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Impact of species selection on plant community, sod tensile strength, and translocation rooting of a pollinator-garden sod

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Abstract

Interest in pollinator gardens is increasing to address pollinator decline. The establishment of perennial native plants often takes a few years and establishment projects are often lost to competition from unwanted weedy vegetation. Mature sod of pollinator-serving, native plants that is free of weeds would be highly desirable to conventional turfgrass sod consumers, thus offering a new revenue stream for traditional sod producers. The objective of this study is to evaluate the influence of four foundational species treatments on 3-year floral biodiversity of pollinator-serving plants, sod tensile strength, and transplant rooting strength. Results suggest that polycultures of pollinator-serving forbs can produce a marketable sod with sufficient tensile strength for lifting and translocating and sufficient ability to establish once relocated. Sod tensile strength, however, is insufficient for lifting when the plant community is not grown over plastic or does not contain a high-shoot density or rhizomatous foundation species such as hard fescue (*Festuca longifolia* Thuill.) or common yarrow (*Achillea millefolium* L.). Unfortunately, adding hard fescue or common yarrow markedly reduces the Shannon diversity index and species richness. The force needed to lift transplanted sod after 3 months was 5553 to 6969 N m⁻² regardless of foundation species treatment and was numerically higher than the force reported by previous researchers to lift sod of various turfgrass species. Collectively, the data suggest that the best balance between preserving floral biodiversity and maximizing sod handling integrity would be approached by establishing pollinator-serving forbs alone or with a blend of native grasses over plastic.

Abbreviations: GRRF, Virginia Tech Glade Road Research Facility; MAS, months after seeding; NGM, native grass mixture; SDI, Shannon diversity index; TRC, Turfgrass Research Center, Blacksburg, VA; YAS, year after seeding.

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1 | INTRODUCTION

Insect pollinators facilitate the reproduction of 87% of angiosperms and 35% of major food crops of the world (Klein et al., 2007; Ollerton et al., 2011). The growing interest in pollinator gardens can contribute as a conservation tool for supporting pollinator diversity in response to

pollinator decline (Goulson et al., 2015; K. L. Larson et al., 2022; Majewska & Altizer, 2020). Pollinator-serving plant communities provide food and shelter resources to pollinators. Practitioners within the green industry often incorporate pollinator-serving plants in managed landscapes by seeding (Campbell et al., 2017; Majewska & Altizer, 2020; Westerhold et al., 2018) and entomologists have touted the benefits of this strategy (J. L. Larson et al., 2017). The establishment of pollinator-serving forbs varies depending on soil conditions and competitive growth habits (Lane et al., 2019). Seed dormancy and slow seedling growth are the primary limitations to the establishment of perennial native plants (Panciera, 1999). The duration required to achieve acceptable standards is determined by management input and ranges from 2 years with recommended management to 5 years with poor management (Panciera, 1999). Seed dormancy varies with species, ecotype, and even local growing conditions and is typically overcome with cold stratification for 14 days prior to planting (Olszewski & Folin, 2009; Panciera, 1999). Without prechilling, some species, such as purple-top, Indian grass, and switchgrass, may not germinate at all in the first year (Panciera, 1999). Weed infestations often limit the success of seeded pollinator gardens due to limited weed management tools and reduced competition from slow-establishing perennial plants (Aldrich, 2002; Angelella et al., 2019; Norcini et al., 2003). Gardens comprising a mixture of annuals, biennials, and perennials exhibited transiently superior performance compared to communities solely composed of perennial plants (Angelella et al., 2019). This superiority stemmed from the longer time required for perennial plants to reach flowering maturity and the increased competition from weeds (Angelella et al., 2019). However, perennials are anticipated to provide greater long-term benefits despite their slower initial growth, typically requiring 2–3 years to achieve peak flowering (Angelella et al., 2019; Corley & Smith, 1990). Likewise, a study conducted in West Virginia demonstrated that native grasses are slow to establish and only produce up to 25% ground cover in some locations even at 3 years after seeding (YAS) (Skousen & Venable, 2007).

