Received: 13 November 2025 | Accepted: 19 February 2026

DOI: 10.1002/csc2.70268

Crop Science

ORIGINAL ARTICLE

Forage & Grazinglands

Interseeding strategies for legume integration into meadow fescue pastures

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Assigned to Associate Editor Erick Santos.

Funding information
USDA CRIS Project; Agricultural Research Service, Grant/Award Number: #5090-12630-005-00D

Abstract

Forage legumes provide a wide range of ecosystem services to grasslands. Improving legume proportion and species diversity of meadow fescue [*Lolium pratense* (Huds.) Darbysh] pasture-based systems can increase the sustainability of a given farming system. This study compared no-till or frost-seeding methods to incorporate clovers (*Trifolium* spp.) or chicory (*Cichorium intybus* L.) into an established meadow fescue sward as pasture-improvement strategies. No-till planting occurred in the fall or spring of 2022 and 2023, and frost seeding occurred during the winter of each year. In addition, this study aimed to quantify biological N_2 fixation (BNF) from the interseeded clovers. Chicory failed to establish in both years of the study, comprising less than 2% of the botanical composition. While no-till planting in the fall or spring, or frost seeding during the winter were successful at establishing clovers, frost seeding may be a more attractive method provided that it may be more economical, requiring less specialized equipment. No-till interseeding in the fall or spring are also adequate strategies. Overall, red clover (*Trifolium pratense* L.) was more productive than white clover (*Trifolium repens* L.) in the first year after planting. Further evaluations into persistence after the first year of clover planting are warranted. As a whole, interseeding clovers into meadow fescue pastures is indeed valuable for improving pasture systems by increasing forage accumulation and fixing up to 20 kg N ha^{-1} $year^{-1}$.

Plain Language Summary

Improving management practices that enhance persistence and productivity of forage legumes is important for increasing the adoption of legume species for livestock production. This study compared no-till or frost-seeding methods to incorporate clovers or chicory as pasture improvement strategies by interseeding into an established meadow fescue monoculture sward. No-till planting occurred in the fall or spring of 2022 and 2023. Chicory failed to establish, and red clover was more productive than white clover. While no-till planting in the fall or spring, or frost seeding during

Abbreviations: BNF, biological N_2 fixation; CP, crude protein; DM, dry matter; IVDDM, in vitro digestible dry matter; LSD, least significant difference; N_{dfa}, nitrogen derived from the atmosphere; OM, organic matter; RC, red clover; WC, white clover.

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the winter were successful interseeding strategies for establishing clovers, frost seeding may be a more attractive method for farmers because it may be more economical, requiring less specialized equipment.

1 | INTRODUCTION

Forage legumes provide wide-ranging benefits to pasture systems (Dubeux et al., 2024; Sollenberger et al., 2019). Developing management practices that enhance the persistence and performance of forage legumes is imperative for increasing adoption of legume species within the context of livestock production. Several methods exist for introducing legumes into established grass sod. In situations where tillage and removal of grass sod are not desired, no-till seeding has been among the best strategies for introducing legumes. No-till seeding, however, requires investment in specialized equipment, mainly planters and tractors (Casler et al., 1999). Frost seeding is yet another practice viable for planting clovers. Frost seeding consists of broadcasting seed during late winter when winter freeze–thaw cycles occur near the soil surface, along with snow or rainfall to help ensure seed–soil contact (Hall et al., 2020).

Meadow fescue is a grass commonly used for grazing or frequent-cutting hay management systems (Casler & van Santen, 2001). This grass is generally adapted to lowlands of central and northern Europe, as well as the US Upper Midwest region (Casler et al., 2015; Casler & van Santen, 2001). Meadow fescue may be especially attractive for its persistence under poorly drained soil conditions (Casler et al., 2015), as well as superior digestibility compared to other perennial cool-season grasses (Brink et al., 2010). However, compared to other perennial cool-season grasses, meadow fescue is generally less productive in terms of biomass accumulation (Brink et al., 2010; Casler et al., 2015; Niemeläinen et al., 2001). The productivity of meadow fescue-based pastures may be enhanced or sustained by the inclusion of legumes. This could also reduce reliance on off-farm nutrient inputs such as synthetic N fertilizer, which incurs additional costs to a farmer. Identifying strategies for legume inclusion into these systems is important for promoting positive economic and environmental outcomes in these production systems.

Evidence from quantitative studies suggests that 30%–50% legume proportions are optimal for maximizing soil-plant-animal-atmosphere outcomes in grass–legume pastures (Caram et al., 2025; Lüscher et al., 2014). In scenarios where grass-dominated pastures are productive but with minimal legume components, the reintroduction of legumes can be challenging but warrants addressing to ensure sustained productivity of these systems. This study compared no-till or frost-seeding methods to incorporate clovers or chicory into a preestablished (5+ years) meadow fescue sward, as these planting methods can serve as pasture renovation strategies. The objective was to evaluate whether interseeding chicory or clovers into meadow fescue could improve production and forage nutritive value during the first year after interseeding. In addition, this study aimed to quantify biological N_2 fixation (BNF) from the interseeded legumes.

