Received: 11 May 2021 | Accepted: 28 December 2021 | Published online: 16 March 2022

DOI: 10.1002/agj2.21001

Agronomy Journal

ARTICLE

Crop Economics, Production, and Management

Transitional organic forage systems in the southeastern U.S.: Production and nutritive value

Jonathan O. C. Kubesch[1] | **Renata L. G. Nave**[2] | **Song Cui**[3] | **Gary E. Bates**[2] | **David M. Butler**[2] | **Vince Pantalone**[2]

[1]Dep. of Crop Sciences, Virginia Tech Univ., Blacksburg, VA 24061, USA

[2]Dep. of Plant Sciences, Univ. of Tennessee, Knoxville, TN 37996, USA

[3]Dep. of Plant and Soil Science, Middle Tennessee State Univ., Murfreesboro, TN 37132, USA

Correspondence
Renata Nave, Dep. of Plant Sciences, Univ. of Tennessee, Knoxville, TN 37996, USA.
Email: rnave@utk.edu

Assigned to Associate Editor Patrick Carr.

Abstract

Limited work has been done to develop organic forage programs in humid subtropical regions despite growing demand for high-value forage and organic products. Alternative crops were compared for optimizing forage production and nutritive value under organic conditions in the southeastern United States. The study was conducted at the Middle Tennessee AgResearch and Education Center, in Spring Hill, Tennessee. Forage treatments consisted of (a) monoculture tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.], (b) monoculture bermudagrass [*Cynodon dactlyon* (L.) Pers.], (c) tall fescue and alfalfa (*Medicago sativa* L.) mixture, (d) bermudagrass and alfalfa mixture, and (e) an annual rotation of winter wheat (*Triticum aestivum* L.) mixed with winter pea (*Pisum sativum* L.) followed by sorghum–sudangrass [*Sorghum bicolor* (L.) Moench *x S. sudanese* (Piper) Stapf.] mixed with cowpea [*Vigna unguiculata* (L.) Walp.] mixture. Perennial treatments were established during the 2017–2018 growing season. Monthly production was measured in the 2018–2019 and 2019–2020 growing seasons. Botanical composition of forage mass fluctuated due to establishment dynamics and weed competition, affecting forage quantity and quality. The annual rotation was the highest-yielding treatment, producing more than 6,000 kg^{-1}, though each tall fescue and tall fescue–alfalfa treatments produced ∼4,000 kg ha^{-1}. Nutritive value was sufficient for most livestock operations, with forage crude protein concentration averaging ∼150 g kg^{-1} across treatments and growing seasons. For transitioning organic producers, a perennial forage will likely favor long-term sustainability, whereas the annual rotation may be useful during the transition period to reduce weed pressure before transitioning to a perennial forage system.

Abbreviations: aNDF, amylase-treated neutral detergent fiber; CP, crude protein; DM, dry matter; FM, forage mass; IVDMD48, 48-h in-vitro dry matter digestibility; MTREC, Middle Tennessee AgResearch and Education Center.

1 | INTRODUCTION

Organic production in the United States is increasing due to greater consumer awareness and corresponding demand (Crowder & Reganold, 2015). Despite a growing desire for forage and organic products nationally (Wieme et al., 2020), limited work has been done to develop organic forage programs, particularly in the southeastern United States and especially on methods when transitioning to organic production. Determining adequate management during the transition period can aid producers wanting to transition their operations from conventional to organic production.

Suppressing weeds can be difficult when transitioning to organic production. As a result, weed populations may increase dramatically without the control provided by synthetic herbicides that are prohibited under organic management (Brainard et al., 2011; Liebman & Davis, 2009). Weed suppression occurred when growing forages in previous research. For example, annual and perennial forages were as effective as synthetic herbicides when growing wheat in controlling wild oat (*Avena fatua* L.) and in suppressing several broadleaf weeds, depending on the forage species (Schoofs & Entz, 2000). Moreover, grain yield of the following pea (*Pisum sativum* L.) crop was sometimes greater following forages than the sprayed wheat crop (Schoofs & Entz, 2000). These results suggest that production of forage crops when transitioning to organic production can be an attractive alternative to growing annual grain and seed crops.

Literature on organic forages tends to focus on growing these crops for dual cover–forage use or within sod-based rotations (Delate, 2009; Delate & Cambardella, 2004; Kristiansen & Merfield, 2006; Liebman & Davis, 2009; Mohler, 2009; Porter, 2009). Recently, forage crops were evaluated within the context of diversified production systems rather than as permanent pasture or hay land (Eichler-Inwood et al., 2015). However, the USDA National Organic Program requires that grazing animals under organic production must maintain at least 30% of dry matter (DM) intake from direct pasture grazing within each grazing season. Therefore, grasslands dedicated for organic forage production are crucial in these systems.

Common forage species in the southeastern United States include perennial grasses such as tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.] and bermudagrass [*Cynodon dactlyon* (L.) Pers.]. Tall fescue is the most widely adapted cool-season grass in the region, though warm-season species like bermudagrass are better suited for summer months (Quinby et al., 2021). Furthermore, legume–grass mixtures are known to provide consistent forage mass (FM) with high nutritive value when compared with grass monocultures (Sleugh et al., 2000). Therefore, the use of legume species, such as alfalfa (*Medicago sativa* L.), mixed with grasses can increase the amount of available forage while reducing the need for N fertilization due to the legume's ability to fix atmospheric N. Rotations of annual cool- and warm-season grasses and legumes can also provide large amounts of high-quality forage during the growing season, but these species must be reseeded each year. Species used in annual rotations in the southeastern United States include winter wheat (*Triticum aestivum* L.), Austrian winter pea (*Pisum sativum* L.), sorghum–sudangrass [*Sorghum bicolor* (L.) Moench × *S. sudanese* (Piper) Stapf.], and cowpea [*Vigna unguiculata* (L.) Walp.].

There is often a FM penalty when transitioning to organic methods, in part because synthetic fertilizers can no longer be used (Brandao et al., 2012; Mohler, 2009; Porter, 2009). Oftentimes, fertility is limited to the biological N fixation that occurs when growing legumes and the N mineralized from soil organic matter (Chapin III et al., 2011; Cooperband, 2002; Magdoff & van Es, 2009). In addition, poor weed control can occur during the transition phase as mentioned previously, resulting in FM depression, though reductions are generally less when growing forages than grain crops (Kniss et al. (2016). Crops grown under organic management must be competitive with weeds (Brainard et al., 2011; Davies et al., 2012; Lammerts van Bueren & Verhoog, 2006; Liebman & Davis, 2009), establish quickly, and form closed canopies or thick sods (Liebman & Davis, 2009). Of the existing forage species generally used in the southeastern United States, some species (e.g., tall fescue) may provide a smoother transition than others [e.g., orchardgrass (*Dactylis glomerata L.*)] due to superior vigor, productivity, and persistence (Buckner at al. et al., 1979).

The present study evaluated five potential treatments for transitional organic forage production in the southeastern United States: two perennial grass monocultures, two perennial grass–alfalfa mixtures, and an annual relay-crop system where a cool-season cereal–legume mixture was followed by a warm-season cereal–legume mixture. The goal was to determine FM and quality of alternative perennial grass and grass–legume mixtures, along with an annual forage rotation, when transitioning to organic production methods. We hypothesized

Core Ideas

- Forages have advantages to grain crops when transitioning to organic production.
- Forage species selection is a key consideration in transitional organic production.
- Weed competition with forages varies depending on forage functional groups.
- Annual forages in rotation are highly productive species in transitioning programs.

that the annual relay crop system consisting of four species (i.e., winter wheat, Austrian winter pea, sorghum–sudangrass, and cowpea) provided greater FM while maintaining forage nutritive value compared with the representative warm- and cool-season perennial species.

2 | MATERIALS AND METHODS

2.1 | Site description and management

The study was conducted at the Middle Tennessee AgResearch and Education Center (MTREC) in Spring Hill, TN, in the southeastern United States (35.68˚ N; 86.91˚ W; 247 m asl). The Köppen climate classification (Kottek et al., 2006) for Middle Tennessee is predominately humid subtropical (Cfa) with warm-to-hot summers and cold-to-mild winters. The experimental site was transitioned to and later certified as organic during the experimental period by Quality Certification Services. Historically, the site was part of an orchard managed using conventional practices with trees distributed uniformly across the experimental area. Trees were removed in 2016, and the site remained fallow until the start of the study in October 2017.