Sodding techniques are commonly employed for the establishment of both cool- and warm-season turfgrass species (Braun et al., 2021; Sharpe et al., 1989) and have potential applications in establishing pollinator gardens. Conventional consumers of turfgrass sod may show interest in initiatives aimed at creating pollinator garden sod. Similarly, turfgrass sod producers should possess the expertise to establish diverse plant communities that serve pollinators and nurture them to maturity, enabling clients to bypass the typical 3-year establishment period. Incorporating spring-flowering plants within turfgrass installations has been identified as a strategy to enhance the pollinator-supporting attributes of green spaces (Pennisi et al., 2021). Previous studies have investigated the

Core Ideas

- Mature, weed-free sod of native pollinator-serving plants offers a potential new revenue source for sod producers.
- Polycultures of pollinator-serving forbs yielded marketable sod with good tensile strength and transplant success.
- Optimal floral diversity and sod handling is achieved by planting forbs alone or with native grasses over plastic.

development of wildflower sod (Johnson & Whitwell, 1997), and the use of plastic barriers has been highlighted as beneficial in sod production processes, aiding in both production and harvesting (Cisar & Snyder, 1992).

We hypothesized that plant communities that serve pollinators could be lifted as sod and translocated to other sites. We also expect that sod tensile strength and translocation rooting would be influenced by altering the foundation species within each plant community with a variety of species that promote shoot density or rhizomatous root systems. Furthermore, foundation species are expected to alter the success rate of other plants among those originally seeded. The objective of our study is to assess the influence of four foundation species compositions on plant biodiversity, sod tensile strength, and translocation rooting strength within sod comprised of 20 pollinator-serving forbs, which are consistently included across all foundation species treatments.

2 | MATERIALS AND METHODS

Three field experiments were conducted as repetitions of a single factor, randomized complete block design with four replications, with one trial site at Virginia Tech Glade Road Research Facility (GRRF) and two experimental sites at the Turfgrass Research Center (TRC), Blacksburg, VA, from November, 2019 to October, 2023. All studies evaluated the mix of four foundation species compositions that were added to a consistent mixture of 20 pollinator-serving forbs (Table 1). The foundation-species treatments included no foundation species, common yarrow (*Achillea millefolium* L.), hard fescue (*Festuca longifolia* Thuill.), and a native grass mixture (NGM) comprised of Indiangrass [*Sorghastrum nutans* (L.) Nash], little bluestem [*Schizachyrium scoparium* (Michx.) Nash], and Virginia wildrye (*Elymus virginicus* L.), respectively. Common yarrow, hard fescue, NGM, and the pollinator-serving forb mix were seeded at 2.2 kg ha⁻¹, 89.7 kg ha⁻¹, 11.2 kg ha⁻¹, and 11.2 kg ha⁻¹, respectively

TABLE 1 List of plant species, seeding rates, and 3-year after seeding relative forb abundance for pollinator-serving forbs and foundational species.

Common name	Scientific name	Seeding rate (kg ha ⁻¹)	3-Year relative forb abundance (% SE)
Pollinator-serving forbs			
Black-eyed Susan	<i>Rudbeckia hirta</i> L.	1.34	4.08, 0.29
Common boneset	<i>Eupatorium perfoliatum</i> L.	0.11	1.66, 0.14
Blue false indigo	<i>Baptisia australis</i>	0.11	0, 0
Swamp verbena	<i>Verbena hastata</i> L.	0.90	0, 0
Common milkweed	<i>Asclepias syriaca</i> L.	0.06	0, 0
Parasol whitetop	<i>Aster umbellatus</i> Mill.	0.11	14.26, 0.72
Foxglove beardtongue	<i>Penstemon digitalis</i> Nutt. ex Sims	0.45	3.78, 0.31
Golden zizia	<i>Zizia aurea</i> (L.) Koch	0.56	2.30, 0.36
Gray goldenrod	<i>Solidago nemoralis</i> Ait.	0.21	12.54, 0.53
Lanceleaf tickseed	<i>Coreopsis lanceolata</i> L.	1.34	6.39, 0.63
Narrowleaf mountainmint	<i>Pycnanthemum tenuifolium</i> Schrad.	0.27	0.39, 0.06
New England aster	<i>Aster novae-angliae</i> L.	0.45	0, 0
Bluejacket	<i>Tradescantia ohiensis</i> Raf.	0.56	0, 0
Smooth oxeye	<i>Heliopsis helianthoides</i> (L.) Sweet	0.67	7.71, 0.40
Partridge pea	<i>Cassia fasciculata</i> Michx.	1.12	3.15, 0.32
Eastern purple coneflower	<i>Echinacea purpurea</i> (L.) Moench	1.79	4.76, 0.29
Swamp milkweed	<i>Asclepias incarnata</i> L.	0.67	0, 0
Wild bergamot	<i>Monarda fistulosa</i> L.	0.13	13.18, 0.57
American senna	<i>Senna hebecarpa</i> (Fern.) Irwin & Barneby	0.27	0, 0
Wrinkleleaf goldenrod	<i>Solidago rugosa</i> P. Mill.	0.07	16.42, 0.70
Foundation species			
Common yarrow	<i>Achillea millefolium</i> L.	2.22	–
Hard fescue	<i>Festuca longifolia</i> Thuill. ‘Aurora Gold’	89.7	–
Native grass mixture	<i>Sorghastrum nutans</i> (L.) Nash		
Indiangrass	<i>Schizachyrium scoparium</i>	3.50	
Little bluestem	(Michx.) Nash	3.50	
Virginia wildrye	<i>Elymus virginicus</i> L.	4.20	–