2 | MATERIALS AND METHODS

2.1 | Experimental site

The experiment was carried out at the colocated USDA-ARS Environmentally Integrated Dairy Management Research Unit and the University of Wisconsin Marshfield Agricultural Research Station (44°7′ N latitude, 90°1′ W longitude) in Stratford, WI. Experimental plots were established on a Withee silt loam (fine-loamy, mixed, superactive, frigid, Aquic Glossudalfs) soil (Soil Survey Staff, 2011) over two consecutive years in 2022 and 2023. All plots measured 1.8 m × 3 m. Weather conditions at the experimental site are presented in Table 1. Soil samples (0- to 10-cm depth) were collected each year (at each different site) prior to establishment of the plots and analyzed at the University of Wisconsin Soil and Forage Analysis Laboratory (Madison, WI), via Bray P1 extraction to determine P and K. The soil tests indicated: (1) pH = 6.9, organic matter (OM) = 41 g kg^{-1}, P = 62 mg kg^{-1}, and K = 121 mg kg^{-1} for 2022; (2) pH = 6.9, OM = 45 g kg^{-1}, P = 56 mg kg^{-1}, and K = 114 mg kg^{-1} for 2023.

2.2 | Treatments, experimental design, and plot management

An experimental area of preestablished (5+ years) meadow fescue was used to conduct this experiment. The field was managed for harvesting hay since establishment. New plots were established each of the two years for this experiment at adjacent sites within the same field. Each year, the experiment was laid out in a randomized complete block design with four replications. In total, there were 17 treatments initially included in the experiment. However, chicory failed to establish, failing to comprise more than 2% of the botanical composition across any of the harvests and across both

TABLE 1 Mean monthly temperatures and rainfall obtained from the University of Wisconsin Marshfield Agricultural Research Station from April to October in 2022 and 2023.

Weather variable	April	May	June	July	August	September	October
2022							
Average temperature (˚C)	3.4	14.1	18.5	20.1	19.0	14.8	8.0
Monthly rainfall (mm)	86	67	71	51	92	130	35
2023							
Average temperature (˚C)	5.8	14.1	19.3	19.6	19.4	16.4	9.3
Monthly rainfall (mm)	94	53	70	99	50	110	200
30-Year average[a]							
Average temperature (˚C)	6.1	13.2	18.6	20.9	19.7	15.2	8.2
Monthly rainfall (mm)	78	105	122	97	102	99	77

[a]30-year average (1993–2023) obtained from National Oceanic and Atmospheric Administration (2023).

TABLE 2 Description of treatments from interseeded clovers (*Trifolium* spp.) into meadow fescue [*Lolium pratense* (Huds.) Darbysh] pastures.

Planting season	Planting years	Planting method[a]	Species[b]	Treatment denomination[c]
Fall	2021, 2022	No-till	Red clover	Fall-RC
Fall	2021, 2022	No-till	White clover	Fall-WC
Fall	2021, 2022	No-till	Red and white clover	Fall-RC-WC
Frost seed	2022, 2023	Broadcast	Red clover	Frost-RC
Frost seed	2022, 2023	Broadcast	White clover	Frost-WC
Frost seed	2022, 2023	Broadcast	Red and white clover	Frost-RC-WC
Spring	2022, 2023	No-till	Red clover	Spring-RC
Spring	2022, 2023	No-till	White clover	Spring-WC
Spring	2022, 2023	No-till	Red and white clover	Spring-RC-WC
–	2017	–	Grass (without N)	Grass
–	2017	–	N-fertilized grass	Grass+N

Abbreviations: RC, red clover; WC, white clover.

[a]No-till planting was carried out using no-till drill with nine rows at 19-cm spacing and 0.6-cm seeding depth. Frost seeding was carried out by manually broadcasting seed within the plot area.

[b]Red clover (*Trifolium pratense* L.) cv. KF Emerald; white clover (*Trifolium repens* L.) cv. Vigilant; Grass, meadow fescue with no N; Grass+N, meadow fescue receiving 109 kg N ha^{-1} $year^{-1}$ N-fertilizer application. Chicory (*Cichorium intybus* L) was included originally as an additional species but removed from analysis as it failed to establish across both years.

