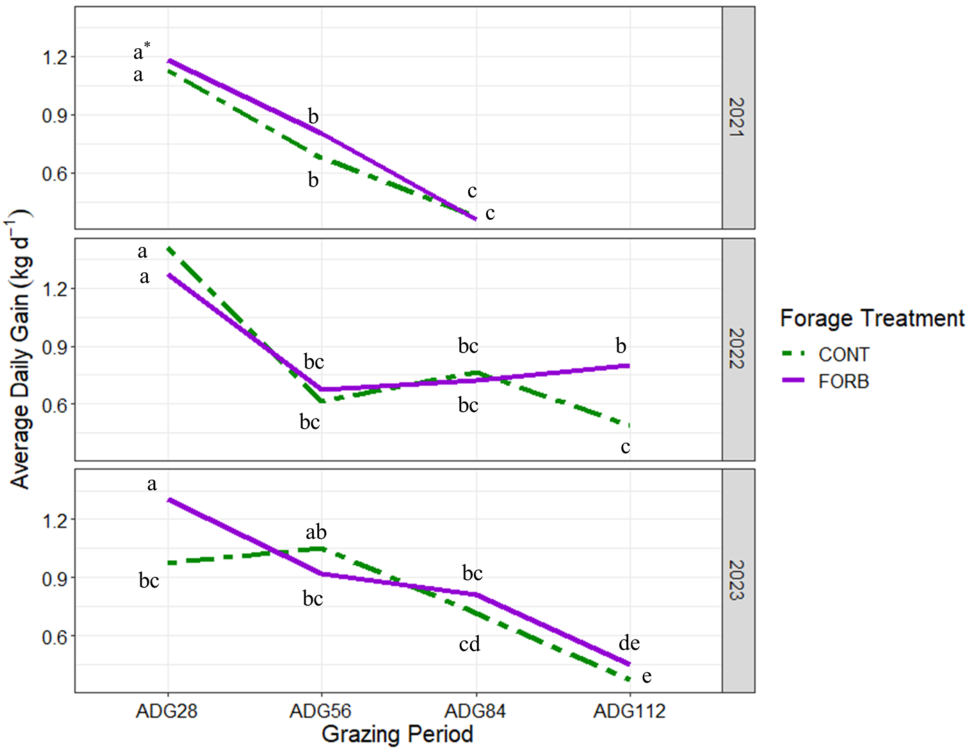

Figure 7. Average daily gain of weaned calves grazing CONT † and FORB pastures by 28-day periods, 2021–2023, at the East Tennessee AgResearch and Education Center, Holston Unit, Knoxville, TN, USA. † Control NWSG mixture, CONT; native warm-season grass, NWSG; forb and NWSG mixture, FORB; average daily gain, ADG; ADG first 28 days of grazing, ADG28; ADG second 28 days of grazing, ADG56; ADG third 28 days of grazing, ADG84; ADG fourth 28 days of grazing, ADG112. * Mean average daily gain among forage treatments and grazing periods within a year without the same letter differed ($p < 0.05$).

Table 4. Mean average daily gains (ADGs) and pasture productivities of weaned calves grazing CONT † and FORB pastures in 2021–2023 at the East Tennessee AgResearch and Education Center, Holston Unit, Knoxville, TN, USA.

Productivity Measurement	Year	CONT	FORB
Season-long ADG (kg d^{-1})	2021	0.66 ^{b,z,*}	0.73 ^{a,z}
	2022	0.71 ^{b,yz}	0.78 ^{a,yz}
	2023	0.74 ^{b,y}	0.81 ^{a,y}
AD (d ha^{-1})	2021	327 ^{c,§}	327 ^{c}
	2022	530 ^{a}	500 ^{b}
	2023	490 ^{b}	490 ^{b}
GAIN (kg ha^{-1})	2021	170 ^{b,z,*}	190 ^{a,z}
	2022	295 ^{b,y}	316 ^{a,y}
	2023	291 ^{b,y}	312 ^{a,y}

† Control NWSG mixture, CONT; native warm-season grass, NWSG; forb and NWSG mixture, FORB; average daily gain, ADG; total bodyweight gain, GAIN; animal days, AD. * Mean season-long ADG and GAIN within each year with different letters differed (a,b,c; $p < 0.05$) between treatments; mean season-long ADG and GAIN within a treatment with different letters differed (y,z; $p < 0.05$) among years. § Mean ADs across years and forage treatments with different letters differed ($p < 0.05$).

