

ORIGINAL ARTICLE

Applied Turfgrass Science

Evaluating Kentucky bluegrass and perennial ryegrass seeding ratios for sod grown on plastic production

Jackie Lyn A. Guevara¹  | Ryan Bearss¹  | Jacob Kilby¹ | John Sorochoan² | John N. Rogers III¹

¹Department of Plant, Soil and Microbial Science, Michigan State University, East Lansing, Michigan, USA

²Department of Plant Sciences, University of Tennessee-Knoxville, Knoxville, Tennessee, USA

Correspondence

Jackie Lyn A. Guevara, Department of Plant, Soil and Microbial Science, Michigan State University, 1066 Bogue St., A154B Plant and Soil Science Building, East Lansing, MI 48824, USA.

Email: guevar13@msu.edu

Assigned to Associate Editor Adam Thoms.

Funding information

Fédération Internationale de Football Association

Abstract

Sod grown on plastic (SOP) is a sod established on a thin layer of growing medium atop a plastic sheet. It can be harvested with minimal damage to the roots, thereby reducing transplant shock. Kentucky bluegrass (KBG; *Poa pratensis* L.) is a commonly used cool-season turfgrass species in sod production and sports fields. However, KBG is slow to germinate, which can leave the initial stages of SOP production vulnerable to erosion and increased production time. We hypothesized that incorporating perennial ryegrass (PRG; *Lolium perenne* L.)—a faster-germinating species—could help stabilize the growing medium until KBG germinates. Thus, the objective of this study was to evaluate the establishment and strength of cool-season SOP seeded with varying KBG and PRG seeding ratios. This study was conducted at the Hancock Turfgrass Research Center in East Lansing, MI, in June–October 2023, and May–September 2024. Six KBG-PRG seeding ratios based on seed count (100:0, 98:2, 96:4, 92:8, 84:16, and 0:100) were evaluated. The addition of 16% PRG resulted in a 58% increase in tensile strength compared with the 100:0 ratio and resulted in a 56:44 KBG-to-PRG shoot ratio.

Plain Language Summary

Sod grown on plastic (SOP) is a sod that is established on a growing medium on top of a plastic sheet. Kentucky bluegrass (KBG) is commonly used due to its rhizomes, which allow it to be harvested as sod. However, its slow germination leaves the soil vulnerable to erosion and increases the time to harvest. Perennial ryegrass (PRG), though uncommon in sod production, germinates quickly and has the potential to stabilize soil during KBG establishment. Thus, this study evaluated six KBG-PRG seed ratios based on seed count (100:0, 98:2, 96:4, 92:8, 84:16, and 0:100) to assess their impact on SOP establishment. After 4 months, sod with 16% PRG showed the highest tensile strength among KBG-dominant mixes.

Abbreviations: KBG, Kentucky bluegrass; PLS, pure live seed; PRG, perennial ryegrass; SOP, sod grown on plastic.

This is an open access article under the terms of the [Creative Commons Attribution](https://creativecommons.org/licenses/by/4.0/) License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2026 The Author(s). Crop, Forage & Turfgrass Management published by Wiley Periodicals LLC on behalf of American Society of Agronomy and Crop Science Society of America.

1 | INTRODUCTION

Kentucky bluegrass (*Poa pratensis* L.; KBG) is a common cool-season turfgrass species used in sod production across the northern United States and southern Canada—valued for its sod-forming abilities and recovery due to its rhizomatous growth habit (Beard et al., 1969). In conventional sod production, KBG is seeded directly on native soils and can take 11–24 months to harvest, ensuring that rhizomes are fully knitted together (Braun et al., 2021, 2022; Decker, 2001). During harvest, a sod cutter removes the sod from the soil by cutting through the roots, which, in turn, causes root damage (Decker, 2001). Consequently, prompt care and immediate transplanting are essential for successful establishment (Beard et al., 1969; Decker, 2001).

High-performance sports fields are typically constructed using a sand-based growing medium to enhance drainage and minimize soil compaction (Bingaman & Kohnke, 1970; Henderson et al., 2005; Kowalewski et al., 2010). However, only a limited number of conventional sod farms grow KBG on a sandy growing medium, posing a challenge for sports field managers. Differences in soil texture between the transplanted sod and the field can lead to soil layering issues (Blake et al., 1981; Gardner, 1953), which may adversely affect root growth and field performance.

An alternative to conventional sod production is sod grown on plastic (SOP), where turfgrass is cultivated on a thin layer of growing medium placed atop a plastic sheet (Bearss et al., 2024; Neel et al., 1978; Sorochan & Rogers, 2001). This method allows the use of a desired growing medium instead of the native soil (Neel et al., 1978; Sorochan & Rogers, 2001), which may help prevent soil layering issues. It can also reduce production time by encouraging roots to interweave upon contact with the plastic (Cisar & Snyder, 1992; Neel et al., 1978; Roberts et al., 2001). During harvest, the sod can be rolled without damaging the roots (Cisar & Snyder, 1992; Neel et al., 1978), thereby reducing transplant shock and increasing rooting after transplant (Neel et al., 1978).

Despite its advantages, SOP production poses unique challenges, particularly for the production of KBG, which generally requires 7–14 days to germinate (Braun et al., 2023; Folck et al., 2023). Typically, SOP production areas are sloped to facilitate surface drainage, which increases the risk of soil erosion—especially following heavy precipitation events. This leaves the surface highly susceptible to erosion during this period due to the absence of an established root system.

Perennial ryegrass (*Lolium perenne* L.; PRG) germinates as early as 5 days (Braun et al., 2023) and offers a potential solution to this problem. It has been used to control soil erosion (Brown et al., 2010) and could stabilize the sandy growing medium during KBG establishment in SOP production. The development of improved PRG has allowed the use of KBG-PRG seed mixtures (Niehaus, 1976),

which are now commonly used in sports fields to improve genetic diversity and resilience to environmental stresses (Dunn et al., 2002).

