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John A. Guretzky

D. D. Redfearn

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Seeding Rate Effects on Forage Mass and Vegetation Dynamics of Cool-Season Grass Sod Interseeded with Sorghum-Sudangrass

John A. Guretzky * and Daren D. Redfearn

Department of Agronomy and Horticulture, University of Nebraska-Lincoln, Lincoln, NE 68583-0915, USA; dredfearn2@unl.edu
* Correspondence: jguretzky2@unl.edu

Abstract: Interseeding annual warm-season grasses into perennial cool-season grasses has the potential to increase summer forage mass and nutritive value. Knowledge of how seeding rate affects annual warm-season grass establishment, forage mass, and vegetation dynamics remains limited. From 2016–2017, we conducted a field experiment evaluating the effects of seeding rates on sorghum-sudangrass (*Sorghum bicolor* × *S. bicolor* var. *sudanense*) density and forage mass and on the frequency of occurrence of plant species in cool-season grass sod in Lincoln, NE. The experiment had a completely randomized design consisting of six replicates of four seeding rates [0, 14, 28, and 35 kg pure live seed (PLS) ha^{-1}] in sod mowed at a 2.5-cm height and one unseeded, non-mowed control treatment. Sorghum-sudangrass establishment increased with seeding rate from an average of 20 to 45 plants m^{-2} as the seeding rate increased from 14 to 35 kg PLS ha^{-1}. Forage mass depended on a seeding rate × harvest interaction, showing positive linear and cubic responses to seeding rate in consecutive harvests at 45 and 90 d after interseeding. To increase forage mass in perennial cool-season grass sod, producers should interseed sorghum-sudangrass with at least 28 kg PLS ha^{-1}. One-time seedings into cool-season, perennial grass sod have no residual effects on subsequent forage mass and vegetation dynamics.

Keywords: annual warm-season grasses; cool-season grass pasture; forage management; improved pasture; pastureland; permanent pasture; perennial cool-season grasses; smooth bromegrass; tall fescue; temperate pastures

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1. Introduction

In temperate environments, perennial cool-season grass pastures offer excellent forage production in spring, but often have limited growth during summer. Planting annual warm-season grass pastures increases forage during summer when the growth of cool-season grasses slows. Complementary grazing systems that utilize annual warm-season grass pastures often see marked improvements in summer forage and cattle production. In Nebraska, cattle grazing sudangrass in summer after grazing smooth bromegrass (*Bromus inermis* Leyss.) in spring showed improved weight gains compared with cattle grazing only smooth bromegrass throughout spring and summer [1]. In central Illinois, use of annual warm-season grass pastures along with cool-season grass pastures increased herbage mass and nutritive value in mid-summer compared with using only cool-season grass pastures [2]. In Wisconsin, use of sudangrass-Kura clover (*Trifolium ambiguum* M. Bieb.) mixtures improved animal weight gains in mid-summer when cool-season grass production slumped [3].

Interseeding perennial cool-season grass pastures with annual warm-season grasses offers a strategy to increasing summer forage production on the same land. In Missouri, researchers found the total forage yield in tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.] with herbicide-killed strips interseeded with sorghum-sudangrass to be 7.82, 5.35, and 3.65 Mg ha^{-1} greater than unseeded tall fescue stands across a three-year period [4]. Yield differences declined across years due to tall fescue encroachment into the one-time killed strips. In an Iowa study, interseeding sorghum into a slot-tilled and herbicide-suppressed reed canarygrass (*Phalaris arundinacea* L.) stand increased dry matter (DM) yields by 35% (~2.24 Mg ha^{-1}), but the sorghum appeared chlorotic and lacked vigor [5]. Seeding in herbicide-suppressed tall fescue sod with N fertilizer banded under the seed may be a strategy to enhance vigor and forage yields of sod-seeded annual warm-season grasses [6]. In West Virginia, researchers found interseeding teff [*Eragrostis tef* (Zucc.) Trotter], whether by broadcast or no-till drill seeding, into tall fescue managed just with haying could increase DM yields relative to unseeded tall fescue [7]. Across a multi-environment study in Kansas and Nebraska, cool-season grass pastures harvested in late spring and interseeded with sudangrass and sorghum-sudangrass without any herbicide suppression had 100–214% greater forage accumulation across summer than unseeded pastures [8] and greater mid- and late-summer yields of crude protein and digestible organic matter [9].