[c]All treatments comprised grass components, and only Grass and Grass+N were monocultures.

years (data not shown). Therefore, all treatments that included chicory were removed from the analyses. In total, 11 treatments were used for the analyses, as indicated in Table 2. Based on soil test recommendations, each plot received 170 and 195 kg K_2O ha^{-1} (0-0-62 N-P_2O_5-K_2O) on May 16, 2022, and May 4, 2023, respectively. The Grass+N treatment received 109 kg N ha^{-1} $year^{-1}$ in 2022 and 2023, and other treatments did not receive N. The N was split applied, following each harvest, applying 36 kg N ha^{-1} in the form of urea (46-0-0, N-P_2O_5-K_2O). All plots were fertilized with 43 kg K ha^{-1} (0-0-62, N-P_2O_5-K_2O) within 3 days after sample collection to provide some nutrient return. No P was added due to high soil P concentrations.

The interseeding methods evaluated within this experiment comprised no-till planting during fall or spring and frost seeding during early spring. The no-till planting was carried out using a Model 3P606NT Great Plains seed drill modified with a cone seeding attachment (Kincaid Equipment Mfg.; 500 Series). The planter contained nine rows with 19-cm spacing. Target seeding depth was 0.6 cm. The meadow fescue field was cut to a 10-cm stubble height prior to the fall clover or chicory seeding each year. Frost seeding was conducted by manually spreading the seed by hand to ensure even distribution across each plot. There was no regrowth during frost seeding, as soils were frozen. The planting and harvest for both years are depicted in Table 3. The seeding rates were 6.7, 1.1, and 4.5 kg ha^{-1} for red clover (RC), white clover (WC), and chicory, respectively, all on a bulk seed basis. RC cv. KF Emerald, WC cv. Vigilant, and chicory cv. Six-point were used for the experiment.

TABLE 3 Dates for planting and harvest for clovers (*Trifolium* spp.) no-till or frost seed broadcasted into established meadow fescue [*Lolium pratense* (Huds.) Darbysh] pastures.

Planting season	Planting date	Harvest date
2022 Harvest year		
Fall	November 8, 2022	June 28, 2022
Winter	March 21, 2022	August 9, 2022
Spring	May 6, 2022	September 19, 2022
2022 Harvest year		
Fall	November 14, 2022	June 9, 2023
Winter	April 14, 2023	July 13, 2023
Spring	May 4, 2023	August 16, 2023

Note: Fall and spring planting were carried out via no-till drill. Winter planting was carried out by frost-seed broadcasting during the winter of each harvest year.

2.3 | Response variables and calculations

All plots were hand-harvested using a sickle knife to a 10-cm stubble height. A 0.25-m^2 quadrat was randomly placed within each plot, and all material above 10-cm stubble height was harvested and placed into a cloth bag. Two quadrats were collected from each plot. All remaining biomass after harvest was mowed using a flail chopper, removing any stubble from the experimental area.

The freshly harvested samples were hand-separated for estimating the botanical composition. The samples were each separated into four components: grass, clovers, chicory, and weeds. Thereafter, all separated samples were dried at 55°C for 48 h and weighed to estimate forage accumulation and botanical composition. The forage accumulation was summed per harvest to provide a total forage accumulation for each year.

All dried samples were ground to pass a 1-mm screen using a Thomas Model 4 Wiley Cutting Mill (Thomas Scientific). All wet chemistry analyses were conducted at the USDA-ARS, Institute for Environmentally Integrated Dairy Management. Subsamples were analyzed separately for grasses and clovers. The subsamples were taken and ball-milled in a Mixer Mill (MM 400; Retsch) at 25 Hz for 9 min. The N concentrations and $\delta^{15}N$ were determined on a Flash EA IsoLink CN analyzer (Thermo Fisher Scientific) coupled to a DeltaQ isotope ratio mass spectrometer (Thermo Fisher Scientific). The crude protein (CP) concentrations were calculated by multiplying total N by 6.25. Determination of in vitro digestible dry matter (IVDDM) concentration was carried out using the DAISY-II method for 48 h (Ankom Technology Corp.) (Holden, 1999).

BNF was determined using the natural abundance method, described by Unkovich et al. (2008). The unfertilized grass was used as the reference plant. The proportion of plant N derived from atmosphere ($\%N_{dfa}$) was estimated using the equation described by Shearer and Kohl (1986):

$$\%N_{dfa} = \frac{\delta^{15}N_{reference} - \delta^{15}N_{N_2-fixing\ legume}}{\delta^{15}N_{reference} - B}$$

where $\delta^{15}N_{reference}$ is the $\delta^{15}N$ for the non N_2-fixing reference plant, $\delta^{15}N_{N2\text{-}fixing\ legume}$ is the $\delta^{15}N$ for the clover, and B is the $\delta^{15}N$ for the N_2-fixing plant grown in the absence of inorganic N. The B values used in this study were −0.94‰ and −1.48‰ for RC and WC, respectively, as reported by Unkovich et al. (2008). The total N accumulation was estimated by multiplying the forage accumulation by the total N concentration. The overall BNF was then estimated by multiplying the total N accumulation by the $\%N_{dfa}$. The quantities of BNF were summed across harvests and expressed as an annual amount.