4. Discussion

The inclusion of forbs in NWSG pastures demonstrated varying degrees of agronomic and animal productivity benefits. Although NWSG tiller and forb densities decreased in FORB after the first season, NWSG plant densities and forage mass remained similar to CONT. Low stocking density during this study allowed for increased selectivity, which resulted in increased weed forage mass but reduced NWSG forage mass in both treatments. Similarly, plant vigor (as indicated by tillers per plant) dropped in both treatments over the course of the study. On the other hand, forb mass increased as a diversity of forbs established over the three years. Forage nutritive composition reflected more stable CP levels throughout the season in FORB compared to the typical seasonal decline in CP observed in CONT. Animal productivity reflected this stability in forage quality, with greater season-long ADG and GAIN demonstrated in FORB without a drop in grazing days. Thus, this diverse system had positive implications for forage and animal production while also developing a diverse landscape for critically important pollinators.

4.1. NWSG and Forb Density

The plant density of native forbs decreased between 2021 and 2023, likely in part due to the seasonal fluctuations in the different forb species and grazing selection. However, forb mass increased from 2021 to 2023, in contrast to the reduction in total forage mass with both treatments. Both the CONT and FORB paddocks were continuously grazed each season, with a relatively low (888 ± 54 kg ha^{-1}) stocking density for these NWSG pastures (1200–1500 kg ha^{-1}; [27]). This lower stocking led to an increase in grazing selectivity for all species, which highlighted the steer grazing preference for the different forbs and may have increased pressure on NWSGs, further allowing forbs to establish and develop. Despite the increase in forb mass, after three grazing seasons under similar continuous low-stocking management, the stands exhibited reduced plant vigor (40 tillers per NWSG plant in 2021 to 20 tillers per plant in 2023), thereby reducing future forage availability and stand longevity. In addition to the stocking density, the application of continuous grazing at this density amplified selectivity of cattle by allowing repeated grazing of preferred forages, while less preferred forages were able to increase in maturity [44]. Over time, overgrazed plants will expend root stores and, consequently, plant productivity, vigor, and persistence will also be reduced. Further, weakened plants in our study resulted in more exposed soil and, in turn, encroachment of species able to tolerate a lower grazing horizon such as white clover (*Trifolium repens* L.) and not readily grazed weeds like small barley (*Hordeum pusillum* Nutt.) and marestail (*Erigeron canadensis* L.; [45,46]), which further reduced forage mass.

Native warm-season grass tiller density decreased after spring 2021 for both forage treatments, though the decrease was less pronounced for CONT. Aside from grazing selectivity, the change in NWSG tiller densities in the FORB treatment was likely due to forb competition and an increase in weed encroachment. Forbs were interseeded into an established NWSG stand and populated natural gaps between the native bunchgrasses. We hypothesized that areas with higher NWSG tiller density would have minimal forb presence compared to areas with lower NWSG tiller densities and more substantial gaps between grass plants, a concept demonstrated in an NWSG stand when interseeded with red clover (*Trifolium pratense* L.; [26]). However, over the three years, forb density was positively correlated with tiller density ($\tau = 0.46$, $p < 0.01$). This trend could have been unduly influenced in 2021, because the forb population density and NWSG tiller density were greater and the forb plants were small (<5 cm). However, this correlation was also observed in 2022 and 2023 when the NWSGs and forb density decreased and forb mass increased compared to 2021. Compared to red clover [26], though, many of the native forbs demonstrated taller growth, increased tillering, and more competition toward the tall-growing NWSGs. This competitive quality likely allowed for the establishment of MSUN, OSUN, CUPP, and PURC. Comparatively, species like LCOR, BESU, PTTF, and STTF established high populations of smaller plants shortly after seeding, allowing them to compete for space. In particular, the biennial BESU and the short-lived perennial LCOR are prolific reseeders and persisted by flowering for long periods during the summer [40] and producing high quantities of seeds.