The experimental area totaled 0.405 ha consisting of individual plots, alleys, and borders. There were 20 experimental units that were each 1.3 m × 3.9 m, arranged in a randomized complete block design with four replications, such that soil type was a blocking factor. Two blocks were situated on Huntington silt loam (fine-silty, mixed, active, mesic Fluvenic Hapludolls; NRCS, 2019) while the other two blocks were on Maury silt clay loam (fine, mixed, active, mesic Typic Paleudalfs; NRCS, 2019). Approximately 30 samples were collected at random throughout the area prior to establishment of the plots and composited to a 6-in depth; soil analyses indicated a pH = 6.3, P = 63 mg kg^{-1}, K = 160 mg kg^{-1}, Ca = 1009 mg kg^{-1}, and Mg = 161 mg kg^{-1}, determined by Mehlich 1 extract.

The site was moldboard-plowed from 12 to 16 Oct. 2017. Tree roots were then removed using a backhoe (New Holland Company), followed by a tillage pass using a disk harrow (Deere & Company) to disintegrate soil clods and smooth the surface. A tractor-mounted rotary tiller box (Deere & Company) prepared the seedbed for planting. The planted treatments included two perennial grass monocultures (tall fescue 'Kentucky 31' and bermudagrass 'Cheyenne II'), two perennial grass–legume mixtures (tall fescue–alfalfa 'WL 358 LH' and bermudagrass–alfalfa), and an annual rotation (winter wheat 'LG 334 SRW' and Austrian winter pea) mixture followed by a sorghum–sudangrass 'AS 6501' and cowpea 'Iron & Clay' mixture.

On 27 Oct. 2017, tall fescue was drill-seeded at 22 kg ha^{-1} using a Hege 1000 series drill (Hege Company) into designated monoculture and mixture plots. The tall fescue–alfalfa plots were mowed to a 7.5-cm stubble height before drill-seeding the legume at 17 kg ha^{-1} on 16 Mar. 2018 (Quinby et al., 2020). Alfalfa was drill-seeded into designated bermudagrass plots on this same date. Bermudagrass plots were rotary-tilled, cultipacked with a Brillion cultipacker (Landoll Company, LLC.), and then hand-broadcast on 4 June 2018. Because of initial establishment problems due to dry seedbed conditions resulting from drought, alfalfa was drill-seeded again into tall fescue–alfalfa and bermudagrass–alfalfa plots on 14 May 2019 at the same rates described previously. Similarly, all bermudagrass plots were hand-broadcast again on 14 May 2019 at the same rates described previously because of poor initial establishment.

The annual rotation plots were established on 10 Oct. 2018 for the first growing season (2018–2019), with the cool-season annual mixture drill-seeded at a rate of 112 kg ha^{-1} winter wheat and 56 kg ha^{-1} Austrian winter pea, and subsequently on 8 Oct. 2019 for the second growing season (2019–2020). The warm-season annual mixture was drill-seeded on 5 June 2019 at a rate of 34 kg ha^{-1} sorghum–sudangrass and 84 kg ha^{-1} cowpea and subsequently on 2 June 2020. Plots for the annual rotation were drill-seeded using a Tye Estate Planter drill (The Tye Co.). The cool-season annual mixtures were terminated on 27 May 2019 for the 2018–2019 growing season and on 25 May 2020 for the 2019–2020 growing season. The warm-season annual mixtures were terminated on 1 Oct. 2019 for the 2018–2019 growing season and on 9 Oct. 2020 for the 2019–2020 growing season. Both cool- and warm-season annuals were terminated using a rotary tiller.

Fertility management began on 7 Mar. 2019 with the application of boron and horse manure. The manure was acquired from a small horse paddock system maintained at the MTREC that does not receive substances prohibited ubder USDA National Organic Program guidelines. The manure was collected and stored in a walk-in cooler from 8 Feb. 2019 to 4 Apr. 2019 and from 3 Feb. 2020 to 3 Apr. 2020. Representative samples were taken from the collected manure prior to application and sent to the University of Arkansas Agriculture Diagnostic Laboratory for analysis. Laboratory analyses for the horse manure indicated P (1 g kg^{-1}), K (1 g kg^{-1}), and Ca (4 g kg^{-1}) concentrations were the same in both 2019 and 2020 and similar for pH (7.7 and 8.0), moisture content (72 and 73%), NO_3–N (35 and 44 mg kg^{-1}), and total N (3 and 2 g kg^{-1}) levels. Conversely, NH_4–N concentration was greater in 2019 than in 2020 (112 vs. 23 mg kg^{-1}). Horse manure was applied at 84 kg ha^{-1} N on a DM basis to the tall fescue monoculture plots on 7 Mar. 2019 and 5 Mar. 2020 and to the bermudagrass monoculture plots on 4 Apr. 2019 and 3 Apr. 2020. Boron (Maxi Granular Boron 15%, Cameron Micronutrients) was applied at 2 kg ha^{-1} to all mixed perennial plots with approval by the Quality Certification Services organic certifier.

2.2 | Botanical composition and species richness

Botanical components consisted of planted grass species, planted legume species (if present), and weeds (grass, legume, and broadleaf species combined) collected during the growing season in 2019. In 2020, the weed component was separated into additional grass, legume, and broadleaf species. Prior to plot harvesting each month, aboveground biomass of two 0.1-m^2 quadrats placed randomly in each plot was collected on 4 April, 3 May, 4 June, 1 July, 6 August, and 4 September in 2019 and on 3 April, 7 May, 2 June, 1 July, 4 August, and 1 September in 2020. These samples were cut to a 5-cm stubble height and separated into forage crops and weed components. Samples were dried at 60 ˚C for 72 h to a constant weight, grass, legume, and weed component weights were recorded, and the proportions to total quadrat DM were computed. If the weighed material was not detected by the scale (<0.1 g), then the species were recorded as zero. An average DM weight of the samples collected in each plot was recorded.

Weed species richness, defined as the number of weed species in each plot as well as the richness by functional grouping (grass, legume, or broadleaf weed), was compared among treatments and years to complement general botanical composition measurements. Species richness identification occurred in each plot on 1 July 2019 and 1 July 2020 using the identification guide of Bryson and DeFelice (2009). Categories of weed species richness were set by equally subdividing the range of species richness values observed in 2019 and 2020. Total species richness and broadleaf weeds species richness were divided into three categories: Low (0–3 species), Medium (4–6 species), and High (>6 species). Grass species richness was divided into Low (<3) and High (>3) categories. Legume species richness was divided into None (<1) and Present (>1) categories. Categorical weed analysis was conducted based on the species counts within treatments and years.

2.3 | Measurements

Forage mass was determined using a Swift silage flail chopper (Heavy Duty Walk Behind Forage Harvester, Swift Machine & Welding Ltd.) equipped with an on-board electronic weighing system. A 0.7 × 3.9 m strip was cut from the center of each plot and FM recorded from April through September during both years. Border material of each plot was cleaned off after harvest. A stubble height of 7.5 cm was set for all species except for the warm-season annuals, which were harvested at a 15-cm stubble height to avoid the removal of the apical meristem and enhance regrowth. Harvests for the 2019 growing season (April through September) began on 4 April for the annual rotation as well as tall fescue monoculture and mixtures and then subsequently for all treatments (including warm-season perennial treatments) on 3 May, 4 June, 1 July, 7 August, and 5 September. Harvests for the 2020 growing season were conducted on 3 April for annual rotation and tall fescue treatments only and for all treatments on 7 May, 2 June, 1 July, 4 August, and 1 September.

The fresh weight of each subsample was determined following harvest using the flail chopper, and then samples were dried for 72 h at 60 ˚C to constant weight for determination of moisture content at harvest and total DM FM. Subsamples were then ground using a Wiley Mill Grinder (Model 4, Thomas Scientific) with a 1-mm screen, with additional grinding using a Cyclone Sample Mill (UDY Corporation), then scanned for crude protein (CP), amylase-treated neutral detergent fiber (aNDF), and 48-hr in-vitro DM digestibility (IVDMD48) concentration determination using a Unity SpectraStar XL-R near-infrared spectroscopy instrument and software InfoStar version 3.11.3 (Unity Scientific). Samples were analyzed using the 2018–2020 Grass Hay calibrations developed by the Near-Infrared Spectroscopy Forage and Feed Consortium. The global *H*-value statistical test compared the samples against the model and other samples within the database for accurate results, where all forage samples fit the equation with $H < 3.0$, and are reported accordingly (Murray & Cowe, 2004).