2.4 | Statistical analyses

All response variables were analyzed using linear mixed model procedures as implemented in SAS PROC GLIMMIX (SAS/STAT 15.1; SAS Institute). Individual plots were considered the experimental unit for each output variable. For responses including total forage accumulation and BNF, the model included treatment as the fixed effect. Block and year were considered the random effects. All other response variables (e.g., botanical composition, nutritive value, $\%N_{dfa}$, and ^{15}N) were analyzed using repeated measures, and the model included treatment, harvest date, and their interaction as fixed effects. Assumptions for normal distribution of the data were assessed using residual diagnostic plots, per Kozak and Piepho (2018). The covariance structure resulting in the lowest corrected Akaike Information Criterion fit statistic was selected for each response variable. Contrast statements were used to carry out preplanned contrasts to compare treatment means of interest: (1) fall versus spring no-till seeding; (2) fall no-till versus frost seeding; (3) spring no-till versus frost seeding; (4) legume versus grass; and (5) legume versus Grass+N. Least squares treatment means were compared through pairwise t-tests using the PDIFF option of the LSMEANS statement in the aforementioned procedure. Based on the recommendations by Milliken and Johnson (2009) and Saville (2015), no adjustment for multiple comparisons was made; means were compared using Fisher's protected least significant difference (LSD). Differences were considered significant at $p \leq 0.05$. The REG procedure in SAS (SAS/STAT 15.1; SAS Institute) was used to analyze the regression of BNF on the proportion of clover in the botanical composition.

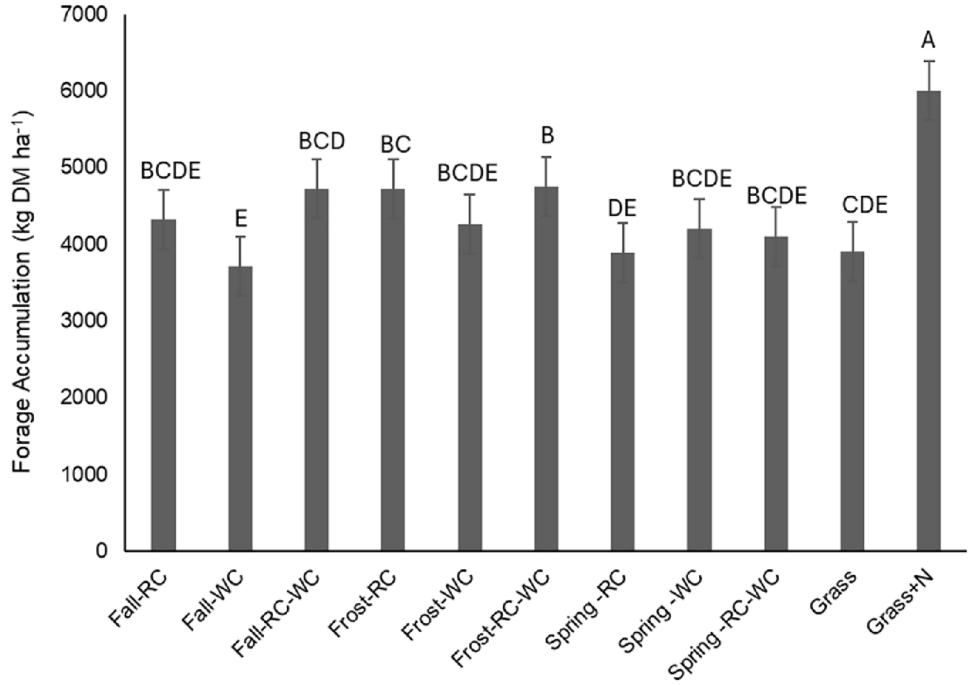


FIGURE 1 Annual forage accumulation from meadow fescue [*Lolium pratense* (Huds.) Darbysh] monoculture and its mixture with red clover (*Trifolium pratense* L.; RC) and white clover (*Trifolium repens* L.; WC) planted under the fall or spring by no-till drill or frost-seeding (Frost) conditions. Means represent average over two consecutive years (2022 and 2023). Bars represent standard error of the mean. DM, dry matter.

3 | RESULTS

3.1 | Forage accumulation and botanical composition

There was a treatment effect ($p < 0.001$) for the total forage accumulation. Across all treatments, Grass+N has the greatest forage accumulation, exceeding over 6000 kg dry matter (DM) ha^{-1} year^{-1} (Figure 1). In contrast, forage accumulation in Grass treatment (which received no N) was 4000 kg DM ha^{-1} year^{-1}. There were also differences ($p = 0.03$) in the season of planting, where spring-planted treatments produced 500 kg DM ha^{-1} less than frost-seeded treatments, on average.