These mixtures have demonstrated superior turf cover and traffic tolerance compared with monocultures (Brede & Duich, 1984; Stier et al., 2008). However, the rapid establishment and competitiveness of PRG can impede the establishment of KBG, potentially affecting the long-term composition of a KBG-dominated stand (Braun et al., 2023; Engel & Trout, 1980; Folck et al., 2023). Larsen et al. (2004) have shown that when KBG and PRG are sown simultaneously, KBG accounted for only 3%–30% of the tillers after 9 or 12 months of establishment, even though it represented 50%–59% of the viable seeds in the mixture. Another study found that a 50:50 KBG-to-PRG mixture by weight resulted in a composition of 67% PRG and 27% KBG after 4 years (Hsiang et al., 1997). Although, as the sod matures, KBG may outcompete PRG depending on the cultivar type, seeding rate, and seeding timing (Stier et al., 2008). Proctor et al. (2015) observed that seeding ratios with high KBG (80%–90% KBG by weight) developed into a stand dominated by >95% KBG within 2 years, and seeding ratios with high KBG reached a similar composition after 3 years.

These research studies highlight the importance of selecting appropriate seeding ratios when aiming to produce KBG-dominated sod, as the initial seeding ratio significantly influences the turfgrass composition. However, Brede & Duich (1984) observed that most of these seeding ratio studies have relied on weight-based measurements. It is important to note that variations in seed size, purity, and germination rates among turfgrass species and cultivars can influence the number of pure live seeds (PLS) per unit weight (Christians et al., 1979). For example, KBG has a smaller seed size than PRG (Braun et al., 2023). As a result, KBG has more seeds per unit weight ($\sim 1,200,000$ seeds lb^{-1}) than PRG ($\sim 240,000$ seeds lb^{-1} ; Braun et al., 2023; Christians et al., 2016). Such differences in PLS can affect the consistency and reliability of these studies. Therefore, calculating the seeding ratio and rates based on PLS is recommended to ensure more accurate and repeatable results.

Although the benefits of KBG-PRG mixtures for sports fields are well documented, their application in SOP production remains limited. To address this gap, a research study was conducted at Michigan State University from 2023 to 2024 to determine the optimal KBG-PRG seeding ratio for SOP production. The objectives of the study were (a) to evaluate the surface stability and harvestability of cool-season SOP seeded with varying KBG-PRG ratios, and (b) to provide a seeding ratio recommendation for sod farmers that mitigates complications of establishing cool-season species on plastic. The researchers hypothesized that incorporating small amounts of PRG into the seed mix could mitigate erosion concerns in SOP production.



FIGURE 1 Sod grown on plastic establishment process at Hancock Turfgrass Research Center, East Lansing, MI, in June 2023. (a) DuraEdge Pro Clay was used as the base and laser-graded to a 1% slope. (b) A white plastic sheet was laid down on the area. (c) Sand was topdressed on top of the plastic sheet, then seeds were sown by hand and fertilizer was applied. (d) A germination blanket was placed over the area, followed by thorough irrigation.

TABLE 1 Particle size distribution of sand used for sod grown on plastic establishment at the Hancock Turfgrass Research Center, East Lansing, MI, in 2023.

Description	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt + clay
Size (mm)	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.15	0.15–0.05	<0.05–0.002
Percentage (%)	12.1	19.6	40.5	19.7	2.1	0.3

2 | MATERIALS AND METHODS

2.1 | Experimental design

Research was conducted in 2023 (June 8–October 6) and 2024 (May 24–September 20) at the Hancock Turfgrass Research Center, East Lansing, MI. Treatments were arranged in a randomized complete block design with three replications and consisted of six KBG:PRG seeding ratios (100:0, 98:2, 96:4, 92:8, 84:16, and 0:100), which followed a pure live seeding rate of 20 PLS inch⁻². Plots measured 5 ft × 5 ft.

2.2 | Site preparation, establishment, and maintenance

The experimental site was laser-graded to a 1% slope to facilitate proper drainage (Figure 1a), and DuraEdge Pro Clay (DuraEdge Products, Inc.) was installed to provide a firm subsurface. A 3-mil, 70% white polyethylene film (Ginegar Plastics Ltd.) was laid over the laser-graded clay base (Figure 1b). A 1-inch sand layer (Table 1) was topdressed

TABLE 2 Vitality HD Sports 2.0 Kentucky bluegrass (*Poa pratensis* L.) seed blend label.^a

Cultivar	Purity (%)	Germination (%)
Bluebank	12.42	85.00
Hampton	12.41	85.00
Fullback	12.39	85.00
Noble	12.22	85.00
Other crop	0.00	—
Inert matter (Xalt seed coating product)	50.56	—
Weed seed	0.00	—

^aVitality.

using Turfco Mete-R-Matic IV Topdresser (Turfco) on top of the plastic sheet (Figure 1c).

Vitality HD Sports 2.0 coated with Xalt (Vitality) and EGS Tri Ryegrass (Landmark Seeds Inc.; Tables 2 and 3) were used as the seed blends for KBG and PRG, respectively. Seeding rates for the six seeding ratios were calculated based on seed count, with a target rate of 20 PLS inch⁻². To determine the

TABLE 3 EGS Tri perennial ryegrass (*Lolium perenne* L.) seed blend label.^a

Cultivar	Purity (%)	Germination (%)
Majesty	33.22	90.00
Spark	33.17	90.00
Salinas II	31.59	90.00
Other Crop	0.22	—
Inert matter	1.80	—
Weed seed	0.00	—

^aLandmark Seeds Inc.**TABLE 4** Seeding rates for Kentucky bluegrass (*Poa pratensis* L.; KBG) and perennial ryegrass (*Lolium perenne* L.; PRG) for the six seeding ratio treatments in East Lansing, MI, in 2023 and 2024.

KBG:PRG	PLS (inch ⁻²)		Actual seeding rate ^a (lb seed 1000 ft ⁻²)			
	KBG	PRG	Seeding rate ^a (lb seed 1000 ft ⁻²)		Actual seeding rate ^b (lb seed 1000 ft ⁻²)	
			KBG	PRG	KBG	PRG
100:0	20	0	4.5	0	10.7	0
98:2	19.5	0.5	4.4	0.2	10.4	0.2
96:4	19.1	0.9	4.3	0.4	10.2	0.5
92:8	18.3	1.7	4.2	0.8	9.9	1.0
84:16	16.8	3.2	3.8	1.6	9.0	1.9
0:100	0	20	0	9.9	0	11.9

Abbreviation: PLS, pure live seed.

