Evaluation of Sedges and Nimblewill as Low-input, Shaded Lawns in Oklahoma, USA

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Keywords. gray sedge, ground cover, Leavenworth's sedge, *Muhlenbergia schreberi*, native plant, palm sedge, Texas sedge

Abstract. Consumers desire low-input turfgrasses that have tolerance to both shade and drought stresses. Several sedges (*Carex* sp.) and nimblewill (*Muhlenbergia schreberi*) are native plants prevalent in dry woodland ecosystems in Oklahoma, USA, and may have potential as alternatives to conventional species in dry shaded turfgrass systems. To evaluate selected species for this purpose, a multilocation field trial was conducted in Stillwater and Perkins, OK. Four sedges [gray sedge (*Carex amphibola*), Leavenworth's sedge (*Carex leavenworthii*), 'Little Midge' palm sedge (*Carex muskingumensis*), and Texas sedge (*Carex texensis*)] and nimblewill were evaluated as alternative turfs for the study. Alternative turfs were compared against two conventional turfgrasses ['El Toro' Japanese lawngrass (*Zoysia japonica*) and 'Riley's Super Sport' bermudagrass (*Cynodon dactylon*)]. The conventional turfgrasses outperformed each sedge and nimblewill in coverage and turf quality. Leavenworth's sedge, gray sedge, and Texas sedge persisted well but did not spread quickly enough to achieve a dense canopy by the end of the 2-year trial. In contrast, nimblewill established quickly but declined in coverage over time. This study demonstrated some sedges and nimblewill can be established and maintained as a low-input turf in dry shade, but development of unique management practices is still required for acceptable performance.

It is estimated that 25% of turf is managed under some form of shade, spanning most sectors of the industry including parks, residential lawns, golf courses, and sports fields (Beard 1973). Fundamentally, shade stress is the reduction in light available for photosynthesis measured in terms of photosynthetic photon flux density (PPFD), which reduces carbohydrates available for normal growth and development (Bell and Danneberger 1999). Plants subjected to shade stress exhibit shallow roots (Baldwin et al. 2008; Jiang et al. 2004), increased internodal distance (Stanford et al. 2005), reduced tillering (Dudeck et al. 1993), and the etiolation of shoots (Allard et al. 1991). Shade caused by trees (foliar or vegetative) can be especially detrimental due to selective filtration of red light, which affects plant phytochrome activity and induces a more severe shade response (Bell et al. 2000; Wherley et al. 2005). Shade ultimately leads to poor-quality turf and plants that are more susceptible to secondary stressors including drought, disease, and traffic (Baldwin et al. 2009; Trappe et al. 2011).

Shade tolerance varies widely among turfgrass species and associated varieties (Baldwin et al. 2009; Dudeck et al. 1993; Trappe et al. 2011). For example, bermudagrass (*Cynodon dactylon*) is widely regarded as having poor shade tolerance and may require over 20 mol·m^2·d^{-1} of photosynthetically active radiation (PAR) to form an acceptable lawn (Chhetri et al. 2019). Zoyiagrass (*Zoysia* sp.) is considered among the more shade-tolerant warm-season turfgrasses having reported minimum light requirements of 10 to 15 mol·m^2·d^{-1} PAR (Zhang et al. 2017). Cool-season turfgrasses such as tall fescue (*Schedonorus arundinaceus*) have excellent shade tolerance, but also have greater water requirements and are susceptible to various abiotic and biotic stresses requiring frequent renovation in the transition zone climate. These traditional choices for residential lawns create a trade-off between higher inputs and shade tolerance (Russell et al. 2020). Recent homeowner surveys revealed that their first preference is for turfgrasses that have low maintenance requirements, with highly ranked preferences for drought and shade tolerance (Ghimire et al. 2016; Yue et al. 2016).

Development of low-input plant materials that can persist as a mowed turf under dry shade would have broad application across the turfgrass industry. Improvement in adaptation of commonly used turfgrass species to dry shaded conditions is an ongoing effort at several research institutions in the United States (Chhetri et al. 2019; Wherley et al. 2011). In addition to turfgrass breeding, there is value in identifying novel species that have adaptation to regular mowing, drought, and shade. Upon exploration of woodlands and mature parks across Oklahoma (USA), one can observe persistent naturalized stands of perennial groundcovers from the genus *Carex* that often create near-monostands with minimal inputs. The genus *Carex* belongs to the sedge family (Cyperaceae) and is home to more than 5000 species with 600 native to North America (Bernard 1990; Goetghebeur 1998). Several of these sedges exhibit turf-like characteristics with some adapted to shade and others sunny exposures (Bernard 1990; McGinnis and Meyer 2011; Schütz 2000). Several of these species are native to Oklahoma and

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	kg·ha^{-1}	0.8922
305.1517	oz/ft^2	g·m^{-2}	0.0033

already sold in the commercial nursery trade. Gray sedge (*Carex amphibola*) is a coarse-textured species having an average leaf width of 0.3 cm (Prairie Wind Nursery, Norman, OK, USA). Texas sedge (*Carex texensis*) is a medium-textured species, while Leavenworth's sedge (*Carex leavenworthii*) is a medium-fine-textured species. Each of these species has shown potential for use in mowed environments, either through personal observation or marketing literature from the industry. In some cases, improved varieties have been released for traits of interest. For example, 'Little Midge' palm sedge (*Carex muskingumensis*) is a dwarf-type selection from an otherwise tall species. In most cases, the Oklahoma nursery trade relies on variety not stated (VNS) nursery stock for the genus.

Published research on sedges has primarily focused on improving seed propagation through light and stratification (Budelsky and Galatowitsch 1999; Crew et al. 2020; Kettenring and Galatowitsch 2007; Schütz 2000) or ecosystem restoration studies to reintroduce sedges into their native habitats (Budelsky and Galatowitsch 1999; Leck and Schütz 2005; Schütz and Rave 1999; Van der Valk et al. 1999). Research aimed at evaluating sedges for use as mowed turf is more limited. Wang et al. (2014) reported acceptable performance of an unnamed sedges under what the authors described as a "low-impact" lawn simulation in California. They also concluded sedges demonstrated reduced water and nitrogen requirements in comparison with traditional lawns in the region. However, landscape professionals may find limited value in the results of this research because it was merely an ecological evaluation of lawn conditions. Development of regional performance data for named species under mowed conditions may broaden their potential for wider use in the landscape.

