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Comparison of Level of Stocking on Clover and Ryegrass Cover Crops Sod-Seeded into Bermudagrass

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Abstract

Annual forages have been used as cover crops in cropland to provide cover to soil, reduce erosion and weed infestation, and enhance soil health. Mixed seedings of "Dixie" crimson clover (*Trifolium incarnatum* L.) and "Apache" arrowleaf clover (*Trifolium vesiculosum* Savi), "Nelson" annual ryegrass (*Lolium multiflorum* Lam.), and a combination of clovers and ryegrass were drilled into "Coastal" bermudagrass (*Cynodon dactylon* [L.] Pers.) plots. During the following two years, cattle grazed these cover crops to predetermined residual stubble heights each late April to early June to assess effects of mob-stocking on cover crop forage accumulation and sustainability. During active vegetative growth of cover crops (April-May), ryegrass had the greatest forage accumulation in Year 1; whereas, ryegrass-clover mix had the greatest forage accumulation in Year 2, which had greater rainfall than Year 1. During active vegetative growth of the cover crops, there was no effect of grazed stubble heights on forage mass accumulation; however, the season-long forage mass accumulation (April-September) was reduced ($P < 0.02$) due to the 10 - 15 cm stubble height. For both years, the season-long forage accumulation was greatest ($P < 0.003$) for the non-overseeded bermudagrass-only plots. The non-N-fertilized clover and clover-ryegrass cover crop plots had similar season-long forage accumulation to the ryegrass plots that were fertilized with 56 kg N/ha. Thus, indirect evidence indicates a potential contribution of legume-derived nitrogen to this loamy fine sand. All grazed stubble heights used in this research were based on USDA-NRCS cover crop management guidelines for humid environments and showed these grazing regimens to be sustainable on a cover crop system with bermudagrass.

Keywords

Cover Crop, Grazing, Bermudagrass, Ryegrass, Clover

1. Introduction

The use of cover crops has long been applied to benefit ecosystems by enhancing soil health attributes. Cover crops have been defined by USDA [1] as crops including grasses, legumes and forbs used for seasonal cover and other conservation purposes. The USDA NRCS Cover Crop (Code 340) Conservation Practice Standard [2] provides national guidelines for planting seasonal grasses, legumes, and forbs as cover crops to support several factors influencing soil health, such as reducing erosion, increasing organic matter, utilizing excess nutrients, and suppressing weeds.

Warm-season perennial grasses such as bermudagrass (*Cynodon dactylon* [L.] Pers.) and bahiagrass (*Paspalum notatum* Flüggé) are the foundation of pasture and forage systems across the Coastal Plains of the United States. Overseeding cool-season annual legumes and grasses into dormant warm-season perennial grass sods is a special type of cover cropping. Overseeding provides a cool-season cover for the dormant grasses; reduces pasture weed infestations; maintains actively growing roots for an extended season; and in the case of legumes, provides N for the system through biological nitrogen fixation [3]. Reference [4] documented that warm-season perennial, sod-forming grasses have been overseeded since the late 1950s with small grains and annual ryegrass [5]-[10]. Cool-season annual forages can be integrated via sod-seeding directly into warm-season perennial pastures, broadcasting onto closely grazed sod, or planting on prepared seedbeds. The sod-seeded cool-season annual grasses and clovers are capable of providing high-quality forage for 60 to 120 d when matched to local climate and soil conditions [11] [12].

In a review of cool-season annual grasses and grass-clover systems for beef cattle in the southeastern United States, Reference [12] concluded that annual ryegrass, small grains (rye, triticale, wheat, oat), and annual clovers can collectively extend fall-winter-spring grazing, reduce reliance on conserved feeds, and improve animal performance relative to warm-season grass monocultures. Within the southeastern Coastal Plain, overseeding dormant bermudagrass and bahiagrass sods with annual ryegrass [13] has become a dominant strategy because of reliable establishment, high cool-season productivity, and broad adaptation, while annual clovers are used to enhance nutritive value and biological N inputs [12] [14].

Successful overseeding relies on careful integration of establishment and grazing management. Reference [15] provided management strategies for bermudagrass overseeded with cool-season annual grasses and legumes for sustainable cow-calf production in the southeastern US. State Extension publications and technical bulletins for the southeastern Coastal Plain recommend closely grazing or mowing bermudagrass or bahiagrass sod prior to seeding to reduce competition and increase light at the soil surface, followed by drilling or broadcasting annual ryegrass and clover seed during regionally appropriate autumn planting windows [14] [16].

These sod-seeding guidelines further emphasize that because clover seed is small and sensitive to planting depth, shallow placement and good seed-soil contact is important, with higher seeding rates recommended when broadcasting compared with no-till drilling. Grazing is typically deferred until cool-season forages reach adequate height and root development, after which moderate to high stocking densities in short grazing bouts help maintain vegetative growth, support clover persistence, and prevent heavy shading that could suppress the underlying bermudagrass. During the spring transition, aggressive grazing or clipping of ryegrass and clover is recommended to facilitate timely recovery of the warm-season sod. Failure to manage cool-season annual forages is frequently cited as a cause of delayed bermudagrass or bahiagrass regrowth in overseeded fields [12].

At the conservation practice level, overseeding of cool-season annuals into warm-season pastures on the southeastern Coastal Plain has been framed within USDA-Natural Resources Conservation Service (NRCS) Pasture and Hay Planting and Forage and Biomass Planting standards (Code 512) [17] [18]. These standards require the use of adapted species and cultivars, adherence to locally validated planting rates, methods, and dates, and application of limestone and fertilizer according to soil test recommendations and Nutrient Management (Code 590) Plans [17]. The NRCS State-level 512 specifications and associated job sheets for the Coastal Plain emphasize inoculation of clover seed with appropriate *Rhizobium* strains, increased seeding rates for broadcast applications, and selection of seed mixtures (annual ryegrass plus crimson or arrowleaf clover) that meet forage and soil protection objectives under specific soil and climate conditions [19]-[21]. The 512 Standard is commonly applied in combination with Prescribed Grazing (Code 528), Forage Harvest Management (511), Herbaceous Weed Treatment (315), and Nutrient Management (590) to balance forage production with soil and water conservation goals in overseeded pasture systems [17] [18].

