Received: 30 May 2025 | Accepted: 14 September 2025

DOI: 10.1002/cft2.70089

Crop, Forage & Turfgrass Management

ORIGINAL ARTICLE

Forage and Grazinglands

Forage mass and botanical composition of four annual forages grown in a loblolly pine silvopasture in the Mid-South USA

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Assigned to Associate Editor Bruno Pedreira.

Funding information
Southern SARE, Grant/Award Number: LS19-316

Abstract

Annual forages are commonly planted in open pasture in the Mid-South, but there is little information on the productivity of these forages when incorporated into silvopasture. The objective was to evaluate four annual forages adapted to the Mid-South, namely, arrowleaf clover (*Trifolium vesiculosum* Savi), crimson clover (*Trifolium incarnatum* L.), tetraploid annual ryegrass (*Lolium multiflorum* L.), and diploid annual ryegrass (*Lolium multiflorum* L.), in a loblolly pine (*Pinus taeda* L.) silvopasture for seasonal forage mass distribution and annual forage accumulation. The forages were tested in a randomized complete block design with three replicates and three harvests per year: Harvest 1 (H1, April), Harvest 2 (H2, May), and Harvest 3 (H3, July) from 2020 to 2022. Both annual ryegrass types had greater forage mass for H1 and H2, with minimal regrowth after H2 and low forage mass for H3. Both annual ryegrass types outperformed the legumes, which largely failed to establish in this environment, contributing <22% of forage mass across harvests despite adequate soil pH, seed bed preparation, and inoculation. Both annual ryegrass types had greater forage mass in the loblolly silvopasture system for H1 and H2 and are more suitable forages for the system than the legumes tested.

Plain Language Summary

Annual forages are commonly planted in open pasture in the Mid-South, but little information is available on their productivity in silvopasture systems. The objective was to evaluate four annual forages adapted to the Mid-South, namely, arrowleaf clover, crimson clover, tetraploid annual ryegrass, and diploid annual ryegrass, in a loblolly pine silvopasture for seasonal forage mass production. Both annual ryegrass types were productive in April and May, and regrowth was minimal after the May

Abbreviations: AL, arrowleaf clover; CC, crimson clover; DM, dry matter; H1, Harvest 1; H2, Harvest 2; H3, Harvest 3; RG, diploid annual ryegrass; TRG, tetraploid annual ryegrass.

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harvest. The annual ryegrass types did not differ in productivity, but both were more productive than the arrowleaf clover and crimson clover, which did not establish.

1 | INTRODUCTION

Implementing silvopasture—the intentional management of trees, forage, and livestock—into pine (*Pinus* spp.) plantations in the Mid-South has the potential to increase land utilization, mitigate farm financial risk through diversification, and provide animal welfare benefits (Jose & Dollinger, 2019). Shade for grazing livestock has been identified as a main driver of silvopasture establishment, and, therefore, establishing forages in thinned existing tree plantations is preferred by producers (Smith et al., 2022; Wilkens et al., 2022). However, silvopasture systems are complex and involve interactions and competition among trees and forages for nutrients, water, and light (Jose et al., 2019), creating microenvironments that differ from open pasture, which may challenge forage establishment and management. To better understand these challenges and generate suitable forage species recommendations for producers, further evaluations of forage mass and accumulation in pine plantations are necessary.