In addition to sedges, dry woodland areas throughout the transition zone commonly host specimens of nimblewill (*Muhlenbergia schreberi*), a warm-season perennial grass traditionally regarded as a weed species in conventional turfgrass systems (de Moraes et al. 2014a, 2014b; Featherly 1938). There is a dearth of information in the published literature on uses of nimblewill for any productive purpose. Featherly (1938) went so far as to state: "This species is found on dry soils in woods and waste places. It is of no economic importance." The authors are unaware of any active breeding efforts to improve the species for forage, erosion control, lawn, or other potential beneficial use typical of a perennial grass. The major contribution to the known literature was a series of papers describing use of nimblewill as a groundcover underneath peach (*Prunus persica*) orchards (Meyer et al. 1992; Olien 1995; Parker and Meyer 1996). Collectively, these papers suggest nimblewill can persist well as a groundcover in managed orchards (i.e., a shaded environment), while reducing arthropod and nematode pest populations, outcompeting most weed species, and not inhibiting tree growth. Interestingly, there does not appear to have been further advancement in use of this species for orchard management since the mid-1990s, suggesting poor acceptance by industry.

To create regional information on performance of native perennial groundcovers for use as managed turf, a field study was conducted to compare selected sedges and nimblewill to industry standard warm-season turfgrasses managed as a low-input shaded lawn.

Materials and methods

Year 1 plot establishment and maintenance. Field trials were planted at the Oklahoma State University (OSU) Entomology and Plant Pathology Experiment Station in Stillwater, OK, USA, and the OSU Cimarron Valley Research Station in Perkins, OK, USA, on 20 and 26 May 2020, respectively. These locations were chosen for the presence of mature pecan trees (*Carya illinoinensis*) that produced relatively uniform shade in the plot area. The soil was tilled, raked, and firmed in preparation for planting plots. The experiment was arranged as a randomized complete block design having four replications. Treatments were assigned in a split-plot structure with two irrigation regimes (whole plot) and eight plant materials (subplot). Of the eight entries in this study, four were sedges (palm sedge, gray sedge, Texas sedge, and Leavenworth's sedge) obtained as plugs from a local nursery (Prairie Wind Nursery). The other four species were from the grass (Poaceae) family, with two being nimblewill sourced from online vendors (Ernst Seeds, Meadville, PA, USA; Roundstone Native Seed LLC, Upton, KY, USA) and the other two entries being 'El Toro' Japanese lawngrass (*Zoysia japonica*) and 'Riley's Super Sport' bermudagrass, which were chosen as industry standard warm-season turfgrasses for moderately shaded lawns in Oklahoma. The soil at the Perkins site was a fine loamy sand (Konowa series; fine-loamy, mixed, active, thermic Ultic Haplustalfs; pH = 7.1; organic matter = 2.5%), and the soil at the Stillwater site was a loam (Easpur series; fine-loamy, mixed, superactive, thermic Fluventic Haplustolls; pH = 7.6; organic matter = 3.3%). Sedges, Japanese lawngrass, and bermudagrass were established as 1-inch plugs on a 6-inch spacing, whereas nimblewill was seeded using a shaker jar at a rate of 44 lb/acre and then covered with a lightweight geotextile material (American Plant Production & Services Inc., Oklahoma City, OK, USA) until seedling emergence. All plots were fertilized with a commercially available 6N–0.9P–0K biosolid product (Milorganite; Milwaukee Metropolitan Sewerage District, Milwaukee, WI) immediately after planting at 44 lb/acre and irrigated daily using portable impact sprinklers until germination of the seeded species. After seed germinated, irrigation was applied uniformly to all plots in the establishment year, with the Perkins location watered twice per week and the Stillwater location watered once weekly with each receiving a total of 1 inch per week. Irrigation was discontinued at both locations on 13 Oct 2020 due to cool wet weather conditions. Glyphosate (Buccaneer Plus; Tenkōz Inc., Alpharetta, GA, USA) was applied as a 2% solution with a hand pump backpack sprayer as needed to prevent cross-contamination between adjacent plots as well as to reduce weed pressure, most notably, crabgrass (*Digitaria* sp.), goosegrass (*Eleusine indica*), and white clover (*Trifolium repens*). Plots were mowed every other week at a 4-inch mowing height using a rotary mower (HRC216; Honda, Minato City, Tokyo, Japan).

For year 2 maintenance, 2 lb/acre oxadiazon (Ronstar 2G; Bayer, Leverkusen, Germany) was applied

19 Mar 2021 to reduce annual weed pressure while plots continued to become established. A 42N–0P–0K polymer-coated urea fertilizer (POLYON 42–0–0 Granular; Harrell's, Lakeland, FL, USA) was applied 13 Apr 2021 at a rate of 44 lb/acre N. Plots were mowed weekly at 4 inches using a rotary mower and clippings returned.

High-efficiency rotary spray nozzles (Rain Bird, Azusa, CA, USA) were used for irrigation that resulted in a system that applied 0.6 inch/h. Run times were set to irrigate twice per week (Mondays and Thursdays) and applied a total of 1 inch every week. Irrigation treatments (irrigated and nonirrigated) were initiated on 4 Jun 2021 for Stillwater and 10 Jun 2021 for Perkins, and irrigation was applied through the first week of October at both locations.

In Nov 2020, an ice storm resulted in loss of several shade-inducing branches in the Perkins site. To maintain shade, a structure was installed on 26 May 2021 to simulate the return of leaves to the pecan trees. The structure was designed as a tent over the plots using steel rope mounted to the neighboring trees such that it created a top ridge in the middle of the plot area 6 ft above the ground. A poly-woven shadecloth was then hung across the top ridge and fastened to PVC pipe that had been mounted horizontally across a series of T-posts on the edge of the plot. Additional T-posts with tennis balls placed on the top were installed underneath the fabric to prevent sagging.

Data were collected every other week from 21 Jul 2020 to 13 Oct 2020 to quantify canopy coverage during establishment using a spectral reflectance meter (RapidSCAN CS-45 Handheld Crop Sensor; Holland Scientific, Lincoln, NE, USA) to calculate a normalized difference vegetation index (NDVI), a digital camera (PowerShot G16; Canon Inc., Tokyo, Japan) mounted to a light box to calculate green coverage using an image processing software (ImageJ ver. 1.53c; National Institutes of Health, Bethesda, MD, USA), and visual ratings of turf quality (TQ) using National Turfgrass Evaluation Program (NTEP) guidelines (Morris and Shearman 2020). Visual TQ, NDVI, and green coverage were measured monthly using the same methods from 14 May to 29 Oct 2021. An additional measurement of green coverage was made 26 Mar 2021 to evaluate early spring greenness. A quantum sensor connected to a data logger (Watchdog 1000 series; Spectrum Technologies, Aurora, IL, USA) with a built-in temperature sensor was used to measure PPFD and ambient temperature at 30-min intervals.