Although researchers have had success interseeding cool-season grass pastures, it remains unknown how fundamental agronomic practices such as seeding rate affect annual warm-season grass establishment, forage mass, and recovery of perennial cool-season grasses in interseeded pastures. Indeed, most evaluations of sorghum responses have taken place in conventional plantings on cropland. One study indicated that forage yields of sudangrass and sorghum-sudangrass, when established in narrow rows (i.e., 17.8 cm), increase with seeding rates up to 33.6 and 53.8 kg ha^{-1}, depending on the year [10]. Research under limited irrigation in New Mexico, however, indicated there was no effect of planting rate on DM yield or nutritive value of conventional and brown midrib forage sorghum grown for silage [11]. Seeding rate also had no effect on DM yield and quality of brachytic dwarf, brown midrib lines of forage sorghum hybrids in Pennsylvania [12]. In Ethiopia, increasing seeding rate increased forage quality, but did not affect DM accumulation of two dual-purpose grain sorghum varieties and one traditional local variety [13].

In summary, the research available indicates that adjusting seeding rate has the potential to alter DM accumulation in conventionally seeded stands, but there is limited research on the responses of perennial grasses interseeded with annual warm-season grasses. The objective of our research was to address this knowledge gap by evaluating how seeding rates affect sorghum-sudangrass establishment, forage mass, and vegetation dynamics in a perennial cool-season grass stand in eastern Nebraska.

2. Materials and Methods

2.1. Location and Experimental Design

We conducted the experiment in perennial cool-season grass sod on East Campus at the University of Nebraska-Lincoln (40°49′40′′ N 96°39′26′′ W, and 358 m ASL). The site had a deep, moderately well-drained urban land-Wymore complex (fine, smectitic, mesic Aquertic Argiudolls) soil with moderate permeability [14], and dominant plant species included smooth bromegrass and tall fescue. Across a 30-year period from 1988-2017, mean annual precipitation and temperature averaged 735 mm and 11 °C in Lincoln [15].

The experiment had a completely randomized design with six replicates of five treatments including four seeding rates (0, 14, 28, and 35 kg PLS ha^{-1}) of sorghum-sudangrass cv. Super Sugar interseeded into mowed sod and one unseeded, non-mowed control. Seeding rates represented 0, 0.5, 1.0, and 1.2 times the rate for conventionally seeding sorghum-sudangrass as a sole crop based on seed source recommendations [16]. The existing sod where we established the experiment had been mowed periodically during spring 2016 but had not been fertilized. On 20 May 2016, we randomized treatments, laid out plots, and mowed all but the unseeded, non-mowed controls to a 2.5-cm stubble height before interseeding sorghum-sudangrass at a 1.25-cm depth. All seed was planted with a Great Plains 3P600 drill (Kincade Equipment Manufacturing) equipped with a cone-seeder to accurately meter the seed in plots that were 1.50-m wide × 4.57-m long. Each plot contained nine rows with 15.25-cm row spacing. The unseeded, non-mowed control had a 10-cm stubble height at the start of the experiment. We applied granular urea (46-0-0) at 70 kg N ha^{-1} to all plots on 8 June 2016 after sorghum-sudangrass emergence and at 90 kg N ha^{-1} in late April the next spring.

2.2. Visual Stand Assessments

We assessed sorghum-sudangrass establishment (i.e., plant density) in June 2016 by counting the number of sorghum-sudangrass plants that emerged along each of the nine rows and dividing by the plot area (i.e., 6.86 m^2). Emergence percentage was computed by dividing plant density by seeding density, assuming 38,062 PLS kg^{-1}. We also evaluated changes in frequency of occurrence of perennial cool-season grass and forb species in the sod with use of a metal frequency grid [17] in June 2016 and 2017. The frequency grid had 25, 15- $\times$ 15-cm cells (i.e., 75 cm sides), and in each cell, we recorded the presence or absence of plant species with values of 1 or 0, respectively. We placed the frequency grid over the five middle rows on one end of the plot and recorded values before flipping the grid over end-to-end three times to count a total of 100 cells within each plot. Frequency of occurrence (i.e., stand percentage) of plant species in each plot was then computed by dividing the sum by 100.