Several annual forages are adapted to the Mid-South, including cereal rye (*Secale cereale* L.), annual ryegrass (*Lolium multiflorum* L.), arrowleaf clover (*Trifolium vesiculosum* Savi; AL), and crimson clover (*Trifolium incarnatum* L.; CC) (Kubesch et al., 2025; Ball et al., 2015) and may be suitable for cultivation in silvopasture. Generally, total forage accumulation is lower in silvopastures versus open pasture (Burner & Belesky, 2004; Kallenbach et al., 2006; Neel & Belesky, 2017), though many cool-season grasses are tolerant to shade, with forage accumulation unaffected until 80% light reduction (Lin et al., 1998). Cereal rye and annual ryegrass have been successfully integrated into Missouri silvopasture (Kallenbach et al., 2006) with only a 20% reduction in forage accumulation compared with open pasture. Commercial annual ryegrass varieties can be diploid (2n = 2× = 14) or tetraploid (2n = 4× = 28) (Beck et al., 2013). The tetraploid varieties have a greater cell content–to–cell wall ratio (Stewart & Hayes, 2011), as well as larger tillers and leaf proportions, resulting in increased digestibility compared with diploid varieties, while diploids create denser stands with smaller tillers (Solomon et al., 2017). Legumes are another option for forage in silvopasture. However, they are more sensitive to shade than grasses, with reduced forage accumulation reported at 55% shade (Pang et al., 2019), although some legume species are unaffected by 80% light reduction (Lin et al., 1998; Pang et al., 2019). For example, CC is tolerant of up to 80% shade (Pang et al., 2019), and AL has previously been successfully established in a loblolly pine (*Pinus taeda* L.) plantation in the Mid-South (Adams et al., 2019).

To address the scarcity of information on forage production in silvopasture systems, the objective of this study was to evaluate four annual forages adapted to the Mid-South, namely, 'Zulu' AL, 'Dixie' CC, 'Feast II' tetraploid annual ryegrass (TRG), and 'Marshall' diploid annual ryegrass (RG), in a loblolly pine silvopasture for seasonal forage mass and total forage accumulation.

2 | MATERIALS AND METHODS

2.1 | Description of field site and experimental layout

The studies were conducted at the USDA-ARS Dale Bumpers Small Farms Research Center near Booneville, AR (35.1401°N, 93.9216°W). The soil type is a Leadvale silt loam (fine-silty, siliceous, semiactive, thermic Typic Fragiudults). Pretest soil fertility analyses of the nutrient availability concentrations indicated P and K at 26 and 75 ppm, respectively; the soil pH was 6.1 (University of Arkansas Diagnostic Laboratory, Fayetteville, AR). The experiment was conducted in a loblolly pine plantation established in 1994 in an east–west orientation. In 2018, the plantation (7 ac) was thinned to rows of various widths ranging from 32 to 40 ft, with ~50 trees ac^{-1}. Three 32-ft alleys were chosen from a set of seven parallel alleys in a 0.9-ac area, with trees averaging 82 ft in height and 1.5 ft in diameter at breast height and a basal area of 98 ft^2 ac^{-1}. Nonexperimental alleys (32 ft wide) of established orchardgrass (*Dactylis glomerata* L.) separated the experimental alleys.

The experimental design was a randomized complete block with four treatments and three replications. A block was considered a single alleyway measuring 32 × 150 ft. Experimental units were randomized within an alley block and were sized 30 × 8 ft. Four annual forages were evaluated: Zulu AL, Dixie CC, Feast II TRG, and Marshall RG. These forages were chosen based on known shade tolerance at a minimum of 55% reduced light (Lin et al., 1998; Pang et al., 2019) and adaptability to the region (Ball et al., 2015). The shade tolerance of AL was unknown, but AL had previously been tested in a loblolly pine silvopature (Adams et al., 2019) and was observed growing in loblolly pine alleys near the experimental site. Marshall RG was chosen due to its common regional use and forage accumulation potential (White & Lemus, 2023). Feast II TRG was chosen because its peak forage mass may occur slightly later in spring than that of Marshall RG (Olson et al., 2018). Zulu AL and Dixie CC were

chosen based on their adaptability to the transition zone and availability.

2.2 | Planting and crop management

Seedbed preparation began in August 2019, with clipping the existing forage to a height of 4 inches, followed by an application of glyphosate (41%, Bayer Crop Science) on August 8 at a rate of 20 fl oz ac^{-1}. Agricultural lime was broadcast over each block at 2 tons ac^{-1} on August 15. On September 9, the alleys were disced (200239, Taylor Pittsburgh Manufacturing) to a depth of 4 inches, glyphosate (41%, Bayer Crop Science) was applied at 20 fl oz ac^{-1} on September 27 to kill any regrowth after discing, and the alleys were disced again on October 1. After discing on October 1, the plots were rolled (Big Guy Field Roller, Grahl Manufacturing) to form a seedbed. Annual fall seedbed preparation (2020 and 2021) included an application of glyphosate (41%, Bayer Crop Science) at 20 fl oz ac^{-1} and rotary tillage (SC 300, Maschio Gaspardo) one time 4–6 weeks later. The dates of fall herbicide application were August 24 and September 15 in 2020 and 2021, respectively, and the dates of tillage were October 5 and October 19 in 2020 and 2021, respectively.

