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RESEARCH REPORT

IDENTIFICATION OF LOW GROWING, SALT TOLERANT TURFGRASS SPECIES SUITABLE FOR USE ALONG HIGHWAY RIGHT OF WAY – FIELD TRIALS

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FINAL REPORT

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16. Abstract

Three roadside trials were established in western MD, central MD, and eastern shore, to identify grass species that require little maintenance yet perform well. Each trial was composed of the same 12 treatments, including an unplanted control, the MDOT SHA turfgrass seed mix, several tall and fine fescue treatments, and several native grass treatments. Fescue treatments established dominance and were competitive against weeds only in western MD. Tall fescue established better and was more resilient to roadside disturbances than hard fescue. However, a 20% tall and 80% fine fescue mix established just as well as the MDOT SHA turfgrass seed mix at one-third the seeding rate. Upland bentgrass (*Agrostis perennans*) contributed to cover and biomass of plots in western MD although it established slowly and was sensitive to salt grit. In central MD, side-oats grama (*Bouteloua curtipendula*) established quickly and produced consistent high coverage that was similar to the best performing tall fescue cultivars Mustang 4 and Titanium 2LS and better than the MDOT SHA turfgrass seed mix in summer. Weeds minimally invaded plots of side-oats grama. Purple lovegrass (*Eragrostis spectabilis*) also established well in central MD but because the vegetative growth habit of the species is inconspicuous, its excellent establishment was only evident when it produced its conspicuous inflorescences. No fescues or native grass species established dominance in the eastern shore trial and grass weeds soon dominated the site. Additional research on side-oats grama could include experimenting with seeding rates, timing of seeding, mowing regime, and genetic sources.

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Executive summary

Highway right-of-way is commonly seeded in Maryland with tall fescue, which establishes quickly, grows vigorously, and is resilient to many stresses encountered along roadsides, such as vehicle traffic, drought, and salt spray. Due to vigorous growth of roadside vegetation, roadsides need be mowed often to preserve sight distance. This project compared ten alternative species and species mixes to the tall fescue turfgrass seed mix the Maryland Department of Transportation State Highway Administration (MDOT SHA) uses. The goal was to identify low growing species that require little maintenance yet perform well along roadsides.

Three roadside trials were established, one each in western Maryland (MD), central MD, and the Eastern Shore, to represent the wide range of climatic conditions that Maryland encounters. Each trial was composed of the same 12 treatments, including an unplanted control, the MDOT SHA turfgrass seed mix mostly composed of tall fescue, several tall and fine fescue treatments, and monocultures as well as mixes of promising native grass species. Each treatment was replicated three times within each of the three trials using 10x10 ft plots that were arranged in a linear transect along the roadside. Plots were monitored from May 2017 to October 2019. At site visits, species were identified, cover of grass, forbs, and bare ground estimated, vegetation height measured, and photos of each plot taken. Biomass was harvested, dried, and weighed when plants reached a mowable height.

As expected, fescue treatments established best across all trials. However, fescue plants in the warm climate of the Eastern Shore remained stunted in height after initial growth, did not establish dominance, and were not competitive against weeds. Although fescues grew better in central MD, fescues were unable to curb weed growth during the hot summer months, requiring maintenance throughout the summer. In contrast, fescue treatments in western MD established 100% cover quickly and were almost entirely weed-free throughout the trial period. Tall fescue established better and was more resilient to roadside disturbances than hard fescue. However, a mix of 20% tall fescue and 80% fine fescues (equal proportions of hard, sheep, chewings, red) established as well as the MDOT SHA turfgrass seed mix in western MD despite a reduction in seeding rate from 200 pounds per acre for the MDOT SHA mix to 68 pounds per acre for the tall/fine fescue mix.

Several native species showed considerable promise as potential roadside species. Side oats grama (*Bouteloua curtipendula*) was the only native species that established a presence in the Eastern Shore although plants covered only a small portion of the plots and were hidden among weeds. In central MD, however, side-oats grama in monoculture or mixed with four other native species established quickly in the first year and produced consistent high coverage that was similar to the best performing tall fescue cultivars Mustang 4 and Titanium 2LS. In contrast to fescue treatments, plots seeded with side oats grama in central MD were minimally invaded by weeds throughout the summer months, grew well but not to a height that required frequent mowing, and produced inflorescences that promised further expansion. Purple lovegrass (*Eragrostis spectabilis*) also established well in central MD and was present in a large portion of the plots where the species was seeded; however, because the vegetative growth habit of the species is inconspicuous, the excellent establishment of purple lovegrass was only evident when it produced its prolific and conspicuous inflorescences. Side oats grama and purple lovegrass did not establish well in western MD. Instead, upland bentgrass (*Agrostis perennans*), a cool season species, contributed significantly in plots it was seeded with four other species. However, upland bentgrass did not establish a noticeable presence until the second year and was sensitive to salt grit application.

In conclusion, the project summarized here provides preliminary evidence of how different species respond to the varied climates of Maryland. However, confidence in the generality of results for each region is low because trials were not replicated within a region. For example, although none of the seeded treatments performed well at the Eastern Shore site, it is not possible to conclude that the treatments would fail along all Eastern Shore roadsides. What we can conclude, however, is that cool season grasses, such as fescues and upland bentgrass, are better suited for roadsides in the cooler regions of MD in Washington, Allegany, and Garret Counties. Side-oats grama and purple lovegrass, two warm season grass species, are better suited for roadsides in the warmer climates of MD. Fescues have the advantage of establishing quickly and are competitive against weeds in the spring and early summer months. Warm season grasses establish more slowly but can be more competitive and resilient to hot weather in the summer and early fall. This knowledge of species complementarity provides motivation for integrating biodiversity in highway right-of-way landscaping.


Side-oats grama at central MD site

Future investigations of roadside vegetation may consider conducting additional roadside trials to gain confidence in the performance of different species and species mixes under the varying MD climates. The results of side-oats grama are particularly tantalizing such that additional research could include experimenting with seeding rates, timing of seeding, mowing regime, genetic sources, and seed mixes. Mixing promising warm season and cool season grass species could be incorporated in roadside trials to apply known biodiversity benefits on grassland performance and resilience to roadsides.

Introduction

The MDOT SHA maintains roadsides along highway right-of-way to provide sight distance and an aesthetic landscape to motorists. However, the turfgrass seed mixtures currently used in Maryland require frequent mowing in often narrow and congested areas, increasing maintenance costs and placing maintenance staff in danger. Further, seed mixtures often fail to establish persistent turf along roadsides, leading to erosion, nutrient leaching, and unsightly roadside environments. The goal of the project is therefore to test the efficacy of planting alternative low growing roadside grasses and seed mixtures that require less maintenance but establish rapidly, be resilient in the harsh roadside environment, and are available and affordable through commercial growers.

A literature search (Engelhardt and Hawkins 2016) identified 25 alternative grass species for use along roadsides in Maryland, paying attention to economic and ecological services (commercial cost, rate of establishment, ease of maintenance, potential for erosion control, ecosystem benefits) and resilience parameters (tolerance to drought, low fertility, freezing, salinity, acidity, wear, and competition). Most of the identified species were cultivated turfgrasses with known cultivars or ecotypes. Some species were nursery-grown native species that are currently not developed as widely available turfgrass but are used in native landscaping, grassland restoration, or mine reclamation. Special attention was given to species with a short plant stature that would require little to no mowing. After rating six economic and ecological services and seven resilience parameters, each species was ranked (Table 1; Engelhardt and Hawkins 2016). Weighting services or omitting some services altogether (e.g., ecosystem benefits) only slightly changed the rankings of species.

Table 1. Rankings for 21 species and species groups (3 Sporobolus spp. and 2 alkaligrass spp.).