Note: Seeding rates of the 20 pollinator-serving forbs were based on a mixture that was applied at 11.2 kg ha⁻¹ consistently across all treatments. Foundational species were added to this mixture at the rates given above. Relative forb abundance based on shoot density 3-year after seeding excluding foundational species.

(Table 1). Seeding rates for common yarrow and hard fescue is based on the author's experience for rates that were expected to produce a moderate, but not dense, seedling stand. All other seeding rates were based on a seed mixture designed for the local geography (ERNMX125, Ernst Seed). Plant communities were seeded on November 21, 2019, at two separate locations at the TRC on 1.8 m × 3.6 m plots. Trial sites at TRC were tilled, smoothed, seeded by hand shaking preweighed seed mixture on each plot, roller packed, and then covered by wheat straw. The following year, on November 11, 2020, a third experimental run was established at GRRF on 1.8 m × 1.2 m plots. At GRRF, 4 Mil clear plastic (Uline) was laid over smooth ground, and 0.3-m-wide tall fescue sod was laid around the trial perimeter and between each experimental block. The area between the sod was then filled with Groseclose loam topsoil (clayey, mixed, mesic, Typic Haplu-

dalfs) collected from a location proximal to both trial sites at TRC. The 2-cm deep soil was allowed to settle for 1 month and any voids due to settling were topdressed with additional soil. Desirable seeds were sown and topdressed with an additional 0.6 cm of soil. Mowing, fertility, and irrigation were withheld throughout experiments with the exception that GRRF plots were irrigated as needed to avoid wilt.

Dominant plant establishment assessments were taken 8 months after seeding (MAS) at the two TRC sites. At this time, cover of foundation species and any pollinator-serving forbs present at >5% plot cover were assessed by annotating species at grid intersect points of a digital grid overlaid on aerial plot photographs comprising 3 m⁻² of each plot at 100 intersects m⁻². The number of intersects subtended by a given species was divided by the total number of intersects to estimate plant cover. Blooms per plot were counted for any of the seeded

pollinator-serving forbs that exceeded 5% vegetative cover. At 3 YAS, a detailed plant community assessment was collected based on shoot counts per plot of all seeded species. This was done on September 28, 2022, at TRC and on September 5, 2023, at GRRF. At GRRF, these assessments were limited to a 1-m wide $\times$ 1.6-m long area to avoid areas that had been previously disrupted by sod relocation. At TRC, the whole plot was assessed as pieces removed for sod tensile strength assessment at 1.5 YAS were replaced and only accounted for 1.3% of the plot area. Species richness was expressed as the total number of unique species per plot. Shannon diversity index (SDI) was calculated as follows:

$$y = - \sum_{i=1}^S P_i \ln P_i, \quad (1)$$

where y is the SDI, S is the total number of plant species in the community, and P_i is the proportion of individuals belonging to i th species. The value of y increases as both the number of species and the evenness of their distribution increase. Since we are assessing 20 native forbs that were seeded in all plots, the maximum y would be 3.0 if all forbs were present and equally abundant in the community. The minimum value would be 0 if there was only one species present. In addition to SDI, the total number of shoots for pollinator-serving forbs was also determined for each plot.