2.3. Harvesting and Forage Mass Determinations

Forage was harvested and DM determined three times in the experiment: (1) in mid-summer at 45 d after interseeding (i.e., 13 July 2016); (2) in late summer at 90 d after interseeding (i.e., 20 September 2016); and (3) in late spring the next year (i.e., 15 June 2017). Before the harvests we visually assessed the plots and estimated that forage consisted mostly of sorghum-sudangrass in the summer harvests and perennial cool-season grasses in the 2017 spring harvest. For the plot harvests, a Carter Harvester (Carter Manufacturing, Brookston, IN, USA) with a 1-m wide flail head was used to cut the middle out of the plot and weigh plot samples on the fly. Subsamples were collected, weighed, dried at 60 °C for at least 48 h, and reweighed to determine DM.

2.4. Statistical Analyses

We used SAS version 9.4 and mixed model procedures to evaluate fixed effects of seeding rate on one-time measurements of sorghum-sudangrass density and emergence percentage [18]. Random effects included replication, and estimate statements evaluated the significance of linear, quadratic, and cubic relationships. For evaluation of fixed effects of seeding rate and harvest on forage mass, and seeding rate and year on frequency of occurrence of plant species, we used mixed model procedures with repeated statements that specified either compound symmetry, autoregressive, or unstructured covariance structures and a subject equal to replication. The covariance structure chosen had smallest fit statistics for information criteria such as Akaike's. Contrast statements compared whether unseeded, mowed and unseeded, non-mowed controls had effects on the forage mass and quantitative relationships of forage mass to seeding rates.

3. Results

3.1. Weather Conditions

Lincoln, NE had more precipitation throughout the spring months of April and May and the summer months of July and August in 2016 than the long-term (i.e., 30-year) average (Figure 1a). However, 2016 had a particularly drier and hotter (Figure 1b) June than the long-term average. April and May coincided with peak spring months of cool-season sod growth, while July and August coincided with peak growth of interseeded sorghum-sudangrass. Dry and hot conditions in June 2016, on the other hand, coincided with time of seeding and emergence of sorghum-sudangrass. In 2017, more precipitation fell in April, May, and June than the 30-year location average, indicating that the cool-season grass sod had excellent conditions for regrowth in the year after interseeding.

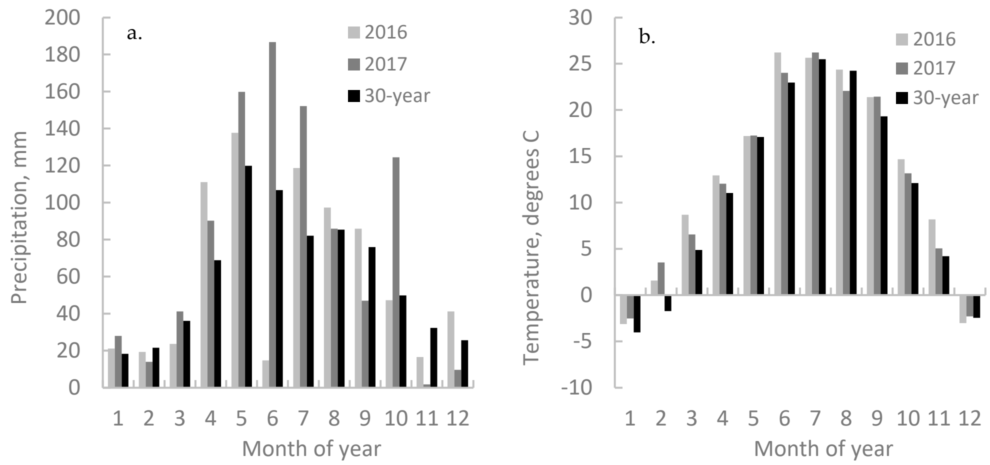

Figure 1. Monthly precipitation (**a**) and average temperature (**b**) at Lincoln, NE in 2016, 2017, and from 1988–2017 (i.e., 30-year average).

3.2. Sorghum-Sudangrass Establishment and Forage Mass

Seeding rate affected sorghum-sudangrass density but not the percentage of seeds planted that emerged (Table 1). Forage mass, meanwhile, depended on seeding rate × harvest interactions (Table 1).

Table 1. Analysis of variance of seeding rate effects on sorghum-sudangrass establishment and seeding rate and harvest effects on forage mass in sod interseeded with sorghum-sudangrass at Lincoln, NE. The symbols, ** and ***, indicate significance at $p \leq 0.01$ and 0.001 levels, respectively.