While not a primary purpose of the USDA NRCS Cover Crop standard, livestock integration is one of five principles identified to provide a successful soil health foundation. This cooperative research between USDA NRCS and Texas A&M AgriLife Research was initiated to determine any needed modifications of Cover Crop Code 340 in humid ecosystems to include stocking management strategies for annual cool-season cover crops sod-seeded into a warm-season perennial grass. Specifically, our objectives were to document grazed stubble heights of overseeded cover crops into Coastal bermudagrass that may result in sustainable forage production.

2. Methods and Materials

2.1. Site Description

This two-year study was conducted at the Texas A&M AgriLife Research and Extension Center at Overton (32.29˚ N, 94.98˚ W) from 2022 to 2024. To determine optimum grazing management strategies and any modifications of Cover Crop Code 340, a well-established stand of "Coastal" bermudagrass [*Cynodon dactylon* (L.) Pers] was sod-seeded with cover crops of clover (*Trifolium* sp.) (CLV), annual ryegrass (*Lolium multiflorum* Lam.) (RYG), and a mix of CLV-RYG. The soil was a Lilbert loamy fine sand (Loamy, siliceous, semiactive, thermic Arenic Plinthic Paleudult).

Two soil samples per replicate plot were taken pre-treatment in December 2021 and post-treatment in December 2023. Each soil sample was divided into four depths: 0 - 10 cm, 10 - 20 cm, 20 - 40 cm, and 40 - 60 cm. Sample analyses were conducted at the Stephen F. Austin State University Soil, Plant, and Water Analysis Laboratory in Nacogdoches, Texas as follows: 1) Macros were extracted using Mehlich 3 and ran on a Thermo 7400 dual view Inductive Coupled Plasma [22] [23]; 2) Soil pH (1:2 soil/water) was determined using a Metrohm pH meter [24]; 3) The EC (1:2 soil/water) was determined on a Mettler Toledo meter [25]; 4) The %CN was measured by total combustion using an Elementar Vario Max-Cube; 5) Organic carbon was determined directly using a total carbon analyzer by reducing the primary sample ignition furnace to 650˚C [26]-[28]. The furnace operates at 950˚C. Sample size was 250 mg; 6) The NH-4 and NO^2 + NO^3-N were measured with a 2 M KCL extraction and ran on a FIA Lab Cadmium Flow Injection instrument [29] [30].

Figure 1 shows the field design for the two replicates of three cover crops and three grazing regimens with targeted residual stubble heights of 10 - 15 cm (GRZ1), 15 - 20 cm (GRZ2), and 20 - 30 cm (GRZ3). A well-established Coastal bermudagrass hay meadow was partitioned into two replicate sections, each at 24.3 m × 91.2 m. These replicates were further partitioned into 12 plots sized at 24.3 m × 7.6 m per plot. A 15 m wide alleyway was provided to allow cattle and machinery movements to and from plots. Cover crops (CLV, RYG, and CLV-RYG) were randomized within each of the three grazing regimens (GRZ1, GRZ2, and GRZ3).

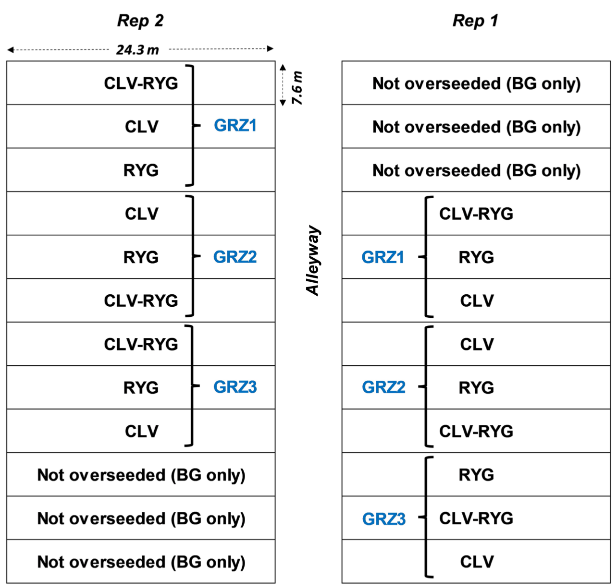


Figure 1. Plot design with two replications of cover crop treatment of clover (CLV), ryegrass (RYG), and clover-ryegrass (CLV-RYG), and grazing regimens (GRZ1, GRZ2, GRZ3).

2.2. Cover Crops and Data Collection

Annual cool-season cover crop forages included a mix of "Dixie" crimson clover (*Trifolium incarnatum* L.) and "Apache" arrowleaf clover (*Trifolium vesiculusom* Savi) (CLV); "Nelson" annual ryegrass (*Lolium multiflorum* Lam.) (RYG); and a mixture of CLV and RYG (CLV-RYG). Cover crops were drilled at 18 cm spacing into bermudagrass (BG) sod with a Kincaid Great Plains Planter, Model No. 3P606NT, on November 17, 2022 in Year 1 and November 1, 2023 in Year 2. Average temperature and total rainfall for Years 1 and 2 are shown in Figure 2 and Figure 3, respectively. The drilled planted areas were 1.2 m wide with 18 cm spacing in the 7.6 m wide x 24.3 m long plots. Seeding rates included 22.4 kg/ha crimson + 11.2 kg/ha arrowleaf for CLV; 33.6 kg/ha for RYG; and the same rates each for CLV-RYG. In Year 1, all plots were hand-fertilized with 336 kg/ha of 0-18-18-8S-4.25Mg-0.18Bo on December 5, 2022. The RYG plots received 56 kg N/ha of 21-0-0 on February 28, 2023. The non-overseeded, non-grazed BG plots (BG only) received 56 kg N/ha of 21-0-0 on June 6, 2023. In Year 2, all plots received 336 kg/ha of 0-18-18-8S-4.25Mg-0.18Bo on December 7, 2023. The RYG plots received 56 kg N/ha of 21-0-0 on February 2, 2024, and non-grazed BG plots received 56 kg N/ha of 21-0-0 on June 7, 2024.

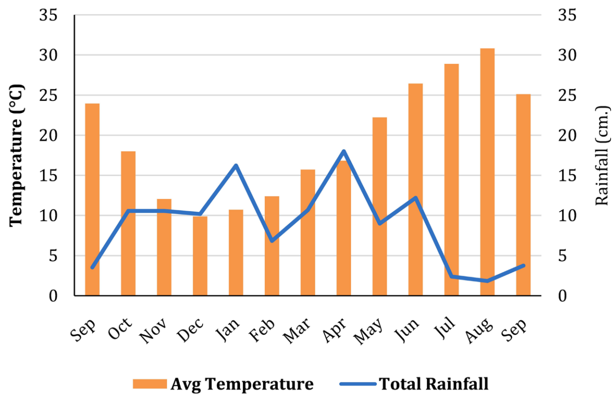


Figure 2. Temperature and rainfall at Overton, Texas for September 2022-September 2023.