2.4 | Statistical analysis

2.4.1 | Continuous data

Analyses were conducted using PROC GLIMMIX from the SAS statistical software package (Version 9.4, SAS Institute). Total annual FM, monthly FM, nutritive value measurements (CP, aNDF, and IVDMD48), and botanical composition (proportion of grass, legumes, and weeds) were evaluated by ANOVA. The five forage treatments and year were considered fixed effects. Block and block × treatment interaction were considered random effects. There were significant year × treatment interactions ($P < .0001$); therefore, results are displayed separately by year. Residual normality was tested using the Shapiro-Wilk test as a requisite assumption of ANOVA. The alpha was set at .05 for statistical significance evaluation in all cases. Fisher's least significant difference test was used for mean separation. Forage mass and the derived nutritive value were analyzed within each month.

2.4.2 | Categorical data

Weed species counts were analyzed categorically. Weed presence was determined by identifying which weeds were present in most plots for each treatment and compared between

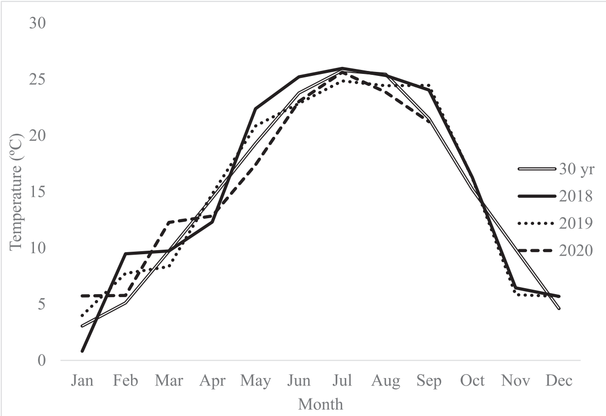

FIGURE 1 Average monthly air temperature (°C) for Middle Tennessee AgResearch and Education Center, Spring Hill, TN, 2018–2020 including the 30-yr average

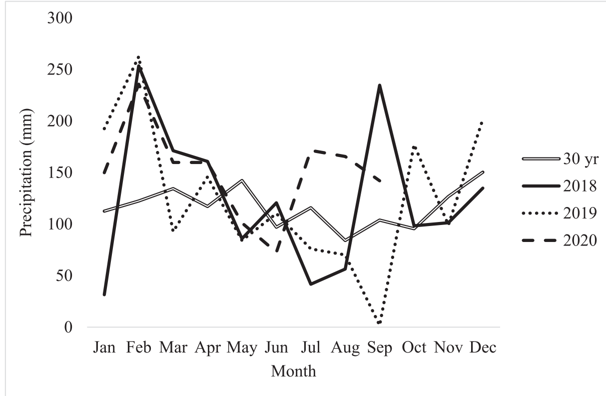

FIGURE 2 Average monthly precipitation (mm) for Middle Tennessee AgResearch and Education Center, Spring Hill, TN, 2018–2020 including the 30-yr average

treatments (when present). Species richness and richness by functional grouping (grass, legume, or broadleaf weed) were also compared by categorical weed analysis based on the species counts within treatments and years using Fisher's exact test. Fisher's exact test was chosen rather than Chi-square test because of the limited number of observations, which would subsequently limit the expected counts (McDonald, 2014). Plots were categorized within treatment or year on the basis of these levels and then analyzed.

3 | RESULTS AND DISCUSSION

3.1 | Weather

Mean temperature and monthly rainfall during the study were collected from the MTREC weather station located on-site within 0.2 km of the field experiment. In 2018, which was the establishment year for the cool-season perennial treatments, temperature was above the 30-yr average (1981–2010) during much of the April through September period, whereas lower-than-average temperatures occurred in 2020 (Figure 1). Air temperature in 2019 hovered near the 30-yr average, except during late summer through early fall when warmer-than-average temperatures were recorded. Precipitation variability across and within years created agronomic challenges, as was observed in previous forage research at the MTREC (Nave et al., 2019; Nave & Corbin, 2018). Early spring generally was wetter than the 30-yr average in all three years, while drier-than-average conditions occurred in May (Figure 2). The dry conditions persisted through June in 2020, while wetter-than-average conditions developed and continued through October that year. Conversely, wet conditions occurred during June in both 2018 and 2019, followed by an extended dry period during July and August. Wet conditions returned in September during 2018, while dry conditions persisted in 2019 until October. Overall, precipitation generally favored forage production in 2020, while dry conditions in 2018 and particularly 2019 resulted in drought-induced forage depression.

TABLE 1 Total forage mass (FM) of five forage treatments during two consecutive years under an organic forage system in the southeastern U.S.

Treatment	Total FM 2019	Total FM 2020
	———kg ha^{-1} yr^{-1}———	
Annual rotation[a]	7,020 A	6,501 A
Bermudagrass	2,949 B	2,251 B
Bermudagrass–alfalfa	4,863 B	3,796 B
Tall fescue	4,211 B	3,976 AB
Tall fescue–alfalfa	4,052 B	4,128 AB
P-value	<.01	<.01
Standard error	507	574

Note. Within a column, means not sharing a common letter are significantly different ($P \geq .05$) based on Fisher's exact test.

[a]Annual rotation, winter wheat with winter pea, and sorghum–sudangrass with cowpea mixture; bermudagrass, bermudagrass monoculture; bermudagrass–alfalfa, bermudagrass and alfalfa mixture; tall fescue, tall fescue monoculture; tall fescue–alfalfa, tall fescue and alfalfa mixture.

3.2 | Forage mass

3.2.1 | Total annual forage mass

The annual crop rotation produced greater amounts of FM than perennial forage treatments in 2019 and greater FM than bermudagrass treatments in both years (Table 1). Differences in total FM produced by perennial forage treatments were not detected in either year. Greater FM production by the annual crop rotation may have occurred because the cool-season species in the annual rotation grew over winter (November through March) while perennial species underwent winter dormancy. Winter wheat and Austrian winter pea can grow at lower temperatures than many cool-season perennial species (Figure 1) (Clark, 2007). Even with the wet, warm winter in 2019 (Figures 1 and 2), the physiological pathways in winter wheat and Austrian winter pea gave these species an advantage over bermudagrass and other warm-season perennial species during the winter and early spring. The drought tolerance of both sorghum–sudangrass and cowpea in the annual rotation allowed this system to remain relatively productive even under dry conditions during late summer 2019. Garcia et al. (2008) found that the DM yield of a system consisting of annual forage species was twice that of a monoculture perennial grass pasture system.

In contrast, differences in total FM produced by annual rotation, tall fescue, and tall fescue–alfalfa treatments were not detected in 2020 (Table 1). Precipitation patterns favored forage growth in these three treatments, and greater than average amounts of precipitation supported continued FM production through September that year (Figure 2). The annual rotation produced more FM than bermudagrass and bermudagrass–alfalfa treatments in 2020, as was the case in 2019.

The presence of alfalfa did not affect total FM when perennial forage mixtures were compared with the corresponding perennial grass monoculture in either year (Table 1), indicating that the contribution by alfalfa to FM was limited. Alfalfa was intercropped with both perennial grass species to take advantage of the biological N fixation provided by the legume (Ledgard & Steele, 1992; Quinby et al., 2020). However, any benefits provided by alfalfa in mixtures were not expressed in FM production in the current study. Previous research on alfalfa–grass mixtures compared with grass monoculture showed that alfalfa–grass mixed swards produced more FM with superior nutritive value as opposed to a grass sward fertilized with synthetic N (Berdahl et al., 2001; Hendricks et al., 2020). Monthly harvests from April through October likely affected alfalfa regrowth and stand persistence negatively in the current study. Pedreira et al. (1999) found that harvesting forage crops too frequently reduced leaf area index and, consequently, photosynthetically active leaves, thereby reducing regrowth.

3.2.2 | Monthly forage mass

Monthly FM differed among forage treatments in 2019, except during June and July (Table 2). Establishment issues with the bermudagrass and bermudagrass–alfalfa treatments that year, along with low FM production by tall fescue, a cool-season species, and by the warm-season annual forage mixture planted in May, explain the low and compressed yields those two months. Interestingly, the seasonal growth patterns of forage treatments were not always consistent with cool- and warm-season species growth curves (Gelley et al., 2016; Nave et al., 2013). In June 2019, the annual treatments performed comparably to the grass and grass–alfalfa mixtures (Table 2), while growth of the cool-season species in tall fescue and the tall fescue–alfalfa mixture was slowed by increasing summer temperatures and reduced soil water availability. Alfalfa in mixtures only affected monthly FM in May 2019 when FM was greater in bermudagrass–alfalfa than bermudagrass plots (Table 2). Similarly, alfalfa was the predominant species during cooler months and likely more productive in mixed bermudagrass–alfalfa stands as opposed to bermudagrass monocultures in previous research (Hendricks et al., 2020). Meanwhile in 2020, bermudagrass and bermudagrass–alfalfa did not differ in May, likely due to increased weed competition generating higher than expected FM in the bermudagrass monoculture.