Species	Cost	Establishment	Maintenance	Erosion	Ecosystem	Resilience	Overall	Grade
Sporobolus	100	90	90	100	100	97	96.2	A
Side-oats grama	82	90	90	100	100	91	92.1	A-
Purple lovegrass	55	95	100	100	100	99	91.4	A-
Little bluestem	80	65	100	100	100	93	89.6	B+
Weeping lovegrass	98	95	85	100	65	93	89.3	B+
Hard fescue	67	90	100	88	89	92	87.7	B+
Upland bentgrass	93	65	100	95	100	73	87.6	B+
Blue Grama	63	80	90	100	100	91	87.3	B
Tufted hairgrass	96	85	82	82	92	84	86.8	B
Red fescue	75	90	100	85	65	88	83.9	B
Sheep fescue	60	65	100	88	89	89	81.9	B-
Buffalograss	45	75	80	100	100	89	81.5	B-
Poverty oatgrass	35	95	100	80	85	93	81.3	B-
Chewings fescue	72	85	100	83	60	86	81.1	B-
Bermudagrass	71	100	70	100	50	82	78.8	C+
Tall fescue	70	85	60	100	60	89	77.3	C
Prairie junegrass	85	50	100	60	85	76	76.0	C
Alkaligrass	92	95	20	85	90	71	75.5	C
Kentucky bluegrass	72	70	65	85	40	69	66.8	D
Zoysia	20	60	100	80	50	90	66.7	D
Perennial ryegrass	83	100	20	90	30	71	65.6	D

The literature review provided a hypothesis for which grass species may be suitable for roadsides under varying conditions. These hypotheses were tested over a 3-year period from 2017 to 2019 in field conditions across three climatic regions of Maryland.

Methods

Sites in western MD, central MD, and the Eastern Shore were selected with MDOT SHA staff in May 2017 to represent the mountains to the sea climatic gradient in Maryland (Figure 1). The western MD site was located along the Finzel westbound on-ramp to I-68. The site was slightly sloped with a northern aspect and bordered by a mowed field. The central MD site was located at the I-70 westbound weigh station between Baltimore and Frederick. The site was located next to a decommissioned road that was used occasionally by trucks for turning and parking. The site was slightly sloped with a northern aspect and bordered by a mowed field and woodland. The Eastern Shore site was located adjacent to MD 662 (Centreville Road) near the US 50 rest stop at the welcome sign to the northern end of Easton. The site had a significant slope facing east with plots bordered by a ditch and an unmowed field.

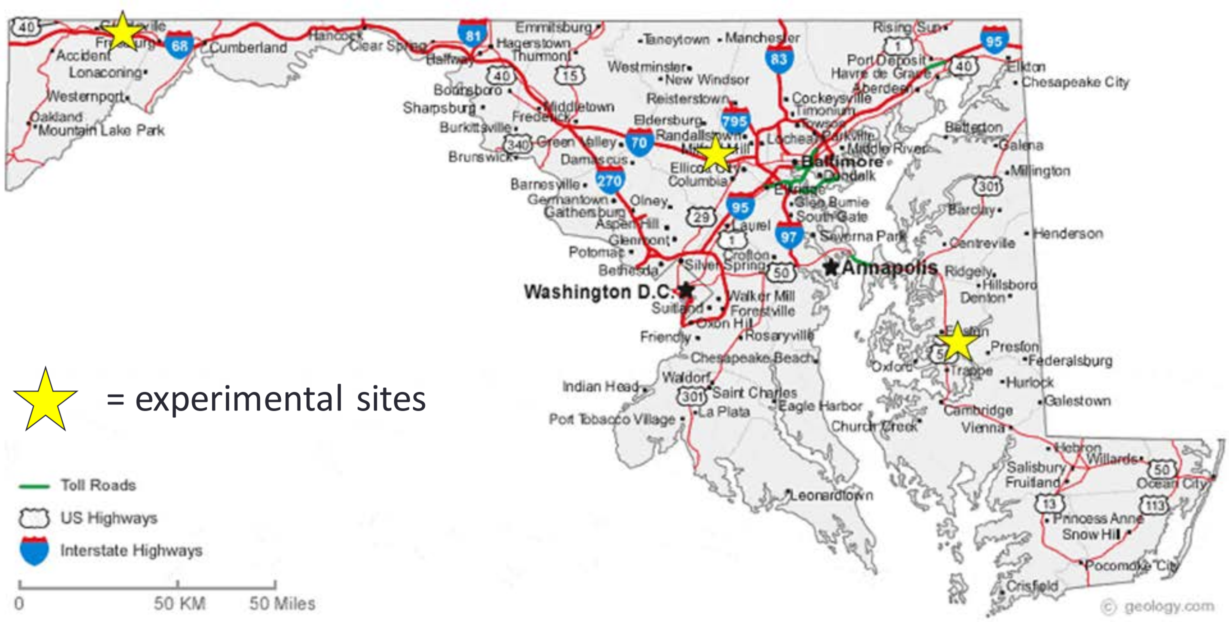

Figure 1. Field site locations in Maryland.

A Maryland Department of Agriculture Certified Pesticide Applicator used glyphosate to kill existing vegetation at each experimental site. After 2-3 weeks, topsoil was removed to 10 cm (4”) below grade, and 10 cm of Furnished Topsoil per 920.01 of MDOT SHA Standard Specifications applied to sub-grade soil at each experimental site (Figure 2). Sites were delineated to be 3 m (10 ft) wide and 110 m (360 ft long). Soils were analyzed by Agrolab (Lab number 2327, 2328, and 2329) for pH, soluble salts, macro and micro nutrients, metals, cation exchange capacity, organic matter, and soil texture and amended with lime and 20-16-12 fertilizer when recommended.

Thirty-six 3x3 m (10x10 ft) plots were established at each site. Twelve seeding treatments were replicated 3 times per site and 9 times total. Treatments were arranged in a replicated randomized block design such that each treatment was randomly chosen to be represented once within each third (block) of the site. Thus, if an environmental gradient existed along the 110-m (360 ft) stretch of a site, treatment effects would not be confounded with environment.

Figure 2. Photos of the Eastern Shore site (left facing south and right facing north). Existing vegetation was killed with glyphosate, the existing soil removed, and new soil added. Plots were seeded the same day that soil was added to the plots. A biodegradable straw blanket was installed immediately after seeding to prevent erosion and provide a better climate for seed germination.

The MDOT SHA Turfgrass Seed Mix treatment, composed mostly of tall fescue (Penn RK4 and Revel IV), was seeded at the recommended rate for highways, which was more than twice as high as the recommended seeding rate for tall fescue supplied from breeders (Table 2). Native species were seeded at a substantially lower rate than any treatments that included fescues. These seeding rate differences reflect differences in seed size and a higher sowing rate for turfgrasses than native grasses that are used for restoration purposes. Seeds were broadcast by hand after delineating each plot with 2"x4' wood planks to catch seeds from blowing into neighboring plots. Seeds were lightly raked into the soil and a Type E Soil Stabilization Matting (SSM) two-sided straw blanket installed over the entire site to prevent erosion and provide a safe site for seed germination.

Table 2. Seeding rates (pounds per acre) for the 12 treatments.

Treatment	**seeding rate (pounds per acre)**
MDOT SHA Turfgrass Seed Mix	200
Unplanted control	0
Tall fescue	90
Hard fescue	60
Mixed fescue	66
Mixed fescue with forbs	66
Dropseed	12
Side-oats grama	30
Purple lovegrass	15
Mixed natives	16
Mixed natives with forbs	16
Native grass mix #2	31

Four tall fescue (4th Millennium SRP, Mustang 4, Titanium 2LS, Traverse 2 SRP) and four hard fescue cultivars (Beacon, Minimus, Spartan II, Sword) were identified as viable candidates for roadsides using data supplied by the National Turgrass Evaluation Program (NTEP). Cultivars needed to perform well in Maryland, be lower in stature, and available for a field trial (e.g., hard fescue cultivar Gotham was replaced by cultivar Minimus owing to availability). Each cultivar was sown in randomly selected 1 x 3 m subplots within the plots designated for the species treatment. The long axes of the subplots were perpendicular to the road surface. Two mixed fescue treatments included tall fescue and 4 fine fescue species (hard, red, chewings, and sheep) in equal quantities. Therefore, tall fescue was 20% and fine fescues 80% of the seed mix. One of the two mixed fescue treatments included eight forb species (*Trifolium repens, Asclepias tuberosa, Coreopsis lanceolate, Eupatorium coelestinum, Lespedeza virginica, Rudbeckia fulgida, Rudbeckia hirta, and Solidago bicolor*)

Native species treatments included monocultures of the top three ranked species - dropseed (*Sporobolus*), side-oats grama (*Bouteloua curtipendula*), and purple lovegrass (*Eragrostis spectabilis*) (Table 1; Engelhardt and Hawkins 2016). Although sand dropseed (*Sporobolus cryptandris*) was the species that was identified to be suitable for roadsides and native to Maryland, prairie dropseed (*Sporobolus heterolepis*) and rough dropseed (*Sporobolus compositus*) were also sown as comparisons, each in subplots that equally divided the

Sporobolus plots into thirds with the long axes of the subplots perpendicular to the roadside. One mixed native species treatment was a mix of 5 native species that were ranked in the top 10 species (Table 1) including sand dropseed, purple lovegrass, little bluestem (*Schizachyrium scoparium*), upland bentgrass (*Agrostis perennans*), and tufted hairgrass (*Deschamsia caespitosa*). This species mix was planted a second time in a second native grass treatment that included the same forbs as were planted with the mixed fescue treatment (see above). A third mixed native species treatment was a mix of five other native species that were ranked in the top 20 species including side-oats grama, blue grama (*Bouteloua gracilis*), buffalograss (*Bouteloua dactyloides*), poverty oatgrass (*Danthonia spicata*), and alkaligrass (*Puccinellia distans*).

