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Low-disturbance restoration of degraded orchardgrass pastures: Forage productivity and soil C and N responses

Renata La Guardia Nave[1] | **Otávio Goulart de Almeida**[1] | **Jennifer Tucker**[2] | **Maria Karoline de Carvalho Rodrigues de Sousa**[3] | **Felipe Fonseca Nassar**[1]

[1]Department of Plant Sciences, University of Tennessee, Knoxville, Tennessee, USA

[2]Department of Animal and Dairy Science, University of Georgia, Tifton, Georgia, USA

[3]Department of Agricultural Sciences, Maranhão State University, São Luís, Maranhão, Brazil

Correspondence
Otávio Goulart de Almeida, Department of Plant Sciences, University of Tennessee, Knoxville, TN 37996, USA.
Email: ogoulart@utk.edu

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Abstract

Degraded cool-season grass pastures pose a major challenge for sustainable forage production in the southeastern United States. Orchardgrass (OG; *Dactylis glomerata* L.), a widely used forage species, often exhibits poor persistence under suboptimal management and environmental stress, requiring restoration. Strategies that minimize soil disturbance while improving productivity and soil quality are needed to support long-term pasture sustainability. This study evaluated six low-disturbance strategies to restore OG pastures while preserving soil quality: (1) control (C-OG), (2) synthetic N fertilization (OG+N; 67 kg N ha^{-1}), (3) fall-seeded alfalfa (*Medicago sativa* L.) (FA), (4) spring-seeded alfalfa (SA), (5) FA combined with crabgrass (*Digitaria sanguinalis* L.; CG) (FA+CG), and (6) SA+CG. Treatments were applied from 2021 to 2022 in Spring Hill, TN, and evaluated for forage mass (FM), root biomass, and soil carbon (C) and nitrogen (N) concentrations. The OG-N treatment produced the greatest FM (2390 kg DM ha^{-1}, where DM is dry matter), while C-OG yielded the least (1927 kg DM ha^{-1}). Alfalfa and alfalfa+CG treatments produced intermediate yields, averaging 2159 kg DM ha^{-1}, and did not differ among them. Root biomass declined over time across all treatments but was unaffected by restoration strategy. Soil C and N concentrations remained stable throughout the 2-year period. These findings indicate that both N fertilization and legume-grass mixtures can enhance productivity without soil disturbance or nutrient loss. Integrating alfalfa and CG into existing OG pastures offers a sustainable restoration approach that supports forage production while maintaining soil health.

Plain Language Summary

Orchardgrass pastures often decline in productivity without proper fertilization or management. Restoring them involves costly tilling and reseeding, which can harm

Abbreviations: CG, crabgrass; DM, dry matter; FM, forage mass; OG, orchardgrass; TRW, total root weight.

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soil health. This study tested six alternative restoration strategies: no intervention, adding nitrogen fertilizer, planting alfalfa (legume), and combining alfalfa with crabgrass (a warm-season grass). These treatments measured forage production and soil health changes (carbon and nitrogen). The pasture receiving nitrogen produced the most forage. Alfalfa-based treatments also increased forage production compared to the untreated pasture, particularly when alfalfa was combined with crabgrass, though they did not yield as much as nitrogen alone. Root mass decreased over the experiment, and none of the strategies caused a loss of soil carbon or nitrogen, suggesting that soil health was maintained. These results show that both nitrogen fertilizer and mixtures of alfalfa and crabgrass can help degraded orchardgrass pastures.

1 | INTRODUCTION

Orchardgrass (OG; *Dactylis glomerata* L.) is a widely used cool-season perennial grass in the southeastern United States, particularly in Tennessee, where it forms the basis of many grazing and hay production systems alongside tall fescue (*Schedonorus arundinaceus* [Schreb.] Dumort), and timothy (*Phleum pratense* L.) (Bates, 2023). Although OG offers high nutritive value and is suitable for both hay and grazing systems (Jonhson et al., 2025), on the other hand, its persistence is limited under conditions of inadequate fertility, improper grazing management, or climatic stress, often requiring renovations within 2–4 years (Bates, 2023). Restoring degraded OG pastures typically involves full reseeding and soil disturbance, which may incur high costs and negatively affect soil structure and long-term soil quality.