^aConverted from number of PLS per square inch.^bActual amount of seed applied, adjusted for the percentage of PLS.

seeding rate for each species, the following calculations were performed: (1) The PLS inch⁻² for each species per treatment was determined by multiplying the target seeding rate (20 PLS inch⁻²) by the seeding ratio (Table 4). (2) The PLS seeding rate (in pounds PLS per 1000 ft²) was then calculated by multiplying the number of PLS in a square inch by seed per pound. To determine seed per pound, each blend was manually counted for seed three times, and the average was converted to seed per pound. The KBG blend averaged 1402 seeds g⁻¹ (635,936 seeds lb⁻¹), while the PRG blend averaged 642 seeds g⁻¹ (291,206 seeds lb⁻¹). (3) The actual seeding rate (in pounds seed per 1000 ft²) was calculated by adjusting the PLS seeding rate based on the calculated percentage PLS from the seed labels (Tables 2 and 3). All plots were hand-seeded in two directions. After seeding, the area was lightly raked with the back side of a leaf rake to facilitate seed-to-soil contact.

A starter fertilizer (12-23-12; Harell's LLC) was applied at the rate of 1 lb phosphorus 1000 ft⁻² along with a polymer-coated urea (44-0-0; Harrel's) at the rate of 1 lb nitrogen 1000 ft⁻². A germination blanket (A.M. Leonard) was placed over the area and irrigated to field capacity (Figure 1d). The

germination blanket was removed 3 weeks after seeding, upon observing adequate seedling emergence under the blanket.

The grass was maintained at a mowing height of 2 inches using a push rotary mower with clippings collected after each mowing. The area was irrigated based on relative potential evapotranspiration, with total irrigation amounting to ~12 inches in 2023 and 19 inches in 2024 (Figure 2). Additional hand watering was applied to areas that were beginning to dry out. Due to the sandy, shallow root zone and frequent irrigation, nitrogen leaching or volatilization may have occurred following the initial fertilizer application, as indicated by the light green color of the plots 1 month after seeding. To address this, granular urea (46-0-0) was applied weekly at the rate of 0.25 lb nitrogen 1000 ft⁻² with a rotary spreader in two perpendicular directions, resulting in a total of 3 lb nitrogen 1000 ft⁻² over the weekly applications.

2.3 | Data collection

Turfgrass cover, sod tensile strength, sod shear strength, stand composition, and shoot density were measured at 4 months after seeding (October 6, 2023, and September 20, 2024). To quantify the percentage of turfgrass cover, a modified method by Richardson et al. (2001) was used. Overhead images of each plot were captured using a Canon PowerShot SX730HS (Canon) digital camera set to macro mode with the following settings: ISO 800, F4.0, and a shutter speed of 1/250s. The images were analyzed using ImageJ software (Schneider et al., 2012). To measure sod tensile strength, one 1 ft × 1.5 ft sod piece was harvested from each plot and pulled apart using a Calrochan Sod Puller (Kowalewski et al., 2008; Sorochoan & Rogers, 2000; Sorochoan et al., 1999), and a CHATIL-LON DFE-200 Digital Force Gauge (AMETEK) was used to measure peak force (pound-force) during sod pull. Sod shear strength was determined from the average of three peak shear resistance (in Newton-meters, or Nm) measurements using a Turf-Tec Shear Strength Tester (Turf-Tec International; Thoms et al., 2022). To measure stand composition and shoot density, three 1-inch × 1-inch samples were collected from each plot. Shoots were counted individually and classified as either KBG or PRG.

2.4 | Statistical analysis

All data were analyzed using R software (R Core Team, 2025). Seeding ratio, year, and seeding ratio × year were treated as fixed effects. Year was treated as a fixed effect to account for substantial variation in climatic conditions between years (Figure 2). Whereas replication (block) was treated as a random effect to account for spatial variability within the research area. The ANOVA was conducted to examine the significance

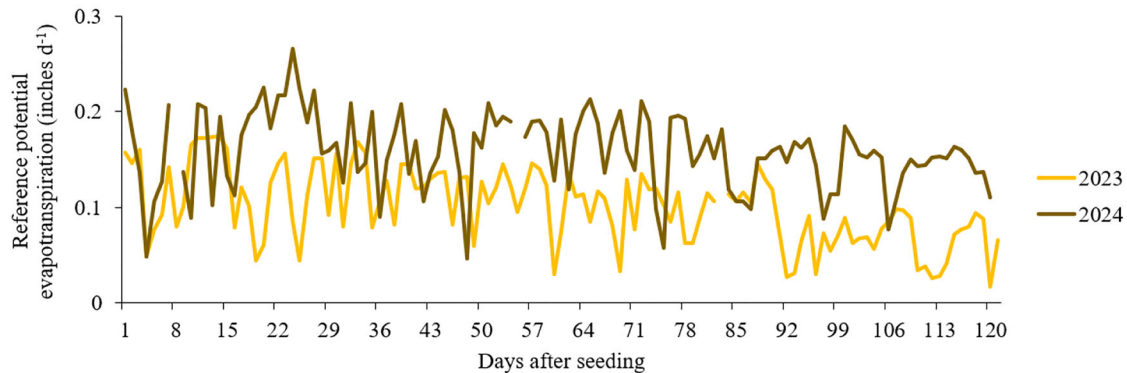


FIGURE 2 Reference potential evapotranspiration recorded (in inches per day) at the Hancock Turfgrass Research Center, East Lansing, MI, in 2023 and 2024. Data were obtained from the Michigan Automated Weather Network (Enviro-weather; <https://mawn.geo.msu.edu/station.asp?id=htc>).

TABLE 5 Analysis of variance testing for the effect of Kentucky bluegrass (*Poa pratensis* L.; KBG) and perennial ryegrass (*Lolium perenne* L.; PRG) seeding ratios and year on turfgrass cover, sod tensile strength, sod shear strength, shoot density and stand composition of a sod grown on plastic and harvested at 4 months after seeding in East Lansing, MI, in 2023 and 2024.

Effect	Turfgrass cover	Sod tensile strength	Sod shear strength	Shoot density	Stand composition	
					KBG	PRG
Ratio (R)	***	***	NS	*	***	***
Year (Y)	***	***	***	***	NS	NS
R × Y	*	NS	NS	*	NS	NS

*Significant at the .05 probability level.