Data were analyzed separately by year due to the addition of an irrigation factor in year 2. Within each year, a combined analysis was conducted with location considered a random effect and species, irrigation, date, and their interactions considered fixed effects. Data were analyzed using a generalized linear mixed model with a repeated measures structure (SAS ver. 9.4; SAS Institute Inc., Cary, NC, USA). Means were separated using Fisher's protected least significant difference test at the $P < 0.05$ level. There were no significant interactions between location and treatment; therefore, data were pooled across location for subsequent analyses.

Results

Establishment year and spring green-up. Each variable used to characterize canopy coverage followed a similar pattern and resulted in a treatment × date interaction. For brevity, only the green coverage data from selected dates (end of summer, end of fall, and end of winter) are presented. Establishment rate at 15 weeks after planting (end of summer) was similar across species (53% coverage) with the exception of palm sedge, which had slightly less green coverage than Japanese lawngrass (Fig. 1). Late season coverage was also similar across most species, with the exception of Leavenworth's sedge, which had greater coverage than bermudagrass and nimblewill obtained from the Roundstone Native Seed LLC seed source (hereafter referred to as nimblewill-Roundstone) (Fig. 2). During spring green-up of the year 2 (Mar 2021), grasses were emerging from complete dormancy, while sedges maintained green color through winter (Fig. 3). Leavenworth's sedge outperformed (28%) both palm sedge (17%) and bermudagrass (18%) with respect to green color on this date. Japanese lawngrass (19%) performed as well as the remaining sedges (22%) and as well as both nimblewill seed sources (23%).

Year 2 growing season: effects of species, date, and irrigation. Shade created by the two locations were similar and ranged from ~5 to 9 $mol{\cdot}m^2{\cdot}d^{-1}$ PAR (Fig. 4). For TQ, NDVI, and green coverage, data were affected by the species × date and irrigation × date interaction terms (Table 1). These responses corresponded with the onset of drought conditions in midsummer through fall (Fig. 5). Entries generally declined during the heat of summer, especially after June, where nonirrigated (24% green coverage) fared slightly worse than irrigated (31% green coverage) plots (data not presented).

Turf quality scores were low (<5) for each species due to the low-input nature of this trial (Fig. 6). The conventional turfgrasses outperformed other species with an average TQ of 3.8 and 4.2 for bermudagrass and Japanese lawngrass, respectively. Nimblewill obtained from the Ernst Seeds source (hereafter referred to as nimblewill-Ernst) performed comparatively well with an average TQ of 3, which was greater than each of the sedges. Gray sedge, Leavenworth's sedge, and Texas sedge, along with nimblewill-Roundstone received poor ratings (<3) but outperformed palm sedge which averaged a rating of 1.2 and did not persist in several replicates.

Similar patterns were observed for NDVI, with both Japanese lawngrass (0.63) and bermudagrass (0.57) resulting in the greatest mean NDVI, and neither being significantly different from each other (Fig. 7). Nimblewill-Ernst (0.52) was not significantly different from bermudagrass, gray sedge (0.46) or nimblewill-Roundstone (0.47). Palm sedge produced the lowest NDVI (0.36), although this was not significantly different from Leavenworth's sedge (0.42). Green coverage demonstrated similar patterns as other metrics (Fig. 8). Japanese lawngrass (62%) outperformed bermudagrass (52%), whereas nimblewill-Ernst (41%) outperformed the sedges (≤ 32%). Nimblewill-Roundstone (35%) was similar to gray sedge (32%), Leavenworth's sedge (27%), and Texas sedge

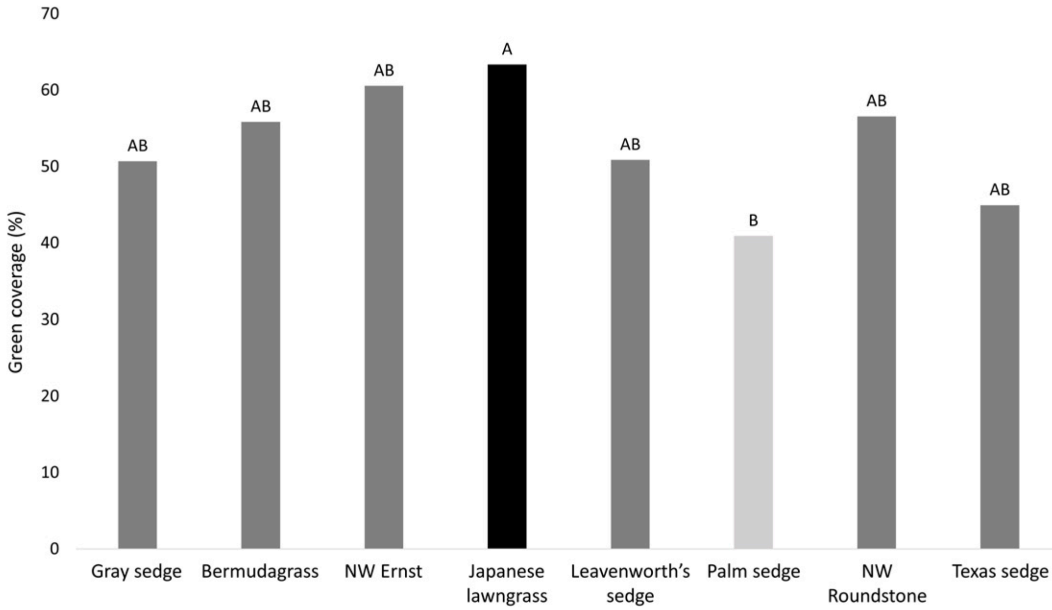

Fig. 1. Percent green coverage on 5 Sep 2020 (during the establishment year) for four sedges, two nimblewill (NW) sources [Ernst (Ernst Seeds, Meadville, PA, USA) and Roundstone (Roundstone Native Seed LLC, Upton, KY, USA)], and two warm-season turfgrasses grown as low-input turfs under moderate shade in Oklahoma, USA. Data were pooled across two locations and two irrigation levels (N = 16). Means labeled with different letters were significantly different according to Fisher's protected least significant difference test at $P < 0.05$.