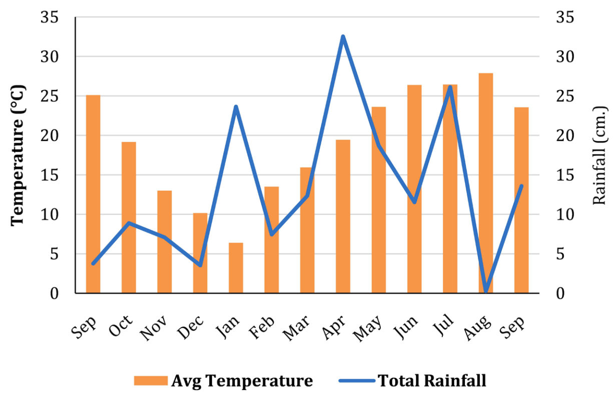


Figure 3. Temperature and rainfall in Overton, Texas for September 2023-September 2024.

Three residual stubble height (STHT) goals were pre-assigned to plots: 10 - 15 cm (GRZ1), 15 - 20 cm (GRZ2), and 20 - 30 cm (GRZ3) to represent medium, low, and very low stocking rates on sod-seeded BG [31]. Reference [32] used a mixture of rye (*Secale cereale* L.) and oat (*Avena sativa* L.) as cover crops in a three-year experiment to evaluate N fertilization levels and three stocking rates to assess stubble residues on cotton lint production. Rye-oat plots were mob-stocked every 14 d to maintain stubble residues of heavy stocked (500 kg DM/ha), moderate stocked (1500 kg DM/ha), and light stocked (2500 kg DM/ha). Although cotton lint yield was not affected by stocking rates, heavy stocking rates reduced soil cover and allowed for increased weed presence.

In both years of our study, two grazing events during the active vegetative growth of the cover crops were required to achieve the three STHT goals. As forage accumulation reached targeted heights, CLV, RYG and CLV-RYG plots were each mob-stocked with 6 to 8 yearling steers (300 kg BW) for short periods (2 to 3 hours) each grazing event. Short grazing periods and lack of water facilities in the plots helped to prevent trampling of forage. Thus, this experiment to compare effects of residual stubble heights under brief grazing events does not provide an accurate accounting of stocking rate. Also, the presence of bermudagrass would affect overall stocking rates. Forage in each plot was grazed to the pre-assigned residual stubble height (STHT) and then remained ungrazed until forage accumulation allowed for another grazing event. In Year 1, the first grazing event was initiated on April 26. The RYG plots were grazed from April 26 to April 28; CLV was grazed from May 1 to May 5; and RYG-CLV was grazed from May 5 to May 10. The GRZ1 was achieved on the six assigned plots in an average of 10 hours over 3.75 days, GRZ2 in 7.3 hours over 2.75 days, and GRZ3 in 4 hours over 1.75 days. The second grazing event for all plots was initiated on June 6 and terminated on June 16, with GRZ1 achieved in 9.3 hours over 3.5 days, GRZ2 in 6.5 hours over 3 days, and GRZ3 in 5.5 hours over 2 days. In Year 2, both grazing events lasted an average of 3.3 days. The first grazing event of Year 2 was initiated on all plots on April 18 and terminated on April 25, with GRZ1 achieved in an average of 8.8 hours, GRZ2 in 6.6 hours, and GRZ3 in 3.8 hours. The second event was initiated on May 14 and terminated on May 22, with GRZ1 achieved in 8.3 hours, GRZ2 in 5.6 hours, and GRZ3 in 4.5 hours. In both years, forage mass samples were taken by hand-clipping forage at 5 cm height from two 929 cm^2 quadrants in each plot. In Year 1, forage mass was harvested pre-grazing from all plots on April 18, May 30, and September 28, 2023. In Year 2, forage mass was harvested pre-grazing from all plots on April 15, May 14, June 25, and September 19, 2024.

Forage nutritive analyses were conducted by the Dairy One Forage Testing Laboratory [33]. At the initiation of stocking in April and May 2023, forage was hand-clipped from all plots. Forage collected for nutritive analyses represented a visual assessment of forage selected by cattle [34]. All analyses were conducted via NIRS except for the 48-hr In Vitro True Digestibility.

2.3. Statistical Analysis

All data were analyzed using SAS 9.4 [35] with PROC GLIMMIX. For forage mass analyses, fixed effects included year, cover crop treatment, grazing regimen, and interactions. Replication was included as a random effect. For soil analyses, fixed effects included cover crop treatment, grazing regimen, soil depth, and interactions. Replication was included as a random effect.

3. Results and Discussion

With Year being a highly significant ($P < 0.001$) factor affecting forage mass and accumulation, results and discussion will be presented by year.

3.1. Year 1

Cover crop residual stubble heights (STHT) during April and May 2023 were achieved for each grazing regimen (**Table 1**). Nutritive values for all treatments, including ungrazed BG, are shown for April (**Table 2**) and May (**Table 3**), 2023. This two-month period included maturation and seed set of cover crops; thus, there were substantial changes in nutritive value components.

Table 1. Cover Crop Residual Stubble Height (STHT) during Year 1 (2023).

Cover crop treatment[1]	Grazing regimen[2]	STHT goal	April 26 - May 10 STHT achieved[3]	June 6 - 16 STHT achieved[4]
		(cm)	(cm)	(cm)
RYG	GRZ1	10 - 15	13	15
	GRZ2	15 - 20	20	23
	GRZ3	20 - 30	30	33
CLV	GRZ1	10 - 15	10	13
	GRZ2	15 - 20	20	18
	GRZ3	20 - 30	28	28
CLV-RYG	GRZ1	10 - 15	15	10
	GRZ2	15 - 20	23	20
	GRZ3	20 - 30	33	30

[1]RYG = ryegrass, CLV = clover, CLV-RYG = clover-ryegrass mix; [2]GRZ1 = residual stubble height of 10 - 15 cm, GRZ2 = 15 - 20 cm, GRZ3 = 20 - 30 cm; [3]Total grazing time ranged from 2 to 13.5 hours over a 1-to-4-day period; [4]Total grazing time ranged from 1.5 to 13 hours over a 1-to-5-day period.