During both years, the progression of treatments producing the most FM followed expectations: the winter wheat and Austrian winter pea annual mixture was the most productive treatment in April, the tall fescue monoculture and tall fescue–alfalfa mixture were comparable to the annual rotation in May, and most of the forage treatments were comparable in June. The tall fescue monoculture was more productive than both the bermudagrass and bermudagrass–alfalfa mixture in May 2020 when cool-season species were favored, as expected. Conversely, FM production by bermudagrass and bermudagrass–alfalfa mixture treatments was comparable or greater than FM production by the tall fescue monoculture in August, when high temperatures favored warm-season grasses.

The FM available at certain periods during the growing season is more important than the total amount of annual FM produced (Belesky et al., 2002; Mitchell et al., 1986). Producers in the southeastern United States and similar humid subtropical regions have seasonal forage deficits relative to supply during both winter and summer (Ball et al., 2015; Mitchell et al., 1986). Results from this study indicate that annual rotations can provide greater amounts of FM during winter as shown in the results from April compared with perennial treatments, due to continuous forage growth and accumulation during winter. However, there are no observed advantages of annual forages to warm-season perennials during summer.

Earlier work on sorghum–sudangrass favors management for nutritive value given its relatively high FM (Creel & Fribourg, 1981; Gelley et al., 2017). The dynamics of sorghum–sudangrass and cowpea mixtures have been examined, but there were challenges in maintaining economic value. Cowpea was not observed to supply additional FM to a mixture compared with a monoculture (Nave et al., 2019), although the addition of cowpea to sorghum–sudangrass showed increased CP concentration.

TABLE 2 Average monthly whole-sward forage mass (FM) of five forage treatments during two consecutive years under an organic forage system the in southeastern U.S.

Treatment	Monthly FM Apr.	May	June	July	Aug.	Sept.
	kg ha^{-1}					
2019						
Annual rotation[a]	2,403 A	1,245 AB	279	340	2,433 A	321 AB
Bermudagrass	–	389 B	–	495	1,800 A	266 ABC
Bermudagrass–alfalfa	–	1,486 A	–	670	2,276 A	433 A
Tall fescue	1,421 B	1,847 A	286	200	360 B	98 C
Tall fescue–alfalfa	1,456 B	1,507 A	180	203	551 B	156 BC
P-value	<.01	<.01	.14	.09	<.01	<.01
Standard error	86.6	246.6	36.2	138.5	162.5	42.5
2020						
Annual rotation	1,496 A	931 ABC	222 AB	503 A	2,341 A	1,010
Bermudagrass	104 B	402 C	149 B	181 B	926 BC	490
Bermudagrass–alfalfa	144 B	794 BC	194 AB	399 AB	1,627 AB	638
Tall fescue	343 B	1,886 A	2,21 AB	256 AB	579 B	692
Tall fescue–alfalfa	358 B	1,699 AB	250 A	263 AB	716 BC	843
P-value	<.01	<.01	.03	.02	<.01	.1
Standard error	98	239.4	19.7	61.7	205	125.7

Note. Within a column, means not sharing a common letter are significantly different ($P \geq .05$) based on Fisher's exact test. Dash indicates insufficient plant material for collection in the designated month.

[a]Annual rotation, winter wheat with winter pea and sorghum–sudangrass with cowpea mixture; bermudagrass, bermudagrass monoculture; bermudagrass–alfalfa, bermudagrass and alfalfa mixture; tall fescue, tall fescue monoculture; tall fescue–alfalfa, tall fescue and alfalfa mixture.

3.3 | Botanical composition and species richness

The proportion of total FM (forages and weeds) contributed by forage grass in the annual rotation was comparable or greater than proportions of FM contributed by perennial grass forages in four of six months in 2019 and five of six months in 2020 (Table 3). The grass contribution to total FM in annual rotation plots made up at least half of the sward composition by the end of the growing season for both the cool- and warm-season (June and September, respectively) annuals (Table 3). Greater relative contribution to sward FM by tall fescue, the cool-season perennial species, occurred through August in 2019 and June in 2020 compared with bermudagrass, the warm-season perennial species, as expected. Lower relative contribution by bermudagrass and bermudagrass–alfalfa to total FM in both years may also reflect difficulties in establishing bermudagrass because of the late planting (4 June), resulting in competition from emerging weeds as a result of warmer soil temperatures.

The contribution by forage legumes to total sward FM was variable across the six months in the annual rotation (Table 4). Austrian winter pea accounted for the legume contribution from April through June and cowpea from July through October in the annual treatment. Differences in legume contribution to FM in the annual rotation versus the perennial forage mixtures were detected in April and May but not in June during 2019. This is likely due to the time of planting of the warm-season portion of the annual rotation (5 June), which was not fully established at the time of sampling. No difference was detected in legume contribution between annual and perennial forage treatments from April through June in 2020. In contrast, legume contributions to sward FM were reduced from July through October during both years in the perennial mixtures compared with the annual rotation where cowpea was grown. Cowpea was a vigorous component of mixtures with sorghum–sudangrass in previous research, though legume contribution to total FM declined by the end of the season (Nave et al., 2019). Moreover, challenges in establishing alfalfa may partially explain the low relative contribution of the legume to sward FM in perennial forage mixtures in both 2019 and 2020.

Weed composition of total sward FM was comparable or greater in bermudagrass and bermudagrass–alfalfa mixtures than in other treatments in both 2019 and 2020 (Table 5). Weed composition was likely highest in the bermudagrass and bermudagrass–alfalfa treatments because of the late planting of those two treatments, as was speculated. Cool-season forages (e.g., winter wheat and tall fescue) were established and competitive with weeds in May, when

TABLE 3 Average forage grass proportion on a percentage basis of five treatments during two consecutive years under an organic forage system in the southeastern U.S.

Treatment	Forage grass proportion Apr.	May	June	July	Aug.	Sep.
	g kg^{-1}					
2019						
Annual rotation[a]	509 B	642 A	821	243 B	569 A	501 A
Bermudagrass	–	55 B	–	202 B	177 B	104 B
Bermudagrass–alfalfa	–	139 B	–	212 B	102 B	74 B
Tall fescue	957 A	861 A	822	788 A	545 A	201 B
Tall fescue–alfalfa	877 A	757 A	780	716 A	333 AB	116 B
P-value	<.01	<.01	.87	<.01	<.01	<.01
Standard error	23	65.9	65.1	79.5	60.7	54.8
2020						
Annual rotation	854 A	968 A	696 A	184 B	492	819
Bermudagrass	0 B	125 B	40 B	667 A	769	512
Bermudagrass–alfalfa	0 B	125 B	123 B	251 B	553	403
Tall fescue	893 A	912 A	772 A	934 A	565	522
Tall fescue–alfalfa	713 A	794 A	625 A	909 A	374	358
P-value	<.01	<.01	<.01	<.01	.15	.19
Standard error	42	87.2	100.9	82.2	100.3	134.1

Note. Within a column, means not sharing a common letter are significantly different ($P \geq .05$) based on Fisher's exact test. Dash indicates insufficient plant material for collection in the designated month.

[a]Annual rotation, winter wheat with winter pea and sorghum–sudangrass with cowpea mixture; bermudagrass, bermudagrass monoculture; bermudagrass–alfalfa, bermudagrass and alfalfa mixture; tall fescue, tall fescue monoculture; tall fescue–alfalfa, tall fescue and alfalfa mixture.

TABLE 4 Average forage legume proportion on a percentage basis of five forage treatments during two consecutive years under an organic forage system in the southeastern U.S.

Treatment	Forage legume proportion Apr.	May	June	July	Aug.	Sep.
	g kg^{-1}					
2019						
Annual rotation[a]	457 A	332 A	0	719 A	344 A	195 A
Bermudagrass–alfalfa	–	84 B	–	27 B	0 B	0 B
Tall fescue–alfalfa	0 B	0 B	7	24 B	0 B	0 B
P-value	<.01	<.01	.42	<.01	<.01	<.01
Standard error	37.8	45	4.3	34.6	42.4	33
2020						
Annual rotation	94	0	124	816 A	477 A	122 A
Bermudagrass–alfalfa	6	21	85	547 B	117 B	3 B
Tall fescue–alfalfa	0	42	29	21 C	11 B	0 B
P-value	.18	.14	.29	<.01	<.01	.02
Standard error	34.5	37.5	51.4	41.1	61.1	24.5

Note. Within a column, means not sharing a common letter are significantly different ($P \geq .05$) based on Fisher's exact test. Dash indicates insufficient plant material for collection in the designated month.