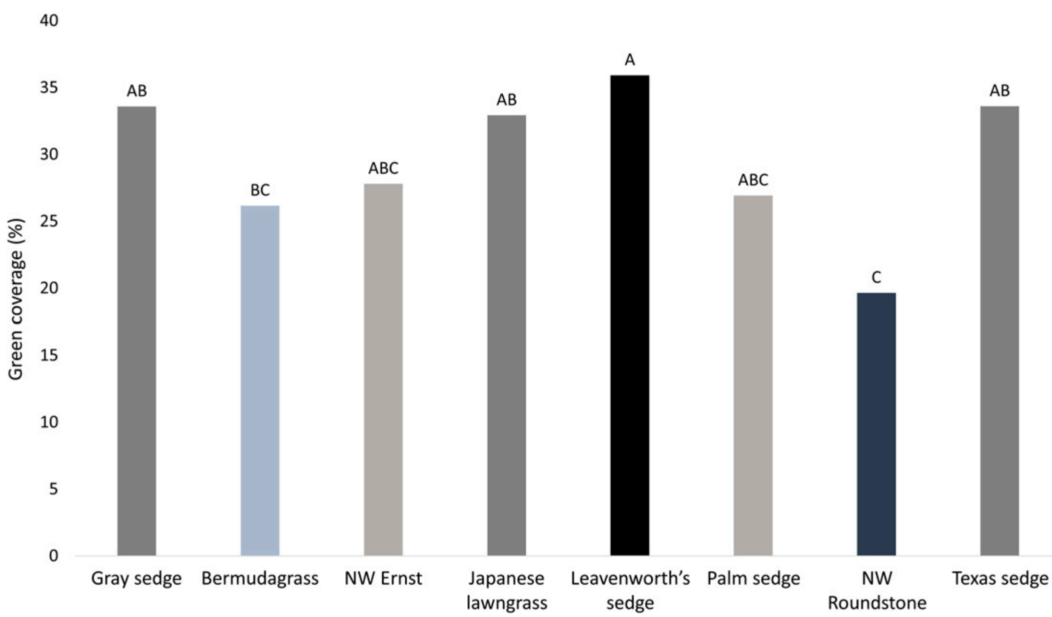

Fig. 2. Spring green up (percent green coverage) measured on 26 Mar 2021 for four sedges, two nimblewill (NW) sources [Ernst (Ernst Seeds, Meadville, PA, USA) and Roundstone (Roundstone Native Seed LLC, Upton, KY, USA)], and two warm-season turfgrasses grown as low-input turfs under moderate shade in Oklahoma, USA. Data were pooled across two locations and two irrigation levels (N = 16). Means labeled with different letters were significantly different according to Fisher's protected least significant difference test at $P < 0.05$.

(31%), with each outperforming palm sedge (16%).

Although the species main effects were largely consistent, there were a few variations across sampling dates that resulted in the significant species × date interaction for each variable. Specifically, TQ of the conventional turfgrasses generally increased from early rating dates and peaked in the middle of the summer with scores of 5.4 and 4.7 in late July for Japanese lawngrass and bermudagrass, respectively (Table 2). In contrast, both nimblewill entries emerged from winter dormancy well but began to decline in TQ as the summer progressed. Nimblewill-Ernst (3.9) outperformed both the bermudagrass (3.4)

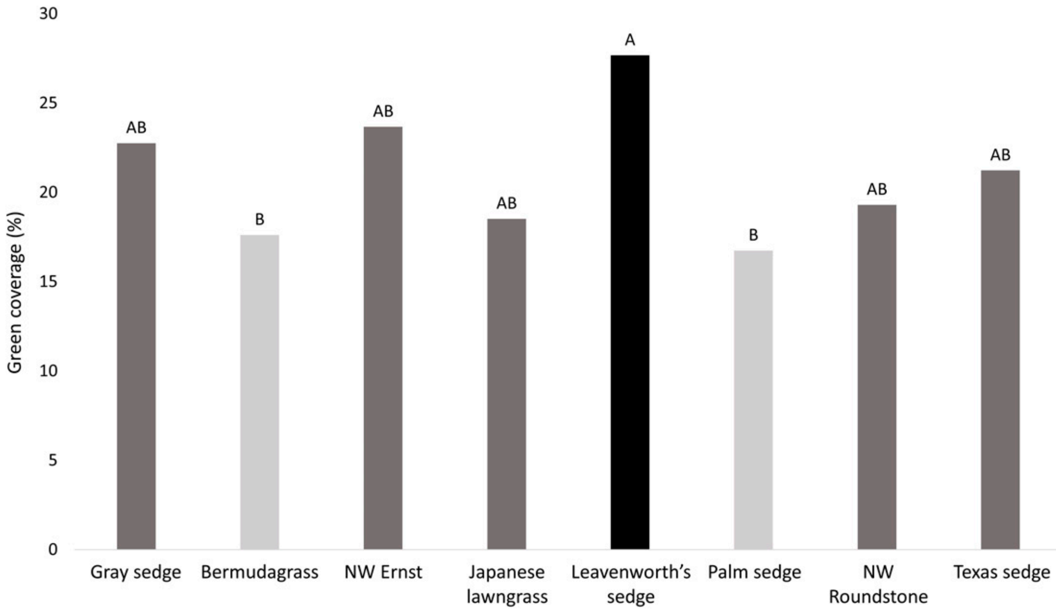

Fig. 3. Percent green coverage from early winter on 5 Nov 2020 for four sedges, two nimblewill (NW) sources [Ernst (Ernst Seeds, Meadville, PA, USA) and Roundstone (Roundstone Native Seed LLC, Upton, KY, USA)], and two warm-season turfgrasses grown as low-input turfs under moderate shade in Oklahoma, USA. Data were pooled across two locations and two irrigation levels (N = 16). Means labeled with different letters were significantly different according to Fisher's protected least significant difference test at $P < 0.05$.