At 1.5 YAS, a single 0.3-m-wide strip of sod was harvested with a conventional sod cutter (Ryan Jr. Sod Cutter, Clark Equipment) on July 15, 2021, at TRC and by vertically cutting with a knife on July 22, 2022, at GRRF. Sod tensile strength was measured as the force needed to horizontally separate sod using a hydraulically driven sod strength machine equipped as discussed in previous research (Goatley et al., 1997). The sod relocation and rooting study utilized sod only from the GRRF experimental site and only from portions of plots that were not utilized for previous sod tensile strength assessment or subsequent plant community assessment. The sod source at the GRRF site was mowed to 10-cm height and harvested by cutting the plant material, which was root-bound over plastic, vertically with a knife into 30 cm $\times$ 30 cm pieces on May 22, 2022, and June 5, 2022. At each of these timings, one piece of sod from each plot was relocated to establish spatially separate trials at the GRRF. The design of these studies was spatially arranged in the same manner as the previous studies. Sod pieces were translocated and placed over expanded metal on freshly tilled and smoothed soil and placed under automated irrigation for 2 weeks. Translocated sod was then allowed to establish naturally without additional irrigation or other resources until 3 months after transplanting. A force meter was then attached to the subtending expanded metal, sod was pulled vertically until separated from the soil, and the maximum force was recorded.

Foundation species vegetative cover 8 MAS, black-eyed Susan vegetative cover 8 MAS, black-eyed Susan bloom density 8 MAS, SDI 3 YAS, species richness 3 YAS, pollinator forb shoot density 3 YAS, sod tensile strength 1.5 YAS, and translocated sod root strength 1.5 YAS were subjected to analysis of variance with sums of squares partitioned to reflect replicate, trial, treatment (foundation species composition), and trial $\times$ treatment effects and interactions. Data were analyzed using PROC GLM in SAS v 9.3 (SAS Institute). Trial was considered a random variable, and the mean square of treatment was tested by the mean square of trial $\times$ treatment. If trial $\times$ treatment interaction was significant, data were separated by trial; otherwise, data were pooled over trials to report significant treatment effects. Appropriate means were separated with Fisher's protected least significant difference at $\alpha = 0.05$.

3 | RESULTS AND DISCUSSION

Of the 20 forbs seeded, only 13 had observable shoots 3 YAS (Table 1). Gray goldendrod, parasol whitetop, wild bergamot, and wrinkleleaf goldenrod comprised over 50% of shoots 3 YAS and were the only forb species that averaged over 10% shoot density (Table 1). Black-eyed Susan, foxglove beard-tongue, lanceleaf tickseed, smooth oxeye, partridge pea, and Eastern purple coneflower each had over 3% shoot density 3 YAS. It has been shown that species richness drives pollinator attraction to pollinator gardens, but relative abundance of forbs present in pollinator gardens is often not reported (Watson et al., 2022). Several studies have evaluated insect richness associated with a given forb or forb complex (Pant & Mopper, 2021; Ruppel et al., 2019), but our understanding of long-term relative abundance of species commonly chosen for pollinator gardens is lacking in the scientific literature.

At 8 MAS, initial plant establishment was predominately comprised of the foundation species with appreciable numbers of black-eyed Susan and infestation by several weeds such as prostrate knotweed (*Polygonum aviculare* L.), smooth crabgrass (*Digitaria ischaemum* Schreb. ex Muhl.), and Canada thistle [*Cirsium arvense* (L.) Scop.]. Weed infestation usually limits pollinator garden success during the initial year of establishment but perennial forbs outcompete weed species in the second or third year (Angelella et al., 2019). For both TRC sites, the trial $\times$ treatment interaction was insignificant for foundation species vegetative cover ($F(6, 33) = 0.28$, $p = 0.94$), black-eyed Susan vegetative cover ($F(3, 21) = 0.93$, $p = 0.44$), and black-eyed Susan bloom density ($F(3, 21) = 0.68$, $p = 0.58$) 8 MAS, so data were pooled over experimental runs to compare the significant effect of foundation species for first-season foundation species cover ($F(3, 33) = 149.4$, $p = < 0.0001$), black-eyed Susan

vegetative cover ($F(3, 21) = 10.55, p = 0.0002$), and black-eyed Susan bloom density ($F(3, 21) = 9.61, p = 0.0003$). Plant establishment metrics for non-foundational plants at 8 MAS were not collected at GRRF.

Foundation species cover 8 MAS was 0%, 35%, 54%, and 17% for no foundation species, common yarrow, hard fescue, and the NGM, respectively (Table 2). The intent of utilizing foundation species was to improve sod tensile strength. Hard fescue, although seeded at 0.25% of the normal rate used for ornamental turf establishment, was seeded at a considerably higher rate than all other foundation species. Previous research demonstrated the weed-suppressive properties of similar *Festuca* species on smooth crabgrass (Breuillin-Sessoms et al., 2021). Common yarrow can create a monoculture and displace existing vegetation under reduced management scenarios (Mann et al., 2022). Skousen and Venable (2007) evaluated native plant establishment and found that mixtures of native grasses, including Indiangrass, were similarly slow to establish as they only produced 25% cover even after 3 years of establishment.