Forage Mass and Nutritive Value

Forage mass and accumulation for non-grazed BG and sod-seeded cover crops are shown for each of three harvest dates and overall seasonal total DM (**Figures 4-8**). At the April 18, 2023 harvest, there were differences ($P < 0.0001$) in forage mass between all cover crops and BG. As anticipated from previous experiments at Overton [36], annual RYG produced the most forage DM in April at nearly 4500 kg/ha (Figure 4). The May 30, 2023 harvest showed the influence of BG in all plots (Figure 5), and the total DM for both harvests (Figure 6) with BG producing the most DM at about 8400 kg/ha. The final harvest on September 28 was exclusively BG and illustrated BG accumulation as affected by cover crop treatments. The total for all harvests (Figure 8) showed the N-transfer contribution in the CLV and CLV-RYG plots, which had the same total DM yields as that of the RYG plots that received 56 kg N/ha during the spring. The non-grazed BG plots with 56 kg N/ha produced the greatest forage DM at more than 14,800 kg/ha. Forage nutritive values for both harvests are shown in Table 2 and Table 3.

Table 2. Forage nutritive value for April 2023.

Cover crop treatment[1]	Grz[2]	Forage[3]	% Crude Protein	% ADF	% aNDF	% Lig-nin	% TDN	IVTD 48 hr, % of DM	Relative Feed Value	% Cal-cium	% Phoph orus	% Magne-sium	% Potas-sium	% Sulfur	% Ash DM
BG	0	BG	20	31	53	3.4	66	83	113	0.30	0.38	0.29	2.38	0.29	12
CLV	1	BG	22	29	49	3.2	70	83	127	0.37	0.35	0.30	2.66	0.29	10
CLV	1	CLV	18	34	40	6.6	67	82	148	1.63	0.15	0.32	1.67	0.15	8
CLV-RYG	1	CLV	25	27	33	8.2	62	77	193	1.53	0.46	0.46	1.22	0.31	11
CLV-RYG	1	RYG	12	34	53	4.3	65	82	110	0.34	0.23	0.33	2.76	0.18	10
RYG	1	BG	21	30	53	3.1	69	81	116	0.46	0.44	0.27	2.25	0.34	10
RYG	1	RYG	11	29	49	1.9	72	82	124	0.40	0.28	0.24	2.15	0.23	6
CLV	2	BG	24	26	46	2.8	70	88	138	0.52	0.44	0.31	2.70	0.32	11
CLV	2	CLV	18	30	38	6.0	70	83	162	1.48	0.20	0.33	1.10	0.10	7
CLV-RYG	2	BG	23	26	47	2.6	72	87	136	0.39	0.40	0.30	2.33	0.32	9
CLV-RYG	2	CLV	21	25	31	5.1	76	93	209	1.76	0.30	0.25	2.23	0.09	7
CLV-RYG	2	RYG	10	28	45	2.0	74	88	138	0.47	0.36	0.20	2.82	0.15	8
RYG	2	RYG	13	30	50	3.2	71	83	122	0.40	0.32	0.23	2.05	0.17	6
CLV	3	CLV	21	32	49	9.7	57	71	122	1.52	0.32	0.57	1.88	0.30	9
CLV-RYG	3	BG	24	27	47	1.6	74	86	136	0.50	0.38	0.34	2.22	0.29	9
CLV-RYG	3	CLV	21	25	30	5.0	75	93	215	1.87	0.32	0.31	1.52	0.06	7
CLV-RYG	3	RYG	9	26	43	1.7	75	90	149	0.47	0.36	0.20	2.88	0.13	8
RYG	3	RYG	11	31	51	3.2	70	81	118	0.38	0.31	0.27	1.86	0.19	7

[1]CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; [2]Stocking regimen to achieve residual stubble height; 1 = 10 - 15 cm, 2 = 15 - 20 cm, 3 = 20 - 30 cm; [3]Forage tested; CLV = clover; RYG = ryegrass; BG = bermudagrass.

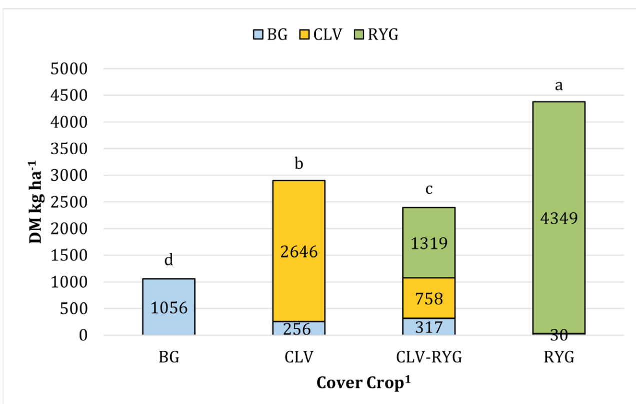
Table 3. Forage nutritive value for May 2023.

Cover crop treatment[1]	Grz[2]	Forage[3]	% Crude Protein	% ADF	% aNDF	% Lig-nin	% TDN	IVTD 48 hr, % of DM	Relative Feed Value	% Calci-um	% Phos-phorus	% Magnes-ium	% Potas-sium	% Sulfur	% Ash DM
BG	0	BG	13	34	65	3.7	60	71	89	0.37	0.24	0.16	1.50	0.36	7
CLV	1	BG	13	33	60	3.3	64	75	98	0.49	0.25	0.17	1.41	0.31	7