Planting occurred on October 3, 2019, October 8, 2020, and October 21, 2021, with a Brillion broadcast seeder (SSP-8). Seeding rates of pure live seed were as follows: AL 10, CC 10, TRG 25, and RG 25 lb ac^{-1}. The plots were fertilized with P (70 lb ac^{-1}) and K (150 lb ac^{-1}) annually each fall on November 25, 2019, November 5, 2020, and November 18, 2021. The annual ryegrass plots were fertilized with N [50 lb ac^{-1}; urea, $CO(NH_2)_2$], twice per year, in March and after the April harvest in 2020, on March 5 and April 8; in 2021, on March 18 and April 12; and in 2022, on March 8 and May 9.

2.3 | Forage mass, total forage accumulation, and botanical composition

Three plot harvests occurred per year: Harvest 1 (H1) in April, Harvest 2 (H2) in May, and Harvest 3 (H3) in July. In 2020, plots were harvested on April 2, May 21, and July 10; in 2021, on April 1, May 24, and July 6; and in 2022, on April 15, May 27, and July 15. In each plot, a 30 × 3 ft area was harvested with a sickle bar mower (C, Jari USA) set at a 2-inch cutting height. Harvested material from each plot was raked into large plastic bins and weighed on a portable scale. Two subsamples (0.5 lb each) were removed after weighing, one for the determination of dry matter (DM) and the second for the determination of botanical composition. A mower-conditioner (835, John Deere Co.) was used 1–3 days after the plot harvest to cut the remaining forage on the plots at a 2-inch cutting height. The extra forage was removed from the plots to allow for unimpeded regrowth of the entire plot.

The subsamples for DM were weighed in the field, dried at 131˚F for 48 hours in a forced-air oven, and reweighed to determine forage DM percentage for the calculation of forage DM mass harvested per harvest date. Botanical composition subsamples for separation were frozen and later separated into two categories: (a) "sown forage" and (b) "weed mass" (i.e., all other species). Samples were dried at 131˚F for 48 hours to determine the forage mass of each component. The proportion of the sown forage or weed mass to the total weight for each harvest was used to calculate the sown forage mass and weed mass. Total forage accumulation for the sown forage and weed mass was determined by summing the sown forage or weed mass from each harvest within a year.

2.4 | Statistical analyses

An ANOVA using the PROC GLIMMIX model procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC) was used to test the fixed effects of year, harvest, and forage, as well as their interactions for forage mass and botanical composition, with block as a random effect. Harvest was considered a repeated measure and addressed with an unstructured covariance structure in the statistical model. When a forage × harvest × year interaction was significant ($P < .05$), variables were analyzed for forage, harvest, and forage × harvest effects within each year, with block as a random effect. Total forage accumulation was tested for the effects of forage, year, and the forage × year interaction, with block as a random effect. The LSMEANS option with a Tukey's adjustment was used to generate individual treatment comparisons. Significance was declared at $P \leq .05$.

2.5 | Environmental data

Temperature (Figure 1a) for 2020–2022 and the 30-year average (1990–2020) showed largely normal temperatures for all years during the growing season for winter annuals. Precipitation (Figure 1b) for 2020–2022 and the 30-year average showed great variation over the three study years. In 2020, precipitation was much greater than the 30-year average in March, April, and May and less than normal in June. In 2021, precipitation was slightly greater than the 30-year average in May and July. In 2022, the precipitation in June was much greater than the 30-year average.