From May 2017 until September 2019, field sites were monitored at least every six weeks during the growing season and at least once every three months for the rest of the year. During monitoring trips in 2017 and 2018, 100 evenly spaced points within a 1 x 1 m grid were assessed for the presence of live vegetation. This approach was not used for most of 2018 and all of 2019 because all plots had reached close to 100% cover with only few bare spots. In 2019, separate estimations of grass, forb, and bare ground cover were made by visual inspection of a 0.5 x 0.5 m quadrat. Estimates of cover were collected by the same observer (Engelhardt) when possible and cross-checked with other observers. Cover percent was estimated to the nearest percent. Observers followed the process of determining whether grass, forbs, or bare ground covered one, two, three, or four quadrants of the quadrat if the same vegetation type were pushed together. Percentages were then adjusted to determine whether cover was barely above or below 25%, 50%, 75%, or 100%, and low amounts of cover were estimated as 1-5%. During 2019 monitoring trips, grass height was measured at 4 random locations within each plot or subplot at the 4 corners of the 0.5 x 0.5 m quadrat used to estimate cover.

Biomass was harvested in August 2017, June and September 2018, and May, June, and October 2019. Biomass was not collected in September 2019 to allow easier identification of species at the end of the project. Biomass was collected in 2017 by hand clipping and in 2018 and 2019 by mowing using an electric lawn mower set at the highest setting (5 cm). Biomass was placed in a 50°C oven for at least 48 hours to remove moisture. Dry vegetation was weighed and a few samples placed back in the oven for 48 additional hours and reweighed to ensure that the vegetation was indeed dry. No samples were discarded until all data were sufficiently quality checked.

During each monitoring trip, a photo was taken of each plot or subplot using a MidOpt (Midwest Optical Systems, Inc.) TB550/660/850 Triple Bandpass Green+Red+850nm NIR (near infrared) filter mounted on a Canon Rebel T7i camera. A 0.25 m^2 quadrat was laid on the ground in each plot, and the photos were taken from directly above it. Photos were taken between 10:00 and 14:00 on sunny or mostly sunny days, and lighting adjusted when necessary. During trips when biomass was harvested, photos of each plot were taken before and after the harvest.

Photos were analyzed using Environment for Visualizing Images (ENVI) software for processing and analyzing geospatial imagery (dataone.org/software-tools/envi). A region of interest (ROI) was drawn on each photo inside of the quadrat and statistics were generated. A digital number representing mean light reflectance was calculated from the digital numbers assigned to all pixels within the ROI for each of the radiation bands recorded. The near-infrared region spanned 835 – 865 nm; red, 543 – 558 nm; green, 468 – 483 nm. A ROI was also assessed over the white frame of the quadrat in each picture for standardization. Using the band means calculated in ENVI, the vegetation indices NDVI (Normalized Difference Vegetation Index) and TVI (Triangular Vegetation Index) were calculated on the standardized bands.

Analyses of variance on multiple comparison of vegetation treatments and sites were performed using R statistical computing with statistical significance set at $\rho \leq 0.05$. Prior to any statistical analyses, each variable was checked for normality and transformed if needed (Sokal and Rohlf 1995). If required, non-parametric tests were used.

Results

In 2017 when plots were establishing, the central MD site produced less than half the plant biomass than the other two sites. However, after the establishment year, the western MD and central MD sites produced consistently twice the amount of biomass as the Eastern Shore site in 2018 and 2019 (Table 3). On average, the western MD site was the most productive, followed by central MD and then the Eastern Shore site (Table 3).

Table 3. Proportion of total biomass harvested at each site during each of 5 harvests.

Harvest month	Year	Western MD	Central MD	Eastern Shore
August	2017	0.47	0.13	0.40
June	2018	0.42	0.46	0.14
September	2018	0.44	0.36	0.19
May	2019	0.45	0.37	0.18
June	2019	0.35	0.46	0.19
October	2019	0.20	0.80	0.00
Average		**0.43**	**0.36**	**0.22**

Most fescue treatments established better during the establishment year (Year 1) than any of the native species treatments. Only the western MD site produced enough fescue biomass to be harvestable (Figure 3) but treatment means did not differ (ANOVA; $F_{1,31}$=2.45, P=NS).

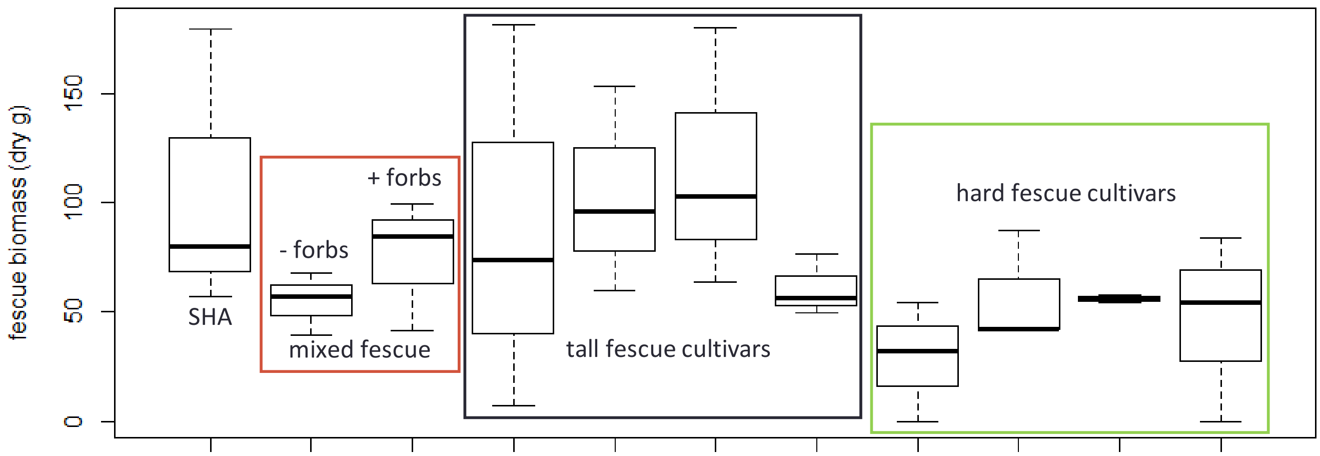

Figure 3. Biomass per 10x10 ft plot of all treatments that contained fescues during the establishment year. Fescue biomass was only harvested at the western MD site because the size of fescue plants at the other two sites was too small to be harvestable in the first year. This was the case for all three years of the study. "SHA" refers to the MDOT SHA Turfgrass Seed Mix that is mostly composed of tall fescue. The "mixed fescue" treatments are composed of equal proportions of tall, hard, sheep, chewings, and red fescues planted with and without forbs. Tall fescue cultivars included, in order from left to right, 4^{th} Millenium SRP, Mustang 4, Titanium 2LS, and Traverse 2 SRP. Hard fescue cultivars included, in order from left to right, Beacon, Minimus, Spartan II, and Sword.

Consequently, fescue treatments, especially those with a tall fescue presence (MDOT SHA Turfgrass Seed Mix, fescue mix, and tall fescue cultivars) had significantly less weed invasion in the first year than the treatments containing native species (Figures 4 and 5). The MDOT SHA Turfgrass Seed Mix treatment was associated with the least weed biomass (Figure 5) whereas the hard fescue treatment was associated with the highest weed invasion.