Alternative restoration strategies that minimize disturbance, such as interseeding legumes or incorporating warm-season grasses, offer potential to improve forage productivity while conserving soil resources (Nave et al., 2025a, 2025b). Cool-season grasses exhibit bimodal growth, with production peaks in spring and fall and limited growth during summer months (Silva, Dillard, et al., 2022). Therefore, integrating warm-season grasses such as crabgrass (CG; *Digitaria sanguinalis* L.) can mitigate summer forage gaps and enhance seasonal productivity. CG establishes readily from seed, tolerates high temperatures and dry conditions, can reseed under appropriate management (Schmidt et al., 2023), and can also contribute to weed suppression (Nassar et al., 2025).

Nitrogen (N) is a critical nutrient in forage systems, often supplied via synthetic fertilizers or through biological N_2 fixation by legumes. Legumes can supply significant quantities of N to companion grasses through rhizobial symbiosis, reducing reliance on external fertilizer inputs (Toribian et al., 2019). Alfalfa (*Medicago sativa* L.) is a deep-rooted, perennial cool-season legume with high nutritive value and broad adaptability (Barnes, 1980; Suwignyo et al., 2023). When integrated with grass species, alfalfa can improve the seasonal distribution of forage biomass and contribute biologically fixed N, thereby reducing external N input requirements (Burt et al., 2022; Jensen et al., 2012). Mixed-species swards also promote complementary rooting patterns, enhancing resource capture from different soil depths (Aponte et al., 2019).

Soil nutrient availability and root development are essential to sustaining productive forage systems. Strategies that include legumes or N fertilization may also influence soil organic carbon (C) and N pools, particularly in the upper soil profile (Silva, Sollenberger, et al., 2022). For example, Silva, Sollenberger, et al. (2022) observed increased soil carbon (C) and N in the surface layer (0–10 cm) following legume integration in perennial warm-season grass systems. However, the effects of these practices on soil properties in cool-season grass-based pastures, such as OG, remain less well defined, particularly under reduced-disturbance restoration approaches.

The objective of this study was to evaluate low-disturbance restoration strategies, including synthetic N fertilization, alfalfa interseeding, and mixtures of alfalfa and CG, on forage mass (FM) production, root biomass, and soil C and N concentrations in degraded OG pastures in Tennessee. We hypothesized that legume- and grass-based treatments would improve forage productivity while maintaining or enhancing soil nutrient status, thereby offering sustainable alternatives to conventional pasture renovation.

2 | MATERIALS AND METHODS

2.1 | Site description and treatments

The research was carried out at the Middle Tennessee AgResearch and Education Center, University of Tennessee, Spring Hill, TN (35°72′ N, 86°96′ W, 810 ft altitude). The soil analysis at the experimental site is Maury silty clay loam, eroded sloping phase with a pH of 6.38, P = 452 kg ha^{-1}, K = 139 kg

ha^{-1}, Ca = 3736 kg ha^{-1}, and Mg = 306 kg ha^{-1} (Mehlich-1 determined nutrient amounts). According to the Köppen climate classification, the experimental site is a humid subtropical climate (Cfa) with temperatures generally ranging from 5°C to 26°C, but it can drop occasionally as low as −15°C (NomadSeason, 2024). The weather data from the experimental site were obtained from NOAA (National Oceanic and Atmospheric Administration) (Table 1).

The experimental site was established 5–8 years ago with OG pastures, and these pastures were visible with poor standing and in need of restoration. Treatments consisted of six restoration strategies: (1) control with no restoration (C-OG), (2) synthetic N fertilization (67 kg N ha^{-1}) (OG+N), (3) fall seeding of alfalfa (FA), (4) spring seeding of alfalfa (SA), (5) fall seeding of alfalfa + seeding of CG (FA+CG), and (6) spring seeding of alfalfa + seeding of CG (SA+CG). The experimental design was a randomized complete block with four replications of 5 m × 15 m for each plot.