[a]Annual rotation, winter wheat with winter pea and sorghum–sudangrass with cowpea mixture; bermudagrass, bermudagrass monoculture; bermudagrass–alfalfa, bermudagrass and alfalfa mixture; tall fescue, tall fescue monoculture; tall fescue–alfalfa, tall fescue and alfalfa mixture.

TABLE 5 Average weed proportion on a percentage basis of five forage treatments during two consecutive years under an organic forage system in the southeastern U.S.

Treatment	Weed proportion					
	Apr.	May	June	July	Aug.	Sep.
	g kg^{-1}					
2019						
Annual rotation[a]	34 B	25B	179	39B	87 D	308 B
Bermudagrass	–	945 A	–	798 A	823 AB	896 A
Bermudagrass–alfalfa	–	777 A	–	762 A	898 A	927 A
Tall fescue	44 A	139 B	178	212 B	455 C	800 A
Tall fescue–alfalfa	123 A	244 B	213	261 B	668 B	884 A
P-value	<.01	<.01	.90	<.01	<.01	<.01
Standard error	60	60	60	70	50	50
2020						
Annual rotation	52C	32B	181 B	0 B	32 B	58
Bermudagrass	1,000 A	875 A	960 A	333 A	231 AB	488
Bermudagrass–alfalfa	994 A	755 A	792 A	202 AB	330 AB	594
Tall fescue	108 C	88 B	228 B	66 AB	435 AB	479
Tall fescue–alfalfa	287 B	164 B	346 B	68 AB	615 A	643
P-value	<.01	<.01	<.01	.03	.01	.07
Standard error	40	100	110	70	100	130

Note. Within a column, means not sharing a common letter are significantly different ($P \geq .05$) based on Fisher's exact test. Dash indicates insufficient plant material for collection in the designated month.

[a]Annual rotation, winter wheat with winter pea and sorghum–sudangrass with cowpea mixture; bermudagrass, bermudagrass monoculture; bermudagrass–alfalfa, bermudagrass and alfalfa mixture; tall fescue, tall fescue monoculture; tall fescue–alfalfa, tall fescue and alfalfa mixture.

bermudagrass and bermudagrass–alfalfa treatments were planted.

Interestingly, even though the alfalfa component contributed only nominal amounts of DM to total FM (Table 4), total FM was comparable between tall fescue–alfalfa and bermudagrass–alfalfa mixtures (Tables 1 and 2). Apparently, relative performance of simple perennial grass–legume mixtures for FM was confounded by weed competition at the start of the growing season, as indicated by weed composition of total FM (Table 5). Bermudagrass and bermudagrass–alfalfa plots were subject to greater weed competition among the treatments (Table 5); however, the bermudagrass component was generally detected in the sward (Table 3).

A study of alternative N fertilization in conventional tall fescue and bermudagrass harvested monthly throughout the growing season produced more FM than the present study (Tables 1 and 2) (Corbin et al., 2018). The discrepancy between past research and the present study may be due to the different warm- and cool-season legumes used and successfully established, as well as the limited weed competition possible under conventional forage management (Corbin et al., 2018; Quinby et al., 2020). Cool-season legume presence extended seasonal FM for the bermudagrass–alfalfa mixtures in previous research (Hendricks et al., 2020; Quinby et al., 2020). Quinby et al. (2020) suggested a 42-d harvest frequency for tall fescue–alfalfa mixtures and a 35-d harvest frequency for bermudagrass–alfalfa mixtures under conventional management. A 28- and 35-d harvest frequency are recommended for bermudagrass–alfalfa mixtures in the southeastern United States (Hendricks et al., 2020; Thinguldstad et al., 2020). Under the monthly harvest regime in the current study, mixtures were cut 7–10 d earlier than recommended (Quinby et al., 2020). This frequent cutting can reduce alfalfa persistence (Tables 2 and 3) (Quinby et al., 2020; Thinguldstad et al., 2020). Prolonging the frequency of harvests in organically managed forage swards may aid in increasing productivity while reducing weed competition.

Weed species richness of legumes and broadleaf weeds increased over time, as plots gradually became weedier, but broadleaf weed species richness was not significantly correlated with treatment (Table 6). Treatments, rather than years, were associated with higher species richness of weedy grasses (Table 6). Most species considered weeds in this study were desirable forage species (e.g., orchardgrass, white clover [*Trifolium repens* L.], red clover [*Trifolium pratense* L.], and crabgrass [*Digitaria sanguinalis* L.]), whereas the main weed of concern was Spiny pigweed (*Amaranthus spinosus* L.). Orchardgrass and white clover were present across all years. Red clover was present in July 2020, and white clover was the primary species detected in 2020 (data not presented). Weed

TABLE 6 Weed species richness associations among grasses, legumes, and broadleaf forbs functional groups within five forage treatments and years by Fisher's exact test under an organic forage system in the southeastern U.S.

Response association	Weed species richness			
	Overall	Grass	Legume	Broadleaf
Treatment	$P = .06$	$P = .04$	$P < .01$	$P = .20$
Year	$P < .01$	$P = .19$	$P = .01$	$P < .01$

Note. Based on Fisher's exact test ($P = .05$).

population shifts were not as pronounced in the study as were expected based on results from other studies (Rosenfeld et al., 2012; Turner, 2012).

Weeds in organic field crops are largely controlled by tillage, defoliation, and prevention (Liebman & Davis, 2009). Dormancy mechanisms allow many weed seeds to persist well beyond the 3-yr transition period (Steinbauer et al., 1955). The annual rotation underwent biannual tillage in addition to planting winter wheat and sorghum–sudangrass, two grass species that are competitive with many weeds (Clark, 2007; Odhiambo & Bomke, 2001). In addition, allelopathy may have improved weed control when sorghum–sudangrass was grown (Clark, 2007; Scott & Weston, 1991; Weston et al., 1998). Tillage controlled weed growth each spring when terminating annual species in the cool-season mixture and before planting the warm-season forage mixture and each fall when terminating the warm-season forage mixture before planting the cool-season forage mixture. Tillage disrupted the developing weed communities, creating conditions that allowed annual crop species to compete with weeds for growth resources.

Monthly harvests of annual and perennial forage treatments from April through September likely increased weed competition by exhausting the root nutrient reserves of these forages. Similar research conducted previously showed that when harvest intervals are longer, weed competition is greatly reduced (Bates & Beeler, 2008; Corbin et al., 2018; Hendricks et al., 2020; Nave et al., 2019; Quinby et al., 2020; Thinguldstad et al., 2020). Weed competition likely affected alfalfa more than perennial grasses at initial establishment. Alfalfa did not establish quickly and so was unable to compete with actively growing weeds from the seedbank in this study, as indicated by the limited amount of FM contributed by the legume component, except for the bermudagrass–alfalfa mixture in July 2020 (Table 4). Additionally, leaf rust (*Uromyces striatus* J. Schröt) was detected in alfalfa plots in summer 2020, likely a consequence of the warm, wet summer, reducing the ability of diseased alfalfa plants to compete with weeds. A strategy to improve the ability of alfalfa to compete with weeds might be to use warm-season annual grasses, such as sorghum–sudangrass, as a smother crop during the summer before fall-planting alfalfa (Forney et al., 1985).

3.4 | Nutritive value

3.4.1 | Crude protein

Crude protein concentration differed among treatments for all months except June in 2019 (Table 7). That year, CP of forage produced by the annual rotation treatment was comparable or higher than CP of forage produced by the perennial treatments, except in August. The CP concentrations were higher in forage produced by tall fescue and the tall fescue–alfalfa mixture than in forage produced by the annual rotation treatments that month, corresponding to a higher proportion of FM consisting of legume and weed DM in both tall fescue treatments than in the annual rotation treatment (Tables 4 and 5). Forage produced by bermudagrass and bermudagrass–alfalfa treatments consistently had low CP concentrations (Table 7), reflecting the relative low proportion of legume DM in the FM produced by the mixture in 2019 (Table 4).

Similarly, CP concentration differed among treatments in 2020, except in April (Table 7). From May to July, forage produced by the annual rotation was consistently higher in CP than the tall fescue and tall fescue–alfalfa mixture, while CP concentration was inconsistent in bermudagrass and bermudagrass–alfalfa forage (Table 7). By the end of the growing season (August to September), tall fescue and tall fescue–alfalfa produced forage with greater CP concentration than the annual rotation. Although the addition of cowpea to sorghum–sudangrass stands increased CP concentration in previous research (Nave et al., 2019), the cowpea proportion in the annual rotation was reduced by the end of the growing season in the present study, thereby reducing CP concentration. In addition, the presence of weed legumes (e.g., white clover, data not presented) in tall fescue and tall fescue mixed plots likely increased CP concentration of forage produced by those treatments during the summer (Tables 5 and 6).