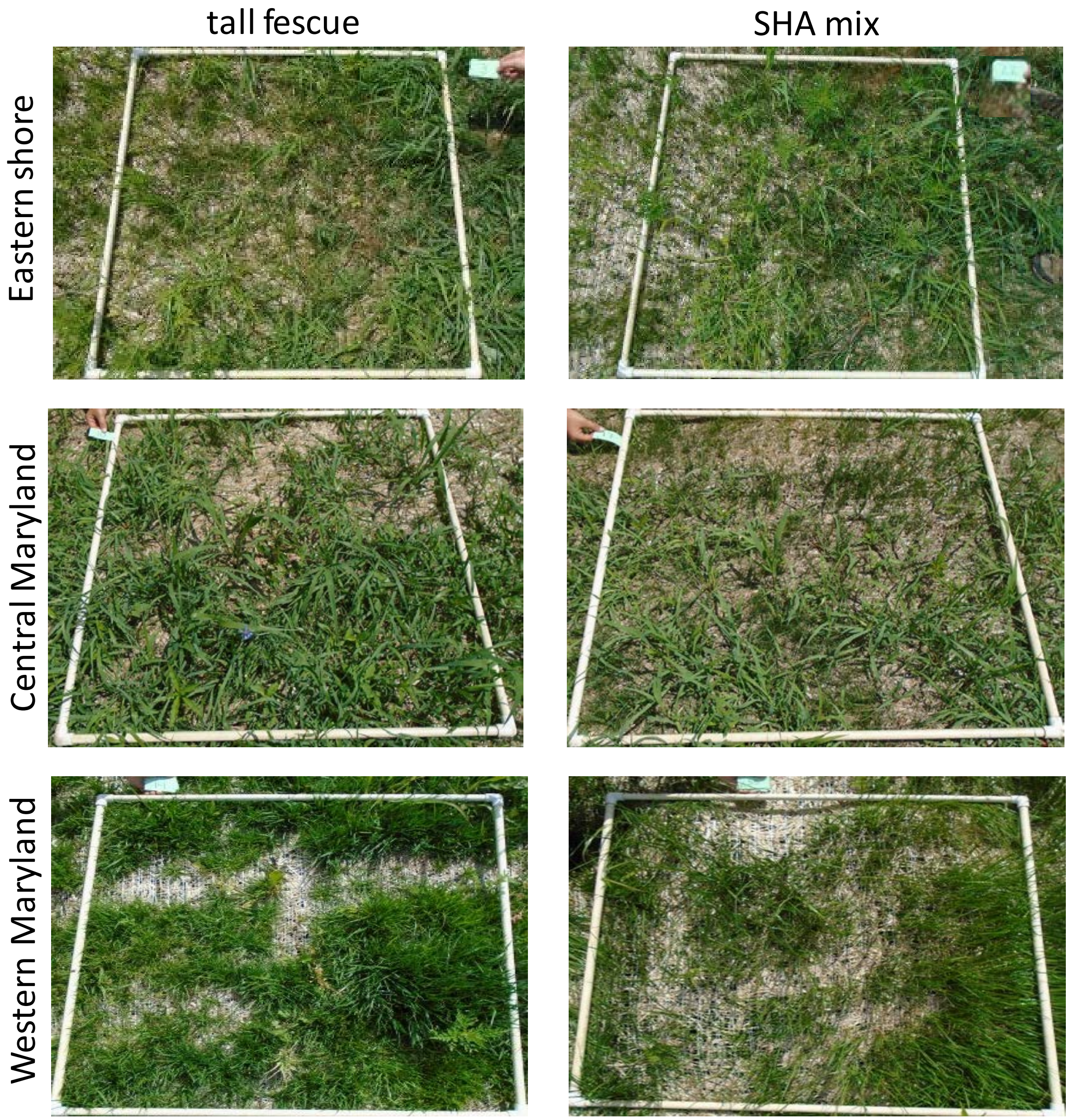

Figure 4. Photos of the tall fescue (left column) and MDOT SHA Turfgrass Seed Mix (right column) after 6-8 weeks of growth in 2017. Fescue treatments at the western MD site (bottom) produced harvestable biomass in the first year with little weed invasion. The fescue treatments at the Eastern Shore (top) and central MD (middle) sites produced short plants (dark green plants) that never reached a height to be harvested. The Eastern Shore and central MD sites were invaded by weedy grasses (light green and taller plants; *Setaria* and *Digitaria* at the Eastern Shore site and *Arthraxon* and *Andropogon* at the central MD site) that continued to dominate throughout the project.

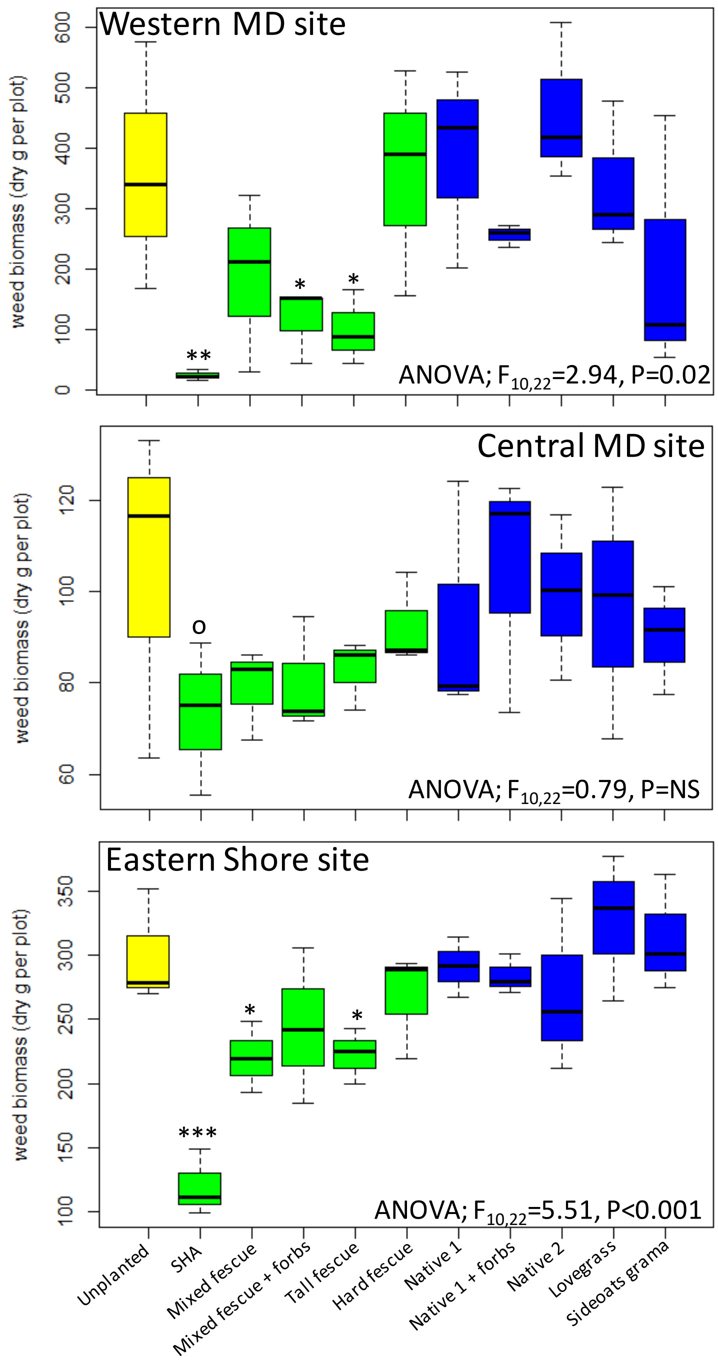

Figure 5. Weed biomass per 3 x 3m (10 x 10ft) plot in 2017. Boxplots show the median (horizontal line), the 25th and 75th percentiles (top and bottom of the box) and minimum and maximum of the data (bottom and top of dashed whiskers). The yellow box highlights the unplanted control, green boxes the treatments containing fescues (“SHA” = MDOT SHA Turfgrass Seed Mix, “Mixed fescue” = equal proportions of tall, hard, sheep, chewings, and red fescue), and blue boxes the treatments containing native species. Stars show P-value levels compared to the unplanted control, where *** < 0.001, ** < 0.01, * < 0.05, and o < 0.1.