3 | RESULTS AND DISCUSSION

3.1 | Forage mass and botanical composition

Forage mass of the sown forage was affected by a three-way interaction ($P = .04$) and was therefore analyzed for

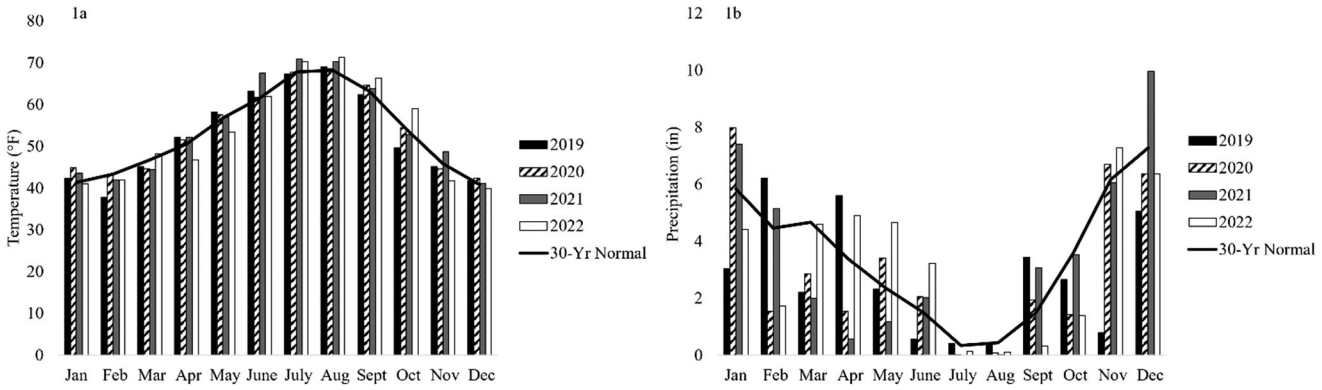


FIGURE 1 (a) Average monthly temperature and (b) total monthly precipitation near Booneville, AR, for 2019–2022 and the 30-year average.