Weed presence improved forage CP concentration for the bermudagrass and bermudagrass–alfalfa treatments in months when these species were not actively growing (Tables 5 and 7). Some of the common weeds that were present [e.g., crabgrass (*Digitaria sanguinalis* L.) and white clover; data not presented], have greater forage CP concentrations than bermudagrass (Ball et al., 2015). The high weed proportion increased CP concentration of forage produced by the bermudagrass monoculture even outside of the bermudagrass growing season (September–May).

3.4.2 | Amylase neutral detergent fiber

The concentration of aNDF differed among treatments for all months except in July 2019 (Table 8). The tall fescue

TABLE 7 Whole-sward crude protein (CP) of five forage treatments during two consecutive years under an organic forage system in the southeastern U.S.

Treatment	CP					
	Apr.	May	June	July	Aug.	Sep.
	g kg^{-1}					
2019						
Annual rotation[a]	190 A	182 A	158	217 A	108 B	145 A
Bermudagrass	–	148 B	–	155 B	77 C	106 B
Bermudagrass–alfalfa	–	158 AB	–	182 AB	86 C	110 B
Tall fescue	152 B	134 B	158	166 B	131 A	142 A
Tall fescue–alfalfa	146 B	134 B	161	172 AB	125 A	134 AB
P-value	<.01	<.01	.47	.01	<.01	<.01
Standard error	6.3	7.3	3.6	10.8	3.9	6.7
2020						
Annual rotation	165	159 A	193 A	258.3 A	107 C	144 C
Bermudagrass	178	149 AB	169 B	171 C	154 AB	152 ABC
Bermudagrass–alfalfa	173	152 AB	189 A	212 B	138 B	147 BC
Tall fescue	196	139 B	170 B	165 C	170 A	166 AB
Tall fescue–alfalfa	177	140 B	171 B	175 C	169 A	169 A
P-value	.20	.01	.02	<.01	<.01	<.01
Standard error	8.7	3.4	5.5	4.8	4.5	4.5

Note. Within a column, means not sharing a common letter are significantly different ($P \geq .05$) based on Fisher's exact test. Dash indicates insufficient plant material for collection in the designated month.

[a]Annual rotation, winter wheat with winter pea and sorghum–sudangrass with cowpea mixture; bermudagrass, bermudagrass monoculture; bermudagrass–alfalfa, bermudagrass and alfalfa mixture; tall fescue, tall fescue monoculture; tall fescue–alfalfa, tall fescue and alfalfa mixture.

monoculture produced forage with greater aNDF concentration than all other treatments in April and May, except for the tall fescue–alfalfa mixture in May. The bermudagrass monoculture and mixture were starting active growth in July, and the annual rotation had a greater proportion of legume compared with both tall fescue treatments (Table 4). The annual rotation produced forage with the greatest aNDF concentration in June (Table 8), likely due to the transition from the cool- to warm-season species and also to the absence of legumes and increased weed proportion during this period (Tables 4 and 5). The lack of differences in July between treatments could be explained by establishment challenges of the bermudagrass and bermudagrass–alfalfa mixture along with the new active growth of the warm-season annuals and the summer dormancy of tall fescue treatments (Table 8). The bermudagrass monoculture was more fibrous than the cool-season perennial treatments in August (Table 8), likely due to the increased maturity of bermudagrass. These differences were minimized by September when only bermudagrass–alfalfa produced forage with greater aNDF concentration than the tall fescue–alfalfa mixture. The lack of differences in forage aNDF concentration is likely to occur in early fall, because cool-season species are growing more actively in mild temperatures during this period, thereby increasing their nutritive value. During the same period, the similarity among the annual rotation, bermudagrass–alfalfa mixture, and tall fescue monoculture was due to the decline of the alfalfa presence in both grass–alfalfa mixtures. The grass species dominated the mixtures and largely determined forage aNDF concentration.

Amylase neutral detergent fiber concentration differed among treatments from April to July 2020 (Table 8). The annual rotation produced forage with greater aNDF concentration than all other treatments in April, largely due to the advanced maturity of the cool-season annual species compared with the new active growth of cool-season perennial species. The tall fescue and tall fescue–alfalfa mixture produced forage with greater aNDF concentration than bermudagrass and bermudagrass–alfalfa from May to July, which is expected based on the physiological maturity of cool- and warm-season species. In July, the annual rotation and the bermudagrass–alfalfa mixture produced forage with the lowest aNDF concentration among treatments. Stringer et al. (1996) observed slight differences in fiber concentration of bermudagrass and bermudagrass–alfalfa mixtures, which is similar to findings from this study. No differences in aNDF forage concentrations were observed by the end of the growing season (August–September), likely due to the advanced maturity of all species.

TABLE 9 Whole-sward in-vitro dry matter digestibility (IVDMD48) of five forage treatments during two consecutive years under an organic forage system in the southeastern U.S.

Treatment	IVDMD48 Apr.	May	June	July	Aug.	Sep.
	g kg⁻¹					
2019						
Annual rotation[a]	808	740 A	738 C	853 A	741 A	722 A
Bermudagrass	–	646 C	–	733 AB	629 C	630 B
Bermudagrass–Alfalfa	–	645 C	–	799 AB	649 C	627 B
Tall fescue	773	689 B	769 B	714 B	708 B	685 A
Tall fescue–Alfalfa	771	671 BC	794 A	745 AB	699 B	687 A
P-value	.09	<.01	<.01	.02	<.01	<.01
Standard error	14.6	6.7	11.4	27.5	7	11.9
2020						
Annual rotation	820	855 A	809	877 A	759 A	777 A
Bermudagrass	844	782 B	783	742 C	693 B	693 C
Bermudagrass–Alfalfa	835	806 AB	800	796 B	708 B	698 C
Tall fescue	874	805 AB	803	753 C	745 A	747 B
Tall fescue–Alfalfa	842	810 AB	800	765 BC	742 A	735 B
P-value	.07	.01	.17	<.01	<.01	<.01
Standard error	11.8	11.4	7.9	9.2	7.2	5.8

Note. Within a column, means not sharing a common letter are significantly different ($P \geq .05$) based on Fisher's exact test. Dash indicates insufficient plant material for collection in the designated month.

[a]Annual rotation, winter wheat with winter pea and sorghum–sudangrass with cowpea mixture; bermudagrass, bermudagrass monoculture; bermudagrass–alfalfa, bermudagrass and alfalfa mixture; tall fescue, tall fescue monoculture; tall fescue–alfalfa, tall fescue and alfalfa mixture.

TABLE 8 Whole-sward amylase-treated neutral detergent fiber (aNDF) of five forage treatments during two consecutive years under an organic forage system in the southeastern U.S.

Treatment	aNDF Apr.	May	June	July	Aug.	Sep.
	g kg⁻¹					
2019						
Annual rotation	491 B	574 B	602 A	448	632 ABC	556 AB
Bermudagrass	–	510 B	–	553	664 A	610 AB
Bermudagrass–alfalfa	–	536 B	–	512	658 AB	612 A
Tall fescue	533 A	664 A	563 B	581	613 BC	574 AB
Tall fescue–alfalfa	502 B	675 A	540 C	592	593 C	553 B
P-value	.02	<.01	<.01	.12	<.01	.01
Standard error	8.5	18.6	7.5	38.8	11.9	12.8
2020						
Annual rotation	555 A	459 AB	507 A	395 C	622	633
Bermudagrass	409 BC	409 B	421 B	504 B	578	624
Bermudagrass–alfalfa	390 C	419 B	421 B	445 C	571	633
Tall fescue	466 B	523 A	527 A	594 A	600	614
Tall fescue–alfalfa	452 BC	522 A	526 A	572 A	590	616
P-value	<.01	<.01	<.01	<.01	.09	.15
Standard error	13.8	15.1	8.8	13.7	12.5	6.3

Note. Within a column, means not sharing a common letter are significantly different ($P \geq .05$) based on Fisher's exact test. Dash indicates insufficient plant material for collection in the designated month.

[a]Annual rotation, winter wheat with winter pea and sorghum–sudangrass with cowpea mixture; bermudagrass, bermudagrass monoculture; bermudagrass–alfalfa, bermudagrass and alfalfa mixture; tall fescue, tall fescue monoculture; tall fescue–alfalfa, tall fescue and alfalfa mixture.