As expected, the unplanted control treatment was colonized by weedy grasses and forbs, and this weed pressure differed among sites. At the western MD site, weedy grass (most common grasses were *Anthoxanthum odorata* and *Elytrigia repens*) varied between 5-50% cover of the unplanted plots from May to August 2019 (Figure 7), whereas the central MD site received less pressure from grass weeds (most common grasses were Setaria sp. and Arthraxon hispidus), with 0-10% grass cover in the unplanted plots (Figure 8). Grass cover stayed relatively consistent in the unplanted plots throughout the growing season at both the western and central experimental sites. At the Eastern Shore site (Figure 9), weedy grass cover (most common grasses were Setaria sp. and Digitaria sp.) was high and increased throughout the 2019 season from about 10% cover in May to over 80% cover in July and August. Given these differences among sites and monitoring periods, comparing grass cover of planted treatments to the control were essential to account for differences in weed pressure.

Grass cover of fescue plots in 2019 was highest in western MD (Figures 6 and 7), often at 100% cover. Central MD grass cover was as high as 90% with 60-80% most common (median) among fescue plots (Figure 8). Grass cover in Eastern Shore was generally lower, between 40 and 60% early in the season and then increasing to 80-90% later in the season as weed grasses invaded (Figure 9).

Figure 6. A plot of tall fescue cultivars at the western MD site. From left to right are subplots (delineated by rebar) of cultivars Traverse 2 SRP, Titanium 2LS, 4th Millennium SRP, and Mustang 4.

Based on the data medians, grass cover of plots seeded with ***tall fescues*** was at least 3 times higher compared to the unplanted control plots in May at the western MD site (Figure 7), at least 6 times higher at the central MD site (Figure 8), and at least 4 times higher at the Eastern Shore site (Figure 9). These significant differences in grass cover remained throughout the growing season at the western MD site. Tall fescue treatments at the central MD site differentiated in grass cover during the growing season, with some treatments experiencing a precipitous decline in cover and an associated increase in forb cover (MDOT SHA Turfgrass Seed Mix and tall fescue cultivar 4th Millennium SRP). The tall fescue cultivars that performed consistently the best (high grass cover and low forb cover) throughout the growing season compared to the unplanted control were the tall fescue cultivars Mustang 4 and Titanium 2LS (Figure 6). The strong differences in grass cover observed at the Eastern Shore site in May disappeared completely, where weedy grass cover in unplanted plots increased to mask planted grass cover in the planted plots (Figure 9). Although planted grasses added to grass cover, weed grass cover swamped any treatment effects.

Grass cover of plots seeded with ***hard fescue*** differed from the unplanted control treatment throughout the growing season at the western MD site (Figure 7) although cover varied widely among plots from 5 to 100% cover. Although no clear differences in grass cover emerged among hard fescue cultivars, cultivar Beacon was the best competitor against forb weeds, whereas cultivar Sword II was the worst competitor. Cover of hard fescue also differed from the unplanted control in May at the central MD site (Figure 8) but then decreased with high variation the rest of the season. Cover of hard fescue cultivar Beacon remained significantly higher and forb cover lower than the unplanted control for most of the season until August. Similarly, cover of the mixed fescue treatment, which was seeded with 80% fine fescue species, was high during much of the growing season although with high variability. Grass cover of treatments seeded with hard fescue was indistinguishable from the unplanted control at the Eastern Shore site (Figure 9).

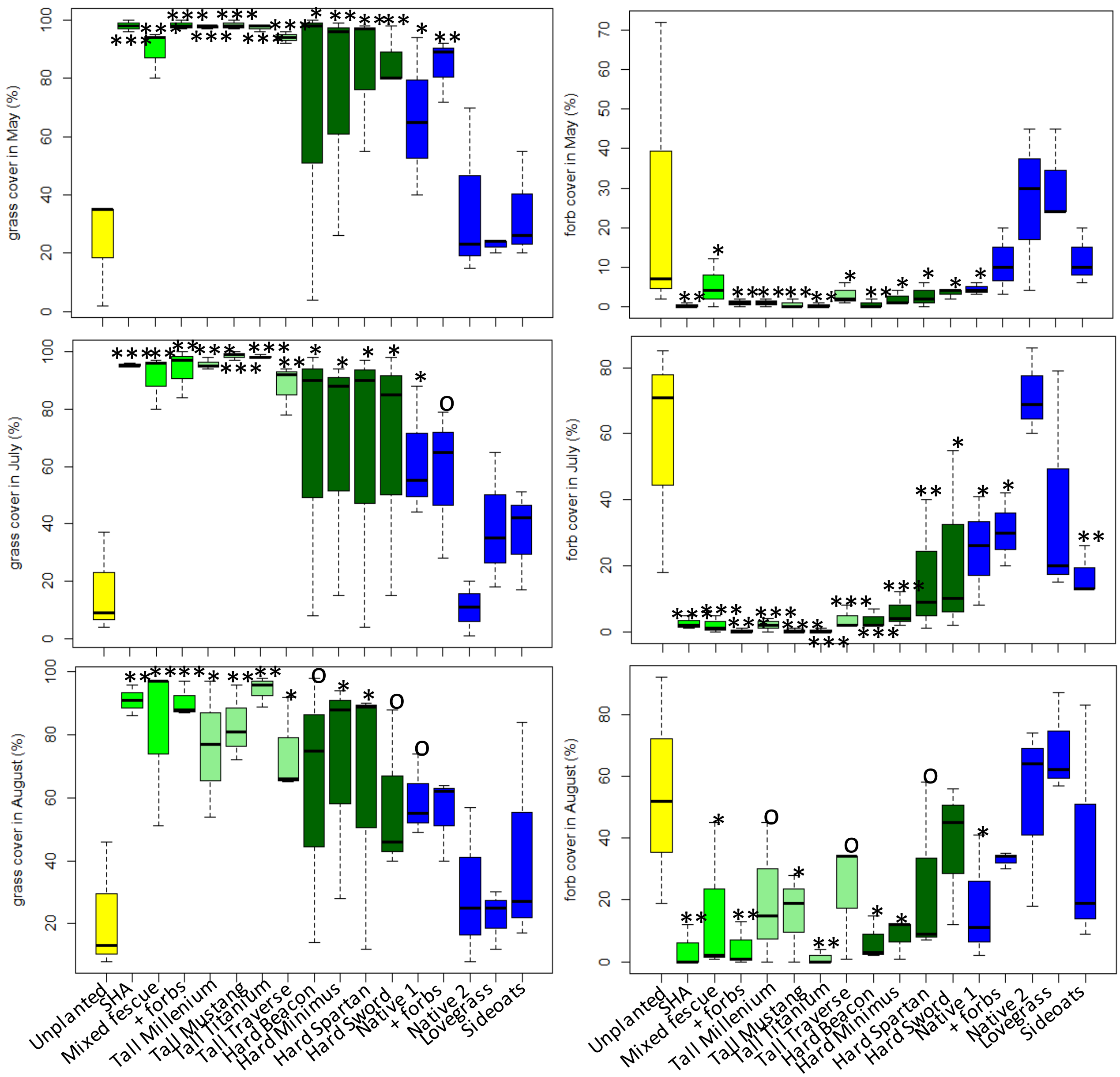

Figure 7. Grass (left column) and forb (right column) cover in May, July, and August at the western MD site. Cover in June not shown. The dropseed treatment was dropped because it did not germinate well across the three sites. Boxplots show the median (horizontal line), the 25th and 75th percentiles (top and bottom of the box) and minimum and maximum of the data (bottom and top of dashed whiskers). The yellow box highlights the unplanted control, green boxes are the treatments containing fescues, and blue boxes are the treatments containing native species. Stars show P-value levels compared to the unplanted control, where *** < 0.001, ** < 0.01, * < 0.05, and o < 0.1.