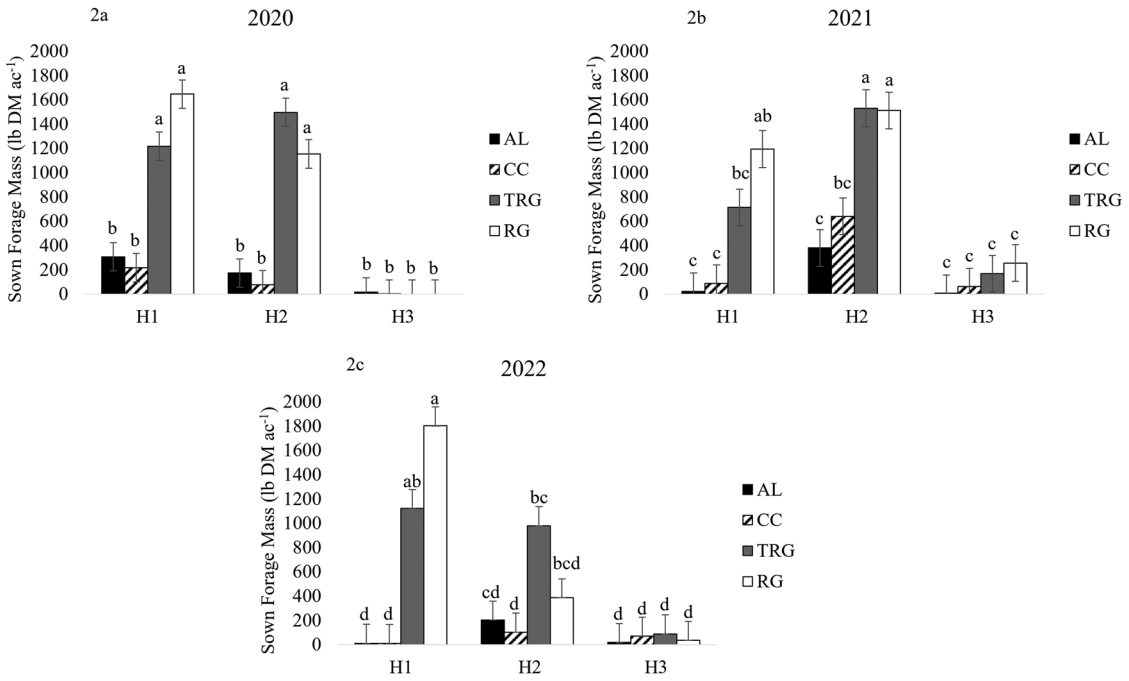


FIGURE 2 Sown forage mass for arrowleaf clover (AL), crimson clover (CC), tetraploid ryegrass (TRG), and diploid ryegrass (RG) for Harvest 1 (H1), Harvest 2 (H2), and Harvest 3 (H3) within each year: (a) 2020, (b) 2021, and (c) 2022. Significant ($P < .0001$) harvest × forage interaction occurred for all years. Means without a common letter within a year differ ($P < .05$). Error bars represent the pooled SEM for each year: 116.7, 151.0, 156.0 lb DM ac^{-1} for (a), (b), and (c), respectively.

forage, harvest, and forage × harvest effects within each year (Figure 2a–c). All years were affected by forage × harvest interactions ($P \leq .02$). In 2020, AL and CC, and TRG and RG, did not differ from one another at any harvest, and the annual ryegrasses had greater sown forage mass compared with that of the legumes for H1 and H2. For H3, sown forage mass decreased for the annual ryegrasses and did not differ among any forages. In 2021, AL and CC, and TRG and RG, did not differ from one another at any harvest, and sown forage mass was greater for both annual ryegrasses compared with that of the legumes for H2. For H1, sown forage mass for RG was greater than for either legume, but TRG did not differ. Forages did not differ in sown forage mass for H3. In 2022, AL and CC, and TRG and RG, did not differ from one another at any harvest. For H1, sown forage mass was greater for the annual ryegrasses than for the legumes. For H2, TRG sown forage mass was similar to H1, while RG forage mass was less in H2 and did not differ from CC. Forages did not differ in sown forage mass for H3.

Weed mass was affected by harvest × forage, year × forage, and harvest × year interactions ($P \leq .05$); no other interactions were significant ($P \geq .11$; Figure 3a–c). Weed mass was similar among years and did not differ among forages for H1 or H3 but was greater for the ryegrasses in H2. Weed mass was generally greater in AL and CC in years 2020 and 2021, while the weed mass in CC did not differ from that of TRG