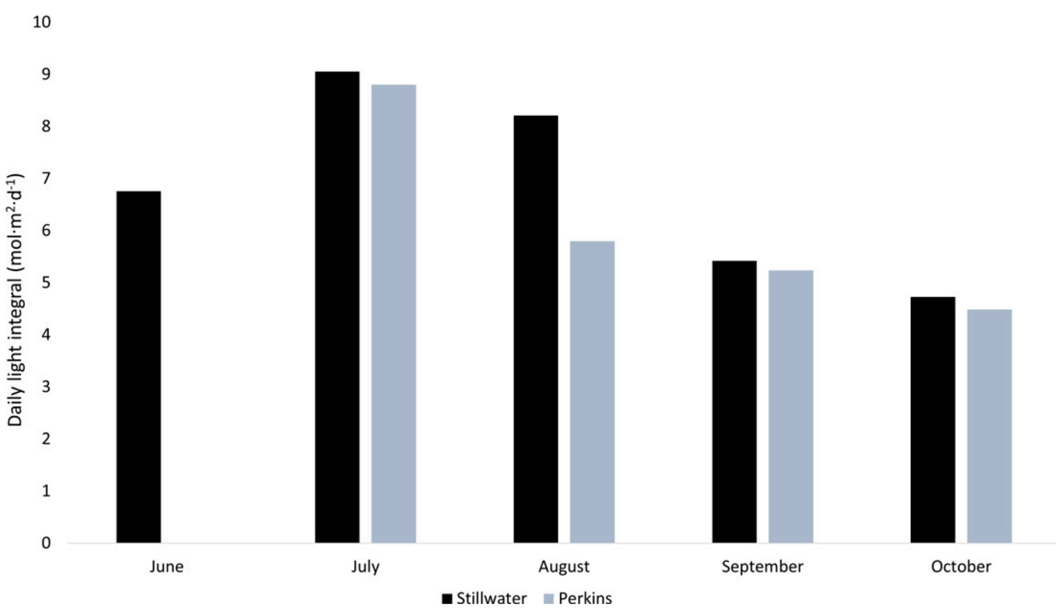

Fig. 4. Average rainfall during the second growing season (2021) in both Stillwater and Perkins, OK, USA; 1 cm = 0.3937 inch.

and Japanese lawngrass (3.6) in June before the decline, which resulted in performance equivalent to the sedges by September. The best performing sedges (gray sedge, Leavenworth's sedge, and Texas sedge) exhibited poor TQ but remained consistent throughout the season, which was indicative of their poor spread but acceptable persistence under the experimental conditions. Both NDVI and green coverage followed similar patterns for the species by date interaction with image analysis (Tables 3 and 4).

Discussion

The superior performance of conventional turfgrasses in this study was attributed to their creeping growth habit which was lacking in all other species (Bernard 1990). Furthermore, these turfgrass entries have the benefit of previous breeding and selection efforts and are considered improved varieties, whereas the other entries are either VNS, selected for non–turf usage or, in the case of nimblewill, likely

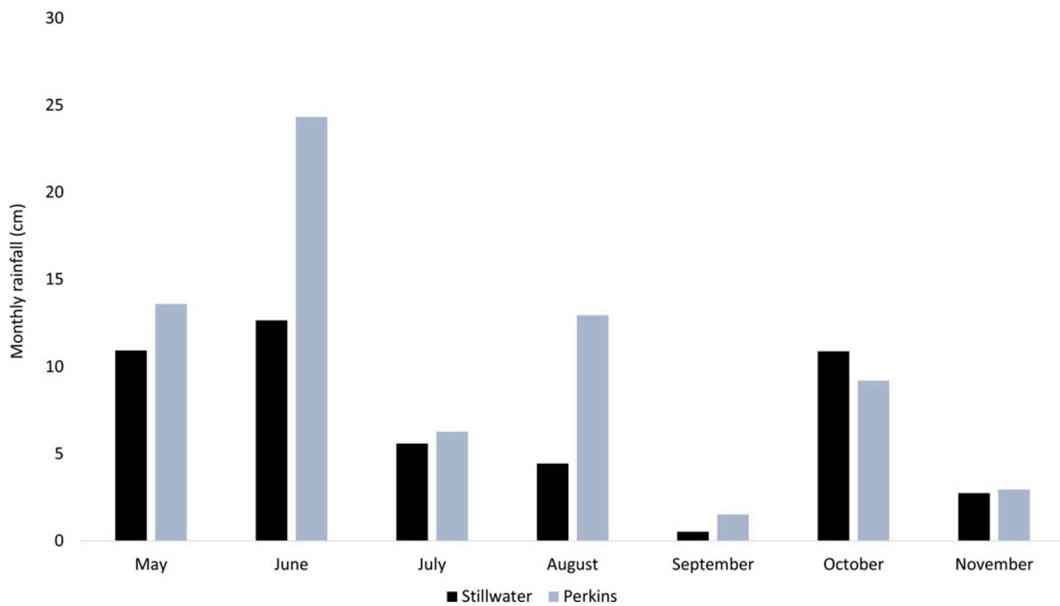

Fig. 5. Average daily light integral from the second growing season calculated from quantum sensors placed in representative areas in Stillwater and Perkins, OK, USA. Plots were established under natural shade caused by mature pecan trees.

Table 1. Summary analysis of variance table for visual turf quality (TQ), normalized difference vegetation index (NDVI), and percent green coverage (measured through image analysis) of plots grown as low-input turfs under moderate shade at two locations in Oklahoma, USA, in 2021.

Effect	df	TQ	NDVI	Green coverage
Species[i]	7	***	***	***
Irrigation[ii]	1	NS	NS	NS
Date	6	***	***	***
Species × Irrigation	7	NS	NS	NS
Species × Date	42	***	***	***
Irrigation × Date	6	**	**	**
Species × Irrigation × Date	42	NS	NS	NS

[i] Species included four sedges, nimblewill, Japanese lawngrass, and bermudagrass.
[ii] The irrigation factor included nonirrigated and irrigated to provide ~1 inch (25.4 mm) of water per week during the growing season.
*, **, ***, and NS = $P \leq 0.001$, $P \leq 0.01$, $P \leq 0.05$, and $P > 0.05$, respectively.

to be wild types. Although bermudagrasses are known to lack shade tolerance, 'Riley's Super Sport' bermudagrass is widely regarded as the most shade tolerant within the species (Baldwin et al. 2008; Chhetri et al. 2019), having been ranked ahead of commonly used interspecific hybrid varieties such as Tifway and Tift 94 (*C. dactylon* × *C. transvaalensis*) under 58% shade cover (Bunnell et al. 2005; Dunne et al. 2017). Japanese lawngrass, as a species, has shown good shade tolerance among warm-season turfgrasses (Baldwin et al. 2009; Russell et al. 2020; Wherley et al. 2011). For example, 'El Toro' maintained >90% turf coverage over 2 years under 49% shade cover in a field trial in Arkansas (Trappe et al. 2011).