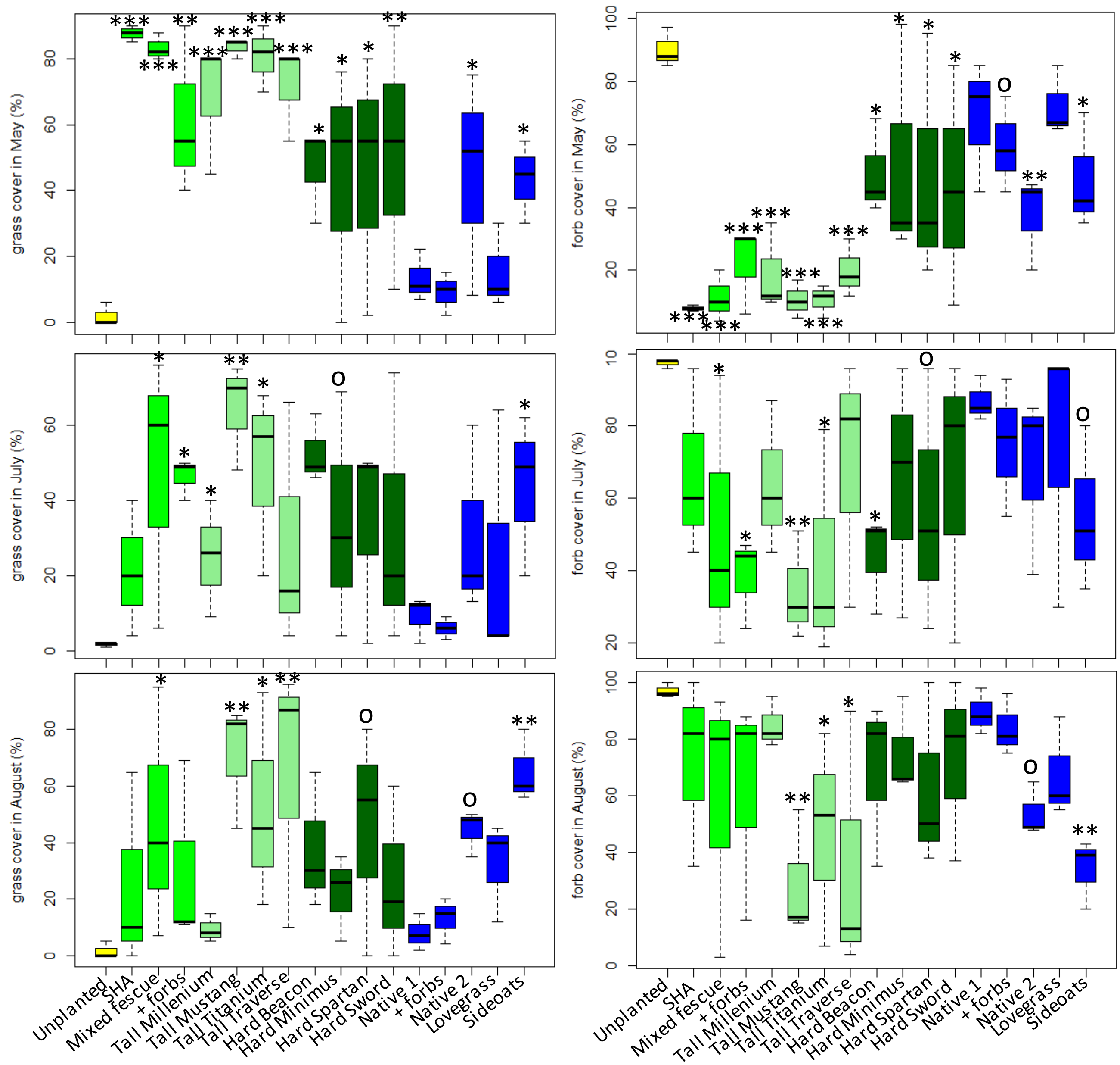

Figure 8. Grass (left column) and forb (right column) cover in May, July, and August at the central MD site. Cover in June not shown. The dropseed treatment was dropped because it did not germinate well across the three sites. Boxplots show the median (horizontal line), the 25th and 75th percentiles (top and bottom of the box) and minimum and maximum of the data (bottom and top of dashed whiskers). The yellow box highlights the unplanted control, green boxes are the treatments containing fescues, and blue boxes are the treatments containing native species. Stars show P-value levels compared to the unplanted control, where *** < 0.001, ** < 0.01, * < 0.05, and o < 0.1.

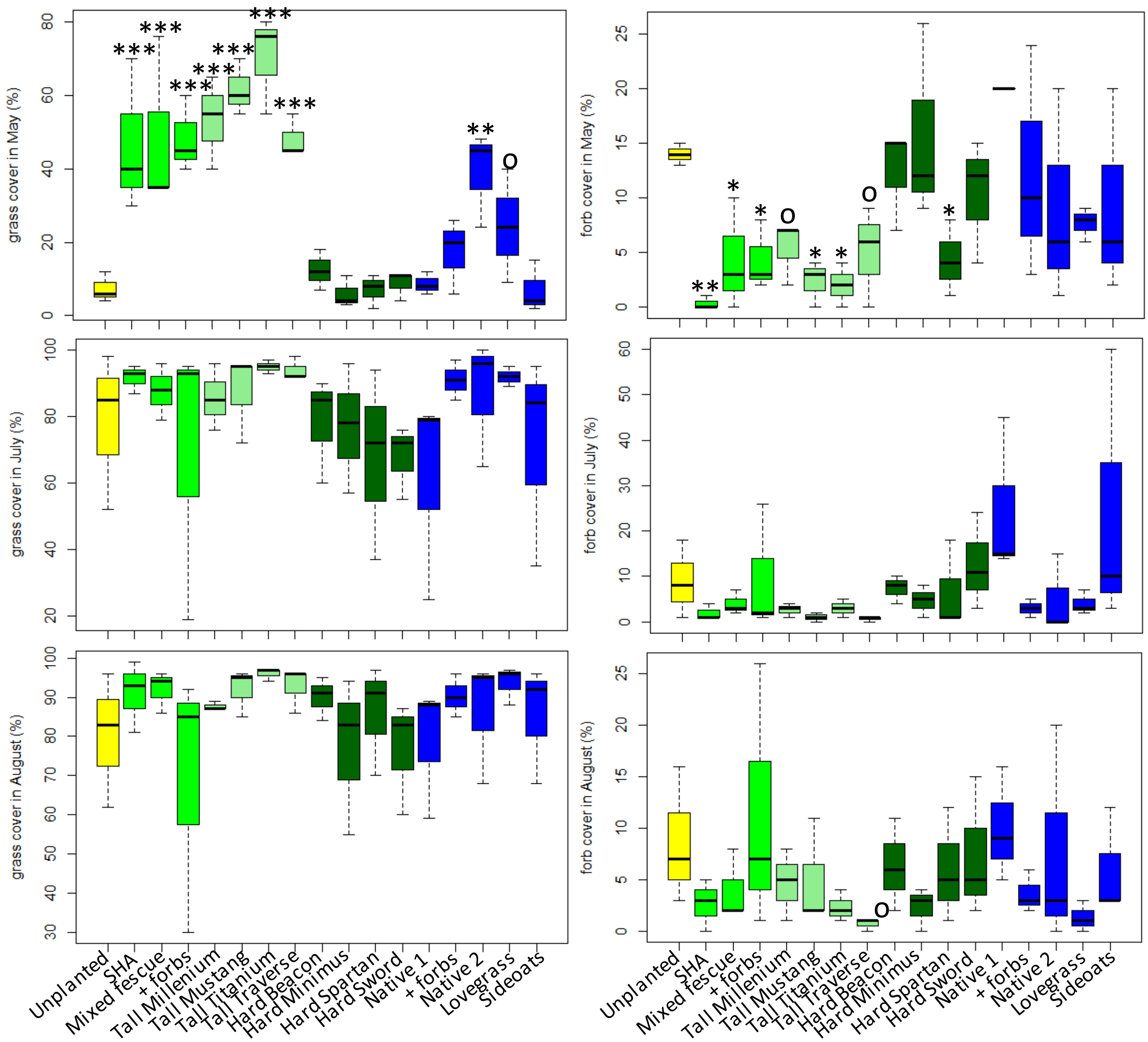

Figure 9. Grass (left column) and forb (right column) cover in May, July, and August at the Eastern Shore site. Cover in June not shown. The dropseed treatment was dropped because it did not germinate well across the three sites. Boxplots show the median (horizontal line), the 25th and 75th percentiles (top and bottom of the box) and minimum and maximum of the data (bottom and top of dashed whiskers). The yellow box highlights the unplanted control, green boxes are the treatments containing fescues, and blue boxes are the treatments containing native species. Stars show P-value levels compared to the unplanted control, where *** < 0.001, ** < 0.01, * < 0.05, and o < 0.1.