Although there was a reduction in the forb population density from 2021 to 2023, most of the initial population was made up of small BESU and LCOR plants (<2.5 cm tall) that established basal rosettes the first year before blooming in the second and third years. Native forbs also demonstrate varying rates of dormancy [47,48]. Cold temperatures or physical scarifications are typically required to break dormancy and enable emergence [47,48]. Because of the timing of spring seeding in 2021, seeds were not naturally exposed to cold temperatures or a freeze–thaw cycle to break dormancy until the winter of 2021–2022. Also, the increase in height, tillering, and species representation of the forbs in 2022 and 2023 may have contributed to the decrease in plant density and increase in plant mass.

The increase in plant diversity resulting from the introduction of a variety of native forbs into an NWSG stand also provides environmental benefits that may reduce input requirements. The incorporation of legumes, in this case STTF and PTTF, can increase soil nitrogen and reduce the need for inorganic N fertilizers [49]. While NWSGs respond to increased N [50], they have higher N-use efficiency [51], and respond less to N application compared to cool-season species [52]. Although the response of native forb to N has not been documented, the C_4 characteristics of most of the forbs (LCOR is a C_3) we evaluated suggest similarly frugal characteristics as NWSGs, thereby reducing the need for N amendments. Reducing such inputs decreases competition for undesirable species like cool-season grasses and forbs that derive greater benefit from fertilizer inputs. Reduced weed presence can improve establishment of native forbs and enhance forage production across the grazing season. Increasing pasture diversity reduces the need for soil amendments, improves soil organic matter content and water retention [16], and increases net primary productivity, N retention, and soil microbial diversity [9,15] compared to monoculture pastures, as well as pastures primarily composed of non-native forages.

4.2. Forb Flowering and Grazing Characteristics

Forb emergence, establishment, and persistence varied among the 18 forb species and was likely due to a variety of agronomic and environmental conditions. Black-eyed Susan exhibited the longest flowering window, similar to previous observations in East Tennessee [40], which, when combined with their prolific seed production, maintained plant populations over the three seasons. Purple coneflower, LCOR, and UPPC were the next most frequent flowering species; however, UPPC was not observed until the second season and in larger numbers until the third season. Each of these species have relatively long flowering windows, but as perennials, the formation and rooting of their basal rosettes likely contributed to their ability to compete and persist. Similar to PURC and UPPC, four other species (CUPP, MSUN, OSUN, and Canada goldenrod [CAGO]) also began by developing rosettes before maturing the following season. Of these species, CUPP was the most obvious in its developmental stages. Cup plant developed two-leaved rosettes 2.5–5.0 cm tall in the first season, followed by larger, more complex four- to six-leaved rosettes the second season, and then tall (>100 cm), thick (~2.5 cm diameter) stems and flowering in the third season. The development of a basal rosette for two years improves competitive position compared to species that relied on early and frequent flowering and thus, resulted in greater persistence. Rosette development allows the plant to acquire the necessary resources it needs including above ground space, root space, and sunlight [53]. Thus, the persistence of perennials brings greater stability to the system and ongoing reproduction (i.e., floral resources) in subsequent growing seasons.

Multiple species were not observed or only observed infrequently over the course of this study. Illinois bundleflower, PDOC, PLAC, partridge pea (PPEA), PUPC, RHBC, SLBC, and WHPC did not establish when interseeded into the NWSG stand. The small seed sizes of the ILBF, PUPC, RHBC, SLBC, and WHPC, the shallow optimal seeding depth (1–1.5 cm), and the presence of thatch (we were not able to burn the sites prior to seeding) may have restricted emergence. Fire may have improved establishment success for these species by reducing thatch and, consequently, increasing the availability of sunlight, heat, and nutrients [54]. Additionally, seeding native legumes (ILBF, RHBC, SLBC, and PUPC) concurrently with the NWSGs has shown greater success in binary mixtures [55,56]; however, the proportion of mass made up of legume forage varied based on the seeding rate, planting method, and the type of native grass.

Forbs were present from May to until late September, and the flowering frequencies varied each month. Forbs primarily flowered from June until early September, but each species exhibited differing flowering windows. Early flowering species included LCOR, BESU, and OSUN, while late flowering species included MSUN, CUPP, and CAGO. Early season flowering forbs tended to have longer flowering periods [40], which for BESU and LCOR may be attributed to their being biennial or short-lived perennials, or LCOR's early initiation of growth as a cool-season species. Because these species persist via reseeding, early and multiple blooms over longer periods afford them the most success, compared to perennial species like MSUN and CUPP, which use much of the season's energy on growth before blooming later in the summer.