Continued

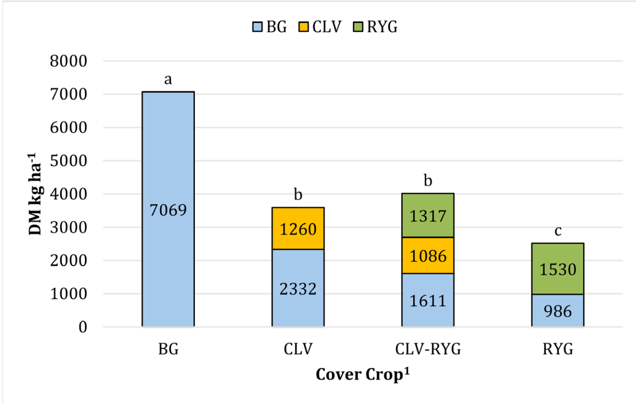
CLV	1	CLV	14	32	42	7.7	66	78	142	1.98	0.18	0.30	1.12	0.03	7
CLV-RYG	1	BG	15	31	61	2.1	66	76	98	0.43	0.22	0.18	1.68	0.43	8
CLV-RYG	1	CLV	13	37	45	7.6	58	71	124	1.51	0.16	0.27	1.15	0.08	6
CLV-RYG	1	RYG	13	35	57	3.4	66	80	101	0.37	0.31	0.18	2.40	0.21	8
RYG	1	BG	23	27	56	1.1	74	85	113	0.22	0.41	0.23	1.76	0.39	8
RYG	1	RYG	15	31	51	3.0	69	84	118	0.38	0.48	0.21	3.13	0.24	10
CLV	2	BG	13	33	61	3.3	64	75	97	0.36	0.25	0.14	1.71	0.32	7
CLV	2	CLV	14	34	43	8.0	63	76	134	1.62	0.21	0.17	2.05	0.07	7
CLV-RYG	2	BG	12	32	61	3.6	64	74	97	0.33	0.26	0.16	1.29	0.35	7
CLV-RYG	2	CLV	14	37	44	8.4	63	77	127	1.52	0.16	0.17	1.44	0.05	7
CLV-RYG	2	RYG	8	39	64	3.9	59	71	85	0.28	0.26	0.15	1.99	0.13	7
RYG	2	BG	20	31	59	1.8	71	82	103	0.41	0.43	0.21	2.52	0.44	8
RYG	2	RYG	13	33	58	3.7	65	81	102	0.36	0.42	0.22	2.83	0.21	10
CLV	3	BG	11	34	57	3.4	65	75	101	0.26	0.23	0.13	1.65	0.26	6
CLV	3	CLV	14	35	44	7.7	62	74	131	1.70	0.21	0.20	1.94	0.04	7
CLV-RYG	3	BG	12	32	62	3.6	63	73	95	0.32	0.23	0.15	1.21	0.26	5
CLV-RYG	3	CLV	13	35	43	7.3	61	74	132	1.51	0.14	0.17	1.31	0.04	6
CLV-RYG	3	RYG	8	40	63	4.4	55	67	85	0.23	0.26	0.14	1.48	0.13	5
RYG	3	BG	19	32	59	2.3	70	80	101	0.40	0.40	0.17	2.34	0.34	8
RYG	3	RYG	10	37	62	3.9	60	71	90	0.29	0.27	0.18	1.69	0.16	6

[1]CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; [2]Stocking regimen to achieve residual stubble height; 1 = 10 - 15 cm, 2 = 15 - 20 cm, 3 = 20 - 30 cm; [3]Forage variety tested; CLV = clover; RYG = ryegrass; BG = bermudagrass.



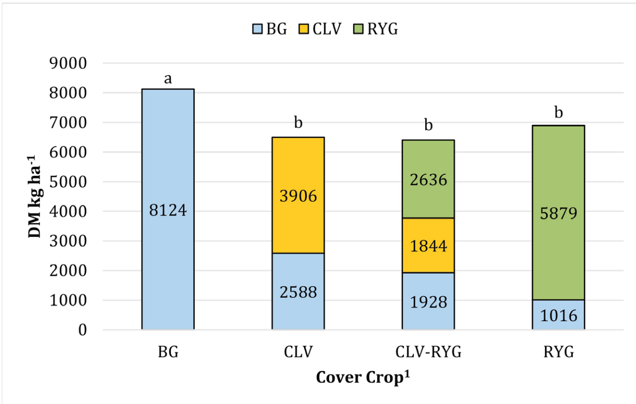
[1]Cover crop: CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; BG only = no cover crop. a-d: Bars with different letters denote harvest amounts that differ at $P < 0.0001$.

Figure 4. Harvest 1 of Year 1 (4/18/23).



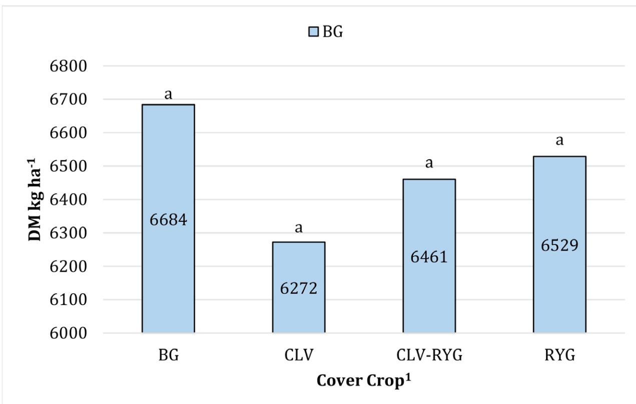
[1]Cover crop: CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; BG only = no cover crop. a-d: Bars with different letters denote harvest amounts that differ at $P < 0.0001$.

Figure 5. Harvest 2 of Year 1 (5/30/23).



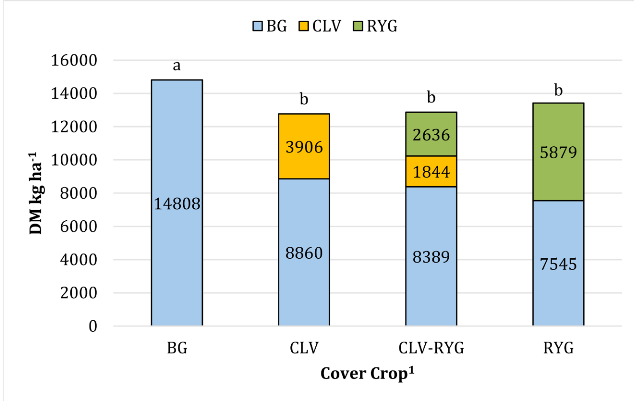
[1]Cover crop: CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; BG only = no cover crop. a-d: Bars with different letters denote harvest amounts that differ at $P = 0.0002$.

Figure 6. Harvests 1 + 2 of Year 1 (4/18/23 - 5/30/23).



[1]Cover crop: CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; BG only = no cover crop.

Figure 7. Harvest 3 of Year 1 (9/28/23).



[1]Cover crop: CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; BG only = no cover crop. a-d: Bars with different letters denote harvest amounts that differ at $P = 0.0002$.

Figure 8. Total of all harvests for Year 1 (4/18/23 - 9/28/23).

3.2. Year 2

The targeted and achieved STHT for grazing regimens on RYG, CLV, and CLV-RYG are shown for April and May 2024 (Table 4). Using various grazing times for each plot during a one-to-several-day period, daily management attention to plot height was very effective in meeting the STHT goals.