Cover of ***native species*** treatments differed across experimental sites. In western MD (Figure 7), the treatments seeded with Native Mix #1 with and without forbs produced significantly higher grass cover and lower weed cover than the unplanted control treatment throughout the growing season. Higher grass cover can be solely attributed to excellent establishment of *Agrostis perennans* (upland bentgrass), which was not seeded in monoculture but was abundant in mixed culture. *Eragrostis spectabilis* (lovegrass), *Sporobolus* sp. (dropseed), and *Schizachyrium scoparium* (little bluestem) were also present in some plots but in very low quantities. In central MD (Figure 8), sideoats grama produced significantly higher grass cover than the unplanted control treatment throughout the growing season and reached close to 80% in one monoculture plot (Figure 10). This species was seeded in the Native Mix #2 treatment, which also established good grass cover but not to the extent than in monoculture. Both treatments that included sideoats grama also significantly reduced forb weed cover compared to the unplanted control with the monoculture reducing weeds to the same levels as the best tall fescue treatment. Although purple lovegrass was obviously abundant in the central MD site (Figure 11), its diminuitive stature did not significantly increase grass cover or reduce weed biomass compared to the control. Sideoats grama was present at the Eastern Shore site such that Native mix #2 had significantly higher grass cover in May (Figure 9); however, after May this treatment could not be distinguished from the unplanted control treatment similar to the rest of the treatments.

Figure 11. Sideoats grama (October 2018) at Central MD site

Figure 10. Purple lovegrass (October 2018) at Central MD site

Discussion

Climate, disturbance regimes, and productivity varied among sites. The western MD site was highly productive (high cover, high biomass) because its cooler climate and higher precipitation is more conducive to biomass production once the weather warms up in the spring. However, grading of the site produced some low spots in four plots that resulted in ponding during the spring. Further, the experimental site in western MD experienced uneven application of road salt grit during snowfall events, which resulted in 1-3 inch deep deposits within and between plots (Figure 12). The central MD site was highly productive, similar to the western MD site, but four plots were disturbed by deep ruts made by trucks. In addition, four plots at the northern end of the site were mowed frequently, which affected data collection and changed the maintenance regime. The Eastern Shore site was located in the hottest climate. The sloped nature of the site decreased the residence time of water in the soil and therefore resulted in droughty conditions in combination with the hotter climate. Productivity of the Eastern Shore site was therefore lowest of all three sites. Thus, the three sites allowed repetition of the same experiment at three sites but the sites were not true replicates owing to the many differences in underlying environmental conditions.

Figure 12. A plot at the western MD site (delineated by red flags and rebar on the roadside and flagging on the meadow side of the plot) sowed with four cultivars of hard fescue (from left to right Sword, Spartan, Minimus, and Beacon). Salt grit was unevenly applied during winter maintenance, causing physical and chemical disturbances within as well as among plots.

The Eastern Shore site was invaded by weeds such that it was hard to discern differences among treatments throughout the experiment (Figure 13). The Eastern Shore site was adjacent to an unmowed field immediately to the east and infrequently mowed fields to the west, both providing abundant weed propagule pressure. In contrast, the western and central MD sites received the least weed pressure because they were bordered by frequently mowed areas. Weed pressure may have also differed among sites if the topsoil that was used to replace the excavated soil contained weed seed. Local topsoil was used at each site and therefore differed for each site. Weeds (foxtail and crabgrass) established within a few weeks at the Eastern Shore site to dominate cover in 2017 whereas weeds established more slowly at the other sites. Given this fast establishment of weeds, a second herbicide treatment 2-3 weeks after topsoil was added at each site would have been beneficial to reduce weed establishment and competition.

Tall fescue treatments performed the best across all sites in terms of establishment, maintenance of grass cover, and reduction of weeds. Western MD provided the best

Figure 13. Plots at the Eastern Shore site in 2018. Although fescues established well in 2017 and reduced initial weed abundance, the site became increasingly invaded by weeds throughout the project. Fescues never reached a height that required mowing.

environmental conditions for these cool-season grasses, with no discernable differences among treatments that contained tall fescues as monoculture or mixed with fine fescues, suggesting that tall fescue cultivar selection is not crucial in this optimal environment. Tall fescue in central MD and the Eastern Shore was more stressed as evidenced by lower cover in central MD during hotter months and poor cover in the Eastern Shore throughout the season. In these hotter and more stressful environments, cultivar selection may be important because some cultivars may be more tolerant to heat and drought. Tall fescue cultivars Titanium 2LS and Mustang 4 performed consistently the best in central MD and the Eastern Shore, suggesting these cultivars might be the best choices for hotter climates. In contrast, tall fescue cultivar 4th Millennium SRP consistently performed the worst across the central MD and the Eastern Shore sites and may therefore be a less ideal choice for the hotter climates of Maryland.

Similar to tall fescue, hard fescues established well in western MD but the species was more sensitive to seasonal ponding and salt grit application as suggested in the higher variability among replicates (Figure 12). The use of hard fescue as monoculture can be a viable alternative to tall fescue in western MD in areas that are well graded and not subjected to salt application. The use of hard fescue in monocultures in the hotter climates of MD, however, is not currently advised as observed by low grass cover, high weed biomass, and high variation within treatments.

The 20/80 mix of tall/fine fescues performed just as well as the MDOT SHA Turfgrass Seed Mix in western and central MD but was applied at 1/3rd the seeding rate of the MDOT SHA Turfrass Seed Mix (68 versus 200 pounds per acre). Fine fescues in the mix included hard fescue, red fescue, chewings fescue, and sheeps fescue. It is unclear which of the fine fescues contributed most to the success of the treatment. Nevertheless, a tall/fine fescue mix may be a good alternative in western and central MD with high initial establishment and cover through time as well as lower seed costs. In contrast, the performance of the fescue mix could not be distinguished from the MDOT SHA Turfgrass Seed Mix or the unplanted plots at the Eastern Shore site and therefore does not provide a clear alternative seed mix for the hot climate of that region.

Although fescues establish well and are therefore often a preferred group of species for practitioners, they are sensitive to heat in the hotter climates of central MD and the Eastern Shore, or may be so productive in cooler climates that they require frequent mowing. Grasses with low plant stature may provide a good alternative as they are more tolerant of heat and need less maintenance. In this roadside experiment, three native grass species (upland bentgrass, sideoats grama, and purple lovegrass) showed particular promise in providing alternatives.

As a cool season grass, upland bentgrass was a highly successful species in western MD, attaining 60 to 80% cover by the second (2018) and especially the third summer (2019). In the first year (2017), however, upland bentgrass established slowly such that weeds were prolific and no different from the unplanted control treatment. Therefore, the use of upland bentgrass by itself is not ideal in areas where practitioners need to show high establishment within the first year.

Upland bentgrass was mixed with 4 other species (purple lovegrass, sand dropseed, little bluestem, and tufted hairgrass) that established poorly, if at all. Upland bentgrass was seeded at 4 pounds per acre within the seed mix, which is 2% of the MDOT SHA Turfgrass Seed Mix seeding rate, 4% of the recommended tall fescue seeding rate, and 6% of the fescue mix seeding rate. The performance of upland bentgrass in western MD is therefore quite notable compared to the highly successful fescues. Using a higher seeding rate should increase the success of upland bentgrass significantly, which would decrease weed establishment. However, the price of upland bentgrass seeds ($15.40 per pound) limits its use over larger areas at higher seedling rates, suggesting that the species needs to be mixed with other species. Upland bentgrass often tended to be more abundant in lower portions of the plots that were farther removed from the roadside, suggesting that the species may be sensitive to road salt and grit. This observation is corroborated by seed supplier Ernst Conservation Seed, which notes that the species has no salinity tolerance. In summary, upland bentgrass shows excellent suitability for western MD; however, slow establishment in the first year, weed establishment, the current high cost of seeds, and low tolerance to road salts decreases its wide-spread use along roadsides in western MD. Its use in mixtures, however, should be investigated further.