**Significant at the .01 probability level.

***Significant at the .001 probability level. NS, not significant.

of the fixed effects and their interactions. Post hoc mean separation tests were conducted using Fisher's protected LSD when F tests were significant at $\alpha \leq 0.05$.

3 | RESULTS AND DISCUSSION

3.1 | Turfgrass cover

The ANOVA results revealed a significant interaction between seeding ratio and year for turfgrass cover (Table 5). In 2023, no significant differences were observed among the seeding ratio treatments. In 2024, significant differences were observed among the seeding ratio treatments. The 100:0 treatment had the lowest turfgrass cover, but the addition of 2%–16% PRG led to an average increase of 57% in turfgrass cover (Figure 3).

The rapid establishment of PRG likely explains its contribution to improved turfgrass cover (Braun et al., 2023). Germination occurs within 3–5 days, whereas KBG requires 7–14 days to germinate, even when improved cultivars are used (Braun et al., 2023; Folck et al., 2023). Another contributing factor in this study was the high nitrogen application during establishment. Due to the quicker germination of PRG,

the applied nitrogen was more readily utilized by PRG than by KBG.

The lower turfgrass cover observed in the 100:0 treatment (Figure 3) can also be explained by the timing of establishment. This study was conducted in May and June (late spring/early summer in Michigan), a period not considered favorable for establishing KBG due to high temperatures (Giolo et al., 2017). If KBG had been seeded during the cooler temperatures of early fall, the results may have differed.

The differences in turfgrass cover observed in the 100:0 treatment between 2023 and 2024 (Figure 3)—with the 100:0 treatment showing significantly lower turfgrass cover among seeding ratio treatments in 2024—can be attributed to variations in precipitation during the first 2 weeks of establishment. In 2023, only one precipitation event occurred, delivering 0.1 inch of rainfall (Figure 4). Whereas, in 2024, there were seven precipitation events, with the highest delivering 0.3 inch of rainfall (Figure 4). This variation in early rainfall likely influenced KBG establishment. Excessive precipitation during germination can lead to soil erosion, washing away seeds and resulting in reduced turfgrass cover in 100:0 plots, as seen in 2024 (Figure 3).

For pastures and lawns, PRG has been recommended to mitigate establishment challenges (Blaser, 1964) and has

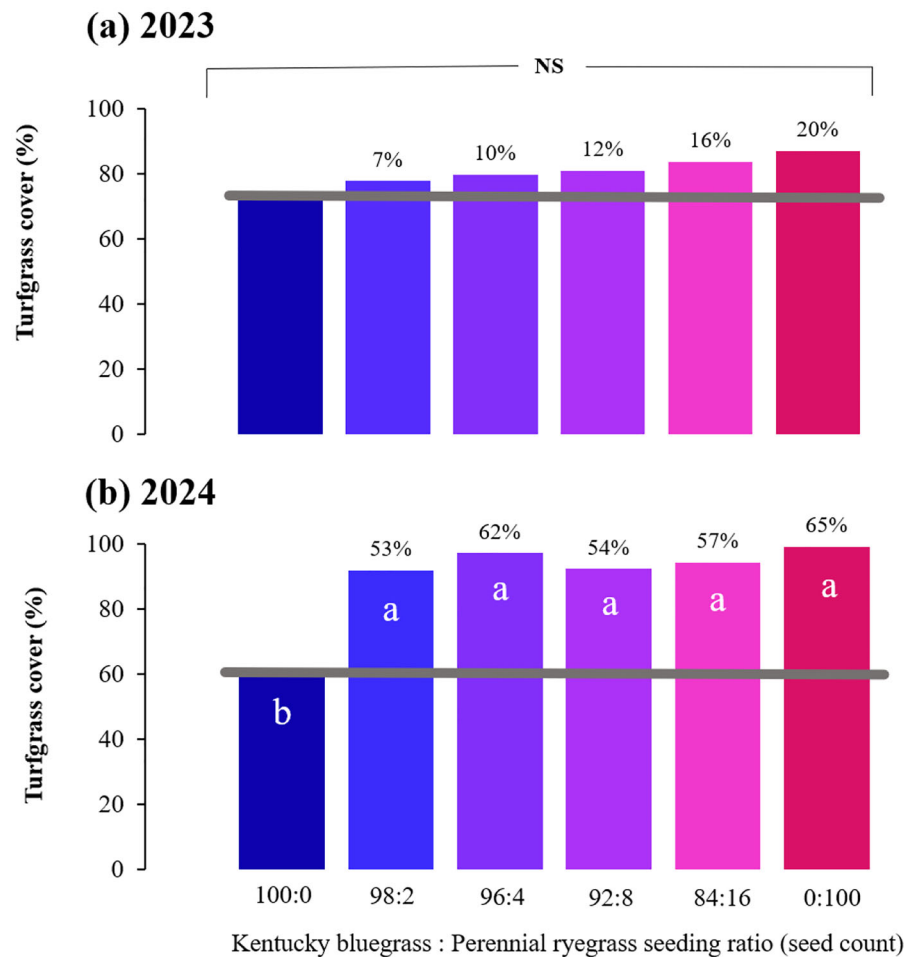


FIGURE 3 Interaction of Kentucky bluegrass (*Poa pratensis* L.) and perennial ryegrass (*Lolium perenne* L.) seeding ratio and year on the percentage of turfgrass cover of sod grown on plastic, harvested 4 months after seeding in (a) 2023 and (b) 2024 in East Lansing, MI. Within each year, means followed by the same letters are not statistically different based on Fisher's protected LSD test ($\alpha \leq 0.05$). The gray line represents the pure Kentucky bluegrass (100:0) mean for that year. The percentages above the bars indicate the increase in turfgrass cover compared with the 100:0 treatment.