Alfalfa (cv. Ameristand 403T) was seeded in the designated plots on either October 19, 2020 (fall), or March 22, 2021 (spring), at a seeding rate of 22 kg ha^{-1}. For the synthetic N-fertilized plots, urea was applied (using a Gandy Drop Spreader with 3′, Gandy Company) on March 24, 2021, at a rate of 67 kg N ha^{-1}. On June 7, 2021, CG (cv. Mojo) was seeded at a rate of 4.5 kg ha^{-1}. Alfalfa and CG were planted using a Hege 1000 series drill (Hege Company). To minimize competition, plots were suppressed and mowed to a 5-cm stubble height before planting alfalfa or CG that were no-till seeded. Data were collected over 2 years, from May 2021 to October 2022.

2.2 | Measurements

2.2.1 | FM of OG-based pasture

The FM was assessed by harvesting a central strip (~8 m^2) within each plot to a stubble height of 7-cm stubble height.

Core Ideas

- Nitrogen fertilization produced the greatest forage mass in restoring orchardgrass pastures.
- Alfalfa and crabgrass mixes improved forage mass without disturbing soil structure.
- Restoration strategies had no negative impact on soil carbon and nitrogen levels over 2 years.

The fresh weight of the harvested forage was recorded, and a subsample from each strip was collected, weighed fresh, and subsequently dried at 60°C in a forced-air oven until a constant weight was achieved (~72 h) to determine dry matter (DM) content and dry FM of OG-based pasture. The total FM for each plot was calculated as the cumulative sum of the FM monthly for all sampling dates. In 2021, sampling occurred on April 15, May 12, June 16, July 14, August 12, and September 15. In 2022, sampling dates were April 18, May 19, June 16, July 18, August 18, and September 26.

2.2.2 | Root biomass

Soil cores (~8 cm diameter) were taken randomly in each plot to a depth of 30 cm and divided into two samples by depth (0–15 and 15–30 cm) at two moments (at the beginning of the experiment and the end of the experiment). Samples were kept frozen in plastic sample bags before being washed. Roots were washed separately for each soil depth to determine the distribution of root biomass. Root samples were separated, transferred onto a sieve, and washed again with water to remove fine mineral particles. The root biomass was dried to a constant weight at 50°C and then weighed on a scale, yielding the root weight (RW) for each soil score: RW depth 1 (0–15 cm) and RW depth 2 (15–30 cm), and the total root weight (TRW).

TABLE 1 Average monthly weather date for 2 years (2021 and 2022) and the historical average in Spring Hill, TN.

Weather variable	Apr	May	Jun	Jul	Aug	Sep	Oct
	Year 1 (2021)						
Average temperature (°C)	13.5	18.0	23.9	25.4	25.5	21.2	17.8
Rainfall (mm)	65	140	93	82	211	118	82
	Year 2 (2022)						
Average temperature (°C)	13.8	20.9	25.3	27.7	25.2	21.3	13.5
Rainfall (mm)	97	110	26	101	115	108	53
	Historic average[a]						
Average temperature (°C)	14.7	19.6	23.9	25.8	25.4	21.6	15.4
Rainfall (mm)	123	133	114	114	87	117	100

[a]Historic average weather data from 1991 to 2021 (30 years).

2.2.3 | Soil carbon and nitrogen

Soil samples (by depth) were similarly collected and analyzed for total C and N as a measure of soil quality in the Ag & Environmental Services Labs Soil, Plant, & Water Laboratory at the University of Georgia. For analysis of C, the samples were first treated with water and 8% hydrochloric acid to volatilize the carbonates from the sample. The soil sample was mixed, allowed to incubate for several hours, and then dried in an oven at 105°C. A representative sample (~0.5 g) was loaded into a steel crucible and combusted in an oxygen atmosphere at 1200°C using an Elementar Vario Max Total Combustion Analyzer. Elemental C and N were converted into CO_2, NO_x, and N_2. These gases were then passed through the infrared cells to determine the C content and a thermal conductivity cell to determine N_2. Results are reported in percentage. This methodology is based on Nelson and Sommers (1996), Bremner (1996), and Kirsten (1979).

2.3 | Statistical analysis

Data were analyzed using PROC MIXED of SAS, with a model that included effects of treatments, year, and their interaction as fixed effects, and the block (replication) effect was considered random (Littell et al., 2006). The covariance structure was chosen based on Akaike's Information Criterion (Wolfinger & O'Connell, 1993). Quantile–quantile plots were used to verify the homogeneity of variance and normality of errors. Treatment means were calculated using LSMEANS and compared by the probability of difference by Student's test ($p \leq 0.05$).