The poor performance for all sedges is due in part to their cespitose growth habit. The plant spacing used in the present trial (6 inches) was chosen based on comments from the nursery providing the plant materials and is likely to be realistic for most installations of these species (R. Faris, personal communication). The present study suggests that closer spacing or higher inputs during establishment may be required to achieve complete coverage of sedges in a timely manner. Unfortunately, closer spacing decreases the economic viability of plugging as a means of establishment due to the added cost of additional plugs. Alternative propagation methods such as seeding or sprigging may warrant future investigation to solve this issue. Preliminary research suggests locally collected seed of Leavenworth's sedge showed greater than 50% germination when subjected to cold, moist stratification for 60 d (Shokoya et al. 2021). However, seed readily shatters, and therefore unique production systems may be required to scale up yields.

Another factor that may have contributed to poor performance among the alternative plant materials is the mowing regime. Sedges readily tolerate mowing, and relatively dense monostands of various species can be observed in mowed parks around the state (personal observation). The mowing regime used in the present study was intended to mimic common mowing practices in these parks, but results from the study were not indicative of the TQ observed in the naturalized stands. It is unclear whether adjustments to mowing frequency or height would have altered appearance and spread of these plants. Furthermore, whether the plants purchased from a local nursery had undergone prior selection, presumably for greater shoot productivity, is not known and could explain why ecotypes in mature lawns would be more turf-like than those used in the present study. Future research should investigate the mowing requirements and genetic

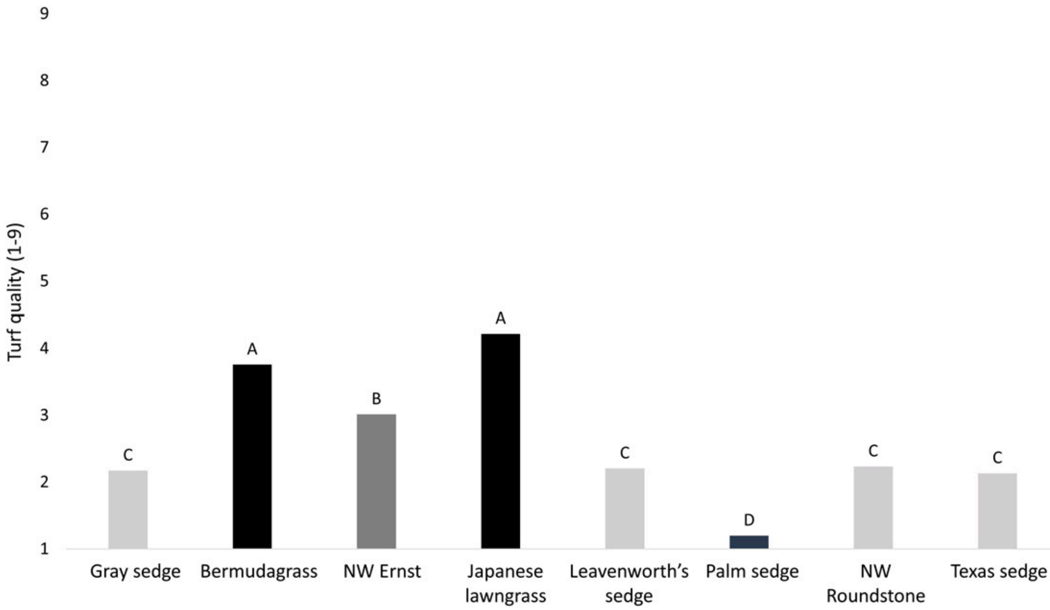

Fig. 6. Entry main effect on turf quality for four sedges, two nimblewill (NW) seed sources [Ernst (Ernst Seeds, Meadville, PA, USA) and Roundstone (Roundstone Native Seed LLC, Upton, KY, USA)], and two warm-season turfgrasses grown as low-input turfs under moderate shade in Oklahoma. Scores were assigned monthly using the National Turfgrass Evaluation Program ratings scale, which ranges from 1 = worst to 9 = best. Data were pooled across two locations, two irrigation levels, and seven dates (N = 112). Means labeled with different letters are significantly different according to Fisher's protected least significant difference test at *P* < 0.05.

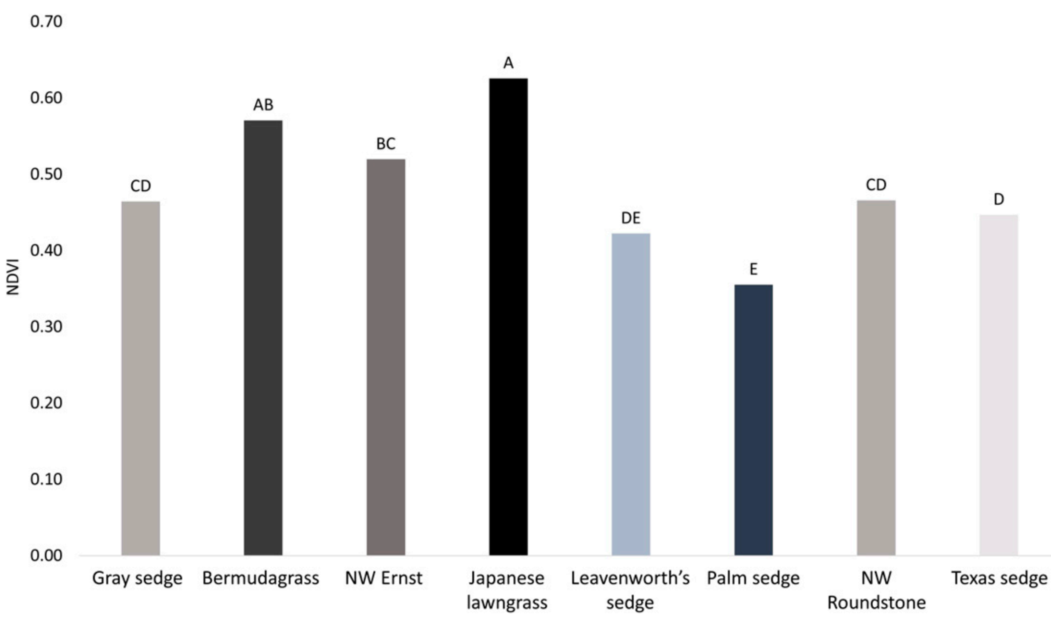

Fig. 7. Entry main effect on normalized difference vegetation index (NDVI) for four sedges, two nimblewill (NW) seed sources [Ernst (Ernst Seeds, Meadville, PA, USA) and Roundstone (Roundstone Native Seed LLC, Upton, KY, USA)], and two warm-season turfgrasses grown as low-input turfs under moderate shade in Oklahoma. Measurements were conducted monthly using a spectral reflectance meter (RapidSCAN CS-45 Handheld Crop Sensor; Holland Scientific, Lincoln, NE, USA), an index with a range from 0.00 to 0.99. Data were pooled across two locations, two irrigation levels, and seven dates (N = 112). Means labeled with different letters are significantly different according to Fisher's protected least significant difference test at *P* < 0.05.

variability of response for sedges regarding their growth, development, and TQ.