The abundance, persistence, flowering, and grazing qualities of forbs can be used to determine the species most suitable for NWSG pasture conditions, and selection can vary based on objectives. Incorporating the readily established, persistent and long-flowering BESU and LCOR would provide high quantities of blooms during the early establishment years to improve pollinator resources, and they were some of the least likely to be heavily grazed. Lanceleaf coreopsis has also shown to be highly preferred by native pollinators in TN [36], further supporting its inclusion in NWSG pastures. Although PTTF and STTF had high abundance overall and are desirable legumes, the high grazing selectivity for these species would primarily contribute to grazing nutrition rather than floral resources for pollinators.

Incorporating a variety of forbs into an NWSG pasture can meet multiple goals, diversify the system as a whole, and contribute to improved soil health [9,15,16]. To broaden the flowering window, early (BESU and LCOR), middle (PURC and OSUN) and late (MSUN and CUPP) flowering species could be included. Collectively, these species could support pollinators throughout the growing season. In the long term, incorporating annual (PPEA), biennial (BESU), and short-lived perennial (LCOR) species combined with perennial species will produce forage and floral resources in the near term, as well as for an extended number of years. Lastly, choosing a balance of species that will or will not be readily grazed can provide cattle forage (STTF, PTTF, OSUN, and CUPP) or support pollinators through maturation and flowering (BESU, CAGO, and LCOR). Overall, a blend of BESU, LCOR, PURC, OSUN, STTF/PTTF, MSUN, and CUPP could nutritionally support grazing cattle, provide floral resources for pollinators, and increase plant biodiversity in NWSG pastures.

4.3. Forage Mass and Forage Nutritive Composition

Forage mass over the grazing season was influenced by pasture management. The 2021 grazing season exhibited greater forage mass compared to 2022 and 2023 despite being primarily composed of NWSGs. However, this difference is likely due to the delayed grazing initiation (27 May) compared to 2022 (4 May) and 2023 (25 April). This delay, combined with the continuous grazing management and low stocking density allowed the NWSGs to accumulate mass and mature earlier in the season. Forbs and weeds contributed <1% of the forage mass in the FORB treatment in 2021 and increased in 2022 and 2023. Despite the growing proportion of weeds and forbs, FORB consistently produced similar forage mass to CONT, differing only in June 2021. The mean NWSG mass in 2021 was similar to the monthly mean mass produced by the same stand during a previous grazing experiment (2340–3909 kg ha^{-1}; [29]). However, 2022 and 2023 had lower forage mass, potentially in part due to a higher number of ADs in this experiment in 2022 and 2023 and the greater selectivity created by the lower initial stocking density compared to previous research at this site (368–393 d ha^{-1}; [29]). This reduction in NWSG mass also further demonstrated the selective grazing pressure and subsequent stand weakening (30–40% reduction in tiller density) observed at the end of the three grazing seasons. The increase in undesirable weed mass from 2021 (<1%) to 2023 (22–70% in CONT and FORB) also highlighted the change in stand composition and increased grazing selectivity for the NWSGs, thereby opening stand gaps for weed encroachment [45,46], which further emphasizes the need for appropriate stocking strategies to maintain desirable forage mass. Although forb plant densities decreased over the three growing seasons, the size of the forbs increased, as measured by increases in total forb mass in 2022 (24%) and 2023 (28%) compared to 2021 (<1%). The need to break seed dormancy, whether through natural processes or before seeding by scarification or cold stratification, is further supported by the increase in forb mass during the second and third grazing seasons compared to the first grazing season.