3.4.3 | Digestibility

In 2019, in vitro digestibility differed among treatments except in April (Table 9). Forage produced by the annual rotation was more digestible than all other treatments in May, when a third of the sward was composed of Austrian winter pea (Table 4). Forage digestibility was lowest for the annual rotation in June (Table 9), during the transition from cool- to warm-season species. The tall fescue–alfalfa mixture produced more digestible forage than the annual rotation during that same month. In contrast, for the remaining summer months (July and August), tall fescue forage in monoculture plots had lower digestibility than the annual rotation. By the end of the growing season, digestibility of forages in the annual rotation remained high, although in September it did not differ from the tall fescue treatments, likely due to the beginning of tall fescue fall regrowth.

Digestibility of forages differed among treatments in 2020, except in April and June (Table 9). For the annual rotation treatment, forage digestibility during the summer months ranged from 759 to 877 g kg^{-1}, which is consistent with data from a similar study on sorghum–sudangrass and cowpea mixtures (Table 9) (Nave et al., 2019). Similar to 2019 results, forage digestibility of the annual rotation remained high in September, likely due to a higher legume proportion and lower weed proportion (Tables 4 and 5). Conversely, the warm-season perennial treatments generally produced the least digestible forage throughout most of the growing season. Bermudagrass–alfalfa mixed stands generally produce forage with adequate nutritive value to support lactating beef cows (NRC, 2017), although these values are correlated to high percentages of alfalfa in the stand (Hendricks et al., 2020). In our study, the proportion of alfalfa in the mixture generally was below that reported in previous research (Hendricks et al., 2020; Quinby et al., 2021), contributing to the reduced nutritive value of the mixture. Forage digestibility of bermudagrass monoculture was consistently lower than the annual rotation, while differences among all perennial treatments were variable and inconsistent.

4 | CONCLUSION

The development of a transitional organic forage program requires evaluation of different species that are adapted to the region. There are many considerations to be made before selecting species, including decisions on weed management, FM, and nutritive value, as well as harvesting schedules. Weed competition in transitioning swards to organic management is an important concern. Weed species richness in the seedbank can remain high, and frequent weed composition monitoring is needed because some weeds can positively influence the FM and nutritive value of the sward. Organic forage selection could include common, nontoxic weeds that are acceptable in forage production systems such as white and red clover as well as crabgrass.

Forage mass was higher in the annual rotation of winter wheat and Austrian winter pea followed by sorghum–sudangrass and cowpea than warm-season perennial treatments. Overall nutritive value was higher in the annual rotation than perennial warm-season treatments, along with tall fescue and tall fescue–alfalfa for most of the growing season, while bermudagrass treatments showed lower overall nutritive value. These results may have differed if alfalfa had successfully established at the beginning of the study.

The long-term sustainability of an organic forage system over time will likely favor a perennial sod mixture such as tall fescue–alfalfa to prevent erosion, while the annual rotation may be useful during the transition period to help reduce weed pressure before transitioning to a long-term perennial forage system. Future studies might consider using a harvest schedule similar to commercial haying operations rather than harvesting monthly. Further grazing evaluation is also needed to determine whether the forage–livestock interaction inflates or decreases the yield penalty of organic forages systems relative to conventional practices.

ACKNOWLEDGMENTS

The authors thank Kevin Thompson and Joe David Plunk at the University of Tennessee Middle Tennessee AgResearch and Education Center for their support and collaboration in this project.

AUTHOR CONTRIBUTIONS

Jonathan O. C. Kubesch: Data curation; Formal analysis; Investigation; Validation; Writing – original draft; Writing – review & editing. Renata L. G. Nave: Conceptualization; Data curation; Funding acquisition; Methodology; Project administration; Resources; Supervision; Writing – original draft; Writing – review & editing. Song Cui: Conceptualization; Funding acquisition; Investigation; Project administration; Resources. Gary E. Bates: Methodology; Visualization. David M. Butler: Methodology; Visualization. Vince Pantalone: Formal analysis; Validation; Visualization.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ORCID

Jonathan O. C. Kubesch https://orcid.org/0000-0002-9306-4518
Renata L. G. Nave https://orcid.org/0000-0002-6872-8079
David M. Butler https://orcid.org/0000-0002-5897-1382

REFERENCES

Ball, D. M., Hoveland, C. S., & Lacefield, G. D. (2015). *Southern forages* (5th ed.). International Plant Nutrition Institute (IPNI).

Bates, G. E., & Beeler, J. (2008). *2008 Cool season annual variety trial report*. University of Tennessee Institute of Agriculture. https://utbeef.tennessee.edu/wp-content/uploads/sites/127/2020/11/2008-Cool-Season-Annual-Grass-Variety-Trial-Report.pdf

Belesky, D. P., Fedders, J. M., Ruckle, J. M., & Turner, K. E. (2002). Bermudagrass–white clover–bluegrass sward production and botanical dynamics. *Agronomy Journal*, *94*, 575–584. https://doi.org/10.2134/agronj2002.5750

Berdahl, J. D., Karn, J. F., & Hendrickson, J. R. (2001). Dry matter yield of cool-season grass monocultures and grass-alfalfa binary mixtures. *Agronomy Journal*, *93*, 463–467. https://doi.org/10.2134/agronj2001.932463x

Brainard, D. C., Bellinder, R. R., & Kumar, V. (2011). Grass–legume mixtures and soil fertility affect cover crop performance and weed seed production. *Weed Technology*, *25*(3), 473–479. https://doi.org/10.1614/WT-D-10-00134.1

Brandao, M., Schmutz, U., & Firth, U. (2012). Farm economics and business planning. In G. Davies & M. Lennartsson (Eds.), *Organic vegetable production: A complete guide* (pp. 208–225). The Crowood Press.

Bryson, C. T., & DeFelice, M. S. (Eds.). (2009). *Weeds of the South*. University of Georgia Press.

Buckner, R. C., Powell, J. B., & Frakes, R. V. (1979). Frakes historical development. In R. C. Buckner & L. P. Bush (Eds.), *Tall fescue* (pp. 1–8). ASA, CSSA, and SSSA.

Chapin, F. S. III, Matson, P. A., & Vitousek, P. M. (Eds). (2011). *Principles of terrestrial ecosystem ecology* (2nd ed.). Springer.

Clark, A. (Ed.). (2007). *Managing cover crops profitably* (3rd ed.). Sustainable Agriculture Network.

Cooperband, L. (Ed.). (2002). *The art and science of composting: A resource for farmers and compost producers*. Center for Integrated Agricultural Systems.

Corbin, M. D., Nave, R. L. G., Bates, G. E., Butler, D. M., & Hawkins, S. A. (2018). Alternatives to conventional nitrogen fertilization on tall fescue and bermudagrass. *Agronomy Journal*, *111*, 275–286. https://doi.org/10.2134/agronj2018.03.0190

Creel, R. J., & Fribourg, H. A. (1981). Interactions between forage sorghum cultivars and defoliation managements. *Agronomy Journal*, *73*(1), 463–469. https://doi.org/10.2134/agronj1981.00021962007300030018x

Crowder, D. W., & Reganold, J. P. (2015). Financial competitiveness of organic agriculture on a global scale. *Proceedings of the National Academy of Sciences*, *112*(24), 7611–7616 https://doi.org/10.1073/pnas.1423674112

Davies, G., Sumption, P., Harlock, S., & Nunis, T. (2012). Crops, seeds, and varieties. In G. Davies & M. Lennartsson (Eds.), *Organic vegetable production: A complete guide* (pp. 35–66). The Crowood Press.

Delate, K. (2009). Organic grains, oilseeds, and other specialty crops. In C. Francis (Ed.), *Organic farming: The ecological system* (pp. 113–136). ASA, CSSA, and SSSA.