	Sorghum-Sudangrass Establishment		
Effect	**Plants m^{-2}**	**Emergence %**	**Forage Mass**
	F value		
Seeding Rate	41.8 ***	2.9	54.6 ***
Harvest			670.9 ***
Seeding Rate × Harvest			5.2 **

Emergence of sorghum-sudangrass in the sod increased linearly with seeding rate, averaging 20 ± 1.3, 32 ± 1.7, and 45 ± 2.7 plants m^{-2} (mean ± SE) when seeded at 14, 28, and 35 kg PLS ha^{-1}, respectively. Emergence percentage, meanwhile, averaged 32 ± 1.3% (mean ± SE). In the first harvest at 45 days after interseeding, forage mass showed a linear response to seeding rate increasing from an average of 1.23 Mg ha^{-1} in unseeded sod to 4.15 Mg ha^{-1} in sod interseeded with sorghum-sudangrass at 35 kg PLS ha^{-1} (Figure 2). In the second harvest at 90 days after interseeding, forage mass showed a cubic response to seeding rate increasing from 3.69 Mg ha^{-1} in unseeded sod to a peak of 7.79 Mg ha^{-1} in sod interseeded with sorghum-sudangrass at 28 kg PLS ha^{-1} (Figure 2). Total forage across the 45 and 90 d harvests also showed a cubic response peaking at 28 kg PLS ha^{-1} (Figure 2). In late spring the next year there were no residual effects of sorghum-sudangrass interseeding; forage mass in the cool-season grass-dominated sod averaged 10.5 ± 0.33 Mg ha^{-1} across seeding rates (mean ± SE). The forage mass of unseeded, mowed and unseeded, non-mowed controls did not differ in any of the harvests.

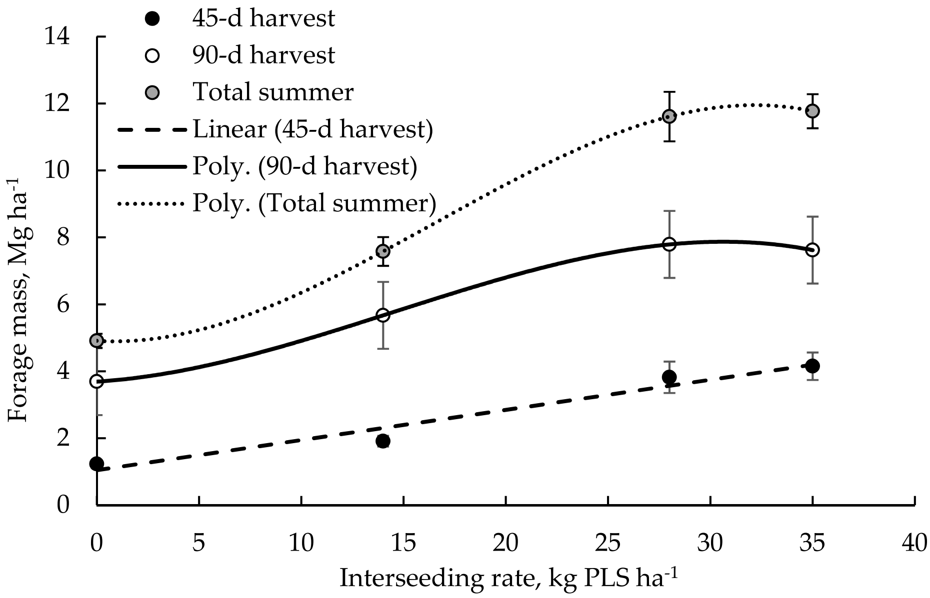

Figure 2. Forage mass in perennial cool-season grass sod interseeded with sorghum-sudangrass in repeated harvests at 45 and 90 d and their total after interseeding at Lincoln, NE.

3.3. Species Composition

Frequency of occurrence of plant species in the sod depended on the year of sampling (Table 2). In early summer soon after interseeding in 2016, sod consisted mostly of smooth bromegrass, Kentucky bluegrass (*Poa pratensis* L.), and tall fescue. Smooth bromegrass and Kentucky bluegrass spread rapidly via rhizomes and, not surprisingly, had frequencies of occurrence averaging 90 and 100%, respectively. Tall fescue also forms sod in response to frequent harvesting, but grows as a bunchgrass when infrequently harvested despite having rhizomes and, coincidently, had a relatively lower frequency of occurrence. In 2017, no seeding took place and forage was allowed to accumulate until late spring. This change in management relative to 2016 resulted in increased percentages of smooth bromegrass and decreased percentages of Kentucky bluegrass and tall fescue. Orchardgrass (*Dactylis glomerata* L.), a bunchgrass, also was present, but had a low frequency of occurrence both years. In terms of forbs, four species were present across the two years, but three showed greatly different frequencies of occurrence from the time after interseeding in 2016 to the residual late spring harvest in 2017. Field bindweed (*Convolvulus arvensis* L.) was present in equal percentages from year to year. However, common dandelion (*Taraxacum officinale* F.H. Wigg.) showed an increase in frequency of occurrence while the legumes white clover (*Trifolium repens* L.) and red clover (*T. pratense* L.) declined across years. The declines in white clover and red clover percentages are likely due to increasing competition from smooth bromegrass, which would have benefited from spring N application and delayed harvesting in spring 2017.