There were treatment ($p < 0.001$) and harvest date ($p < 0.001$) effects for botanical composition, but no interaction between both ($p = 0.25$; Figure 2). The proportion of clovers was low (<3% DM) at the first harvest, increasing to more than 20% for the remaining harvests, averaged across all treatments. RC had 10% units greater proportion in the botanical composition than WC across all treatment combinations (contrast $p = 0.001$). For all planting periods, the proportion (39%) of clover was greater when in a mixture of RC and WC, with the greatest proportion observed during the second harvest under frost-seeded treatment. The grass proportion was greater than 90% across treatments for the first harvest and decreased with increasing proportions of clover in successive harvests (Figure 2). Weeds comprised less than 2% of the botanical composition throughout each of the harvests for all treatments, except for non-N fertilized grass, where weeds comprised 20% of the DM. The main weed species within this experimental area were dandelions (*Taraxacum officinale* F.H. Wigg.) and foxtail (*Hordeum murinum* L.).

3.2 | Forage nutritive value and biological N_2 fixation

For the grass components, there were treatment ($p = 0.001$) and harvest date ($p < 0.0001$) effects on CP concentrations. Overall, the CP concentrations of the grass increased through the season from 83 to 125 g kg^{-1} from Harvest 1 to Harvest 4, respectively. The Grass+N and frost seed-RC grass had the greatest CP concentrations, averaging 109 g kg^{-1}. The CP concentrations within the clovers did not differ by treatment ($p = 0.75$), but there was a harvest date effect ($p = 0.001$). The clover CP concentrations were greatest at the initial and final harvests, averaging 260 g kg^{-1}. In the remaining harvests, the CP concentrations averaged 200 g kg^{-1} across treatments.

The IVDDM concentrations within the grass component averaged 647 g kg^{-1} across all treatments. There were no treatment ($p = 0.48$) or harvest date ($p = 0.12$) effects within the IVDDM of the grass components. For the clover components, the IVDDM concentrations approached significance for treatment ($p = 0.07$; Table 4). On average, the IVDDM concentration across the clover components was 762 g kg^{-1}.