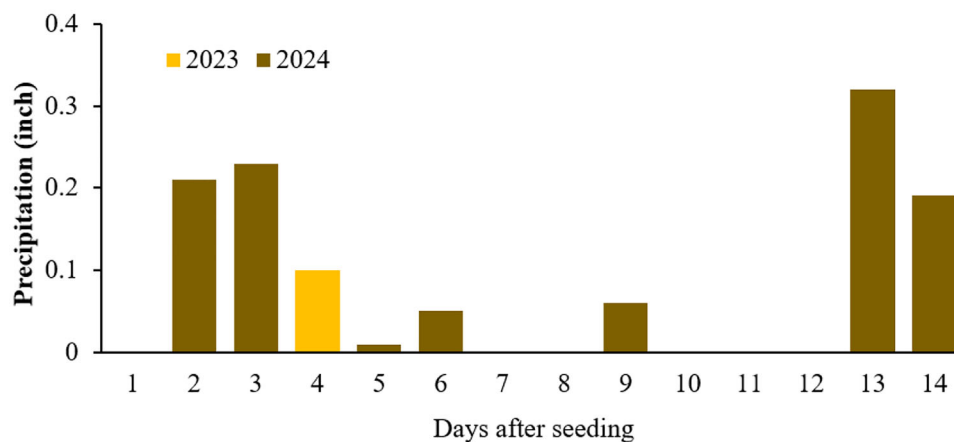


FIGURE 4 Total precipitation (in inches) during the first 2 weeks of turfgrass establishment at the Hancock Turfgrass Research Center, East Lansing, MI, in 2023 and 2024. Data were obtained from the Michigan Automated Weather Network (Enviro-weather; <https://mawn.geo.msu.edu/station.asp?id=htc>).

also been used effectively for soil erosion control (Brown et al., 2010). By stabilizing the soil surface and providing rapid cover, PRG promotes better establishment. This benefit was demonstrated by the improved turfgrass cover achieved when PRG is incorporated into the seed mix, highlighting its value as a beneficial component in KBG-dominated SOP production.

3.2 | Sod strength

Tensile strength refers to the resistance of sod to being pulled apart and is commonly used to assess its harvestability. It quantifies the breaking point of the sod during handling (Li et al., 2013). In contrast, shear strength measures the stability of the sod surface (Li et al., 2013).

The ANOVA results revealed no significant interaction between seeding ratio and year for sod tensile and shear strength (Table 5). As a result, the main effects of seeding ratio and year were further examined. Both factors influenced sod tensile strength. All seeding ratio treatments exceeded 38 lb-force—the minimum threshold for harvestable, mature KBG sod (Figure 5a), as measured using the Calrochan Sod Puller (Sorochan & Rogers, 2000). Pure KBG (100:0) exhibited the lowest tensile strength, while pure PRG (0:100) demonstrated a significantly higher tensile strength—80% greater than that of pure KBG. The addition of 2%, 4%, or 8% PRG did not significantly increase tensile strength. Whereas the inclusion of 16% PRG resulted in a 58% increase in tensile strength (Figure 5a).

The low tensile strength observed in the 100:0 treatment can likely be attributed to the age of the sod at the time of harvest. Braun et al. (2022) reported that conventionally grown KBG sod exhibited increasing sod tensile strength over time, suggesting that the results of the present study may differ if evaluated over a longer establishment period. In KBG, rhizomes are the primary contributors to its sod-forming abilities (Rieke & Beard, 1969). However, substantial rhizome development typically does not occur until the later stages of development (Etter, 1951; Moser et al., 1968).

In contrast, tall fescue (*Schedonorus arundinaceus*)—a bunch-type species similar to PRG—did not show the same increase in sod strength over time in a conventional sod production system (Braun et al., 2022). However, results may differ in SOP production, where roots become “bound” by the plastic. This allows bunch-type species with strong primary rooting systems to knit together and form a sod (Decker, 2001), mimicking the sod-forming ability of rhizomes in KBG.

Therefore, this study demonstrated that incorporating PRG into the seed mix helped stabilize the sandy growing medium, resulting in a good “nurse” plant in KBG-dominated SOP production. The addition of 16% PRG significantly increased

sod tensile strength in young, KBG-dominated sod, where rhizomes are not yet fully developed. However, over time, mixtures with higher KBG percentages may perform better than observed in this study.

Regarding shear strength, the ANOVA showed no significant interaction between seeding ratio and year, and the seeding ratio did not significantly influence shear strength (Table 5). These findings suggest that adding PRG has a limited effect on improving surface stability. Other factors, such as soil type and soil moisture, have been shown to influence shear strength (Henderson et al., 2005). Since this study used the same soil type and maintained similar water content throughout, no differences in shear strength were observed.

Additionally, year had a significant effect on both tensile and shear strength, with values being higher in 2023 compared with 2024 (Figure 5). This difference may be attributed to the higher reference potential evapotranspiration observed in 2024 compared with 2023 (Figure 2). Although irrigation was based on reference potential evapotranspiration estimates, the timing and application of supplemental irrigation may have been inadequate, potentially leading to differences that affected sod strength development.

3.3 | Turfgrass stand composition and density

Turfgrass stand composition is a critical consideration, particularly when a sod farmer aims to produce KBG-dominated sod. When KBG and PRG are grown together, PRG often out-competes KBG (Engel & Trout, 1980; Hsiang et al., 1997; Larsen et al., 2004). To address this issue, 84:16 KBG-to-PRG and lower seeding ratios were examined in this study. This decision was informed by findings from Gibeault et al. (1980), who demonstrated that an 85:15 KBG-to-PRG ratio by weight resulted in an approximate 50:50 KBG-to-PRG shoot ratio after 3 years.

No interaction between species composition and year was detected, indicating consistent trends across both 2023 and 2024 (Table 5). As a result, pooled data from both years were analyzed. The overall stand composition generally aligned with the seeding ratios, but KBG plant counts were slightly lower than anticipated based on initial viable seed counts (Table 6). This aligns with findings from Larsen et al. (2004), who reported that simultaneous sowing of KBG and PRG often results in deviations from the initial seed ratios, with higher PRG and lower KBG plant counts than expected.