3 | RESULTS AND DISCUSSION

3.1 | FM of OG-based pasture

FM of OG-based pasture was influenced by both treatment and year ($p = 0.0102$ and $p < 0.0001$, respectively), but it was not affected by date × treatment interaction ($p > 0.05$). The OG-N treatment produced the highest FM (2390 kg DM ha^{-1}), while the untreated control (C-OG) exhibited the lowest FM at 1927 kg DM ha^{-1}. Alfalfa only (FA, SA) and alfalfa + CG mixtures (FA+CG, SA+CG) did not differ from one another and averaged 2159 kg DM ha^{-1}. FM in 2022 was substantially higher than in 2021 (2679 vs. 1639 kg DM ha^{-1}; Figure 1), reflecting interannual weather variation (Table 1).

These findings reaffirm the well-established role of synthetic N fertilization in rapidly enhancing pasture productivity (Burt et al., 2022; Silva, Sollenberger, et al., 2022). However, the performance of alfalfa-based treatments, particularly those combined with CG, demonstrates their potential as ecologically sound alternatives. Alfalfa, a deep-rooted, N-fixing legume, contributes to nutrient cycling and productivity through symbiotic N fixation, while CG helps offset the seasonal forage slump typical of cool-season systems (Guretzky et al., 2021; Nassar et al., 2025; Nave et al., 2025b), extending the grazing season (Sosinski et al., 2022). Although these biologically based treatments did not match the yield of OG+N, their performance exceeded that of the control, providing a valuable option for systems seeking to reduce external inputs.

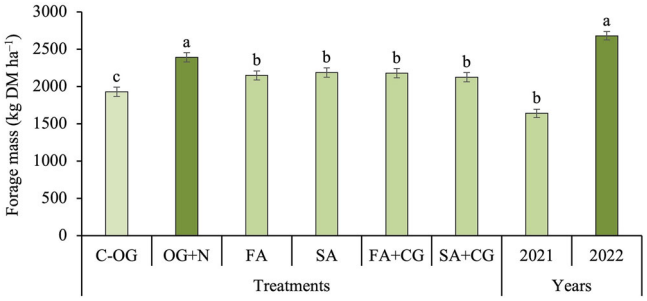


FIGURE 1 Forage mass of orchardgrass-based pasture affected by treatment and year in Spring Hill, TN. Treatments: (1) control with no restoration (C-OG), (2) synthetic N fertilization (67 kg N ha^{-1}) (OG+N), (3) fall seeding of alfalfa (FA), (4) spring seeding of alfalfa (SA), (5) fall seeding of alfalfa + seeding of CG (FA+CG), and (6) spring seeding of alfalfa + seeding of CG (SA+CG).

The treatments mixing alfalfa in spring or fall showed a difference in FM compared to using synthetic N fertilizer; however, the FM was greater than that of C-OG (Nave et al., 2025a). The lack of statistical differences among the alfalfa and alfalfa + CG treatments also suggests flexibility in implementation timing (fall or spring) and species combinations, which can facilitate producer adoption. In this companion study, alfalfa and CG made up a significant part of the sward, which not only improved the FM OG-based pasture compared to the control but also encouraged complementary rooting patterns and nutrient cycling (Nave et al., 2025a). These results align with previous studies, which have shown that the strategic use of legumes and warm-season grasses can sustain or enhance forage availability across seasons without compromising stand persistence or nutritive value (Aponte et al., 2019; McDonald et al., 2020).

3.2 | Soil analysis

3.2.1 | Root biomass

The TRW declined over time ($p = 0.0205$), decreasing from 3204 to 2537 kg DM ha^{-1} from the beginning to the end of the experiment period, respectively. This decline was driven primarily by reductions in the upper soil layer (0–15 cm), which decreased from 2871 to 2058 kg DM ha^{-1} ($p = 0.0039$).