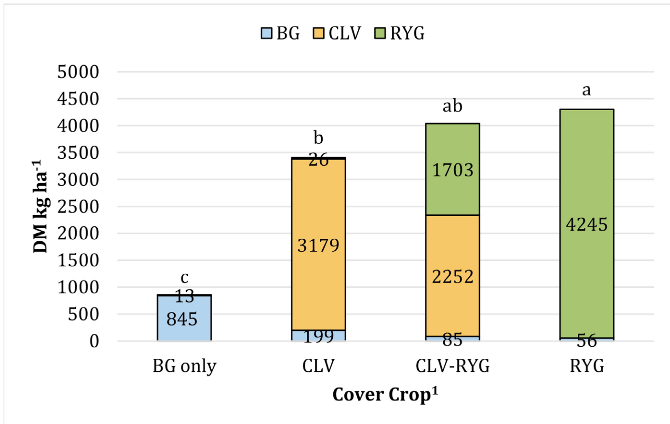
Table 4. Cover Crop Residual Stubble Height (STHT) during Year 2 (2024).

Cover crop treatment[1]	Grazing regimen[2]	STHT goal	April 18 - 25 STHT achieved[3]	May 14 - 22 STHT achieved[4]
		(cm)	(cm)	(cm)
RYG	GRZ1	10 - 15	7.6	15.2
	GRZ2	15 - 20	17.8	25.4
	GRZ3	20 - 30	30.5	33.0
CLV	GRZ1	10 - 15	10.2	15.2
	GRZ2	15 - 20	20.3	22.9
	GRZ3	20 - 30	28.0	33.0
CLV-RYG	GRZ1	10 - 15	12.7	10.2
	GRZ2	15 - 20	20.3	17.8
	GRZ3	20 - 30	33.0	33.0

[1]CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; [2]GRZ1 = residual stubble height of 10 - 15 cm, GRZ2 = 15 - 20 cm, GRZ3 = 20 - 30 cm; [3]Total grazing time ranged from 1.5 to 12.5 hours over a 1-to-8-day period; [4]Total grazing time ranged from 1.5 to 12.5 hours over a 1-to-10-day period.

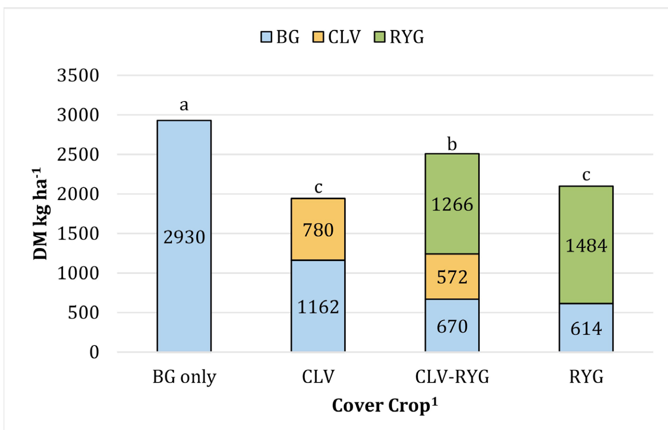
3.2.1. Forage Mass and Nutritive Value

Forage DM and accumulation for all plots in 2024 are shown in Figures 9-15. At the first harvest on April 15, there was no difference in DM from RYG or CLV-RYG (**Figure 9**). At the second harvest on May 14, BG-only plots had the greatest DM mass at more than 2800 kg/ha, and CLV-RYG plots had more ($P < 0.001$) DM accumulation than CLV or RYG plots (**Figure 10**). The total forage mass for both harvests showed RYG and CLV-RYG plots to have the most DM (**Figure 11**). At the third harvest on June 25, BG only plots had nearly twice as much forage DM as the cover crop plots (**Figure 12**). A five-year experiment with "Coastal" BG documented that accumulation of DM mass was greater with a stubble height of 5 cm, infrequent harvests of 35 to 40 cm of growth, and the application of 268 kg N/ha [37]. They also showed that stubble height was less important for Coastal BG production than either frequency of defoliation or rate of N fertilizer. In our experiment, the combined forage DM from all three harvests



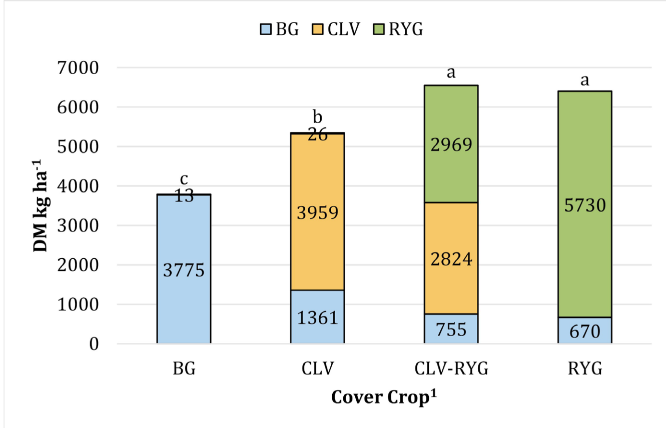
[1]Cover crop: CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; BG only = no cover crop. a-d: Bars with different letters denote harvest amounts that differ at $P < 0.0001$.

Figure 9. Harvest 1 of Year 2 (4/15/24).



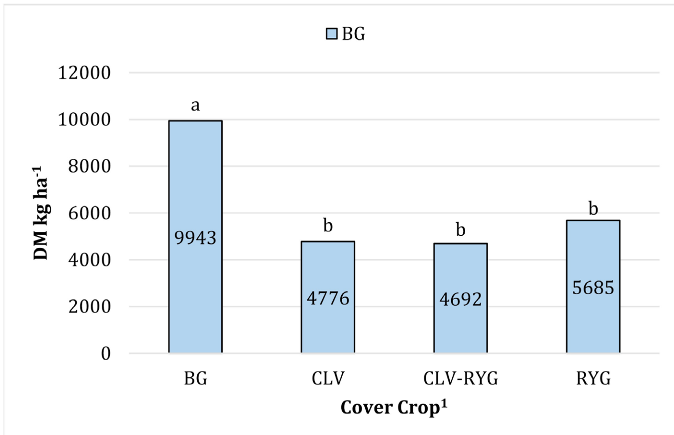
[1]Cover crop: CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; BG only = no cover crop. a-d: Bars with different letters denote harvest amounts that differ at $P = 0.0002$.

Figure 10. Harvest 2 of Year 2 (5/14/24).



[1]Cover crop: CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; BG only = no cover crop. a-d: Bars with different letters denote harvest amounts that differ at $P < 0.0001$.