In this study, an 84:16 KBG-to-PRG seeding ratio resulted in a 56:44 KBG-to-PRG shoot ratio. However, it should be noted that contamination of KBG in pure PRG plots and PRG in pure KBG plots was observed (Table 6). This

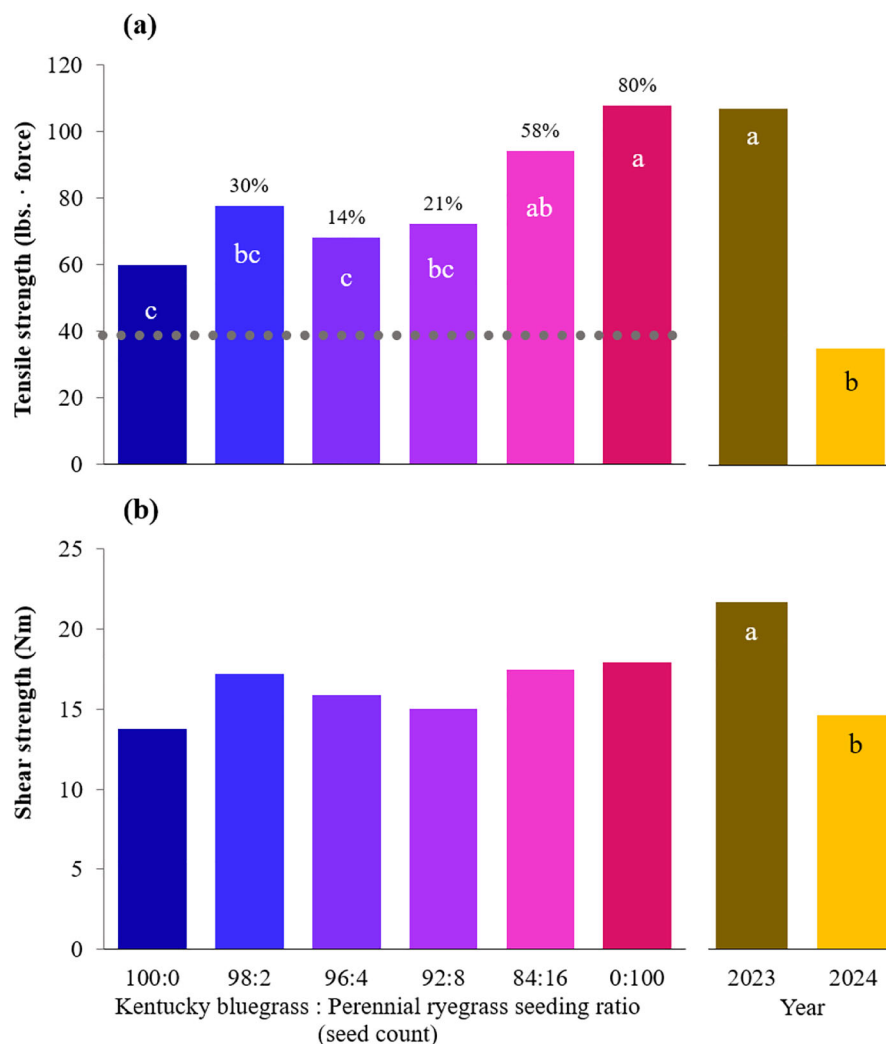


FIGURE 5 Effect of Kentucky bluegrass (*Poa pratensis* L.) and perennial ryegrass (*Lolium perenne* L.) seeding ratio and year on (a) sod tensile strength and (b) shear strength of sod grown on plastic, harvested 4 months after seeding in East Lansing, MI, in 2023 and 2024. Within seeding ratio and year, means followed by the same letters are not statistically different based on Fisher's protected LSD test ($\alpha \leq 0.05$). The dotted gray line represents the minimum tensile strength value required to harvest a mature Kentucky bluegrass sod (Sorochoan & Rogers, 2000).

contamination may be attributed to surface drainage within SOP production, which could have carried seeds into adjacent plots during irrigation or rainfall events.

3.4 | Perennial ryegrass SOP

One unexpected finding in this study was that the pure PRG plots exhibited the highest turfgrass cover (Figure 3) and tensile strength (Figure 5a) among all seeding ratio treatments. PRG has a bunch-type growth habit—characterized by a lack of rhizomes and stolons but a strong primary rooting system—which limits its ability to be harvested as big roll sod. However, SOP production has proven effective for turfgrass species with a bunch-type growth habit, such as tall fescue (Decker, 2001). Given that the 0:100 treatment exceeded

the minimum threshold for harvesting mature sod using the Calrochan Sod Puller (Sorochoan & Rogers, 2000), further research could explore refining the establishment techniques for PRG SOP.

4 | Study limitations and future research

The use of cultivar blends rather than single cultivars may have confounded the results, making it difficult to determine which cultivar contributed most to the increased sod strength and turfgrass cover. Future research should compare individual KBG and PRG cultivars to better isolate their effects. In addition, the relatively short study period and spring seeding time likely favored PRG over KBG. Studies established in the fall and conducted over longer durations would

TABLE 6 Effect of Kentucky bluegrass (*Poa pratensis* L.; KBG) and perennial ryegrass (*Lolium perenne* L.; PRG) seeding ratios and year on the shoot density and stand composition of a sod grown on plastic harvested at 4 months after seeding in East Lansing, MI, in 2023 and 2024.

Seeding ratio ^a (KBG:PRG)	Shoot density ^b		Species composition ^b	
	2023	2024	KBG (%)	PRG (%)
100:0	18	34ab	91a	9c
98:2	16	12c	83a	17c
96:4	14	27abc	76ab	24bc
92:8	13	19bc	70ab	30bc
84:16	13	24bc	59b	41b
0:100	13	42a	10c	90a

Note: Within a column, means followed by the same letters are not statistically different based on Fisher's protected LSD test ($\alpha \leq 0.05$).

Abbreviation: PLS, pure live seed.

^aBased on 20 PLS inch⁻².

^bShoots were individually counted from 1-inch² samples and classified as either KBG or PRG.

provide further insight into species' performance under different establishment conditions.

The high nitrogen application—5.2 lb 1000 ft⁻²—during the course of a single SOP production may have favored PRG over KBG, contributing to the results observed in this study. Future studies investigating nitrogen fertility practices, including optimal rates and timing of application, would provide practical recommendations for fertility strategies in SOP production.

5 | CONCLUSIONS

This study demonstrated the effectiveness of incorporating PRG into KBG-dominated SOP, offering valuable insights for cool-season sod farmers. While KBG remains popular for its familiarity and proven performance, adding PRG to the seed mix provides several advantages; A KBG-PRG mixture enables farmers to produce more resilient sod in less time, as early as 4 months, meeting the growing demand for high-quality sod for sports fields and improving profitability. The addition of 16% PRG was found to provide an optimal balance, enhancing turfgrass cover and achieving acceptable sod strength while maintaining a KBG-dominated sod (56:44 KBG-to-PRG shoot ratio).