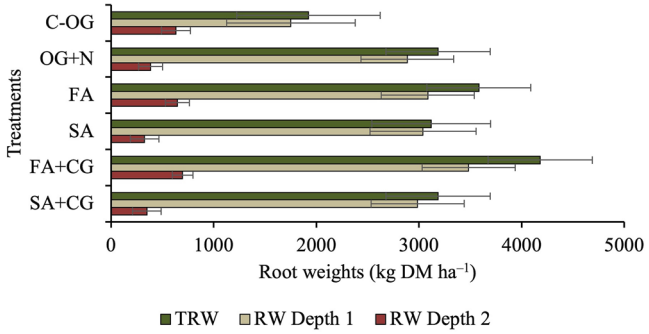


FIGURE 2 Root weight (RW) under orchardgrass-based pasture roots on total root weight (TRW), RW depth 1 (0–15 cm), and RW depth 2 (15–30 cm) at the beginning of the experiment in March 2021, in Spring Hill, TN. Treatments: (1) control with no restoration (C-OG), (2) synthetic N fertilization (67 kg N ha^{-1}) (OG+N), (3) fall seeding of alfalfa (FA), (4) spring seeding of alfalfa (SA), (5) fall seeding of alfalfa + seeding of CG (FA+CG), and (6) spring seeding of alfalfa + seeding of CG (SA+CG).

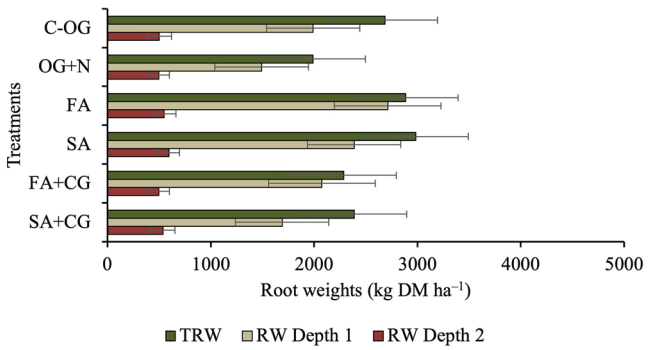


FIGURE 3 Root weight (RW) under orchardgrass-based pasture roots on total root weight (TRW), RW depth 1 (0–15 cm), and RW depth 2 (15–30 cm) at the end of the experiment in October 2022, in Spring Hill, TN,. Treatments: (1) control with no restoration (C-OG), (2) synthetic N fertilization (67 kg N ha^{-1}) (OG+N), (3) fall seeding of alfalfa (FA), (4) spring seeding of alfalfa (SA), (5) fall seeding of alfalfa + seeding of CG (FA+CG), and (6) spring seeding of alfalfa + seeding of CG (SA+CG).

No treatment or date × treatment interaction effects were observed ($p > 0.05$; Figures 2 and 3).

The uniform decline in root biomass across treatments suggests that short-term restoration efforts had limited influence on belowground dynamics. This is not unexpected, as changes in root systems typically manifest over longer timeframes and are subject to seasonal variation in environmental conditions such as precipitation and temperature (Derner et al., 2006; Silva, Dillard, et al., 2022). It is also possible that transitioning from a degraded to a more productive state prompted an initial shift in root turnover or allocation strategies without net increases in standing biomass. Future assessments that include root turnover rates and rhizodeposition could provide more insight into treatment impacts on belowground C inputs (Jackson et al., 1997).

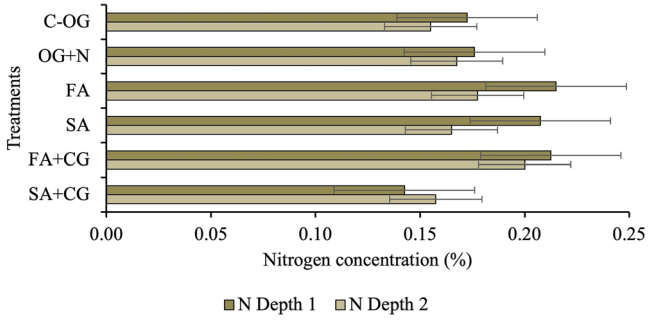


FIGURE 4 Nitrogen concentration (%) at depth 1 (0–15 cm) and depth 2 (15–30 cm) at the beginning of the experiment in March 2021, in Spring Hill, TN,. Treatments: (1) control with no restoration (C-OG), (2) synthetic N fertilization (67 kg N ha^{-1}) (OG+N), (3) fall seeding of alfalfa (FA), (4) spring seeding of alfalfa (SA), (5) fall seeding of alfalfa + seeding of CG (FA+CG), and (6) spring seeding of alfalfa + seeding of CG (SA+CG).