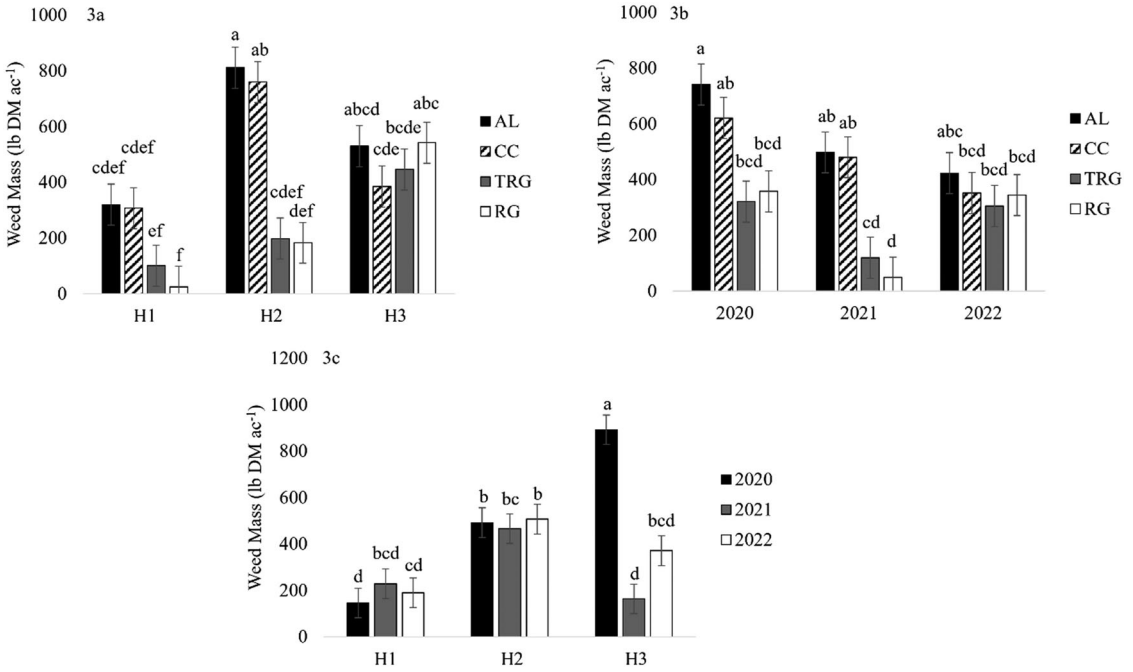


FIGURE 3 (a) Weed forage mass for arrowleaf clover (AL), crimson clover (CC), tetraploid ryegrass (TRG), and diploid ryegrass (RG) for Harvest 1 (H1), Harvest 2 (H2), and Harvest 3 (H3) across years. (b) Weed forage mass for AL, CC, TRG, and RG for each year ($P = .05$). (c) Weed mass for each harvest and year ($P < .0001$). Means without a common letter differ ($p < .05$). Error bars represent the pooled SEMs of 73.5, 73.5, and 63.7 lb DM ac^{-1} for (a), (b), and (c), respectively.

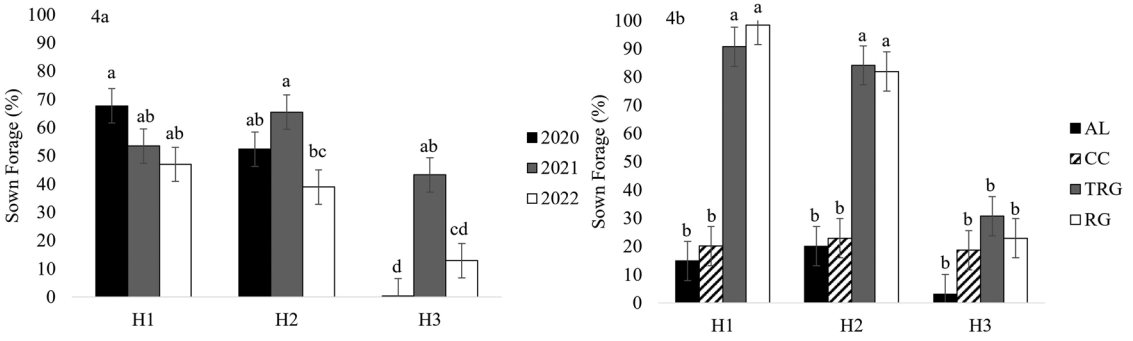


FIGURE 4 (a) Proportion of the sown forage for Harvest 1 (H1), Harvest 2 (H2), and Harvest 3 (H3) for each year ($P < .001$). (b) Proportion of the sown forage for arrowleaf clover (AL), crimson clover (CC), tetraploid ryegrass (TRG), and diploid ryegrass (RG) for H1, H2, and H3 ($P < .0001$). Means without a common letter differ ($P < .05$). Error bars represent the pooled SEM: 6.1% and 6.9% for (a) and (b), respectively.

or RG in 2020. In 2022, weed mass was the same among all forages. For harvests by year, weed mass was greatest for H3 in 2020, while weed mass was similar among years for H1 and H2.

Proportion of the sown forage was affected by harvest × year and harvest × forage interactions ($P < .001$); no other interactions were significant ($P \geq .13$; Figure 4a,b). In 2020, the proportion of the sown forage was greater for H1 and H2 compared with H3; in 2021, no differences among harvests were observed; and in 2022, the proportion of sown forage was greater for H1 compared with H3, but H2 was intermediate and did not differ. The proportions of the sown forages were greater for TRG and RG than for AL and CC for H1 and H2, but the proportions of the sown forages did not differ for H3.