Little to no research has been conducted to examine the ability of sedges to grow and persist as alternative turf (Greenlee 2009). Texas sedge has been referenced as an option for low-maintenance lawns, but there have

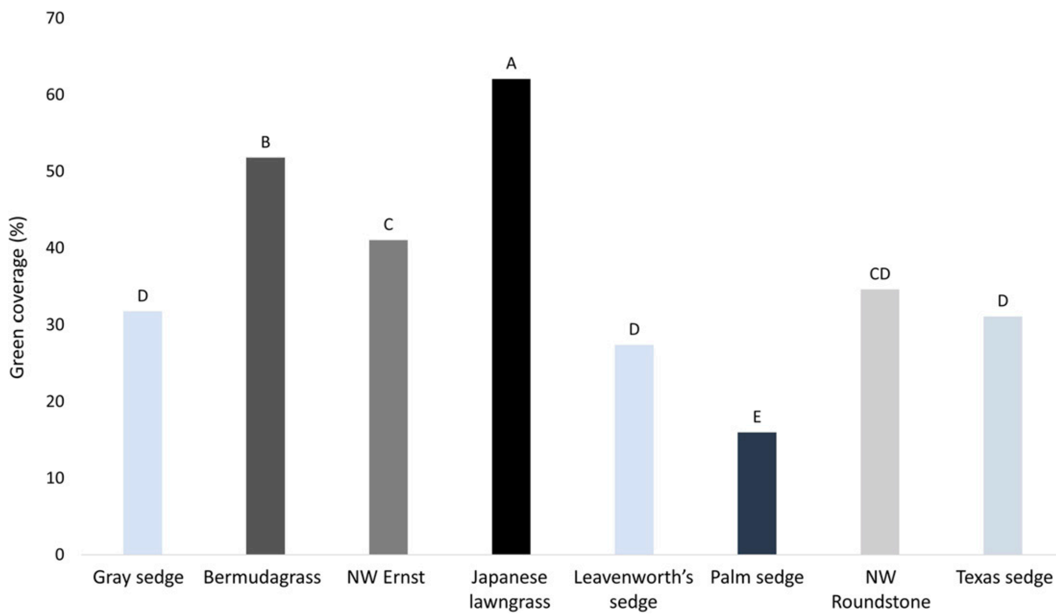

Fig. 8. Entry main effect on percent green coverage for four sedges, two nimblewill (NW) seed sources [Ernst (Ernst Seeds, Meadville, PA, USA) and Roundstone (Roundstone Native Seed LLC, Upton, KY, USA)], and two warm-season turfgrasses grown as low-input turfs under moderate shade in Oklahoma. Percent green coverage is based on the amount of green coverage over a specific area and was calculated using Image J software, values range from 0% to 100%. Data were pooled across two locations, two irrigation levels, and seven dates (N = 112). Means labeled with different letters are significantly different according to Fisher's protected least significant difference test at *P* < 0.05.

Table 2. Species × date interaction effect on turf quality (TQ) ratings for plots grown as low-input turfs under moderate shade in Oklahoma, USA, in 2021. Data are pooled across two locations and two irrigation levels (N = 16).

	14 May	11 Jun	22 Jun	28 Jul	25 Aug	5 Oct	29 Oct
Species				TQ[i]			
Bermudagrass	2.0 c[ii]	3.4 ab	4.1 a	4.7 b	4.3 a	3.8 a	4.2 a
Gray sedge	2.3 bc	1.9 c	2.1 c	2.0 de	2.4 bc	2.3 b	2.2 b
Leavenworth's sedge	2.7 ab	2.3 c	2.3 c	1.7 e	2.0 c	2.1 bc	2.3 b
Palm sedge	1.2 d	1.1 d	1.3 d	1.2 f	1.2 d	1.4 c	1.0 d
Texas sedge	2.4 bc	2.0 c	1.8 cd	2.0 de	2.3 c	2.3 b	2.1 bc
Japanese lawngrass	3.1 a	3.6 a	4.0 a	5.4 a	4.8 a	4.3 a	4.3 a
NW-Ernst[iii]	2.8 ab	4.1 a	4.0 a	3.6 c	3.0 b	2.0 bc	1.7 bcd
NW-Roundstone[iii]	2.3 bc	2.7 bc	3.1 b	2.5 d	2.0 c	1.8 bc	1.4 cd

[i] Scores assigned using the National Turfgrass Evaluation Program scale (1 = worst to 9 = best).
[ii] Means followed by the same letter in a given row are not significantly different according to Tukey's honestly significant difference test at $P \leq 0.05$.
[iii] Nimblewill sourced from either Ernst (Ernst Seeds, Meadville, PA, USA) or Roundstone (Roundstone Native Seed LLC, Upton, KY, USA).

been no trials or studies dedicated to growing any of the three species in low-input conditions until this current study. The similar performance of gray sedge, Leavenworth's sedge, and Texas sedge suggests each of these species has similar promise for use as low-input lawns, and personal preference for leaf texture should be the deciding factor. More specific screening efforts are required to determine the relative shade, drought, traffic, and mowing tolerances of individual species.

The poor performance of palm sedge, a dwarf selection of an otherwise tall sedge species, suggests this species and/or this subspecies population are not well-adapted to low-input lawns in Oklahoma. Palm sedge routinely exhibited the lowest green coverage throughout the first growing season and was unable to grow or spread at an acceptable rate for the remainder of the study. Nurseries have primarily described optimal growing conditions for palm sedge as needing moist soil conditions, which were not the conditions tested through this study as even the irrigated plots were maintained at relatively dry conditions (New Moon Nursery, Woodstown, NJ, USA; Bohn's Farm and Greenhouse Inc, Maryville, IL, USA).

The lack of an irrigation × species interaction may correspond to both treatments being relatively dry and most not having reached full canopy coverage. Alternatively, low-input species such as those used in this study may not be as responsive to higher soil moisture; therefore, further study with a broader range

Table 3. Species × date interaction for normalized difference vegetation index (NDVI) for plots grown as low-input turfs under moderate shade in Oklahoma, USA in 2021. Data are pooled across two locations and two irrigation levels (N = 16).