Figure 11. Harvests 1 + 2 of Year 2 (4/15/24-5/14/24).



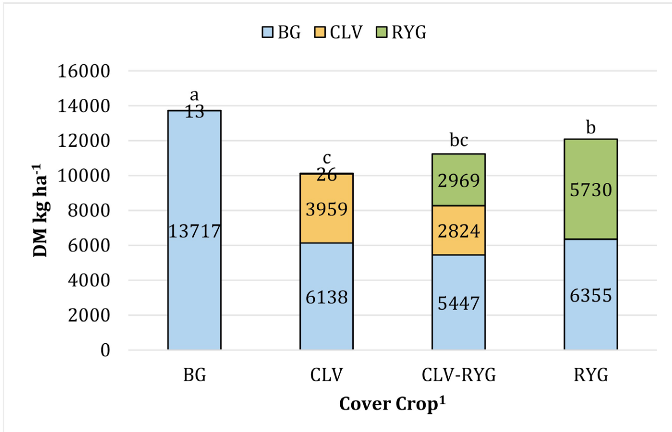
[1]Cover crop: CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; BG only = no cover crop. Bars with different letters denote harvest amounts that differ at $P < 0.0001$.

Figure 12. Harvest 3 of Year 2 (6/25/24).

illustrated the productivity of BG-only vs the three cover crop plots (Figure 13). However, at the fourth harvest on September 19, all plots showed similar BG mass (Figure 14). This productivity of BG emphasized some evidence of nutrient cycling and available soil N from cover crop plots. Figure 15 shows the total forage DM for the season, with non-stocked BG producing the most forage at more than 20,000 kg/ha. This result was similar to other sod-seeded experiments that showed reduced BG DM production during spring from overseeding cool-season annual forages [36]. In addition, they showed that non-overseeded Coastal bermudagrass had a large number of weeds at the first harvest on May 7.

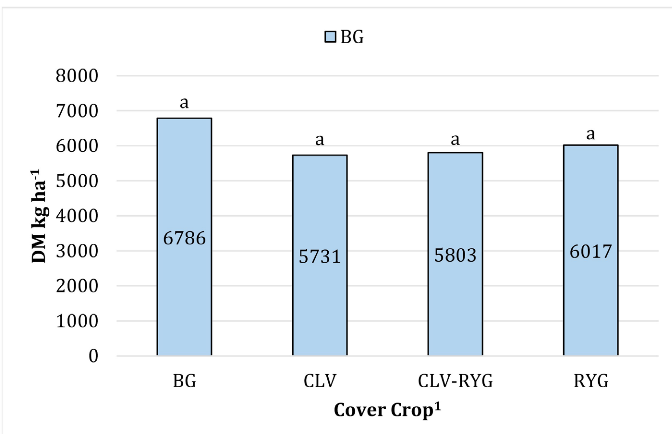
3.2.2. Soil Analysis

Initial soil samples sent to collaborators in Vernon, Texas, were lost in tornado destruction of buildings at the Texas A&M AgriLife Research and Extension Center at Vernon. However, final soil samples for treatments are shown in Table 5. Although all plots had received ECCE-100 limestone at 2242 kg/ha at the beginning of the experiment, soil pH was lower than expected. The $NO^2 + NO^3$ levels were significantly higher at the 0 - 10 cm depth compared to other soil depths. The %N was very low at all soil depths measured. Percent soil C was also low for cover crops, grazing regimens, and at all soil depths to 60 cm. The resultant C:N ratios of about 7.65 were similar across treatments and soil depths. Although there were some slight differences in soil components among cover crop plots, there was essentially no impact of grazing regimen on soil components. Organic matter remained low on this sandy loam, acidic soil and was not affected by cover crop treatment nor grazing regimen.



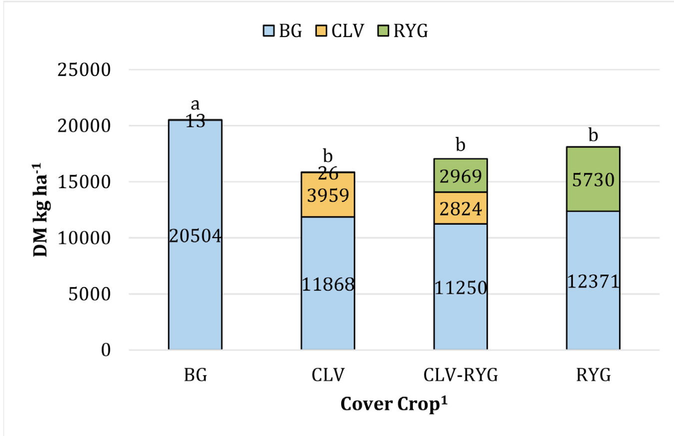
[1]Cover crop: CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; BG only = no cover crop. a-d: Bars with different letters denote harvest amounts that differ at $P = 0.0006$.

Figure 13. Harvests 1 + 2 + 3 of Year 2 (4/15/24-6/25/24).



[1]Cover crop: CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; BG only = no cover crop.

Figure 14. Harvest 4 of Year 2 (9/19/24).



[1]Cover crop: CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; BG only = no cover crop. a-d: Bars with different letters denote harvest amounts that differ at $P = 0.0045$.

Figure 15. Total of all harvests for Year 2 (4/15/24-9/19/24).

Table 5. Cover crop soil analyses by cover crop treatment, stocking regimen, and soil depth, Year 2.