Black-eyed Susan was the only species among those seeded as pollinator-serving forbs that exceeded 5% cover in any plot 8 MAS (Table 2). Black-eyed Susan vegetative cover was highest, ranging from 33% to 35% in plots seeded with NGM or no foundation species and varied in tandem with foundation species cover for common yarrow and hard fescue (Table 2). Black-eyed Susan bloom density exhibited a consistent relationship with black-eyed Susan vegetative cover across all plant communities and ranged from 10 to 12 shoots m^{-2} in the communities with a native grass foundation or no foundation to 4 shoots m^{-2} in communities with a hard fescue foundation (Table 2). Johnston et al. (2015) evaluated the establishment success of 12 grasses and 17 forbs after seeding and found that black-eyed Susan had a higher establishment rate among other species with greatest ground cover over 1 YAS.

At 3 YAS, the final plant community assessment based on shoot density per plot revealed consistent trends with respect to the influence of foundation species on plant community metrics across all three trial sites. The interaction of trial $\times$ foundation species was insignificant for species richness ($F(6, 33) = 0.47, p = 0.83$), forb shoot density (not including common yarrow) ($F(6, 33) = 0.26, p = 0.95$), and SDI ($F(6, 33) = 0.21, p = 0.97$). These metrics were pooled across the three experimental runs to compare the significant effect of foundation species for species richness ($F(3, 33) = 79.3, p < 0.0001$), forb shoot density ($F(3, 33) = 18.7, p < 0.0001$), and SDI ($F(3, 33) = 31.0, p < 0.0001$). Species richness was 11, 9, 6, and 4 for plots with no foundation species, NGM, common yarrow, and hard fescue foundation species, respectively (Table 2). These trends in species richness among the targeted pollinator-serving forbs 3 YAS are inversely related to trends in initial foundation cover 8 MAS (Table 2). Higher foundation species coverage from hard fescue and common

TABLE 2 Effect of foundation species on black-eyed Susan cover and count, species richness, pollinator-serving forb shoot density, and Shannon diversity index.

Foundation species	Foundation species cover ^a (%)	Black-eyed Susan cover ^a (%)	Black-eyed Susan bloom (No. m^{-2})	Species richness ^b (No. plot ⁻¹)	Forb shoot density ^b (No. m^{-2})	Shannon diversity index ^b
No foundation species	0 ^c	33a	10ab	11a	66a	1.31a
Common yarrow	35b	23b	8.8b	6c	9.4bc	0.16c
Hard fescue	54a	15c	4.0c	4d	4.6c	0.08c
Native grass mixture	17c	35a	12a	9b	24.5b	0.86b

Note: Native grass mixture consists of Indiangrass, little bluestem, and Virginia wildrye mixture. Means followed by the same letter within each column are not different based on Fisher's protected least significant difference ($\alpha = 0.05$).

^aData were pooled over two experimental sites at Turfgrass Research Center, Blacksburg, VA, and collected 8 months after seeding.

^bData were collected 3 years after seeding and pooled over three experimental sites, comprised of two sites at Turfgrass Research Center and another one at Glade Road Research Facility, Blacksburg, VA.

^cThis treatment was not included in the analysis for this response because it did not contain any variance.

TABLE 3 Effect of foundation species on tensile strength and transplanting success of 1.5-year-old sod based on force to separate a 0.3-m-wide sod or lift sod 4 months after transplanting^a.

Foundation species	Sod tensile strength (N)			Force to lift sod (N m ⁻²)
	TRC1	TRC2	GRRF	
No foundation species	69b	78b	186a	5880b
Common yarrow	147a	157a	216a	5662b
Hard fescue	206a	215a	245a	5553b
Native grass mix	29b	39b	216a	6969a

Abbreviations: GRRF, Glade Road Research Facility; TRC, Turfgrass Research Center.