AUTHOR CONTRIBUTIONS

Jackie Lyn A. Guevara: Conceptualization; data curation; formal analysis; investigation; methodology; visualization; writing—original draft; writing—review and editing. **Ryan Bearss:** Methodology; project administration; resources; supervision; visualization; writing—review and editing. **Jacob Kilby:** Investigation; methodology; writing—

review and editing. **John Sorochan:** Conceptualization; funding acquisition; project administration; supervision; validation; writing—review and editing. **John N. Rogers III:** Conceptualization; funding acquisition; investigation; project administration; supervision; validation; visualization; writing—review and editing.

ACKNOWLEDGMENTS

We thank the Fédération Internationale de Football Association for funding this research.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ORCID

Jackie Lyn A. Guevara  <https://orcid.org/0000-0002-1958-6887>

Ryan Bearss  <https://orcid.org/0000-0002-0216-352X>

REFERENCES

- Beard, J., Rieke, P., & King, J. (1969). Sod production of Kentucky bluegrass. In *Proceedings of the First International Turfgrass Research Conference* (pp. 509–513). Sports Turf Research Institute.
- Bearss, R., Guevara, J. L., Kilby, J., Rogers, E., Rogers, J. N. III., Fielder, R., Burbrink, C., Navarette, I., Williams, T., Dickson, K., & Sorochan, J. (2024). Surface performance characteristics of carpet-mat stabilized cool-season sod over drainage cells for temporary stadium installation. *International Turfgrass Society Research Journal*, 15(1), 121–125. <https://doi.org/10.1002/its2.158>
- Bingaman, D. E., & Kohnke, H. (1970). Evaluating sands for athletic turf. *Agronomy Journal*, 62(4), 464–467. <https://doi.org/10.2134/agronj1970.00021962006200040010x>
- Blake, G., Taylor, D., & White, D. (1981). Sports-turf soils: Laboratory analysis to field installation. In *Proceedings of the Fourth International Turfgrass Research Conference* (pp. 209–216). International Turfgrass Society.
- Blaser, R. E. (1964). *Principles of making turf mixtures for roadside seedings*. Virginia Council of Highway Investigation and Research, School of Engineering and Applied Science, University of Virginia. <https://onlinepubs.trb.org/Onlinepubs/hrr/1963/23/23-014.pdf>
- Braun, R. C., Courtney, L. E., & Patton, A. J. (2023). Seed morphology, germination, and seedling vigor characteristics of fine fescue taxa and other cool-season turfgrass species. *Crop Science*, 63(3), 1613–1627. <https://doi.org/10.1002/csc2.20936>
- Braun, R. C., Watkins, E., Hollman, A. B., Mihelich, N. T., & Patton, A. J. (2021). Investigation of cool-season species, seeding rate, and nitrogen fertilization in sod production: I. Establishment and sod tensile strength. *Agronomy Journal*, 113(5), 4176–4189. <https://doi.org/10.1002/agj2.20810>
- Braun, R. C., Watkins, E., Hollman, A. B., Mihelich, N. T., & Patton, A. J. (2022). Management, harvest, and storage characteristics of low-input cool-season turfgrass sod mixtures. *Agronomy Journal*, 114(3), 1752–1768. <https://doi.org/10.1002/agj2.21051>
- Brede, A. D., & Duich, J. M. (1984). Establishment characteristics of Kentucky bluegrass-perennial ryegrass turf mixtures as affected by seeding rate and ratio. *Agronomy Journal*, 76(6), 875–879. <https://doi.org/10.2134/agronj1984.00021962007600060004x>