	$NO^2 + NO^3$	pH	EC	P	K	Ca	Mg	S	Na	N	C	C:N	OM
	ppm		*us/cm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	%	%		%
Cover crop[1]													
CLV	13.93	4.56	97.97	93.85	81.81	380.47^{f}	56.31	13.75	63.24	0.11	0.80	7.45	1.61
CLV + RYG	20.04	4.52	94.40	87.35	85.43	312.49^{fg}	49.58	13.16	60.13	0.11	0.88	7.82	1.76
RYG	15.48	4.39	110.15	80.19	97.82	241.77^{g}	41.94	13.19	53.56	0.16	0.81	7.62	1.61
BG only	16.92	4.48	101.26	61.64	55.10	311.74^{fg}	47.23	13.77	69.07	0.49	0.86	7.82	1.72
Stocking regimen[2]													
GRZ1	15.26	4.64^{d}	87.03	92.79	106.87	407.58^{h}	62.95^{h}	15.61^{j}	57.13	0.13	0.74	8.23	1.49
GRZ2	18.32	4.37^{e}	110.36	84.20	73.62	247.23^{i}	41.00^{i}	12.66^{k}	61.02	0.09	0.75	7.86	1.50
GRZ3	15.87	4.45^{e}	105.13	84.39	84.56	279.93^{i}	43.88^{i}	11.84^{k}	58.77	0.16	1.00	6.80	2.00
Soil depth													
0 - 10 cm	37.13^{a}	4.89^{a}	236.39^{a}	67.49^{b}	112.74^{f}	694.56^{a}	101.53^{a}	15.50^{h}	60.24	0.08	0.67	8.73	1.34
10 - 20 cm	13.14^{b}	4.14^{c}	71.42^{b}	107.05^{a}	74.28^{g}	141.13^{c}	25.15^{c}	13.37^{hi}	55.53	0.09	0.54	6.98	1.07
20 - 40 cm	8.73^{b}	4.24^{c}	62.47^{bc}	108.07^{a}	70.11^{g}	119.92^{c}	22.19^{c}	12.47^{i}	61.91	0.19	0.93	6.52	1.85
40 - 60 cm	6.94^{b}	4.69^{b}	33.08^{c}	65.91^{b}	96.28^{fg}	290.70^{b}	48.24^{b}	12.14^{i}	58.22	0.14	1.19	8.27	2.38

[1]CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; BG only = no cover crop, bermudagrass only; [2]GRZ1 = residual stubble height of 10 - 15 cm, GRZ2 = 15 - 20 cm, GRZ3 = 20 - 30 cm; ^{abc}: Values followed by different superscripts differ at $P < 0.0001$; ^{de}: Values followed by different superscripts differ at $P = 0.0024$; ^{fg}: Values followed by different superscripts differ at $P < 0.05$; ^{hi}: Values followed by different superscripts differ at $P < 0.02$; ^{jk}: Values followed by different superscripts differ at $P = 0.0004$.

In a four-year experiment, Reference [38] used cereal grain rye as a cover crop that was grazed by cattle before no-till planting of cotton. When the rye canopy height approached 30 cm, 250 kg stocker cattle were added. Cattle were removed when rye had been grazed to a 10 to 15 cm stubble height. The four-year average lint yield tended to be greater for non-grazed treatments but were significantly different in only one year. Although grazing rye increased risk of reducing cotton lint yield in two out of four years due to soil moisture availability, there was a positive economic benefit to the grazing crop management system. Reference [39] grazed warm-season cover crops in the Texas Rolling Plains and reported that grazing did not affect stored soil water compared to ungrazed areas. Grazing a warm-season cover crop in the Southern Piedmont region of Georgia, US in which cattle consumed 90% of the available forage resulted in no substantial damage to the soil in a no-tillage experiment [40]. In the semi-arid Great Plains region of the US, Reference [41] reported that grazing cover crops did not negatively impact several components of soil health properties. However, they documented that grazing increased bulk density and decreased soil organic C. Reference [42] documented higher soil microbial biomass C with low stocking rates when cereal grain rye was overseeded in bermudagrass. They also reported that extending the length of grazing season of a plant improved soil health even in a bermudagrass system.

The loss of the initial pre-experiment soil samples did not allow for any indications of enhanced soil nutrient status due to treatments during this two-year experiment. However, the final soil analyses of the Lilbert loamy fine sand documented the inherently low organic matter, but the responsiveness of forage dry matter production to low levels of inorganic fertilization. Thus, the soil health status during this experimental period proved to be very effective in the overall forage production of cover crops and bermudagrass.

3.3. Summary

The forage accumulation of cover crops during their active growth period (April-May) showed dominance of RYG in Year 1, but both RYG and CLV-RYG had more forage mass than CLV in Year 2 (**Table 6**). In addition, there were no effects of grazing regimen on forage mass during the active vegetative growth stages of cover crops in either year. Total season long forage accumulation for both years is shown in **Table 7**. With BG mass included, there were no differences in total season forage mass between cover crops in either year, although Year 2 had substantially more DM accumulation than Year 1 as a response to increased rainfall (**Figure 2** and **Figure 3**). In both years, the targeted STHT of 10 - 15 cm resulted in less total season forage accumulation than both the 15 - 20 cm and 20 - 30 cm STHTs ($P < 0.02$). Although grazing is not a primary purpose of the standard USDA-NRCS cover crop code, the stubble heights we used on cover crops seeded into a bermudagrass sod provided documentation that these grazing regimens in this humid environment were a sustainable system. The persistence, adaptation, and sustainability of bermudagrass in the Southeastern US provide additional soil cover when using winter annual cover crops.

Table 6. Effect of cover crop treatment and grazing regimen on cover crop forage accumulation during vegetative growth of cover crops for two years.

	Year[1]	Year[2]
Treatment	**DM (kg/ha)**	
Cover crop[1]		
RYG	5878 [a]	5729 [a]
CLV-RYG	4479 [b]	5793 [a]
CLV	3906 [b]	3959 [b]
Stocking regimen[2]		
GRZ1	4665 [a]	4816 [a]
GRZ2	4626 [a]	5137 [a]
GRZ3	4973 [a]	5528 [a]

[1]CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; [2]GRZ1 = residual stubble height of 10 - 15 cm, GRZ2 = 15 - 20 cm, GRZ3 = 20 - 30 cm; [abc]: Within a treatment group, values in a column with different letters differ at $P < 0.0001$.

Table 7. Effect of cover crop treatment and grazing regimen on total season forage accumulation including BG mass for two years.

	Year[1]	Year[2]
Treatment	**DM (kg/ha)**	
Cover crop[1]		
RYG	13,407 [a]	16,572 [a]
CLV-RYG	12,866 [a]	16,176 [a]
CLV	12,765 [a]	14,927 [a]
Stocking regimen[2]		
GRZ1	12,390 [b]	13,966 [e]
GRZ2	13,596 [a]	16,572 [d]
GRZ3	13,052 [a]	17,139 [d]

[1]CLV = clover; RYG = ryegrass; CLV-RYG = clover + ryegrass; [2]GRZ1 = residual stubble height of 10 - 15 cm, GRZ2 = 15 - 20 cm, GRZ3 = 20 - 30 cm; [abc]: Within a treatment group, values in a column with different letters differ at $P < 0.003$; [def]: Within a treatment group, values in a column with different letters differ at $P < 0.023$.

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Conflicts of Interest

The authors declare no conflicts of interest regarding this data and manuscript.

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