^aMeans followed by the same letter within each column are not different based on Fisher's protected least significant difference ($\alpha = 0.05$).

yardow substantially decreased species richness. Likewise, the total shoot density of pollinator-serving forbs, excluding foundation species, ranged from 4.6 to 66 m⁻² with a similar mean rank to that of species richness (Table 2). Kiss et al. (2022) also demonstrated that forbs performed better in fallow land compared to grassland comprised of *Festuca* spp. The cover and richness of 20 forbs were lower in *Festuca* spp. plots than in fallow plots in the second YAS (Kiss et al., 2022).

The SDI exhibited a positive association with species richness and forb shoot density, as shown in Table 2. The treatment without foundation species displayed an SDI of 1.3, exceeding that of the NGM foundation treatment with an SDI of 0.86 (Table 2). The SDI values for common yarrow and hard fescue ranged from 0.08 to 0.16, notably lower compared to other treatments, attributed to the high shoot density of these foundation species and the limited establishment and associated species richness of the seeded pollinator-serving forbs (Table 2). In a separate study conducted in Wisconsin, the establishment success of native grasses such as little bluestem and Indiangrass, along with forb mixtures, resulted in an SDI of 1.7, while plots containing *Poa* spp. and other weedy species yielded an SDI of 0.7 (Roubik et al., 2013).

Sod tensile strength 2 YAS was dependent on the trial ($p = 0.01$), so data are presented separately across the three trial locations. At all experimental sites, volumetric soil moisture was monitored to select sod harvest times with consistent soil moisture as recommended by previous researchers (Braun et al., 2022). The resulting volumetric moisture contents from three readings per plot across all three sites were $13 \pm 5.7\%$ standard deviation (data not shown). The trial interaction was likely caused by the consistency in sod tensile strength demonstrated at GRRF compared to distinct differences between foundation species treatments evident at TRC1 and TRC2 (Table 3). At both trial sites at TRC, sod tensile strength was 147–215 N for plots that contained hard fescue or common yarrow as the foundation species and not more than 78 N for plots that contained no foundation species or NGM (Table 3). By comparison, a mixed grass species sod

comprising 60% Kentucky bluegrass (*Poa pratensis* L.) routinely used by the Minnesota Department of Transportation had a tensile strength of 219 N (Friell et al., 2017). Previous research also showed that the maximum tensile load to tear sod was approximately 258 N for *Festuca rubra* ssp. *commutata* and *Festuca brevipila* 'Tracey' mixture at 2 years after planting (Braun et al., 2022). At the GRRF site where plants were grown over plastic, sod tensile strength was equivalent for all plant communities and ranged from 186 to 245 N (Table 3).

Translocation success of sod was measured at two experimental sites from sod collected on two occasions, but only sod grown over plastic from GRRF was used for this purpose as it had high enough tensile strength across all plant communities for lifting and translocating. The interaction of experimental run $\times$ foundation species was insignificant for 3-month sod rooting strength ($p = 0.87$), so data were pooled over the two experimental runs to compare the significant effect of foundation species ($p < 0.0001$). The plant community with a native grass foundation required 6969 N m⁻² to lift after transplanting. This is significantly more force than needed for the other foundation species treatments which was similar to that of traditional turfgrasses, which ranged from 5553 to 5880 N m⁻² (Table 3). These data are slightly higher than that reported by Goatley and Schmidt (1991) for post-transplant root lift force of Kentucky bluegrass at 1 and 2 months after transplanting which ranged from 1980 to 5939 N m⁻² depending on treatment date and biostimulant application. Bingham (1974) also showed that 4746 to 5904 N m⁻² of force was required to pull Kentucky bluegrass (*Poa pratensis* L.) sod vertically from the soil 28 days after establishment. Results suggest that polycultures of pollinator-serving forbs can produce a marketable sod with sufficient tensile strength for lifting and translocating and sufficient ability to establish once relocated. Sod tensile strength, however, is insufficient for lifting when the plant community is not grown over plastic or a high-shoot density or rhizomatous foundation species, such as hard fescue or common yarrow, is not added to the plant community.

4 | CONCLUSION

Despite improving sod tensile strength when not grown over plastic, hard fescue and common yarrow would not be recommended as foundation species for a pollinator-serving forb sod as these species reduced species richness and diversity indices. The most successful approach to producing sod for pollinator-serving plant communities appears to be growing a variety of forbs over plastic without a foundation species or with a mixture of native grasses.