Poor legume establishment drove several sown forage mass and weed mass differences among harvests, years, and forages, particularly between grasses and legumes. The soil pH was within the acceptable range for both AL and CC (Ball et al., 2015), but the site was poorly drained and prone to spring flooding, to which both species are sensitive (Ball et al., 2015). The proportion of the sown forage was <22% for both legume species across years and harvests, while annual ryegrass maintained >81% of the sown forage for H1 and H2. The proportion of the sown forage was <30% for all forages for H3. Growth for all tested forages would have likely ended

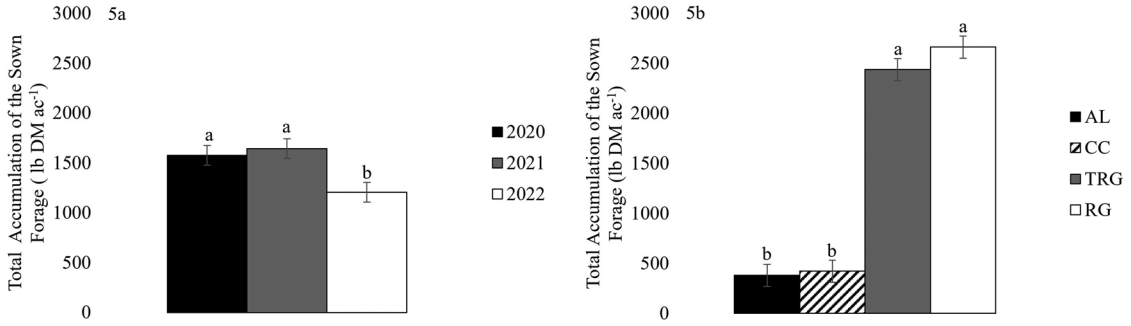


FIGURE 5 (a) Total accumulation of the sown forage for each year ($P < .004$). (b) Total accumulation of the sown forage for each forage ($P < .0001$): arrowleaf clover (AL), crimson clover (CC), tetraploid ryegrass (TRG), and diploid ryegrass (RG). Means without a common letter differ ($P < .05$). Error bars represent the pooled SEMs of 99 and 111 lb DM ac^{-1} for (a) and (b), respectively.

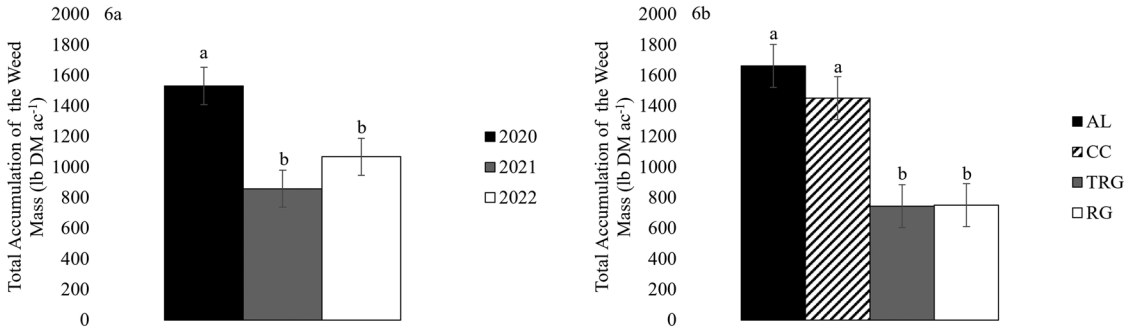


FIGURE 6 (a) Total accumulation of the weed mass for each year ($P = .0025$). (b) Total accumulation of the weed mass for each forage ($P < .0001$): arrowleaf clover (AL), crimson clover (CC), tetraploid ryegrass (TRG), and diploid ryegrass (RG) ($P = 0.0001$). Means without a common letter differ ($P < 0.05$). Error bars represent the pooled SEMs of 121.6 and 140.4 lb DM ac^{-1} for (a) and (b), respectively.

prior to H3 (July 1; Ball et al., 2015), and weed mass for H3 generally consisted of the dead forage mass of the sown forage and volunteer summer weeds.