Table 2. Frequency of occurrence of perennial cool-season grass species at a 225-cm^2 scale in sod at the University of Nebraska-Lincoln East Campus Horticulture Research Area as affected by sorghum-sudangrass seeding rate in 2016, year sampled (2016 and 2017), and their interaction. The symbols, * and ***, indicate significance at $p \leq 0.05$ and 0.001 levels, respectively.

	Perennial Cool-Season Grasses			
Effect	**Smooth Bromegrass**	**Kentucky Bluegrass**	**Tall Fescue**	**Orchardgrass**
	F value			
Seeding Rate	1.4	0.4	1.4	0.7
Year	4.5 *	27.0 ***	3.3	0.7

Table 2. *Cont.*

	Perennial Cool-Season Grasses			
Effect	**Smooth Bromegrass**	**Kentucky Bluegrass**	**Tall Fescue**	**Orchardgrass**
Seeding Rate × Year	1.4	0.4	1.4	0.7
		Frequency of occurrence (%)		
2016	90	100	21	3
2017	100	68	7	1
		Forbs		
Effect	**Field Bindweed**	**Common Dandelion**	**White Clover**	**Red Clover**
		F value		
Seeding Rate	2.0	1.8	0.1	1.4
Year	0.5	107.1 *	169.0 ***	15.2 ***
Seeding Rate × Year	2.0	1.8	0.1	1.4
		Frequency of occurrence (%)		
2016	42	1	49	10
2017	37	45	1	1

4. Discussion

Interseeding perennial cool-season grasses with annual warm-season grasses has the potential to increase forage mass and nutritive value. In this study, we evaluated sorghum-sudangrass establishment, forage mass, and perennial plant species responses to sorghum-sudangrass seeding rate in cool-season sod consisting mostly of smooth bromegrass, tall fescue, and Kentucky bluegrass across a two-year period in Lincoln, NE. Both years had favorable precipitation and air temperatures for growth of the cool-season sod before the interseeding of annual warm-season grasses in 2016 and the evaluation of sod recovery in 2017. However, June 2016, the month of interseeding, had poor precipitation and an average air temperature above the long-term location average, indicating a stressful environment for the emergence and early growth of sorghum-sudangrass seedlings. Nonetheless, seedling emergence of sorghum-sudangrass averaged 32% ± 1.3%, and the number of seedlings that emerged increased linearly with seeding rate. At another eastern NE location (i.e., Mead), where research on interseeding annual warm-season grasses also took place in 2016, emergence of sorghum-sudangrass averaged 97% (unpublished data), indicating less establishment of sorghum-sudangrass at Lincoln in 2016, the reasons for which remain unclear.

Forage mass responses to seeding rate depended on the harvest. A positive linear forage mass response at 45 d after interseeding indicates that seeding at the highest rate of 35 kg ha^{-1} would result in earlier forage availability. However, cubic forage mass responses to seeding rate at 90 d after interseeding and in the summer total of the 45 and 90 d harvests indicate that producers can produce similar forage by interseeding at 28 kg ha^{-1}. At 28 kg ha^{-1}, forage accumulation summed across the 45 and 90 d harvests in sorghum-sudangrass interseeded sod exceeded that in unseeded sod by 136% (Figure 2; 11.61 and 4.91 Mg ha^{-1}). At the other eastern Nebraska location (i.e., Mead), smooth bromegrass interseeded with sorghum-sudangrass at 42 kg ha^{-1} had 102% greater forage accumulation than unseeded smooth bromegrass in 2016 [8] and comparable dry matter yields (10.54 and 5.22 Mg ha^{-1}, respectively) to our study when harvested twice at 45 and 90 d after interseeding, despite the greater seeding rate (i.e., 1.5 times conventional seeding rate of 28 kg ha^{-1}) and seedling emergence percentage.