AUTHOR CONTRIBUTIONS

Whitnee B. Askew: Data curation; investigation; methodology; writing—original draft; writing—review and editing. **Navdeep Godara:** Data curation; formal analysis; investigation; visualization; writing—original draft; writing—review and editing. **John R. Brewer:** Data curation; investigation; methodology; writing—review and editing. **Clebson G. Gonçalves:** Data curation; investigation; methodology; writing—review and editing. **Michael Goatley:** Conceptualization; methodology; supervision; validation; writing—review and editing. **Shawn D. Askew:** Conceptualization; formal analysis; investigation; methodology; project administration; supervision; validation; visualization; writing—original draft; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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REFERENCES

- Aldrich, J. H. (2002). Factors and benefits in the establishment of modest-sized wildflower plantings: A review. *Native Plants Journal*, 3, 67–86. <https://doi.org/10.3368/npj.3.1.67>
- Angelella, G. M., Stange, L., Scoggins, H. L., & O'Rourke, M. E. (2019). Pollinator refuge establishment and conservation value: Impacts of seedbed preparations, seed mixtures, and herbicides. *HortScience*, 54, 445–451. <https://doi.org/10.21273/HORTSCI13600-18>
- Bingham, S. W. (1974). Influence of selected herbicides on rooting of turfgrass sod. In E. C. Roberts (Ed.), *Proceedings of the Second International Turfgrass Research Conference* (pp. 372–377). ASA, CSSA, SSSA. <https://doi.org/10.2135/1974.proc2ndintlurfgrass.c55>
- 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, 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, 1752–1768. <https://doi.org/10.1002/agj2.21051>
- Breuillin-Sessoms, F., Petrella, D. P., Trappe, J. M., Mihelich, N. T., Patton, A. J., & Watkins, E. (2021). Field evaluation of weed suppression of hard fescue (*Festuca* spp.). *Crop Science*, 61, 2812–2826. <https://doi.org/10.1002/csc2.20506>
- Campbell, B., Khachatryan, H., & Rihn, A. (2017). Pollinator-friendly plants: Reasons for barriers to purchase. *HortTechnology*, 27, 831–839. <https://doi.org/10.21273/HORTTECH03829-17>
- Cisar, J. L., & Snyder, G. H. (1992). Sod production on a solid-waste compost over plastic. *HortScience*, 27, 219–222. <https://doi.org/10.21273/HORTSCI.27.3.219>
- Corley, W. L., & Smith, A. E., Jr. (1990). *Evaluation of wildflower plant species and establishment procedures for Georgia road sites* (GDOT Research Project No. 8604 Final Report). University of Georgia.
- Friell, J., Watkins, E., Horgan, B., & Cavanaugh, M. (2017). Sod strength characteristics of 51 cool-season turfgrass mixtures. *Agronomy Journal*, 109, 1749–1757. <https://doi.org/10.2134/agronj2016.05.0295>
- Goatley, J. M., & Schmidt, R. E. (1991). Biostimulator enhancement of Kentucky bluegrass sod. *HortScience*, 26, 254–255. <https://doi.org/10.21273/HORTSCI.26.3.254>
- Goatley, J. M., Smith, D. B., Gerard, P. D., & Coats, G. E. (1997). Comparing sod strength parameters of warm-season turfgrasses using a hydraulically driven sod strength machine. *HortTechnology*, 7, 421–426. <https://doi.org/10.21273/HORTTECH.7.4.421>
- Goulson, D., Nicholls, E., Botias, C., & Rotheray, E. L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science*, 347, 1255957. <https://doi.org/10.1126/science.1255957>
- Johnson, A. M., & Whitwell, T. (1997). Selecting species to develop field-grown wildflower sod. *HortTechnology*, 7, 411–414. <https://doi.org/10.21273/HORTTECH.7.4.411>
- Johnston, C. R., McCullough, P. E., & Shilling, D. G. (2015). Native plant establishment on Georgia roadsides. *Agronomy Journal*, 107, 990–996. <https://doi.org/10.2134/agronj14.0555>
- Kiss, R., Deák, B., Tóth, K., Lukács, K., Rádai, Z., Kelemen, A., Miglécz, T., Tóth, Á., Godó, L., & Valkó, O. (2022). Co-seeding grasses and forbs supports restoration of species-rich grasslands and improves weed control in ex-arable land. *Scientific Reports*, 12, Article 21239. <https://doi.org/10.1038/s41598-022-25837-4>
- Klein, A. M., Vaissiere, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B*, 274, 303–313. <https://doi.org/10.1098/rspb.2006.3721>
- Lane, I. G., Wolfen, J., Watkins, E., & Spivak, M. (2019). Testing the establishment of eight forbs in mowed lawns of hard fescue (*Festuca brevipila*) for use in pollinator conservation. *HortScience*, 54, 2150–2155. <https://doi.org/10.21273/HORTSCI14336-19>