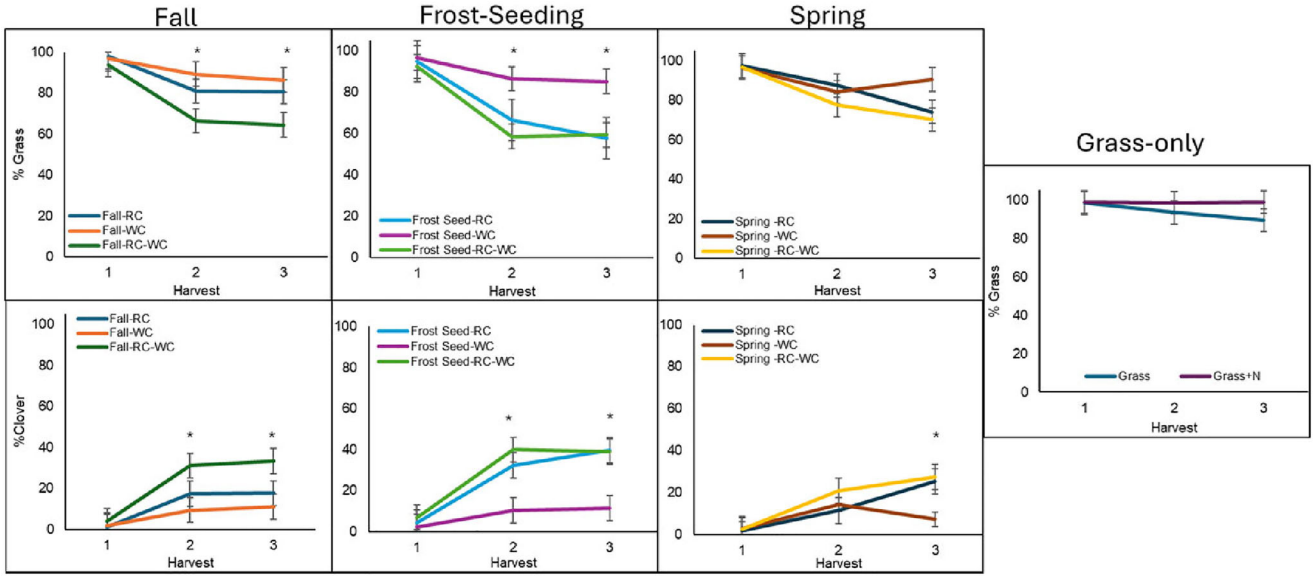


FIGURE 2 Proportion of grass and clover (dry matter [DM] basis) in the botanical composition from fall or spring no-till interseeded, or frost-seeded red (RC) or white (WC) clovers (*Trifolium spp*.) into meadow fescue [*Lolium pratense* (Huds.) Darbysh] grass pastures. Means are averages across two years (2022-2023). Dates for Harvest 1 were June 28, 2022, and June 9, 2023; Harvest 2 were August 9, 2022, and July 13, 2023; Harvest 3 were September 19, 2022, and August 16, 2023. Grass+N depicts N-fertilized grass and Grass depicts non-N fertilized grass. Error bars denote the standard error of the mean. Asterisks depict treatment differences within harvest date according to least significant difference (LSD) at 5% significance.

TABLE 4 Nutritive value by component (grass or clover) from fall or spring no-till interseeded, or frost-seeded (Frost) red (RC) or white (WC) clovers (*Trifolium* spp.) into meadow fescue [*Lolium pratense* (Huds.) Darbysh], and δ^{15}N and $\%N_{dfa}$ from the clovers.

Item	Grass		Clover			
Treatment[a]	CP (g kg^{-1})	IVDDM (g kg^{-1})	CP (g kg^{-1})	IVDDM (g kg^{-1})	δ^{15}N (‰)	N_{dfa} (%)
Fall-RC	99BC[b]	647	267	754	0.380	80
Fall-WC	102BC	650	223	796	−0.132	81
Fall-RC-WC	97C	623	226	745	0.061	82
Frost-RC	106AB	651	240	758	0.121	80
Frost-WC	99BC	638	204	–[c]	−0.233	83
Frost-RC-WC	102BC	644	241	767	0.065	82
Spring-RC	96C	638	233	756	−0.111	81
Spring-WC	100BC	649	206	764	0.040	81
Spring-RC-WC	103BC	656	214	754	−0.168	82
Grass	97C	645	–	–	–	–
Grass+N	113A	680	–	–	–	–
SEM	3.2	9.25	29.5	26.2	0.239	1.8
p-value	0.0010	0.48	0.75	0.07	0.61	0.96

Note: The treatment Grass+N depicts N-fertilized grass and Grass depicts non-N fertilized grass.

Abbreviations: CP, crude protein; IVDDM, in vitro digestible dry matter; N_{dfa}, N derived from atmosphere; SEM, standard error of the mean.

[a]No-till planting was carried out using drill with nine rows at 19-cm spacing and 0.6-cm seeding depth. Frost seeding was carried out by manually broadcasting seeding within the plot area.

[b]Means not sharing a common letter indicate differences according to least significant difference (LSD) at 5% significance.

[c]Missing data, due to lack of sample for analysis.

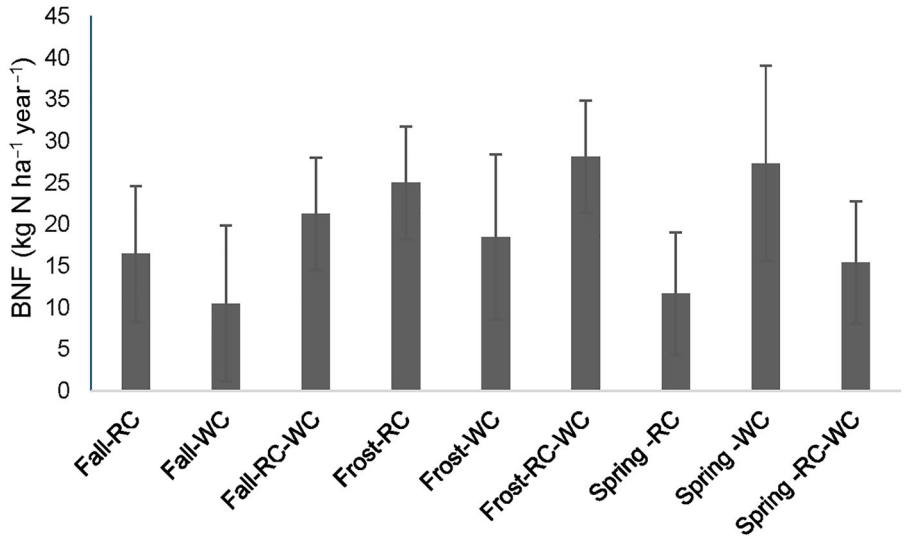


FIGURE 3 Biological N_2 fixation (BNF) from red (RC) and white (WC) clovers no-till interseeded during fall or spring, or frost seeded (Frost) into meadow fescue [*Lolium pratense* (Huds.) Darbysh] pastures. Means are averages across two years. Error bars denote the standard error of the mean ($p = 0.73$).