	14 May	11 Jun	22 Jun	28 Jul	25 Aug	5 Oct	29 Oct
Species	NDVI						
Bermudagrass	0.38 c[i]	0.66 b	0.71 a	0.62 b	0.64 a	0.48 ab	0.49 a
Gray sedge	0.47 ab	0.51 d	0.48 c	0.48 cd	0.46 b	0.42 bc	0.43 abc
Leavenworth's sedge	0.48 b	0.50 d	0.44 cd	0.38 f	0.38 bc	0.35 cde	0.40 abc
Palm sedge	0.38 c	0.47 d	0.38 d	0.41 ef	0.33 c	0.32 e	0.31 d
Texas sedge	0.46 ab	0.50 d	0.43 cd	0.45 de	0.44 b	0.40 bcd	0.44 ab
Japanese lawngrass	0.49 ab	0.72 a	0.76 a	0.72 a	0.67 a	0.52 a	0.51 a
NW-Ernst[ii]	0.53 ab	0.73 a	0.71 a	0.52 c	0.45 b	0.33 cde	0.36 bcd
NW-Roundstone[ii]	0.53 a	0.61 c	0.61 b	0.46 d	0.39 bc	0.32 de	0.35 cd

[i] Means followed by the same letter in a given row are not significantly different according to Tukey's honestly significant difference test at $P \leq 0.05$.

[ii] Nimblewill sourced from either Ernst (Ernst Seeds, Meadville, PA, USA) or Roundstone (Roundstone Native Seed LLC, Upton, KY, USA).

Table 4. Species × date interaction for percent green coverage from image analysis for plots grown as low-input turfs under moderate shade in Oklahoma, USA in 2021. Data are pooled across two locations and two irrigation levels (N = 16).

	14 May	11 Jun	22 Jun	28 Jul	25 Aug	5 Oct	29 Oct
Species	%						
Bermudagrass	31.0 c[i]	67.8 b	77.8 ab	56.3 b	62.9 a	35.2 ab	31.4 ab
Gray sedge	54.5 ab	37.7 c	38.2 d	20.5 cd	28.8 bc	25.9 cd	16.2 cd
Leavenworth's sedge	47.0 b	40.4 c	30.2 de	13.0 de	21.4 bc	22.8 cd	17.1 cd
Palm sedge	20.0 d	28.1 d	19.7 f	8.0 e	12.8 c	19.8 d	3.4 e
Texas sedge	49.0ab	37.0 cd	26.0 ef	23.8 c	30.0 bc	28.6 bc	23.2 bc
Japanese lawngrass	50.0 ab	78.2 a	83.7a	75.7 a	65.8 a	40.6 a	40.7 a
NW-Ernst[ii]	49.7 bc	79.3 a	70.6 b	24.9 c	31.5 b	22.1 cd	9.8 de
NW-Roundstone[ii]	57.2 a	60.7 b	54.6 c	18.2 cd	19.2 bc	22.1 cd	10.0 de

[i] Means followed by the same letter in a given row are not significantly different according to Tukey's honestly significant difference test at $P \leq 0.05$.

[ii] Nimblewill sourced from either Ernst (Ernst Seeds, Meadville, PA, USA) or Roundstone (Roundstone Native Seed LLC, Upton, KY, USA).

of irrigation treatments may be necessary to understand production needs of these plants (Hilaire et al. 2008; Pincetl et al. 2018; Wang et al. 2014).

Examples of intentional nimblewill plantings in the literature are rare and typically associated with the plant as a weed species (Waldrep and Freeman 1964). During research to evaluate chemical control options for nimblewill, de Moraes et al. (2014b) observed that nimblewill biomass accumulation and growth was slow during the first 5 weeks following germination. Previously, Olien (1995) used a 2.2 $g \cdot m^{-2}$ seeding rate in consecutive years in addition to mechanical mowing and annual weeding to establish nimblewill as a ground cover in peach production. In their report, they were able to create a dense enough ground cover to reduce the ring nematode (*Criconemella xenoplax*) to acceptable levels. Meyer et al. (1992) used a 0.7 $g \cdot m^{-2}$ seeding rate for a similar study, but found establishment was slower than from plugs. The seeding rate used in the present study (5 $g \cdot m^{-2}$) quickly established a dense turf and could be used to guide future studies. According to the seed supplier, nimblewill has approximately 750,000 seeds/lb, and similar sized turfgrass seed often requires a planting rate of 20 to 40 $g \cdot m^{-2}$ (Roundstone Native Seed LLC). Follow-up experiments should be used to improve these seeding rate recommendations, particularly if more turf-type nimblewill germplasm can be obtained. The late-season decline in performance for nimblewill is consistent with use of upright ecotypes of the species and poor tolerance to mowing. Further details on the origin of the seed are lacking, which is to be expected with unimproved native seed stock. It is not clear whether seed was sourced from plants that had been subjected to selection pressure from mowing or were simply nonmowed ecotypes from woodland areas. Between the two seed sources, nimblewill-Ernst performed slightly better than nimblewill-Roundstone, which suggests some variation exists within the species. Selection of ecotypes persisting as weeds in fine turf may lead to better understanding of heritability of turf-type traits within the species.

This study provides evidence that gray sedge, Leavenworth's sedge, and Texas sedge can persist under low-input mowed conditions during the heat of summer under shade in Oklahoma. Furthermore, sedges provide year-long green color similar to what cool-season turfgrasses provide, presumably with superior drought and disease resistance (Bernard 1990; Schütz 2000). Continued efforts to increase stand density, either through higher planting rates or alternate propagation methods, is needed to advance these species that show promise for use as sustainable turf alternatives for dry shaded conditions. Selection of turf-type traits from naturalized stands in low-input parks and lawns may further improve performance of these species under frequently mowed conditions. Finally, acceptance of these species in the landscape and nursery trades will require consideration for their sensitivity to herbicides (e.g., sulfonylureas) that are commonly used in conventional turfgrass systems.

Conclusions

This study provides one of the first descriptions of intentional establishment of several native perennial species as mowed turf. Conventional warm-season turfgrasses (bermudagrass and Japanese lawngrass) outperformed the native sedges for coverage and turf quality, predominantly because of their creeping growth habit and ability to establish dense cover quickly. Persistence and year-long color retention were observed from most of our sedges, while fast establishment was noted for nimblewill. Nimblewill, gray sedge, Leavenworth's sedge, and Texas sedge have the potential to be used as an alternative to conventional turfgrass species, but adjustments to establishment methods and improvement within species may be required to increase acceptance of these plants for use in fine turf culture.

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