Other research on various sorghum types has generally found positive responses to seeding rates greater than those which we evaluated, but in quite different environments and management contexts. A study in Ethiopia, for example, evaluated five seeding rates (12.5, 25, 50, 75, and 100 kg ha^{-1}) of grain sorghum varieties broadcast sown into disk harrowed and plowed fields and managed as dual-purpose grain and forage crops [13]. Increasing the seeding rate increased plant stand count and forage quality by reducing stalk thickness, neutral detergent fiber, acid detergent fiber, and acid detergent lignin, but it did not affect DM accumulation [13]. This study concluded that increasing seeding rates above the 12.5 kg ha^{-1} recommended for grain could help improve forage potential of dual-purpose grain sorghum varieties in Ethiopia. Thinner stalks and improved nutritive value could increase palatability, improve grazing efficiency, and help resource poor farmers that cannot afford to chop and feed thicker forages. In research in New Mexico, there was no effect of low (185,185 plants ha^{-1}), medium (214,815 plants ha^{-1}), and high (249,383 plants ha^{-1}) planting rates on DM yield or nutritive value of conventional and brown midrib forage sorghum silage crops seeded in rows with 76-cm centers [11]. For comparison, planting rates in our experiment were greater at 532,868, 1,065,836, and 1,332,170 PLS ha^{-1} at 14, 28, and 35 kg PLS ha^{-1} based on 38,062 PLS kg^{-1}. Relative to existing literature, our research is probably most comparable to research on seeding rates in Wisconsin, which found that sudangrass and sorghum-sudangrass yields increased when established in narrow rows (i.e., 17.8 cm) with seeding rates up to 33.6 and 53.8 kg ha^{-1}, depending on the year [10]. Seeding in established sod and the hot, dry conditions in the month following seeding likely contributed to a low emergence percentage in our study, but we still found maximum yields at a lower seeding rate of 28 kg ha^{-1} compared to the earlier research in Wisconsin.

Forage accumulation is likely to be greater if stands are harvested only once at 90 d after interseeding. This was not evaluated in our study, but has been observed on average across multiple environments in Kansas and Nebraska, including the other eastern Nebraska location in 2016 [8]. Indeed, harvesting only once at 90 d increased forage accumulation by 69% [8], crude protein yields by 126% [9], and in vitro organic matter digestibility yields by 202% [9] relative to harvesting twice at 45 and 90 d after interseeding sorghum-sudangrass. However, harvesting twice versus once increased 90 d crude protein concentrations by 30% [9] and might fit better in grazing systems that need forage in mid-summer or cannot stockpile the forage for utilization later in summer.

In 2017, recovery of the cool-season sod was excellent, indicating resilience to potential stress of a one-time interseeding and growing of an additional crop, and though the frequency of occurrence of plant species varied from year to year, no effects of the previous season's seeding rate were observed. Few studies have evaluated forage production and species responses the year after interseeding annuals. In southern Illinois, herbicide-suppressed tall fescue no-till seeded with soybean [*Glycine max* (L.) Merr.] was able to achieve 40% of fall forage production compared to unsuppressed tall fescue with soybean, but in some years, it was difficult to maintain a live tall fescue sod [19]. In a West Virginia study that evaluated tall fescue interseeded with teff, botanical composition varied from year to year as in our study, but impacts on DM yields of tall fescue in years after interseeding were not reported and presumably negligible [7]. Interseeding the same area year-after-year, especially if combined with herbicide suppression, might reduce the capacity of perennial cool-season grass systems to absorb disturbance and maintain essentially the same function, structure, identity, and feedbacks, thereby lessening resilience [20]. In a study in Florida, researchers observed perennial weeds beginning to emerge after three years of continuous no-till planting of corn (*Zea mays* L.) in herbicide-suppressed bahiagrass (*Paspalum notatum* Flugge) sod, and rye (*Secale cereale* L.) residue [21].

Lastly, research on timing and rates of N fertilizer, in addition to research on seeding rates and other agronomic variables such as sod suppression, is needed in sod that is interseeded with annual warm-season grasses or other crops. Perennial cool-season grasses are conventionally fertilized in spring. Yet in this research, we fertilized the sod in summer after the emergence of sorghum-sudangrass. It is unclear whether changes in the timing and rates of N fertilizer affect sorghum-sudangrass establishment, forage mass, and frequency of occurrence of plant species in interseeded pastures. Increased presence of annual weeds has been related to reductions in N fertilization of cool-season grass pastures in spring [22], though no such responses were observed in our study.

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