No treatment differences ($p = 0.75$) were found for the clover $\delta^{15}N$, averaging 0.002‰ across treatments (Table 4). Similarly, the $\%N_{dfa}$ did not differ by treatment ($p = 0.95$) and averaged 81% across treatments. For the total BNF, there were also no treatment differences ($p = 0.73$). The clovers fixed an average of 20 kg N ha^{-1} $year^{-1}$ across all treatments (Figure 3). The regression between the proportion of clover in the botanical composition versus BNF showed an R^2 of 0.66 (Figure 4).

4 | DISCUSSION

The timing and method of interseeding the clovers into preestablished meadow fescue sward showed differences in terms of the forage production, but overall, RC interseeding using the frost-seeding method provided the best chance of successful establishment. Frost seeding of RC also provided greater forage accumulation relative to non-N fertilized grass. While all three (spring or fall no-till interseeding, or frost seeding) strategies to establish the clover species were successful to an extent, frost seeding may be especially attractive for interseeding clovers, since minimal equipment is required compared to the need for a no-till drill, therefore making it a more economical manner for improving pastures (Singer et al., 2006). In regions where frost-heave cycles are evident through the winter seasons, farmers can take advantage of these climatic and environmental conditions for incorporating clovers into grass pastures (Castillo et al., 2022). Another management strategy to consider that was not observed in this experiment, but is equally as important, is the control of competition from the grass component, both during the planting and establishment phases. Competition from grass is often thought to be more critical than the seeding method for ensuring the success of the clover establishment (Mueller & Chamblee, 1984; Schlueter & Tracy, 2012). Therefore, ensuring that residual grass biomass is removed before planting is a good measure to ensure proper establishment of interseeded clovers (Schlueter & Tracy, 2012). Once legume seedlings have emerged, controlling grass regrowth is important to ensure legumes are able to compete for light and nutrient resources (Cuomo et al., 2001). Control of grass regrowth can be achieved using machinery with high cutting heights, if necessary, or managing grazing livestock to high residual stubble heights.

Several studies have suggested that in temperate grass–legume mixtures, a proportion of 30%–50% legume is the optimum range to maximize the soil-plant-animal-atmospheric outcomes (Lüscher et al., 2014; Nyfeler et al., 2009, 2011). While this study only focused on the year of planting, it indicates that RC is better than WC at sustaining high proportions within the botanical composition in the first year of establishment. Of the three planting strategies, spring planting had the least clover proportions early in the season, increasing throughout the season, while the fall and frost-seeding strategies remained largely above 30% after the first harvest. Evaluations beyond the first year of production are warranted, especially since the proportion of clovers within the botanical composition of pasture systems fluctuates within and among years (Chapman et al., 2017).

Forage nutritive value was analyzed for each component of the mixture (i.e., grass or clover) to test whether legume inclusion improved the nutritive value of the companion grass. Within the clovers, the nutritive value did not differ across treatments, and both CP and IVDDM concentrations were within the accepted range for clovers (Brink & Fairbrother,