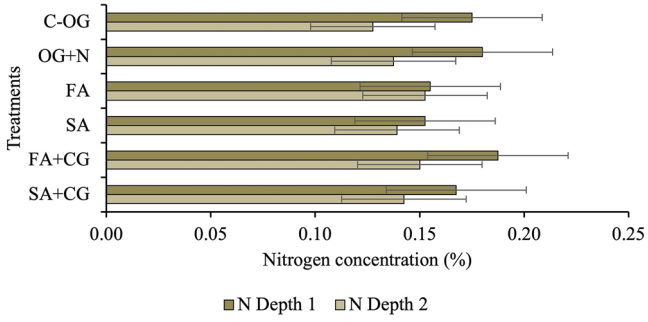


FIGURE 5 Nitrogen concentration (%) at depth 1 (0–15 cm) and depth 2 (15–30 cm) at the end of the experiment in October 2022, in Spring Hill, TN. Treatments: (1) control with no restoration (C-OG), (2) synthetic N fertilization (67 kg N ha^{-1}) (OG+N), (3) fall seeding of alfalfa (FA), (4) spring seeding of alfalfa (SA), (5) fall seeding of alfalfa + seeding of CG (FA+CG), and (6) spring seeding of alfalfa + seeding of CG (SA+CG).

3.2.2 | Soil nitrogen

The N concentration did not have differences among date, treatment, and date × treatment interaction at depth 1 ($p = 0.1776$, $p = 0.7374$, and $p = 0.3415$, respectively) and depth 2 ($p = 0.0676$, $p = 0.3249$, and $p = 0.9904$, respectively). Figure 4 shows the treatments at the beginning of the experiment, while Figure 5 shows the treatments at the end of the experiment.

The absence of short-term effects on soil total N is consistent with prior research showing that biologically fixed N from legumes, as well as applied synthetic N, may be quickly assimilated into plant biomass or immobilized in

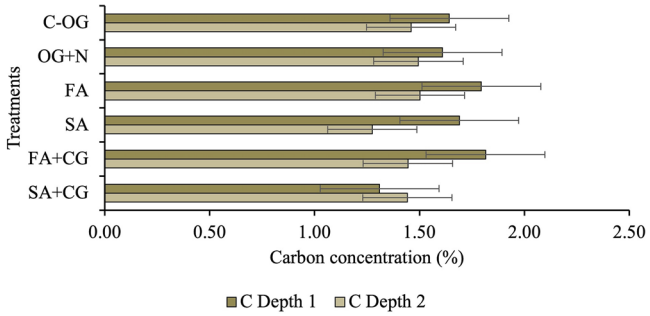


FIGURE 6 Carbon concentration (%) at depth 1 (0–15 cm) and depth 2 (15–30 cm) at the beginning of the experiment in March 2021, in Spring Hill, TN. Treatments: (1) control with no restoration (C-OG), (2) synthetic N fertilization (67 kg N ha^{-1}) (OG+N), (3) fall seeding of alfalfa (FA), (4) spring seeding of alfalfa (SA), (5) fall seeding of alfalfa + seeding of CG (FA+CG), and (6) spring seeding of alfalfa + seeding of CG (SA+CG).

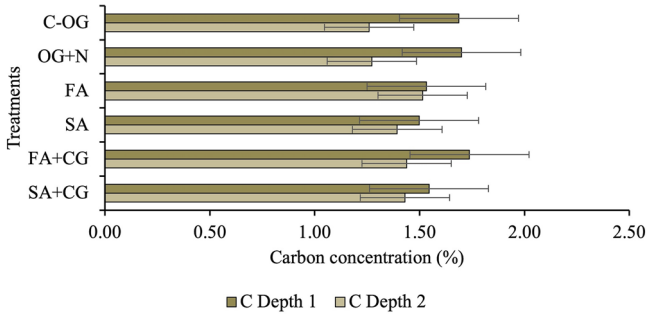


FIGURE 7 Carbon concentration (%) at depth 1 (0–15 cm) and depth 2 (15–30 cm) at the end of the experiment in October 2022, in Spring Hill, TN. Treatments: (1) control with no restoration (C-OG), (2) synthetic N fertilization (67 kg N ha^{-1}) (OG+N), (3) fall seeding of alfalfa (FA), (4) spring seeding of alfalfa (SA), (5) fall seeding of alfalfa + seeding of CG (FA+CG), and (6) spring seeding of alfalfa + seeding of CG (SA+CG).