Delate, K., & Cambardella, C. A. (2004). Agroecosystem performance during transition to certified organic grain production. *Agronomy Journal*, *96*, 1288–1298. https://doi.org/10.2134/agronj2004.1288

Forney, D. R., Foy, C. L., & Wolf, D. D. (1985). Weed suppression in no-till alfalfa (*Medicago sativa*) by prior cropping of summer-annual forage grasses. *Weed Science*, *33*, 490–497. https://doi.org/10.1017/S0043174500082710

Garcia, S. C., Fulkerson, W. J., & Brookes, S. U. (2008). Dry matter production, nutritive value, and efficiency of nutrient utilization of a complementary forage rotation compared with a grass pasture system. *Grass and Forage Science*, *63*(3), 284–300. https://doi.org/10.1111/j.1365-2494.2008.00636.x

Gelley, C., Nave, R. L. G., & Bates, G. (2016). Forage nutritive value and herbage mass relationship of four warm-season grasses. *Agronomy Journal*, *108*, 1603–1613. https://doi.org/10.2134/agronj2016.01.0018

Gelley, C. H., Nave, R. L. G., & Bates, G. E. (2017). Influence of height-based management on forage nutritive value of four warm-season forage grasses. *Crop, Forage & Turfgrass Management*, *3*, 1–9. https://doi.org/10.2134/cftm2016.10.0067

Hendricks, T. J., Tucker, J. J., Hancock, D. W., Mullenix, M. K., Baxter, L. L., Stewart, R. L., Segers, J. R., & Bernard, J. K. (2020). Forage accumulation and nutritive value of bermudagrass and alfalfa–bermudagrass mixtures when harvested for baleage. *Crop Science*, *60*, 2792–2801. https://doi.org/10.1002/csc2.20222

Inwood, S. E. E., Bates, G. E., & Butler, D. M. (2015). Forage performance and soil quality in forage systems under organic management in the southeastern United States. *Agronomy Journal*, *107*(5), 1641–1652. https://doi.org/10.2134/agronj14.0472

Kniss, A. R., Savage, S. D., & Jabbour, R. (2016). Commercial crops yields reveal strengths and weaknesses for organic agriculture in the United States. *Plos One*, *11*(8), e0161673. https://doi.org/10.1371/journal.pone.0161673E

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, *15*(3), 259–263. https://doi.org/10.1127/0941-2948/2006/0130

Kristiansen, P., & Merfield, C. (2006). Overview of organic agriculture. In P. Kristiansen, A. Taji, & J. Reganold (Eds.), *Organic agriculture: A global perspective* (1st ed., pp. 1–23). CSIRO Publishing.

Lammerts van Bueren, E. T., & Verhoog, H. (2006). Organic plant breeding and seed production: Ecological and ethical aspects. In P. Kristiansen, A. Taji, & J. Reganold (Eds.), *Organic agriculture: A global perspective* (1st ed., pp. 123–137). CSIRO Publishing.

Ledgard, S. F., & Steele, K. W. (1992). Biological nitrogen fixation in mixed legume/grass pastures. *Plant and Soil*, *141*, 137–153. https://doi.org/10.1007/BF00011314

Liebman, M., & Davis, A. S. (2009). Managing weeds in organic farming systems: An ecological approach. In C. Francis (Ed.), *Organic farming: The ecological system* (pp. 173–195). ASA, CSSA, and SSSA.

Magdoff, F., & Van Es, H. (2009). *Building soils for better crops: Sustainable soil management*. Sustainable Agriculture Research and Education.

McDonald, J. H. (2014). *Handbook of biological statistics* (3rd ed.). Sparky House Publishing.

Mitchell, R. L., Mclaren, J. B., & Fribourg, H. A. (1986). Forage growth, consumption, and performance of steers grazing bermudagrass and fescue mixtures. *Agronomy Journal*, *78*(1), 675–680. https://doi.org/10.2134/agronj1986.00021962007800040024x

Mohler, C. L. and Johnson, S. L. (Eds.). (2009). *Crop rotation on organic farms: A planning manual* (pp. 91–94). Natural Resource, Agriculture, and Engineering Service.

Murray, I., & Cowe, I. (2004). Sample preparation. In C. A. Roberts et al. (Eds.), *Near infrared spectroscopy in agriculture* (pp. 75–115). ASA, CSSA, and SSSA.

Nave, R. L. G., & Corbin, M. (2018). Forage warm-season legumes and grasses intercropped with corn as an alternative for corn silage production. *Agronomy*, *8*(199), 1–9. https://doi.org/10.3390/agronomy8100199

Nave, R. L. G., Quinby, M. P., Griffith, A. P., Corbin, M. D., & Bates, G. E. (2019). FM, nutritive value, and economic viability of cowpea overseeded in tall fescue and sorghum–sudangrass swards. *Crop, Forage & Turfgrass Management*, *6*(1), e20003. https://doi.org/10.1002/cft2.20003

Nave, R. L. G., Sulc, R. M., & Barker, D. J. (2013). Relationships of forage nutritive value to cool-season grass canopy characteristics. *Crop Science*, *53*(1), 341–348. https://doi.org/10.2135/cropsci2012.04.0236

NRCS. (2019). *Web soil survey*. USDA NRCS. https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

NRC. (2017). *Nutrient requirements of beef cattle*. National Academy Press.

Odhiambo, J. J. O., & Bomke, A. A. (2001). Grass and legume cover crop effects on dry matter and nitrogen accumulation. *Agronomy Journal*, *93*(2), 299–307. https://doi.org/10.2134/agronj2001.932299x

Pedreira, C. G. S., Sollenberger, L. E., & Mislevy, P. (1999). Productivity and nutritive value of 'Florakirk' bermudagrass as affected by grazing management. *Agronomy Journal*, *91*(5), 796–801. https://doi.org/10.2134/agronj1999.915796x

Porter, P. (2009). Managing weeds in organic farming systems: An ecological approach. In C. Francis (Ed.), *Organic farming: The ecological system* (pp. 51–67). ASA, CSSA, and SSSA.

Quinby, M. P., Nave, R. L. G., Bates, G. E., & McIntosh, D. (2020). Harvest interval effects on the persistence and productivity of alfalfa grown as a monoculture or in mixtures in the southeastern United States. *Crop, Forage & Turfgrass Management*, *6*, e20018. https://doi.org/10.1002/cft2.20018

Quinby, M. P., Nave, R. L. G., Sulc, R. M., Castillo, M. S., Bates, G. E., Schneider, L. G., & McIntosh, D. W. (2021). Comparison of alfalfa mixed with tall fescue and bermudagrass on forage accumulation, botanical composition, and nutritive value. *Crop Science*, *61*(5), 3746–3774. https://doi.org/10.1002/csc2.20461

Rosenfeld, A., Sumption, P., & Davies, G. (2012). Organic vegetable production systems. In G. Davies & M. Lennartsson (Eds.), *Organic vegetable production: A complete guide* (pp. 17–34). The Crowood Press.

Schoofs, A., & Entz, M. H. (2000). Influence of annual forages on weed dynamics in a cropping system. *Canadian Journal of Plant Science*, *80*(1), 187–198. https://doi.org/10.4141/P98-098

Scott, J. E., & Weston, L. A. (1991). Cole crop (*Brassica oleracea*) tolerance to clomazone. *Weed Science*, *40*, 7–11. https://doi.org/10.1017/S0043174500056861

Sleugh, B., Moore, K. J., George, J. R., & Brummer, E. C. (2000). Binary legume-grass mixtures improve forage yield, quality and seasonal distribution. *Agronomy Journal*, *92*(1), 24–29. https://doi.org/10.2134/agronj2000.92124x

Steinbauer, G. P., Grigsby, B., Correa, L., & Frank, P. (1955). A study of methods for obtaining laboratory germination of certain weed seeds. *Proceedings of the Association of Official Seed Analysts*, *45*, 48–52.

Stringer, W. C., Morton, B. C., & Pinkerton, B. W. (1996). Row spacing and nitrogen: Effect on alfalfa-bermudagrass quality components. *Agronomy Journal*, *88*, 573–577. https://doi.org/10.2134/agronj1996.00021962008800040013x

Thinguldstad, B., Tucker, J. J., Baxter, L. L., Segers, J. R., Hancock, D. W., & Stewart, R. L. (2020). Alfalfa response to low potassium under different harvest regimes in Coastal Plains. *Agrosystems, Geosciences & Environment*, *3*(1), e20029. https://doi.org/10.1002/agg2.20029

Turner, B. (2012). Weed management. In G. Davies & M. Lennartsson (Eds.), *Organic vegetable production: A complete guide* (pp. 99–120). The Crowood Press.

Weston, L. A., Nimbal, C. I., & Jeandet, P. (1998). Allelopathic potential of grain sorghum [*Sorghum bicolor* (L.) Moench] and related species. In S. Inderjit, K. M. M. Dakshini, & C. L. Foy (Eds.), *Principles and practices in plant ecology: Allelochemical interactions*. CRC Press.

Wieme, R. A., Reganold, J. P., Crowder, D. W., Murphy, K. M., & Carpenter-Boggs, L. A. (2020). Productivity and soil quality of organic forage, quinoa, and grain cropping systems in the dryland Pacific Northwest, USA. *Agriculture, Ecosystems & Environmment*, Doi.org/10.1016/j.agee.2020.106838

How to cite this article: Kubesch, J. O. C., Nave, R. L. G., Cui, S., Bates, G. E., Butler, D. M., & Pantalone, V. (2022). Transitional organic forage systems in the southeastern U.S.: Production and nutritive value. *Agronomy Journal*, *114,* 1269–1283. https://doi.org/10.1002/agj2.21001