As a warm-season grass, side-oats grama showed considerable promise in central MD, where the species established quickly in the first year and attained up to 80% cover in 2019. This species was seeded in monoculture at 30 pounds per acre, which was higher than the recommended 10-15 pounds per acre; yet, the seeding rate was only 15% the seeding rate of the MDOT SHA Turfgrass Seed Mix in monoculture and 3% (6 pounds per acre) of the MDOT SHA Turfgrass Seed Mix seeding rate when sideoats grama was mixed with 4 other species (Native mix #2). A relatively high germination rate (50-73%) has been reported for this species (Harrington and Meikle 1992, Tinsley et al. 2006) as well as high seedling vigor (Sedivec et al. 2001). However, in a roadside trial in Virginia (Doak et al. 2004), sideoats grama established poorly (<53% cover). In Ohio (Thorne and Cardina 2011) and Minnesota (Miller et al. 2013), the species performed poorly and was not able to sustain a viable population. In addition, side-oats grama was competitive against weeds as evidenced by a consistent reduced weed cover in plots that supported side-oats grama. In contrast, weed cover in fescue plots increased during the hot summer months when fescues were stressed and less competitive. The excellent establishment and consistent performance of sideoats grama in central MD is notable and should be studied further. The species also germinated reasonably well at the Eastern Shore site and was a noticeable component of plots in the first year of the study. However, just like the rest of the plots, plots seeded with sideoats grama were invaded with weeds that swamped any treatment effects. A higher seeding rate in the Eastern Shore may be needed to offset the stressful conditions the hotter climate poses.

The warm-season grass purple lovegrass established a notable presence at the central MD site when seed heads emerged in August even though its diminuitive stature did not register in cover and biomass estimates. This species was seeded at 15 pounds per acre in monoculture and 3 pounds per acre in mixture with 4 other species, which is substantially lower than any fescue seeding rate. Qing et al. (2013) noted a 60% germination rate when spring temperatures reach 30 to 35^{o}C (Baskin and Baskin 1969, Qing et al. 2013) suggesting that delayed germination may decrease its competitiveness against species, including weeds, that germinate earlier. Although purple lovegrass shows promise for use along MD roadsides, it is currently not available commercially. Therefore, this species requires more research and development to become a viable roadside species. This species could potentially be mixed with side-oats grama although more research into mixes needs to be conducted.

Sand dropseed was initially ranked first of 20 roadside grasses for use along roadsides (Table 1), yet, it only established in one spot and one plot in central MD. Rough dropseed showed better establishment in western and especially central MD but establishment was slow and patchy, and plants were tall. Prairie dropseed did not establish at all. Therefore, unless the seeds used were not viable, the dropseeds are not viable candidates for MD roadsides.

Little bluestem showed some establishment in central and western MD but the species did not attain any critical cover. Poverty oatgrass was observed only once in a plot in western MD. Although its low stature is suitable, its low establishment is concerning. Buffalograss, blue grama, tufted hairgrass, and alkaligrass were not present in any plots across all three sites and are therefore not considered viable alternative grasses for MD roadsides.

Conclusions

1. The most promising roadside grass treatments for western MD were the MDOT SHA Turfgrass Seed Mix, tall fescue cultivars 4th Millenium SRP, Mustang 4, Titanium 2LS and Traverse 2 SRP, and a 20/80 mix of tall and fine fescues. The performance of hard fescue cultivars in monoculture was unreliable under the variable conditions of roadsides, suggesting that hard fescue is best planted in western MD in combination with more reliable tall fescue cultivars. Fine fescues in the 20/80 tall/fine fescue mix included an even mix of hard, red, chewings, and sheep fescue to enhance resilience to variable roadside conditions. Tall fescue mixed with fine fescue may allow a lower seeding rate (half to one third of the currently applied rate that MDOT SHA uses for its Turfgrass Seed Mix), which would decrease seeding costs. Fescues only needed to be mowed in May and June and were competitive enough in western MD to withstand weed infestation even during fescue senescence in July-September. Upland bentgrass may be an excellent alternative to fescues in areas with no road salt application. Scalping would kill the sod of upland bentgrass because growing tips are located above the soil surface; therefore, upland bentgrass should not be mowed past May and only with a high mower deck setting. The availability of upland bentgrass would need to be developed to allow its use at larger spatial scales in western MD.

2. The most promising roadside grass treatment for central MD was side-oats grama because it established well, was low in stature, and was competitive against weeds in monoculture and mixed culture throughout the growing season. Side-oats grama is an excellent species to include in monocultures and mixes, in mowed or low-input settings. Tall fescue cultivars Mustang 4 and Titanium 2LS also performed well; however, grass weeds were able to establish dominance in all fescue treatments during the hot summer months of July, August, and September, suggesting fescues need to be continuously maintained throughout the summer. Another promising alternative grass species is purple lovegrass, which produced an obvious purple hue across plots even though its diminuitive stature did not contribute to measured cover or biomass. However, this species is not commercially available and was not immune to weeds, suggesting it needs to be developed and used in mixes.

3. Weeds dominated the eastern shore site. Even though fescues and side-oats grama established a visible presence at the site, plants were stressed and did not establish dominance in plots. The seeded species therefore did not offer promising options. Although buffalograss and blue grama were used in a mix and were predicted to perform well in the hot Eastern Shore conditions, the species did not establish and therefore did not offer viable alternatives to heat-sensitive fescues. It is possible that the Eastern Shore site was

too drought stressed and received too much weed pressure to establish well irrespective of species used.

Potential future directions

The roadside experiment established the same 12 experimental treatments in three trials across three climatic regions in Maryland. Although the trials provided preliminary information on which species, cultivars, and species mixes perform best within different regions, they cannot determine how general the findings are for any given region. This requires replication within a climatic region and is the logical next step for those treatments that showed promise in the trials.

Side-oats grama emerged as a viable alternative species to plant in central MD and potentially in the Eastern Shore. The species established fast, was competitive against weeds, and was short in stature. Future research should include experimenting with seeding rates in monoculture and studying seed mixes that include side-oats grama at varying densities. Mixtures may include other warm season grasses, such as purple lovegrass, and/or cool season fescues. A mixture of warm and cool season grass species may be interesting to increase resilience of the grass community against roadside disturbances and to enhance resistance to weeds throughout the growing season. Finally, side-oats grama is a rare species in Maryland (state rank S2). The roadside trial reported here, however, used side-oats grama cultivar 'Butte', which is native to Kansas. Therefore, future research should include identifying native genotypes to Maryland, studying the growth and survival of the genotypes, and comparing establishment and growth of native genotypes to commercially available cultivars.

Upland bentgrass grew well in western MD but is best used in areas that do not receive salt spray and that are not mowed. Future research should study how upland bentgrass may be included in seed mixes that are used to establish no-mow and low-input areas in western MD.

No grass species performed well in the Eastern Shore trial. Although buffalograss was considered an excellent candidate species for the hotter climate of eastern shore, it did not germinate in the Eastern Shore or at the other two sites. Future research might study what environmental conditions in Maryland are suitable for the species while continuing to search for other species that perform well along Eastern Shore roadsides.

Identifying salt-tolerant species to use along roadsides is important in those areas that receive salt spray and grit during winter months. The current trials deployed alkaligrass as a known salt-tolerant species. However, this species did not germinate at any location. Field trials along roadsides receive varying levels of salt even within plots and sites and can therefore only be observational in nature, which limits inferences that can be drawn. Salt tolerance may be best studied in a greenhouse setting where salt concentrations can be carefully manipulated and replicated.

If mower decks are so low that they scalp the soil surface, frequent mowing can kill grasses such as side-oats grama. Side-oats grama produces growing tips above the surface of the soil and is more vulnerable to mowing. Future research should therefore experiment with the effects of mowing frequency and height on the growth of seeded species as well as the trade-off with weed abundance.

The roadside experiment introduced new topsoil to each experimental site after the application of herbicide to existing vegetation and subsequent excavation of existing soil to 4" depth. Treatments were seeded immediately to take advantage of soil moisture and to install a straw blanket for erosion control. Future studies might consider applying a second herbicide treatment 2-3 weeks after topsoil application, but before seeding, to decrease initial weed competition.

The experiments were established in the spring. Future research could study the benefits of seeding roadside grasses in the fall, which would allow in-situ seed stratification and natural germination in the spring. In addition, a second seeding in mid-summer could be explored to assess whether plot establishment can be enhanced with a second seeding.

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