3.2 | Total forage accumulation

Total accumulation of the sown forage was affected by year ($P = .0004$) and forage ($P < .0001$) (Figure 5a,b). Total accumulation of the sown forages was greater in 2020 and 2021 compared with 2022, and it was greater for the annual ryegrasses compared with the legumes.

Total accumulation of the weed mass was affected by year ($P < .0001$) and forage ($P = .003$) (Figure 6a,b). Total accumulation of the weed mass was greater in 2020 compared with 2021 and 2022, during which total accumulation of the weed mass did not differ and was greater for the legumes compared with the ryegrasses.

Total accumulation of the sown forage was much greater for the annual ryegrasses than the legumes, while total accumulation of weed mass was much greater for the legumes than the annual ryegrasses. The legume CC is tolerant of shade (Pang et al., 2019), but wet conditions may have hindered establishment and forage accumulation at this site. Adams et al. (2019) successfully established AL in a loblolly pine plantation, but forage mass was much lower in the pine alleys compared with the forage mass of plots in full sun, indicating the sensitivity of AL to light restriction. Annual ryegrasses are better adapted to wet soil conditions and are shade tolerant (Lin et al., 1998), though a 20% reduction in DM production was observed in Missouri silvopasture for cereal rye–annual ryegrass mixtures (Kallenbach et al., 2006). Variety trials in Mississippi have recorded annual ryegrass total accumulation from 7000 to 8000 lb ac^{-1} (Redfearn et al., 2005), while West et al. (1988) recorded total accumulation of 6170 lb DM ac^{-1} in Arkansas. Total forage accumulation for the sown forage in this study was substantially lower, averaging 2985 lb DM ac^{-1} for RG across years. Without a full-sun control, it is unknown whether the lower-than-expected forage accumulation was due to reduced light or to other factors, such as waterlogged soils. An advantage to diploid or tetraploid genetics was not observed in this study, and other studies have reported inconsistent forage accumulation differences (Redfearn et al., 2002), likely due to the influence of genetics × environment interactions (Solomon et al., 2017).

4 | CONCLUSIONS AND IMPLICATIONS

The two legumes, AL and CC, were chosen for this study due to their adaptation to the Mid-South and reported tolerance to shade, but both legumes largely failed to establish in this shaded environment, contributing <22% of forage mass despite adequate soil pH, seed bed preparation, and inoculation, though waterlogged soils were an issue at this site. Both annual ryegrasses, TRG and RG, were productive for the first two harvests (April and May), with little regrowth before the third harvest in July. The total accumulated forage was lower than recorded for the same forages in open pastures in Arkansas. Site conditions were challenging, with waterlogged soil throughout the spring; however, winter annuals were chosen for evaluation due to previous observations of water competition between trees and perennial forages in loblolly pine systems during summer months when precipitation was limited. Winter forages can capitalize on available water in the spring and do not compete with trees in the summer. In this study, the annual ryegrasses were productive in April and May, while the legumes did not establish well in the Mid-South environment.

AUTHOR CONTRIBUTIONS

Christine C. Nieman: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; supervision; validation; visualization; writing—original draft; writing—review and editing. **Dirk Philipp**: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; resources; visualization; writing—review and editing. **Jonathan O. C. Kubesch**: Visualization; writing—review and editing.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the field support of Michelle Armstrong (USDA-ARS, Booneville, AR), Kolten Wright (USDA-ARS, Booneville, AR), and Robert Rhein (University of Arkansas) in completing this project. This research was supported through the Southern Sustainable Agriculture Research project # LS19-316.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the USDA.

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How to cite this article: Nieman, C. C., Philipp, D., & Kubesch, J. O. C. (2025). Forage mass and botanical composition of four annual forages grown in a loblolly pine silvopasture in the Mid-South USA. *Crop, Forage & Turfgrass Management*, *11*, e70089. https://doi.org/10.1002/cft2.70089