- Larson, J. L., Dale, A., Held, D., McGraw, B., Richmond, D. S., Wickings, K., & Williamson, R. C. (2017). Optimizing pest management practices to conserve pollinators in turf landscapes: Current practices and future research needs. *Journal of Integrated Pest Management*, 8, 18. <https://doi.org/10.1093/jipm/pmx012>
- Larson, K. L., Lerman, S. B., Nelson, K. C., Narango, D. L., Wheeler, M. M., Groffman, P. M., & Grove, J. M. (2022). Examining the potential to expand wildlife-supporting residential yards. *Landscape and Urban Planning*, 222, 104396. <https://doi.org/10.1016/j.landurbplan.2022.104396>
- Majewska, A. A., & Altizer, S. (2020). Planting gardens to support insect pollinators. *Conservation Biology*, 34, 15–25. <https://doi.org/10.1111/cobi.13271>
- Mann, A., Majeski, M., & Pokorny, M. (2022). *Plant guide for common yarrow (Achillea millefolium L.)*. USDA-Natural Resources Conservation Service.
- Norcini, J. G., Aldrich, J. H., & Martin, F. G. (2003). Tolerance of native wildflower seedlings to imazapic. *Journal of Environmental Horticulture*, 21, 68–72. <https://doi.org/10.24266/0738-2898-21.2.68>
- Ollerton, J., Winfree, R., & Tarrant, S. (2011). How many flowering plants are pollinated by animals? *Oikos*, 120, 321–326. <https://doi.org/10.1111/j.1600-0706.2010.18644.x>
- Olszewski, M. W., & Folin, G. J. (2009). Germination responses of purpletop and big bluestem caryopses subjected to distilled water or potassium nitrate prechilling, sodium hypochlorite, and storage. *HortScience*, 44, 1407–1411. <https://doi.org/10.21273/HORTSCI.44.5.1407>
- Panciera, M. (1999). Native grass establishment: Pitfalls and potentials. In J. C. Ritchie, J. A. Dickerson, & C. A. Ritchie (Eds.), *Proceedings of the 2nd Eastern Native Grass Symposium* (pp. 14–24). USDA-ARS and USDA-NRCS.
- Pant, A., & Mopper, S. (2021). Variation in insect richness on six prairie plant species. *Southeastern Naturalist*, 20, 212–226. <https://doi.org/10.1656/058.020.0123>
- Pennisi, S. V., Waltz, F. C., Jr., & Miller, W. B. (2021). Persistence and performance of spring-flowering bulbs in warm- and cool-season turfgrasses in a subtropical climate. *International Turfgrass Society Research Journal*, 14, 304–310. <https://doi.org/10.1002/its2.45>
- Roubik, J., Reinartz, J., & Meyer, G. (2013). Use of small-scale disturbances to establish native plants in an abandoned agricultural field. *Field Station Bulletin*, 33, 18–40.
- Ruppel, N. J., Riley, S. M., Mumford, E. D., & Swedo, B. L. (2019). Pollinator visitation frequency associated with native and non-native plants in a Mid-Atlantic Piedmont (USA) urban garden. *Virginia Journal of Science*, 70, 15.
- Sharpe, S. S., Dickens, R., & Turner, D. L. (1989). Herbicide effects on tensile strength and rooting of bermudagrass (*Cynodon dactylon*) sod. *Weed Technology*, 3, 353–357. <https://doi.org/10.1017/S0890037X00031948>
- Skousen, J. G., & Venable, C. L. (2007). Establishing native plants on newly-constructed and older-reclaimed sites along West Virginia highways. *Land Degradation & Development*, 19, 388–396. <https://doi.org/10.1002/ldr.846>
- Watson, T. L., Martel, C., & Arceo-Gómez, G. (2022). Plant species richness and sunlight exposure increase pollinator attraction to pollinator gardens. *Ecosphere*, 13, e4317. <https://doi.org/10.1002/ecs2.4317>
- Westerhold, C. M., Wortman, S., Todd, K., & Golick, D. (2018). Knowledge of pollinator conservation and associated plant recommendations in the horticultural retail industry. *HortTechnology*, 28, 529–535. <https://doi.org/10.21273/HORTTECH03973-18>

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