microbial pools (Franzluebbers & Stuedemann, 2009). Detectable increases in soil N stocks, especially in systems without tillage, generally require several years of consistent input accumulation and are influenced by factors such as residue quality, soil type, and microbial activity (Jensen et al., 2012; Silva, Sollenberger, et al., 2022). Moreover, the relatively small amount of applied N (67 kg N ha^{-1}) in the OG+N treatment may have been largely utilized by plants during active growth, leaving little residual N to accumulate in the soil matrix. This is supported by the high FM observed in the OG+N treatment.

3.2.3 | Soil carbon

Total soil C concentrations did not differ across date, treatments, or their interaction at either depth 1 ($p = 0.7636$, $p = 0.7678$, and $p = 0.6084$, respectively) or depth 2 ($p = 0.5820$, $p = 0.9057$, and $p = 0.8927$, respectively). Figure 6 shows the treatments at the beginning of the experiment, while Figure 7 shows the treatments at the end of the experiment.

This outcome aligns with the initial hypothesis that low-disturbance restoration methods, particularly no-till interseeding of legumes and warm-season species, would preserve soil C stocks over time. The short duration of the study (2 years) may have limited the detection of C accumulation or redistribution, as C sequestration in perennial systems often occurs slowly and is influenced by factors such as root turnover, litter inputs, and microbial efficiency (Conant et al., 2001; Franzluebbers, 2010). Importantly, the lack of C loss indicates that restoration strategies did not degrade soil organic matter pools, maintaining the integrity of soil health during the transition.

These findings underscore the importance of considering restoration timeframes when evaluating soil responses. While aboveground productivity responded rapidly to treatments, especially N fertilization, soil indicators of ecosystem function may require longer periods to exhibit detectable change. Nonetheless, the observed stability in soil C and N under all restoration strategies supports their suitability for use in sustainable forage systems.

4 | SUMMARY AND CONCLUSIONS

This study demonstrated that declining OG-based pastures can be effectively restored using low-disturbance strategies that maintain soil integrity while improving forage productivity. Among the tested approaches, N fertilization resulted in the highest FM, highlighting its immediate agronomic benefits. However, interseeding alfalfa, alone or in combination with CG, also improved forage production relative to the untreated control and represents a more sustainable alternative.

The inclusion of alfalfa and CG offers potential to reduce reliance on synthetic inputs while enhancing seasonal FM. Although total root biomass declined over time, this trend was consistent across all treatments and likely reflected environmental variability rather than restoration effects. Importantly, no changes in soil C and N concentrations were observed over the 2 years, suggesting that these restoration strategies preserved soil nutrient status without inducing degradation.

Collectively, these findings support the use of legume-grass mixtures as viable tools for pasture restoration. While changes in C and N may require longer timeframes to emerge, the absence of nutrient loss combined with improved aboveground productivity highlights the potential of these approaches to advance the ecological and economic sustainability of forage-livestock systems.

AUTHOR CONTRIBUTIONS

Renata La Guardia Nave: Conceptualization; funding acquisition; investigation; methodology; project administration; resources; supervision; validation; visualization; writing—original draft; writing—review and editing. **Otávio Goulart de Almeida**: Data curation; formal analysis; methodology; validation; visualization; writing—original draft; writing—review and editing. **Jennifer Tucker**: Conceptualization; investigation; methodology; project administration; validation; visualization. **Maria Karoline de Carvalho Rodrigues de Sousa**: Methodology. **Felipe Fonseca Nassar**: Methodology.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ORCID

Renata La Guardia Nave https://orcid.org/0000-0002-6872-8079
Otávio Goulart de Almeida https://orcid.org/0000-0003-3003-2591
Jennifer Tucker https://orcid.org/0000-0003-2005-9926

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