Crude protein, NDF, and ADF displayed predictable trends over each grazing season and, like forage mass, can be largely dependent on forage management and forage maturity [57]. In 2021, the concentrations of CP, NDF, and ADF were generally similar among treatments due to the similar forage compositions. The FORB treatment maintained higher CP concentrations later in the season compared to CONT. The neutral detergent fiber tended to be lower during most of the season for FORB compared to CONT. The lower concentrations of NDF in July and August 2021 for the FORB treatment could have been due to a less mature stand, which could be the result of high grazing pressure. Acid detergent fiber differed later in the season, with FORB being lower than CONT. These differences in 2022 and 2023 can be attributed to the growing concentration of forb forage mass the last two grazing seasons. Forbs have shown to have moderate to high (105–189 g kg^{-1} DM) CP concentrations and low (<410 g kg^{-1} DM) NDF and ADF concentrations [40]. Combining forbs with NWSGs that tend to have low to moderate (81–147 g kg^{-1} DM) CP, high (56–78 g kg^{-1} DM) NDF, and high (35–45 g kg^{-1} DM) ADF [27,29] stabilizes the CP and fiber concentrations throughout the grazing season, as the forbs mature differently than the grasses. Forbs also produce more CP and lower fiber concentrations throughout maturity than high-production grasses like NWSGs [58]. The stabilization of CP and reduction in fiber toward the end of the grazing season, in particular, is advantageous to graziers seeking to improve gains and ease the transition from fiber-dense C_4 pastures to lower-fiber C_3 pastures in the fall by maintaining a ruminal microbiome most suited to both forage types [59]. The improvement in forage quality later in the season in the FORB treatment can also reduce the reliance on supplemental feeds.

4.4. Pasture Productivity and Animal Performance

Average daily gains across the grazing periods were similar between the CONT and FORB treatments, except in late 2022 and early 2023 when FORB produced higher ADGs. Both treatments exhibited similar, declining trends in ADG as the season progressed and were comparable to previous work on grazing of similar blends of NWSG [26–29]. Despite the similarities in ADGs during distinct grazing periods, season-long ADG was greater for calves grazing FORB each year. The stable CP and lower fiber concentrations of the FORB forage may have stabilized the ADGs across the season to produce higher overall ADGs. This pattern was also reflected in the greater GAINs in FORB compared to CONT each year. Animal days were similar in 2021 due to grazing for the same lengths of time for both treatments. However, ADs were the greatest in the CONT treatment in 2022, perhaps due to a lower grazing preference of the established forbs in FORB and subsequent reduction in NWSG mass. Animal days were also greater in 2022 and 2023 compared to 2021 because grazing length was determined by forage availability and not a set schedule, which allowed cattle to graze both earlier and later in the season to maximize forage utilization. Although the pastures were grazed longer, grass utilization appeared more uneven during the longer seasons, when cattle had greater time to selectively graze more vegetative patches. Overall, the inclusion of forbs produced higher season-long ADGs and GAINs; however, forage management (e.g., continuous and low-density grazing) of both treatments, ultimately, determined the quantity, quality, and maturity of forage available to produce the gains long term.

4.5. Limitations and Further Study

This study illuminates the differences in pasture and animal productivity in continuously, lightly stocked CONT and FORB paddocks. Although continuous grazing is common among backgrounding operations in the eastern U.S. and has been successfully demonstrated with NWSGs [29], stocking density and adjustments are necessary to consider. Adjusting initial stocking, or using rotational stocking throughout the season, should be applied to maintain NWSGs in a vegetative state throughout much of the season. Grazing selectivity should be minimized to improve stand longevity, reduce weed encroachment, and perhaps improve forb utilization. Patch-burn grazing is another grazing strategy that can be used on NWSG stands [60]. However, the utilization of rest or different stocking densities through rotation or burning have not been explored in a diverse NWSGs and forb pasture system and opens the door to future study. Furthermore, adjusting grazing season length, and thus ADs, based on pasture condition alongside stocking and rotational management methods could also improve stand utilization and longevity. This research sought to adjust grazing season length based on stand condition in 2022 and 2023. However, stocking density was not high enough for uniform grazing and season-long sustainability of the entire paddocks, which may have led to an increase in selectivity that was further highlighted by the longer season length. Therefore, a combination of pasture rest, stocking density, and stocking rate should be explored in diverse native pastures.

5. Conclusions

Forbs showed varying degrees of establishment, persistence, flowering window, and grazing preference when incorporated into continuously, lightly stocked NWSG pastures. To nutritionally support grazing cattle, provide floral resources for pollinators, and increase plant biodiversity, a blend of BESU, LCOR, PURC, OSUN, STTF/PTTF, MSUN, and CUPP can be interseeded into NWSG pastures. The diverse FORB pastures consistently produced high-quality forage and greater season-long ADGs and GAINs. Interseeding forbs into NWSG pastures improves biodiversity and can support both growing cattle and critical pollinators in a dual-purpose system.

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