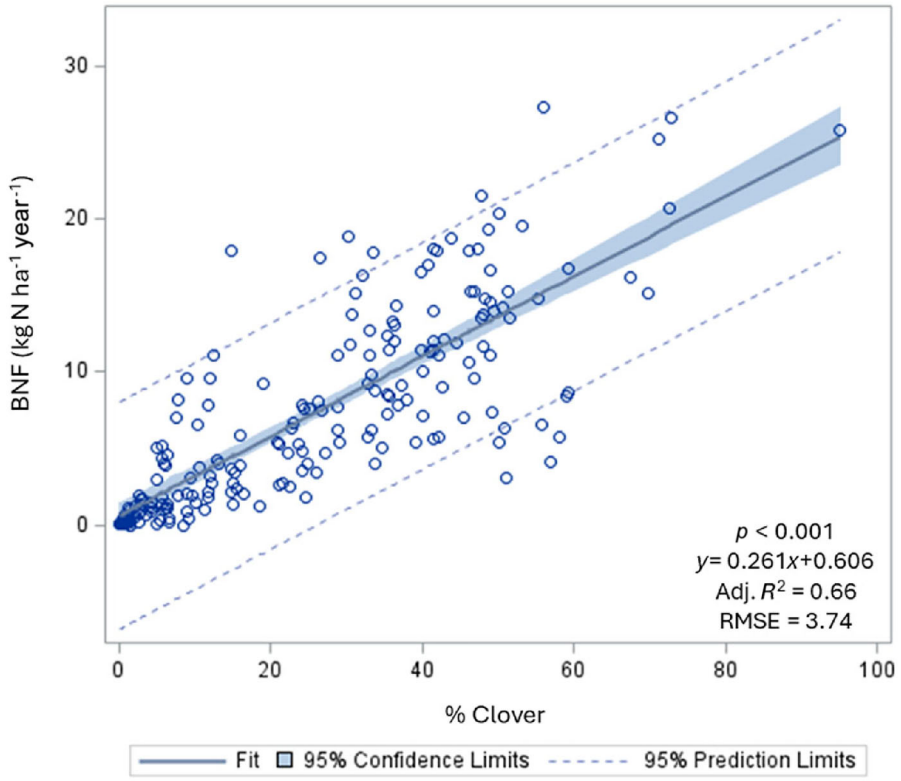


FIGURE 4 Regression between proportion of clover (% clover) on the botanical composition and biological N_2 fixation (BNF) from clovers (*Trifolium* spp.) interseeded into meadow fescue [*Lolium pratense* (Huds.) Darbysh]. RMSE, root mean squared error.

1992; Jaramillo, Dubeux, et al., 2021). Nitrogen fertilization improved the CP concentrations within the N-fertilized grass treatment, which is commonly reported in the literature (Collins, 1991). There was some evidence that the clovers improved CP concentrations of the grass components within this study, as the grass within the frost-seeded RC treatment had greater CP concentrations than the non-N fertilized grass. This is likely attributed to the high proportion of clover within the botanical composition of this treatment, as referenced above. As a whole, the clover inclusion did not influence the nutritive value of the grass, considering the first year of production. In grass–legume swards, sharing of N resources occurs through direct or indirect mechanisms (Dubeux et al., 2007). Direct mechanisms include direct root contact, while indirect mechanisms include root and nodule decomposition as well as returns through aboveground litter decomposition and urine and dung deposition (Dubeux et al., 2007). Adequate establishment and root growth are key for sharing resources within grass–legume swards. Therefore, it may be speculated that greater differences within the grass's nutritive value may be observed during the second year, provided that clovers sustain an adequate proportion. Further studies are warranted to quantify potential benefits from long-term clover inclusion into meadow fescue swards.

BNF is an important ecosystem service in temperate grasslands when clovers are included in a system. The total BNF from a given grass–legume system is directly influenced by factors including the proportion of the given legume in the pasture's botanical composition, forage accumulation, N concentration, and $\%N_{dfa}$ (Unkovich et al., 2008). The data from this study provide further evidence of this, as the amount of BNF increased with increasing proportion of clover. The overall BNF observed within this study was low and is attributed to the low clover proportions. In pure stands, clover species are reported to fix up to 155 kg N ha^{-1} $year^{-1}$ (Brink, 1990).

Another important result from this study was that chicory does not establish well, when interseeded into existing sod, at the tested seeding rate. Similar observations have been reported by others (Rogers et al., 2013; Skinner & Dell, 2010). Skinner and Dell (2010) reported adequate establishment from similar planting methods adopted in the current study. However, they reported poor persistence beyond the first year. Further research may be warranted to evaluate strategies (e.g., increasing seeding rates and cultivar selection) to incorporate chicory or other forbs, as there may be value in increasing species diversity within temperate pasture systems (Jaramillo, Sheridan, et al., 2021).

5 | CONCLUSION

As a whole, interseeding clovers into meadow fescue pastures can improve forage accumulation and fix 20 kg N ha^{-1} $year^{-1}$. The data confirm that no-till planting and frost seeding are

viable strategies for establishing clovers onto meadow fescue pastures. RC was more productive than WC. As a planting strategy, frost seeding RC is likely a more advantageous alternative for farmers, since frost seeding requires less specialized equipment. However, no-till interseeding in the fall or spring may also be recommended as an alternative. Questions related to persistence and productivity beyond the first year warrant further investigation.

AUTHOR CONTRIBUTIONS

David M. Jaramillo: Conceptualization; data curation; formal analysis; investigation; project administration; supervision; writing—original draft; writing—review and editing. **Lisa M. Bauman**: Conceptualization; investigation; project administration; writing—review and editing. **Lais O. Lima**: Investigation; resources; writing—review and editing. **Jason Cavadini**: Conceptualization; methodology; resources; writing—review and editing.

ACKNOWLEDGMENTS

The study was funded through USDA CRIS Project #5090-12630-005-00D. Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply either recommendation or endorsement by the USDA. The USDA is an equal opportunity provider and employer. The authors would like to thank Scott Fisher and the Marshfield Agricultural Research Station farm staff for their help with field management. The authors would also like to thank Robin Ogden, Grace Vos, and Meridith Anderson for helping with processing and sample analysis.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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How to cite this article: Jaramillo, D. M., Bauman, L. M., Lima, L. O., & Cavadini, J. (2026). Interseeding strategies for legume integration into meadow fescue pastures. *Crop Science*, *66*, e70268. https://doi.org/10.1002/csc2.70268