- Brown, R. N., Percivalle, C., Narkiewicz, S., & DeCuollo, S. (2010). Relative rooting depths of native grasses and amenity grasses with potential for use on roadsides in New England. *HortScience*, 45(3), 393–400. <https://doi.org/10.21273/HORTSCI.45.3.393>
- Christians, N. E., Patton, A. J., & Law, Q. D. (2016). *Fundamentals of turfgrass management* (5th ed.). Wiley. <https://doi.org/10.1002/9781119308867>
- Christians, N. E., Wilkinson, J. F., & Martin, D. P. (1979). Variations in the number of seeds per unit weight among turfgrass cultivars. *Agronomy Journal*, 71(3), 415–419. <https://doi.org/10.2134/agronj1979.00021962007100030008x>
- Cisar, J. L., & Snyder, G. H. (1992). Sod production on a solid-waste compost over plastic. *HortScience*, 27(3), 219–222. <https://doi.org/10.21273/HORTSCI.27.3.219>
- Decker, H. F. (2001). Producing sods over plastic in soilless media. In J. Janick (Ed.), *Horticultural reviews* (Vol. 27, pp. 317–351). Wiley. <https://doi.org/10.1002/9780470650813.ch8>
- Dunn, J. H., Ervin, E. H., & Fresenburg, B. S. (2002). Turf performance of mixtures and blends of tall fescue, Kentucky bluegrass, and perennial ryegrass. *HortScience*, 37(1), 214–217. <https://doi.org/10.21273/HORTSCI.37.1.214>
- Engel, R. E., & Trout, J. R. (1980). Seedling competition of Kentucky bluegrass, red fescue, colonial bentgrass, and temporary grasses. In J. B. Beard (Ed.), *Proceedings of the Third International Turfgrass Research Conference* (pp. 379–389). ASA, CSSA, SSSA. <https://doi.org/10.2135/1974.proc3rdintlurfgrass.c44>
- Etter, A. G. (1951). How Kentucky bluegrass grows. *Annals of the Missouri Botanical Garden*, 38(3), 293–375. <https://doi.org/10.2307/2394639>
- Folck, A. J., Bigelow, C. A., Jiang, Y., & Patton, A. J. (2023). Genotypic variation in germination rate, seedling vigor, and seed phenotype of Kentucky bluegrass cultivars. *Crop Science*, 63(5), 3065–3078. <https://doi.org/10.1002/csc2.21045>
- Gardner, W. (1953). Physical properties of soils with special reference to water management. In *Proceedings of the 7th Annual Pacific Northwest Turf Conference* (pp. 20–26). Pacific Northwest Turf Association, & The State College of Washington.
- Gibeault, V. A., Autio, R., Spaulding, S., & Youngner, V. B. (1980). Mixing turfgrasses controls Fusarium blight. *California Agriculture*, 34(10), 11–12. <https://californiaagriculture.org/article/111243-mixing-turfgrasses-controls-fusarium-blight>
- Giolo, M., Dalla Montà, A. D., Barolo, E., Ferrari, F., Masin, R., & Macolino, S. (2017). High-temperature effects on seed germination of fourteen Kentucky bluegrass (*Poa pratensis* L.) cultivars. *Agronomy Research*, 15(1), 123–132. https://agronomy.emu.se/wp-content/uploads/2017/03/Vol15Nr1_Giolo.pdf
- Henderson, J. J., Crum, J. R., Wolff, T. F., & Rogers, J. N. III. (2005). Effects of particle size distribution and water content at compaction on saturated hydraulic conductivity and strength of high sand content root zone materials. *Soil Science*, 170(5), 315–324. <https://doi.org/10.1097/01.ss.0000169906.02485.7f>
- Hsiang, T., Carey, K., He, B., & Eggen, J. L. (1997). Composition of mixtures of four turfgrass species four years after seeding under non-wear conditions. *International Turfgrass Society Research Journal*, 8, 671–679.
- Kowalewski, A. R., Rogers, J. N. III., Crum, J. R., & Dunne, J. C. (2010). Sand topdressing applications improve shear strength and turfgrass density on trafficked athletic fields. *HortTechnology*, 20(5), 867–872. <https://doi.org/10.21273/HORTTECH.20.5.867>
- Kowalewski, A. R., Rogers, J. N. III., & VanLoo, T. D. (2008). Pre-harvest core cultivation of sod provides an alternative cultivation timing. *Applied Turfgrass Science*, 5(1), 1–10. <https://doi.org/10.1094/ATS-2008-0421-01-RS>
- Larsen, S. U., Andreassen, C., & Kristoffersen, P. (2004). Differential sowing time of turfgrass species affects the establishment of mixtures. *Crop Science*, 44(4), 1315–1322. <https://doi.org/10.2135/cropsci2004.1315>
- Li, D., Henderson, J., Vanini, J. T., & Rogers, J. N. III. (2013). Research tools and technologies for turfgrass establishment. In J. C. Stier, B. P. Horgan, & S. A. Bonos (Eds.), *Turfgrass: Biology, use, and management* (Vol. 56, pp. 1189–1239). ASA, CSSA, SSSA. <https://doi.org/10.2134/agronmonogr56.c31>
- Moser, L. E., Anderson, S. R., & Miller, R. W. (1968). Rhizome and tiller development of Kentucky bluegrass (*Poa pratensis* L.) as influenced by photoperiod, cold treatment, and variety. *Agronomy Journal*, 60(6), 632–635. <https://doi.org/10.2134/agronj1968.00021962006000060014x>
- Neel, P. L., Burt, E. O., Busey, P., & Snyder, G. H. (1978). Sod production in shallow beds of waste materials. *Journal of the American Society for Horticultural Science*, 103(4), 549–553. <https://doi.org/10.21273/JASHS.103.4.549>
- Niehaus, M. H. (1976). Effect of cultivar, seeding rate, and nitrogen fertilization on Kentucky bluegrass-perennial ryegrass turf mixtures. *Agronomy Journal*, 68(6), 955–957. <https://doi.org/10.2134/agronj1976.00021962006800060028x>
- Proctor, C. A., Weisenberger, D. V., & Reicher, Z. J. (2015). Kentucky bluegrass and perennial ryegrass mixtures for establishing Midwest lawns. *HortScience*, 50(1), 137–140. <https://doi.org/10.21273/HORTSCI.50.1.137>
- Richardson, M. D., Karcher, D. E., & Purcell, L. C. (2001). Quantifying turfgrass cover using digital image analysis. *Crop Science*, 41(6), 1884–1888. <https://doi.org/10.2135/cropsci2001.1884>
- R Core Team. (2025). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing [Computer software]. <https://www.R-project.org/>
- Rieke, P., & Beard, J. (1969). Factors in sod production of Kentucky bluegrass. In *Proceedings of the First International Turfgrass Research Conference* (pp. 514–521). Sports Turf Research Institute.
- Roberts, B. R., Decker, H. F., Ganahl, L. M., & Yarmark, E. (2001). Biosolid residues as soilless media for growing creeping bentgrass sod. *HortTechnology*, 11(3), 451–455. <https://doi.org/10.21273/HORTTECH.11.3.451>
- Schneider, C. A., Rasband, W. S., & Eliceiri, K. W. (2012). NIH Image to ImageJ: 25 years of image analysis. *Nature Methods*, 9(7), 671–675. <https://doi.org/10.1038/nmeth.2089>
- Sorochan, J., Calhoun, R., & Rogers, J. N. III. (1999). Apparatus to measure turfgrass sod strength. *1999 Annual Meeting Abstracts*, 91, 137. ASA, CSSA, SSSA.
- Sorochan, J. C., & Rogers, J. N. III. (2000). Measuring sod strength of Kentucky bluegrass and Supina bluegrass. *TurfGrass Trends*, 8(9), 6–9.
- Sorochan, J. C., & Rogers, J. N. III. (2001). The effect of mulch type for turfgrass establishment within a refined wood fiber mat over plastic. *Journal of Environmental Horticulture*, 19(2), 61–64. <https://doi.org/10.24266/0738-2898-19.2.61>

- Stier, J. C., Koeritz, E. J., & Garrison, M. (2008). Timing the establishment of Kentucky bluegrass: Perennial ryegrass mixtures for football fields. *HortScience*, 43(1), 240–244. <https://doi.org/10.21273/HORTSCI.43.1.240>
- Thoms, A. W., Bearss, R., Rogers, J. N. III., & Sorochan, J. C. (2022). An evaluation of mat hybrid turfgrass systems under simulated traffic. *International Turfgrass Society Research Journal*, 14(1), 385–389. <https://doi.org/10.1002/its2.58>

How to cite this article: Guevara, J. L. A., Bearss, R., Kilby, J., Sorochan, J., & Rogers, J. N. III (2026). Evaluating Kentucky bluegrass and perennial ryegrass seeding ratios for sod grown on plastic production. *Crop, Forage & Turfgrass Management*, 12, e70112. <https://doi.org/10.1002/cft2.70112>